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SPATIAL STRUCTURE AND CO_2 EMISSIONS DUE TO COMMUTING: AN ANALYSIS ON ITALIAN URBAN AREAS

ANDREA CIRILLI & PAOLO VENERI

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Comitato scientifico:

Renato Balducci
Marco Crivellini
Marco Gallegati
Alberto Niccoli
Alberto Zazzaro

Collana curata da:
Massimo Tamberi

Spatial Structure and CO_2 Emissions Due to Commuting: an Analysis on Italian Urban Areas[*]

Andrea Cirilli [◊] and Paolo Veneri [§]

Abstract

The aim of this paper is to investigate whether and to what extent the spatial configuration of an urban area affects its level of environmental externalities. Starting from previous contributions to this field of research, it examines several features of urban spatial structure – such as compactness, monocentricity, concentration and functional diversity – and attempts to gauge their environmental implications in terms of per capita CO_2 emissions associated with a given pattern of commuting (i.e., mode of commuting and distance travelled). The main finding of the analysis on the 111 largest Italian urban areas is that urban spatial configuration is an important determinant of travel patterns and the associated level of per capita CO_2 emissions. In particular, smaller, more compact and less monocentric areas are associated with lower levels of CO_2 per commuter, with socio-demographic characteristics also playing a role.

Key words: urban spatial structure, commuting, environmental costs, CO_2 emissions.

JEL classification codes: Q56, R14, R41.

1. INTRODUCTION

Daily traffic flows are at the origin of many environmental externalities generated by economic and social processes. Among such externalities, air pollution and climate change have attracted much attention among researchers and policymakers, provoking a controversy about the most effective ways to reduce these negative environmental effects. In this regard, some scholars – including new urbanists and advocates of "smart

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[◊] Bank of Italy, Rome (e-mail: andrea.cirilli@bancaditalia.it). The views expressed herein are those of the authors and do not necessarily reflect those of the Bank of Italy.
[§] Dipartimento di Economia, Università Politecnica delle Marche, Piazza Martelli 8, 60121 Ancona, Italy (e-mail: p.veneri@univpm.it).

growth" – argue that the characteristics of built environment and of urban spatial structure play an important role in shaping the patterns of mobility.

One assumption often made is that a low-density and dispersed urban area (UA) tends to be more dependent upon automobile use and requires longer commutes, proving to be less sustainable in terms of air pollution and global warming externalities. However, It is debatable whether a compact area performs better than a dispersed one in terms of CO_2 and other pollutant emissions. In fact, while it is widely recognised that the latter model of urban development encourages a more intense use of private motorised means of transport, it is also maintained that the former is likely to be beset with congestion problems – which make journeys-to-work slower – thus increasing polluting emissions per kilometre travelled. Moreover, the advocates of the *ville emergent* have argued that free-market decisions about localisation and construction – which is more likely to lead to scattered development – could be more environmentally sustainable than centralised planning (Dubois-Taine and Chalas, 1997).

A model of "compact" urban development may prove less efficient also given individuals' preference to live in low-density suburbs, which tend to be greener and safer than dense central areas in the US (Bruegmann, 2005). This point may not be relevant to the European context, where the hinterlands of metropolitan areas are rarely characterised by improved urban quality (Calafati, 2008). Indeed, even assuming that a scattered spatial structure is associated with commuting externalities, the latter could be reduced by means of Pigouvian tools, such as taxes and congestion tolls. Solutions of this kind, however, more common in the US, appear hardly feasible in Europe, where taxation on traffic and especially on fuel is already high.

The aim of this paper is to verify whether and to what extent the characteristics of urban spatial structure explain the levels of CO_2 emissions generated by commutes. In order to answer this research question, an indicator of per commuter CO_2 emissions is proposed on the basis of the characteristics of home-work trips within each UA (i.e., transport mode and distance travelled). Secondly, the spatial configuration of the UAs is examined by looking at various spatial dimensions, such as the degree of compactness of the residential structure, the archetypical model of spatial development (monocentric, polycentric or dispersed), the degree of clustering of activities and its internal functional diversity. In this way it is possible to isolate the role of different elements that characterise contemporary UAs, instead of focusing on residential density alone.

The research question outlined above is addressed through an empirical analysis on the Italian urban system. Nationwide studies on this issue are still lacking in Italy, although the peculiar spatial development that has characterised Italy in the last decades (Calafati, 2009) would warrant specific attention. Nonetheless, the scientific community has significantly contributed to this field of research with a number of case studies (Camagni *et al.* 2002b, Travisi *et al.*, 2010). In this work the empirical analysis is carried out on the 111 largest Italian UAs, identified with those Local Labour Systems (LLSs)[1] whose central municipality had at least 50 000 inhabitants in 2001. The LLS has been chosen as the unit of analysis because it makes it possible to focus on clusters of integrated municipalities rather than just on single urban municipalities, given the profound re-organisation of the Italian territory in recent decades (see Section 2).

The work is structured as follows: Section 2 looks at the evolution of the spatial structure of the Italian UAs in recent decades and briefly reviews its main implications in terms of collective – and especially environmental – costs. Section 3 examines the relationship between UA spatial configuration and its internal pattern of commutes against an appropriate theoretical background. Section 4 provides a descriptive analysis of both urban spatial structures and commuting patterns in Italy, while Section 5 introduces the CO_2 environmental indicator and the other relevant variables. Section 6 presents the empirical analysis and its results, which are commented upon and questioned. Finally, Section 7 makes some concluding remarks and puts forward some policy recommendations.

2. THE CHANGING SPATIAL CONFIGURATION OF ITALIAN URBAN AREAS

The archetypical Italian (and European) city exhibits the well-known characteristics of the *compact city*. It is densely inhabited, with a strong urban identity and a high “relational density” based on proximity (Burton, 2000). During the past five decades, however, a new pattern of urban

[1] A LLS is defined as a cluster of contiguous municipalities with a high degree of self-containment in terms of journeys-to-work, thus constituting a single labour market (ISTAT-Sforzi, 1997).

development has arisen in Italy too which has led to the formation of the so-called *dispersed city*. Today, all the contemporary Italian UAs can be considered dispersed cities (Secchi, 2005).

Albeit belatedly if compared with the US and other European countries, the Italian territory has undergone a “restructuring process” that has given rise to new forms of spatial organisation. Following a period – extending approximately from the 1950s to the 1970s – of intense spatial concentration of both population and employment, the major Italian cities have experienced a process of suburbanisation and decentralisation that has gradually led to the formation of many dispersed UAs (Cirilli, 2010). In most of the latter, the municipalities surrounding the central cities have increased the degree of their physical and relational integration. This phenomenon of “territorial coalescence” (Calafati, 2009) has often resulted in rapid and disordered expansion of settlements, thus obfuscating the historical polycentricity of European UAs. In the 1990s, European policy-makers began to address the costs associated with urban dispersion, and a wide-ranging debate arose among scholars on the economic and social rationale of this pattern of spatial organisation (Bruegmann, 2005; Burchell *et al.* 2005; Brueckner, 2001; Altshuler, 1997; Gordon and Richardson, 1997).

2.1 Urban dispersion and its determinants

Urban dispersion can be defined as a pattern of spatial development characterised by a low residential density, a small concentration of population and employment in the central business district (CBD), and a low degree of proximity and functional diversification (Muñiz *et al.*, 2006). Physical discontinuity may be another of its distinguishing features, in that newly-built settlements are not necessarily contiguous to the older city.

Urban dispersion has evidently been fostered by the fast-growing rate of new house construction in recent decades. This in its turn has been determined by a wide array of factors, ranging from decreasing interest rates to the rising number of one-person families and “second homes?” (Trilla, 2001). In regard to the localisation of urban activities, residential functions have been crowded out in many UAs’ CBD by high value-added tertiary activities able to afford higher rents. Furthermore, the revitalisation of existing real estate in historic city centres may be much costlier than building new settlements in suburban areas. A dispersed (and disordered) urban development may also be the undesirable outcome of a high degree of administrative fragmentation and of fiscal competition among local municipalities to attract investments. Likewise, the lack of effective public decision-making at the appropriate territorial scale has often resulted in the building of isolated agglomerations of houses, thus leading to the formation of discontinuous and highly land-consuming settlements.

Urban dispersion is also the result of wider changes in terms of technological progress and individual preferences. Advances in the ICT industry have significantly influenced localisation decisions. Enhanced centralised control and coordination in large firms' headquarters, for instance, have favoured the territorial dispersion of their productive units and back-office activities (Sassen, 2006). Moreover, technological progress in the transport sector, as well as public programmes for road infrastructure construction, have decreased transportation costs, hence widening the radius of *circadian cycles* without increasing travel duration. In regard to the role of individual preferences, an increasing number of households have come to prefer low-density areas, which allow closer contact with nature, a quieter environment and lower congestion levels (Gordon and Richardson, 1997). In addition, isolated housing permits a higher degree of social segregation based on income (and cultural) differences (Camagni *et al.*, 2002a).

2.2 The effects of urban dispersion

The advocates of public intervention in terms of urban planning argue that free interactions among individual preferences are unlikely to lead to an efficient outcome because of several market failures (Banister, 1997; Brueckner, 2001; Camagni *et al.*, 2002b). The latter ultimately stem from economic as well as social and environmental costs incurred by society, but individual agents do not fully (or even at all) take these into account when they make their decisions regarding transport mode, localisation and land use. From this perspective, urban dispersion is often associated with a variety of "collective" costs (Altshuler, 1997; Burchell *et al.*, 2001; Calafati, 2003).

As regards pure economic costs, a recent study applied to a Spanish case has estimated that private costs – costs of projecting, licensing and building, other urbanisation burdens, heating, water, cleaning and power consumption – and public costs – connection to water and sewage systems and to other utilities – are, respectively, two and seven times higher for an isolated house than a flat in a block (Henry, 2007).

Urban dispersion also entails major non-economic costs (Massey and Denton, 1988; 1993; Deurloo and Musterd, 1998; Cutler *et al.*, 1999). Firstly, a dispersed UA tends to be less accessible, especially to children, the elderly and the disabled. Secondly, there is a tendency for a clear separation to arise among different social groups because of income levels or racial identity. Thirdly, high residential densities may enhance the sense of safety (Jacobs, 1961; Elkin *et al.*, 1991), although a positive relationship between density and urban crime has been found as well (Newman, 1972; Coleman, 1985; Burton, 2000). In a dispersed area, moreover, urban identity tends to weaken, though it may turn into a "sense of community" (Delgado, 1999). This effect is often associated with scarce acceptance of novelty, diversity and tolerance, and thus – following Florida's theory (2002) – with less capacity to innovate.

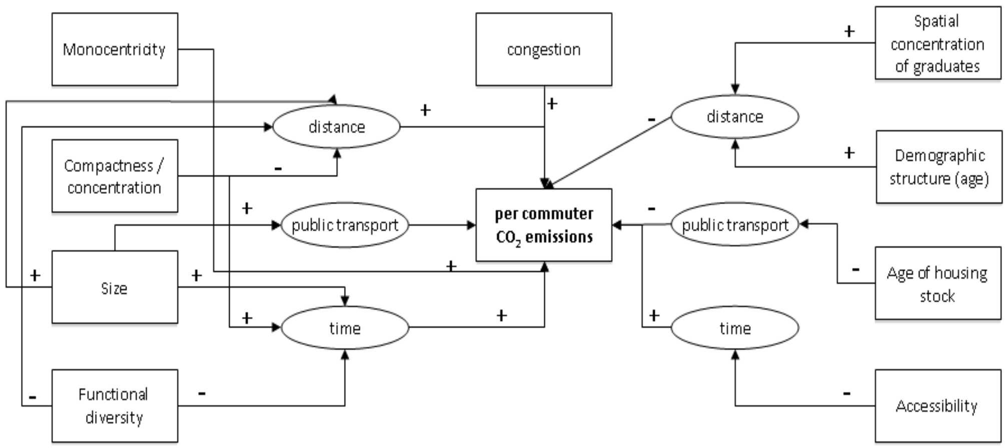
Two groups of effects can be identified in regard to the environmental implications of urban dispersion. One concerns the direct environmental costs of house building undertaken in a discontinuous or scattered manner, as opposed to a more compact pattern of development. Isolated housing implies more waterproof land and water consumption, a larger loss of rich soil and a higher degree of land fragmentation – factors which in their turn entail less diversity in land uses. The other effect stems from the pattern of commuting associated with urban dispersion (Anderson *et al.*, 1996) and consists in noise and air pollution, occupation of land potentially available for more ecological uses and, finally, traffic accidents. Other effects prove relevant at the global level as well, and they concern energy consumption, exhaustion of non-renewable energy sources and gas emissions (CO_2, CFC, CH_4, N_2O, O_3), which ultimately contribute to climate change (Muñiz *et al.*, 2006).

3. URBAN SPATIAL CONFIGURATIONS AND COMMUTING EXTERNALITIES

This section proposes a logical framework for the relationships – to be tested in the next sections – between spatial structure and commuting externalities. The pattern of commutes within an UA is assumed to be affected by its spatial structure, although such a relationship is by no means straightforward. Figure 1 depicts the expected causality links between spatial structure and socio-demographic characteristics, on the one hand, and per capita CO_2 emissions due to commuting on the other.

The spatial organisation of UAs influences individual travel behaviour through several channels (Ewing and Cervero, 2001; Giuliano and Narayan, 2003; Vance and Hedel, 2008)[2]. Firstly, low-density areas are more difficult to be reached and served efficiently by a pervasive system of public transportation, mainly because of the lack of scale economies (Ellison, 1995). Secondly, the demand for public transportation tends to be lower in a dispersed area, especially where the walking distance from homes to public transport nodes is long enough for cars and motorbikes to prove more competitive. Besides, public means of transport are on average more time-consuming than private ones, especially in low-density areas (Cirilli and Veneri, 2009). Furthermore, the increase in average individual incomes has raised the opportunity cost of time-consuming (public) means of transport.

Figure 1 Flow-chart of factors influencing average per capita CO_2 emissions



Despite a large body of research on this issue, the net effect of compactness – as measured by residential density – on commuting patterns is still ambiguous. On the one hand, the direct effect of density may be a reduction in the distance travelled from home to work (Giuliano, 1989; Banister, 1997), a better environment for walking, cycling and transit services, and a lower level of oil consumption (Newman and Kenworthy, 1989). Moreover, residential density is expected to be positively associated

[2] A useful review on these topics may be found also in Dieleman *et al.* (2002), Snellen *et al.* (2002).

with the use of public means of transport, which may imply less pollution and congestion externalities (Banister, 1997; Camagni *et al.*, 2002a; 2002b).

On the other hand, densely inhabited areas are usually exposed to a congestion externality (Anas *et al.*, 1998) which tends to be more severe in compact cities, where the bulk of commutes develop radially towards the central business district (CBD). Congested areas are characterised by longer trips for a given distance, which clearly increase the level of polluting emissions. Hence, the analysis of the relationship between density and CO_2 emissions should control for congestion levels.

The environmental implications of a compact model of urban development are difficult to gauge also because the effect of density should be purged of those of other relevant variables that also affect travel behaviour, like functional diversity, accessibility, and the intensity of mass transit use (Cervero and Kockelman, 1997; Cervero and Murakami, 2010). Accessibility, in particular, according to the bid rent theory (Alonso, 1964), plays a fundamental role in shaping the spatial organisation of economic activities and the consequent traffic flows. What is thought to be the effect of density may instead be the effect of accessibility, since the latter reduces both the distance travelled and the duration of commutes, thereby allowing a wider range of choices among the transport means (Cervero and Murakami, 2010; Muñiz and Galindo, 2005). Indeed, the analysis of the relationship between spatial structure and commuting externalities should control for the level of accessibility.

The externalities of commuting are also influenced by other spatial characteristics of UAs, such as the degree of polycentricity and the degree of clustering of the settlements within each area (Tsai, 2001; Veneri, 2010). In smaller areas, the degree of monocentricity often goes hand in hand with the degree of compactness. Both monocentric and polycentric UAs, however, may be compact, albeit to different extents and in different ways. It may be the case, especially for larger (metropolitan) areas, that the most efficient spatial structure is compact *and* polycentric (Carrol, 1977; Edwards, 1977; Haines, 1986). Indeed, as an UA expands, so a single centre becomes more difficult to reach for an increasing number of people (especially those living in the suburbs). A polycentric area, by contrast, may be more accessible, provided it replicates the scale of a smaller and better-organised area – especially if the various sub-centres develop in line with the existing public transportation infrastructure. Hence, the degree of monocentricity is supposed to be associated with higher CO_2 emissions, especially in large UAs.

Urban size is another important driver of commuting externalities (Cervero and Murakami, 2010 – p. 416), in that journeys tend to be longer in large-scale areas because of a congestion effect. Nevertheless, larger areas are more likely to be endowed with an efficient public transport system, although, on the whole, the distance and the congestion effects are expected to prevail. Urban size is therefore supposed to be associated with higher CO_2 emissions.

Commuting externalities are also affected by functional diversity in land use (Frank and Pivo, 1994; Cervero, 1996; Pouyanne, 2006). A mixed land use tends to reduce the distances travelled by citizens during their circadian cycles, encouraging non-auto commutes for work and other purposes (Cervero, 1996). Hence, a balanced spatial distribution between residential and productive functions is assumed to have a virtuous effect on CO_2 emissions due to commuting. However, the effect of mixed land use on individual travel behaviour also depends on the preference of households – which cannot be taken for granted in the high-income group of workers (Levine, 1998) – to live as close as possible to their workplaces.

Travel behaviours, moreover, also vary according to commuters' socio-economic characteristics, such as age, income and education. Younger workers, for instance, are expected to live in the suburbs because of lower house prices and therefore to take longer and less sustainable trips. The spatial distribution of high-skilled employment appears to be another relevant factor. Given the evidence that more educated people on average travel longer distances to work, a relatively high spatial concentration of high-skilled employment in the CBD – where the bulk of the economic process takes place – may increase the share of co-location between home and workplaces.

Finally, the average age of the housing stock is introduced to capture UAs' recent dynamics, which, at least in Italy, have mainly resulted in scattered development of new settlements, hence requiring longer trips by private cars (Camagni *et al.*, 2002b). Therefore, the higher the proportion of newly built houses, the higher the expected impact of polluting emissions due to commuting.

4. COMMUTING PATTERNS IN THE ITALIAN URBAN AREAS

This section explores the sample of the 111 Italian largest UAs. Due to limited data availability, only home to work trips have been considered, hence ruling out other kinds of journeys (e.g., for educational, consumption or recreational purposes). Likewise, commutes between different UAs have not been taken into account, since the units of analysis are self-contained systems by definition.

The cornerstone of the dataset – which draws on the Italian Population Census – is represented by the number of commuters between any pair of municipalities within each UA (i.e., Local labour system). These trips are disaggregated by transport mode and duration. For each trip from one municipality to another – within the same area –, the point-to-point distance has been computed by the use of Universal Transverse Mercator (UTM) coordinates.

Table 1: Commuters and point-to-point distances by modes of commuting within the Italian urban areas, 2001

Mode	Mode description	Commuters		Distance
		abs. val.	% val.	Km
1	Train	98,007	1.09	13.7
2	Tram	80,100	0.89	12.3
3	Underground	167,684	1.87	13.7
4	Urban bus or trolley bus	450,183	5.02	11.4
5	Extraurban bus or coach	107,566	1.20	12.2
6	School or business bus	50,940	0.57	10.8
	Public transport	*954,480*	*10.64*	12.3
7	Private car (driver)	5,557,294	61.93	11.0
8	Private car (passenger)	420,680	4.69	10.1
9	Motorbikes or scooters	624,071	6.96	9.5
10	Bikes, foot or other means of transport	1,416,359	15.78	8.4
	Private transport	*8,018,404*	*89.36*	9.7
		8,972,884	100.00	11.0

Source: our elaboration on Istat Population Census data, 2001

The choice of the commuting mode is strongly biased towards private means of transport (89.4% over the total number of commuters; Tab. 1). Even ruling out those commuters that travel on foot, by bike or as passengers in a private car, this share is still high (68.9%). Hence, public transportation accounts for only 10% of total commutes and, among all the available options, only urban and trolley buses concentrate a significant share of mobility demand (5%), while rail transport is much less widespread. It is worth noting, however, that longer distances are travelled on average when public means of transport are used (12.3 Km as opposed to 9.7; Tab. 1).

Other relevant insights may be obtained by looking at the average duration of commutes, which strongly varies depending on the transport mode (private vs. public). In fact, around 52% of public transport users spend 30 minutes or longer in their travels, whereas 81.2% of private transport users spend less than 30 minutes (Tab. 2). This discrepancy may have a twofold explanation: on the one hand, commuters prefer public means of transport when they have to travel longer distances. Public means of transport, however, could be relatively less efficient than private ones for a given distance, since the duration of commutes does not necessarily reflect physical distance.

Both factors are expected to come into play. Indeed, when mass transit is used, it turns out that the average distance travelled by commuters increases with the commute duration, while this does not hold for private transport users (see Tab. 2). This finding seems to suggest that public means of transport are relatively less efficient when short distances are travelled, while private transportation is exposed to congestion problems especially in the longer trips.

Table 2: Commuters and average distances by duration of commuting within the Italian urban areas, 2001

Commute duration	Public transport		Private transport*	
minutes	*commuters, %*	*distance, Km*	*commuters, %*	*distance, Km*
0-15	11.6	8.0	50.9	7.0
15-30	36.3	10.4	35.1	10.4
30-60	42.0	13.2	12.6	14.5
> 60	10.1	16.3	1.5	14.9

* private transport here does not include bikes and othermeans of transport

Source: our elaboration on Istat Population Census data (2001)

Table 3: Shares of urban commuters that use public means of transport by macro-region and population class, % values, 2001

UAs' population	North	Centre	South	Islands
>400,000	16.0	17.3	13.6	6.7
200,000-400,000	6.1	4.2	4.2	5.5
100,000-200,000	6.1	3.2	4.7	2.6
<100,000	2.3	2.2	3.1	1.1

Source: our elaboration on Istat Population Census data (2001)

Table 4: Commute duration by mode of transport and macro-region, % values, 2001

Commute duration	Public means of transport				Private means of transport			
minutes	North	Centre	South	Islands	North	Centre	South	Islands
0-15	11.2	10.4	14.8	17.1	56.3	55.4	62.5	57.7
15-30	37.2	31.6	42.2	46.4	31.3	30.1	29.3	34.0
30-60	43.0	43.8	36.7	31.7	11.3	12.6	7.3	7.6
> 60	8.7	14.2	6.3	4.8	1.2	1.9	0.9	0.7
total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: our elaboration on Istat Population Census data (2001)

On looking at the share of public transport users, it is found that it increases with population size, whatever the macro-region an UA belongs to (Tab. 3). On average, Northern UAs show higher shares of public transport users than the others (especially those in the South and in the Islands). This gap is clearly associated with the high degree of heterogeneity of the Italian macro-regions in terms of average income, institutional quality and infrastructural endowment.

The average duration of intra-urban commutes has been also analysed with respect to the macro-region (Tab. 4) of the UAs, distinguishing in each case between private motorised and public modes of transport. From Table 4 it is worth noting that in Southern and Islands' UAs, on average, the share of public transport users that travel for less than 30 minutes is higher than in Central and Northern Italy.

5. DATA AND VARIABLES

5.1 The dependent variable

The environmental impact indicator proposed in what follows builds upon the methodology of Camagni *et al.* (2002b), but introduces two novelties with respect to the weighting technique of commutes. First of all, transport modes (e.g. car, train, underground, bus, etc.) are weighted on the basis of the level of CO_2 emissions per passenger per kilometre, as estimated by Amici della Terra (2005; Tab. 5).

Table 5 Per passenger per kilometre CO_2 emissions by transport mode

Means of transport	CO_2 (grams/km)
Train	35
Tram	32
Underground	21.3
Urban Bus	72
Extra-urban Bus	26
School or Company Bus	31
Car	105
Motorbike	80
Bike, on foot, other	0

Source: Amici della Terra (2005)

The weights attached to the different transport modes take into account the amount of CO_2 emissions generated by each category of transport means, depending on the number of passengers that can be accommodated, as well as on the time needed to travel a given distance. Public means of transport, indeed, carry on average many more passengers than a private ones, with a significant saving in energy and a reduction in polluting emissions. Moreover, all public transport means (especially rail transportation) make a smaller contribution to congestion.

Secondly, the longer the commute, the larger its impact in terms of both (air and noise) pollution and congestion. In this case, however, commutes are weighted according to their distances, rather than their duration, thus obtaining an absolute measure of CO_2 emissions generated by each UA's "typical commuter". Indeed, the duration of commutes is a somewhat ambiguous measure, since a longer duration may reflect either a longer distance travelled or a less efficient mode of transport given a certain distance; all the more so as the time efficiency of the different categories of transport means is already embedded in their respective weights.

CO_2 emissions per commuter per kilometre are calculated for each UA as in (1). All commutes – disaggregated by transport modes – between any couple of municipalities within each UA have been re-aggregated by weighting with the transport mode as in Amici della Terra (2005), and with the physical distance between that pair of municipalities:

(1) $$pc\_CO_2 = \sum_i \sum_j \sum_k f_{ijk} w_k d_{ij} / \sum_i \sum_j \sum_k f_{ijk} ,\qquad k=1,2...10;$$

where f_{ijk} are the commuters that use the k-th means of transport and travel from municipality i to municipality j within a given UA; w_k is the weight attached to the k-th means of transport – as shown in Table 5 – and d_{ij} is the distance between the i-th and the j-th municipality.

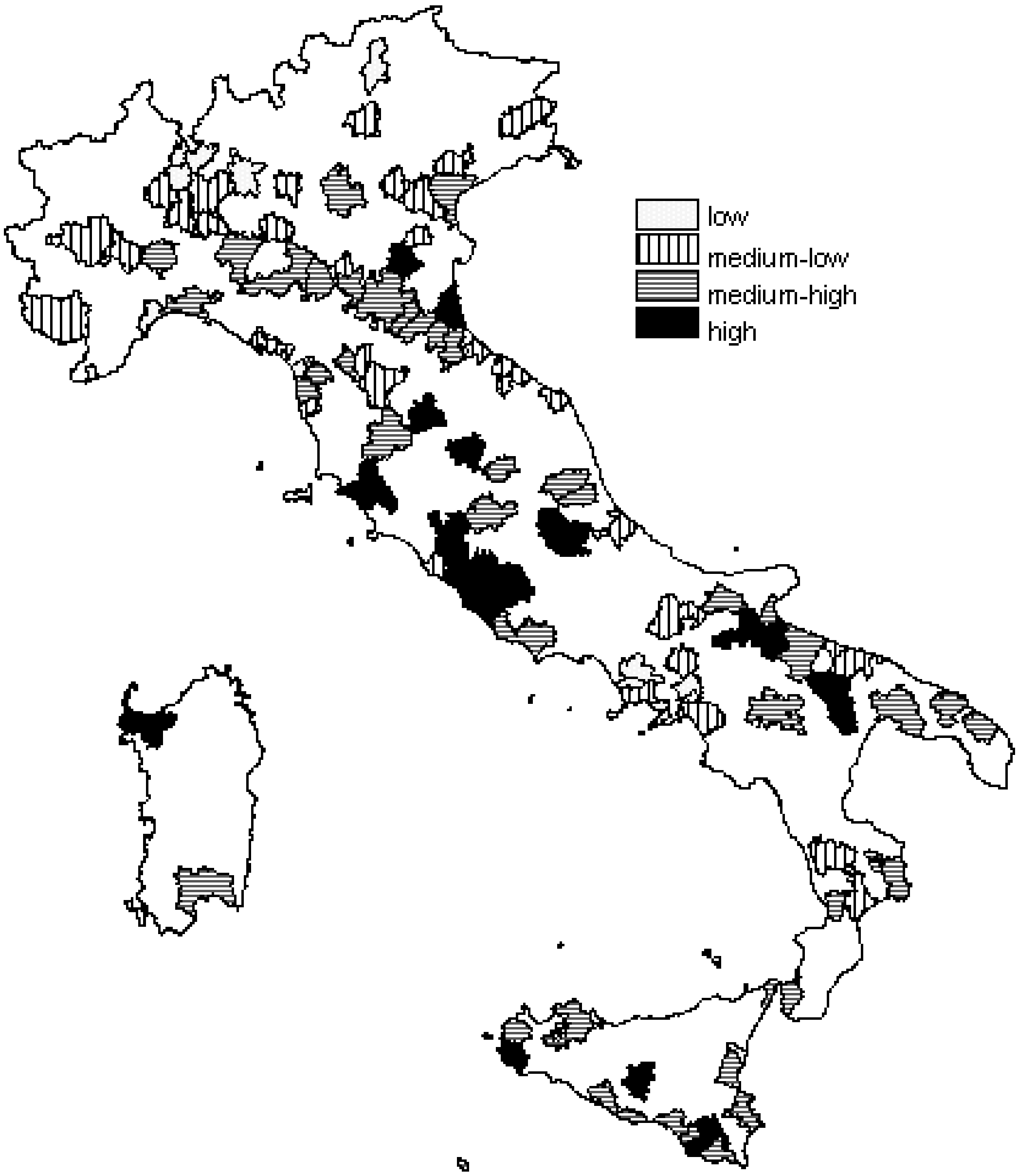
Table 6 shows some descriptive statistics, both at the sample and sub-sample levels. The overall variation range is between 241 (Castellammare di Stabia) and 2 475 (Rome). On average, the lowest levels of emissions are found in Northern UAs and the highest in those of the Islands and Central Italy. One may also note that the indicator takes higher values in the small- and medium-scale areas.

Table 6 CO_2 per commuter: summary statistics over the whole urban system and over sub-samples by macro-region and population class, 2001

Urban areas	Obs	Mean	Std. Dev.	Min	Max
Italy	111	948.8	385.2	240.8	2475.0
North	28	685.6	164.7	452.8	1,078.6
Centre	39	1081.9	386.6	553.7	2,475.0
South	28	911.7	415.5	240.8	1,691.4
Islands	16	1150.2	358.9	385.5	1,794.3
> 400,000	17	954.7	439.8	452.8	2475.0
200,000 - 400,000	26	777.3	276.8	288.6	1256.9
100,000 - 200,000	47	991.1	358.8	240.8	1859.9
< 100,000	21	1061.8	462.3	385.5	1755.0

Source: our calculations on Istat Population Census data, 2001

Figure 2 Italian urban areas by quartile classes of the impact indicator, 2001



Source: our elaboration on Istat Population Census data (2001)

In Figure 2 the Italian UAs are mapped by quartile classes of CO_2 emissions per commuter. Overall, the worst performing UAs are found in Central Italy (especially in Lazio and in some areas of Tuscany and Emilia

Romagna), as well as in the Islands and in some areas of Puglia. In regard to metropolitan areas (i.e., UAs with more than 400 000 inhabitants in 2001), intra-urban commutes tend to have a higher environmental impact in Rome and a few Southern UAs like Taranto, Cagliari, Palermo and Catania, while Lombardy's UAs – including Milan – fare relatively better.

5.2 The independent variables

Different patterns of intra-urban commutes may generate different levels of environmental impacts. These patterns, in their turn, may vary depending on how UAs are spatially organised. This section, therefore, presents some variables that capture the spatial configuration of the UAs in the sample and that are thought to influence per commuter CO_2 emissions, according to the model depicted in Figure 1. In Table 7 all the relevant variables are defined and reported with their means and standard deviations. All of them have been computed drawing on the 2001 Istat Population Censuses, Istat Industry and Services Census and Isfort.

Urban form is measured from both an intensity-based and a spatial structure-based perspective. In the former, gross residential density (*density*) approximates the UA's degree of compactness (i.e., the higher the density, the more compact the area). In the latter, three variables are introduced in order to describe the UA's spatial configuration. The degree of urban monocentricity is measured by the share of employment concentrated in the central municipality. Then, two concentration indexes *à la* Gini are computed: one (*gini_area_empl*) is used to assess whether urban employment is evenly distributed from a spatial point of view or concentrated in some municipalities (Tsai, 2005). The other (*gini_pop_empl*) works as a proxy for functional diversity at the urban level, because it takes a value of zero when population distribution reflects employment distribution from a spatial point of view, implying that residential and productive functions match. The spatial structure of UAs also depends on their size, which is measured here as the employment level in each UA.

As regards the social characteristics of commuters, the empirical analysis takes account of the age of population – measured with a standard index of demographic structure (see Table 7) – and the spatial distribution of high-skilled workers – measured as the share of graduates in the central municipality over the total number of each UA's graduates.

The accessibility of UAs is also controlled for, by taking into account their infrastructural endowment as approximated by the Isfort accessibility index (Ministero dei Trasporti e delle Infrastrutture, 2005). Finally, account is taken of the recent dynamics of the UAs by looking at the proportion of houses built after 1982 over the total number of houses in 2001 (*house_age*). This variable is expected to assume higher values in those UAs where rapid urbanisation processes have taken place in recent decades.

Table 7 Variables descriptions, sources and statistics for 111 Italian urban areas

Variable name	Conceptual meaning	Variable description	Data source	Descriptive statistics mean	std. dev.
pc_CO2	CO2 emissions	average daily CO2 emissions per commuter.	Istat, Amici della Terra	948.84	385.23
pc_PM10_NOx	PM10 and NOx emissions	average daily PM10 and NOx emissions per commuter	Istat, Amici della Terra	52.69	21.53
density	compactness of the built environment	residential density (population over total area) in 2001	Istat	466.58	520.84
pivot_empl_share	degree of monocentricity	central municipality's share of total employment[b] of the UA in 2001	Istat	0.65	0.18
gini_area_empl	employment concentration	sum, for each municipality within a UA, of the differences in absolute value between the area and the employment[b] shares of that municipality over the whole UA in 2001	Istat	0.40	0.17
gini_pop_empl	functional diversity	sum, for each municipality within a UA, of the differences in absolute value between the population and the employment[b] shares of that municipality over the whole UA in 2001	Istat	0.12	0.06
house_age	recent urban dynamics	proportion of houses built after 1982 over the total number of houses in 2001	Istat	0.21	0.06
empl	size of the UA	number of employed people in 2001	Istat	113,322	206,258
demo_str	age of population	population structure index: people aged between 40 and 65 over people aged between 15 and 39	Istat	60.49	8.31
grad_distr	spatial distribution of human capital	central municipality's share of total graduates of the UA in 2001	Istat	0.10	0.03
accessibility	accessibility	endowment of transport infrastructures	Isfort	61.22	12.85
accidents	congestion	share of traffic accidents over the total number of commuters in 2001	Istat	0.05	0.02

[a] according to Istat classification

[b] people that work in the city but do not necessarily reside in it

Table 8 Bivariate correlations among independent variables

	pc_CO2	NOx_PM10	density	pivot_emp	gini_areal	gini_pop	house	empl	demo	grad	access.	accid.	public_sh
pc_CO2	1												
pc_NOx_PM10	1.00	1											
density	-0.59	-0.57	1										
pivot_empl_share	0.50	0.51	-0.30	1									
gini_area_empl	-0.26	-0.27	-0.01	-0.14	1								
gini_pop_empl	-0.12	-0.12	-0.14	-0.26	0.57	1							
house_age	0.14	0.13	-0.18	-0.20	-0.18	0.17	1						
empl	-0.04	-0.04	0.47	-0.34	0.38	0.22	-0.21	1					
demo_str	0.06	0.03	-0.07	0.13	0.20	-0.13	-0.68	0.31	1				
grad_distr	-0.24	-0.26	0.06	-0.50	0.36	0.56	0.20	0.41	-0.05	1			
accessibility	-0.28	-0.29	0.40	-0.29	0.07	-0.10	-0.32	0.51	0.45	0.16	1		
accidents	0.11	0.07	0.08	0.24	-0.08	-0.27	-0.28	-0.03	0.47	-0.35	0.17	1	
public_share	-0.03	0.01	0.38	0.11	0.31	0.13	-0.47	0.66	0.26	0.09	0.22	-0.09	1

Source: our on Istat Census data (1981, 2001)

Before the relationship between the spatial configuration of UAs and their per commuter impact in terms of CO_2 emissions is tested empirically, some summary statistics are presented (Tab. 7), along with the correlation structure among all the relevant variables (Tab. 8). Table 8 suggests that the impact of commuting tends to be lower in more compact and monocentric UAs, where public transportation proves relatively more competitive. The share of mass transit users is likely to be higher in more compact UAs, where employment is more spatially concentrated and where urban dynamics have been less intense in the last two decades covered by the analysis. In addition, the intensity of the urbanisation process in recent decades is associated with a lower share of public transport users (Tab. 8). This may indicate that new settlements have been established in discontinuous manner and not necessarily in line with the pre-existing public transport infrastructure, as already highlighted by Camagni, Gibelli and Rigamonti (2002b). In newly urbanised settlements, commuters tend to use private motorised means of transport, but they also travel shorter distances to their workplaces on average, because they tend to find accommodation close to the latter. Overall, the negative environmental effect induced by the transport mode choice is likely to be only partly off-set by the positive distance effect.

6. EMPIRICAL RESULTS AND INTERPRETATIONS

In the econometric analysis, the environmental impact indicator – as computed in Section 5.1 – was regressed on the main variables describing UAs' spatial configurations and their functional diversity, as well as on other variables meant to control for UAs' infrastructural accessibility and their recent dynamics, according to the model depicted in Figure 1.

On investigating the effects of spatial structure on commuting patterns, indeed, several studies have sought to control for endogeneity and simultaneity issues, especially with respect to the effect of density on the number of vehicle miles travelled (VMT) (Bhat and Guo, 2007; Brownstone and Golob, 2009). In fact, individual decisions about residential and job locations may be influenced by the preference for a given mode of transport and a shorter commute duration. In addition, the UAs' spatial structure may be affected by the quali-quantitative endowment of public transport infrastructures.

In our analysis, all the characteristics of spatial configuration were treated as potential sources of endogeneity biases. Hence, in addition to OLS, we carried out a two-stage least square (2SLS) estimation where the four main spatial structure variables – those related to density, concentration, degree of monocentricity and functional diversity – were instrumented by the corresponding variables referred to 1951 data. As shown in Table 9, the estimates obtained with the OLS and the 2SLS methods gave rise to very similar results. In particular, almost all the main regressors related to urban spatial structure are significant at either a 99% or a 95% confidence level. The only two variables that do not seem to play a significant role in the explanation of CO_2 emissions are those used to control for UAs' functional diversity and the age of their housing stock. As regards the model's goodness of fit, more than eighty percent of total variance is accounted for, which seems a good result for a cross-section analysis.

The main finding is that densely inhabited UAs appear to be more sustainable in terms of per commuter CO_2 emissions, even after controlling for accessibility and socio-demographics. Moreover, monocentric UAs – as well as UAs with an even spatial distribution of employment – generate higher levels of polluting emissions. This finding may suggest a certain virtuosity of a polycentric spatial configuration – i.e., decentralised and concentrated – consistently with the recent findings by Veneri (2010) on Italian metropolitan areas. Moreover, the larger the city, the higher the level of per commuter CO_2 emissions, since in larger UAs commuters travel longer distances, thereby offsetting the beneficial effect due to a more intense use of public means of transport.

The accessibility of the UAs is associated, as expected, with lower levels of CO_2 emissions, since in more accessible areas commuters are able to reach their workplaces more rapidly and with a wider set of options among transport means. On the other hand, traffic congestion – approximated by the share of yearly accidents over the total number of commuters – implies longer journeys and therefore generates higher levels of emissions.

Commuters' socio-demographic characteristics play a role as well. In particular, a high concentration of skilled workers in the central municipality entails more environmental externalities, consistently with the assumption that more educated people tend to travel longer distances (Schwanen *et al.* 2001). More specifically, graduates are likely to obtain better jobs (and better pay), thus developing a preference for larger houses in the outskirts, which in turn implies longer commutes to the CBD.

Table 9 Estimation results: dependent variable: pc_CO2

variable	OLS		OLS		IV		IV	
(intercept)	-0.505		-3.294	***	-0.437		-3.251	***
	0.633		0.006		0.705		0.010	
density	-0.464	***	-0.483	***	-0.480	***	-0.486	***
	0.000		0.000		0.000		0.000	
pivot_empl_share	0.491	***	0.433	***	0.389	***	0.406	***
	0.000		0.000		0.000		0.000	
gini_area_empl	-0.283	***	-0.265	***	-0.331	***	-0.342	***
	0.000		0.000		0.000		0.000	
gini_pop_empl	-0.018		-0.047		-0.005		0.056	
	0.635		0.173		0.961		0.488	
house_age	0.128		0.173	**	0.088		0.148	*
	0.144		0.026		0.343		0.081	
empl	0.411	***	0.400	***	0.422	***	0.407	***
	0.000		0.000		0.000		0.000	
demo_str	-0.605	**	0.311		-0.599	**	0.313	
	0.027		0.286		0.044		0.314	
grad_distr	-0.420	***	-0.299	**	-0.469	**	-0.469	***
	0.006		0.029		0.015		0.009	
accessibility	-0.273	**	0.142		-0.321	**	0.135	
	0.021		0.252		0.014		0.307	
accidents	0.214	***	0.097		0.227	***	0.107	
	0.005		0.152		0.004		0.136	
x_coord			0.000				0.000	
			0.372				0.564	
y_coord			0.000	***			0.000	***
			0.000				0.000	
n. obs.	111		111		111		111	
Adj. R-squared	0.818		0.863		0.812		0.848	
F-statistic	50.51(0.000)		58.54(0.000)		45.38(0.000)		50.4(0.000)	
mean VIF	2.29		2.79					
Breusch-Pagan	5.55(0.852)		17.25(0.141)		5.55(0.852)		17.25(0.141)	
Reset	2.27(0.109)		1.43(0.245)		2.27(0.109)		1.43(0.245)	
Moran's *I*	3.01(0.001)		1.20(0.115)		2.42(0.008)		0.46(0.323)	

*** statistically significant at 99%; ** statistically significant at 95%; * statistically significant at 90%.

Table 10 Estimation results: dependent variable: pc_PM10_NOx

variable	OLS		OLS		IV		IV	
(intercept)	6.723	***	4.000	***	6.946	***	4.037	***
	0.000		0.000		0.000		0.001	
density	-0.426	***	-0.444	***	-0.448	***	-0.455	***
	0.000		0.000		0.000		0.000	
pivot_empl_share	0.478	***	0.422	***	0.360	***	0.374	***
	0.000		0.000		0.000		0.000	
gini_area_empl	-0.269	***	-0.252	***	-0.300	***	-0.309	***
	0.000		0.000		0.000		0.000	
gini_pop_empl	-0.013		-0.040		-0.038		0.017	
	0.726		0.213		0.665		0.816	
house_Age	0.059		0.098		0.014		0.067	
	0.467		0.174		0.871		0.381	
empl	0.391	***	0.380	***	0.404	***	0.389	***
	0.000		0.000		0.000		0.000	
demo_str	-0.749	***	0.116		-0.783	***	0.114	
	0.004		0.669		0.005		0.687	
grad_distr	-0.425	***	-0.306	**	-0.418	**	-0.405	**
	0.003		0.017		0.020		0.013	
accessibility	-0.250	**	0.132		-0.316	***	0.121	
	0.023		0.253		0.010		0.316	
accidents	0.164	**	0.057		0.180	**	0.068	
	0.019		0.367		0.013		0.296	
x_coord			0.000				0.001	
			0.243				0.305	
y_coord			-0.006	***			-0.005	***
			0.000				0.000	
n. obs.	111		111		111		111	
Adj. R-squared	0.816		0.861		0.807		0.853	
F-statistic	49.85(0.000)		57.59(0.000)		43.98(0.000)		52.07(0.000)	
mean VIF	2.29		2.79					
Breusch-Pagan	5.49(0.856)		19.29(0.082)		5.49(0.856)		19.27(0.082)	
Reset	2.29(0.106)		1.42(0.246)		2.29(0.106)		1.42(0.246)	
Moran's *I*	2.64(0.004)		1.37(0.085)		2.19(0.014)		0.56(0.286)	

*** statistically significant at 99%; ** statisticalli significant at 95%; * statistically significant at 90%.

The relationship shown in Figure 1 was also tested with respect to pollutant emissions other than CO_2. In particular, indicators of environmental impact in terms of per commuter PM_{10} and NO_x emissions were alternatively adopted as dependent variables in the estimation framework. These indicators were computed in a similar way to the CO_2 impact indicator (1), using, however, specific weights for the commuting modes as in Amici della Terra and Enea (2003 – p. 52). Again the results were perfectly consistent with those obtained with CO_2 weights – in terms of sign and size of the coefficients – with both the OLS and the IV estimations (Tab. 10).

Standard diagnostics were carried out to ascertain whether the underlying classic assumptions of the OLS model had been violated. Problems of either heteroskedasticity and multi-collinearity did not seem to arise (see the Breusch-Pagan tests and VIF statistics in Tables 9 and 10). In regard to the possible spatial autocorrelation of residuals, the Moran's *I* statistics showed that in the baseline specifications of the models (CO_2 and NOx & PM_{10}) the residuals were not spatially independent, which could imply biases in the estimated coefficients.

This spatial correlation problem may have been due to the omission of relevant variables, to unobserved spatial heterogeneity, or to a spatial dependence problem. The Reset test reported at the bottom of Tables 9 and 10 ruled out a problem of omitted variables, while spatial dependence did not appear to be relevant in a cross section of UAs, where only intra-urban commutes were taken into account (i.e., a spill-over effect was unlikely). As a result, the autocorrelation of residuals may have been caused by spatial unobserved heterogeneity, which can be corrected by including latitude and longitude coordinates in the regression. As shown by the Moran's *I* statistics, this correction was able to clean off the spatial autocorrelation bias, and this result was robust to the use of different spatial weighting matrixes.[3] This finding confirms that commuting behaviours also vary according to the UAs' geographical location, and especially on their longitude (Northern vs. Southern areas).

7. CONCLUDING REMARKS

Cross-section analysis on the 111 largest Italian UAs has corroborated this paper's hypothesis that smaller, more compact, and less monocentric UAs are associated with lower levels of per commuter CO_2 emissions. Population density proves to be one of the main determinants of per commuter emissions – even after controlling for UA accessibility –

[3] Moran's *I*s reported in Tables 9-10 were computed using four-nearest-neighbours binary standardised matrixes. The results are consistent with other spatial matrixes, computed on the base of the inverse of distance among UAs, applying different thresholds of minimum distance.

consistently with the findings of important contributions to this field of research in the European literature (Muñiz and Galindo, 2005). The results are also consistent with the assumption that polycentric UAs represent an efficient spatial configuration in terms of per commuter pollutant emissions. Commuters' socio-demographic characteristics also play a role. In particular, travel behaviours seem to be affected by the spatial distribution of the most educated workers and, ultimately, by the population age structure, on which housing preferences also depend. These results prove quite robust after a number of checks are carried out with respect to the estimation technique.

Reducing the negative externalities generated by transport and vehicle use is certainly an important policy goal. These externalities, which mainly consist in traffic congestion and polluting emissions, can be dealt with by urban and regional planners in different ways, also depending on the cultural, institutional and economic background being considered. In the US literature, some scholars suggest that the use of Pigouvian taxes is the most efficient way to curb traffic externalities (Brownstone and Golob, 2009). However, in the Italian – and, to some extent, European – case, where oil taxes and parking tariffs are already high, it would hardly be effective (and politically acceptable) to adopt only these policy tools. The analysis developed in this paper, indeed, confirms that spatial planning – by influencing the functional and morphological organisation of UAs – can be effective in reducing CO_2 and other polluting emissions due to commuting. Hence, the design of new settlements on the basis of a more sustainable pattern of vehicle use represents a fundamental policy strategy, albeit one bound to display its beneficial effects much more slowly than other tools (e.g., taxes). Besides environmental sustainability, efficient urban planning could also enhance the return on public investment in transport infrastructures.

REFERENCES

Alonso, W. 1964. *Location and Land Use*. Harvard University Press, Cambridge, MA.

Altshuler, Alan A. 1997. "Review of the cost of Sprawl," *Journal of the American Planning Association*, 43, 207-209.

Amici della Terra. 2005. *I costi ambientali e sociali della mobilità in Italia. Quinto Rapporto*. Roma: Ferrovie dello Stato.

Amici della Terra and Enea. 2003. *Valutazione del vantaggio, in termini di minori costi ambientali e sociali, di un forte sviluppo del trasporto collettivo in ambito urbano*. Roma: Amici della Terra.

Anas, Alex, Richard Arnott, and Kenneth A. Small. 1998. "Urban spatial structure," *Journal of Economic Literature*, 36, 1426-1464.

Anderson, William P., Pavlos S. Kanaroglou, and Eric J. Miller. 1996. "Urban Form, Energy and the Environment: A Review of Issues, Evidence and Policy," *Urban Studies*, 33, 7-35.

Banister, David. 1997. "Reducing the need to travel," *Environment and Planning B, Planning and Design*, 24, 437-499.

Bhat, Chandra R. and Jessica Y. Guo. 2007. A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. *Transportation Research B*, 41, 5006-5026.

Brownstone, David and Thomas F. Golob. 2009. The impact of residential density on vehicle usage and energy consumption. *Journal of Urban Economics*, 65, 91-98.

Brueckner, Jan K. 2001. "Urban sprawl: Lessons from urban economics," in W.G. Gale and J.R. Pack (eds.), *Brookings-Wharton Papers on Urban Affairs*, Washington, D.C.: Brookings Institution, 65-89.

Bruegmann, Robert. 2005. *Sprawl: a compact history*. Chicago: The University of Chicago Press.

Burchell, Robert W., Anthony Downs, Barbara McCann, and Sahan Mukherji. 2005. *Sprawl Costs. Economic Impacts of Unchecked Development*. Washington, DC: Island Press.

Burton, Elizabeth. 2000. "The Compact City: Just or Just Compact? A Preliminary Analysis," *Urban Studies*, 37, 1969-2001.

Calafati, Antonio G. 2003. "Economia della città dispersa," *Economia Italiana*, 1, 215-231.

Calafati, Antonio G. 2008. "Urban Sprawl Italian Style", *Scienze Regionali – Italian Journal of Regional Science*, 7(3), 99-108.

Calafati, Antonio G. 2009. "Macro-Regions, Local Systems and Cities: Conceptualisation of Territory in Italy since 1950", *Scienze Regionali – Italian Journal of Regional Science*, 8(3), 11-34.

Camagni, Roberto, Maria C. Gibelli, and Paolo Rigamonti. 2002a. *I costi collettivi della città dispersa*. Firenze: Alinea.

Camagni, Roberto, Maria C. Gibelli, and Paolo Rigamonti. 2002b. "Urban mobility and urban form: the social and environmental costs of different patterns of urban expansion," *Ecological Economics*, 40, 199-216.

Carrol, T. O. 1977. "Calculating Community Energy Demand", in R. J. Burby and A. F. Bell (eds.), *Energy and the Community*, Cambridge, MA: Ballinger.

Cervero, Robert. 1996. "Mixed Land-Use and Commuting: Evidence from the American Housing Survey," *Transportation Research A*, 30, 361-377.

Cervero, Robert and Kara Kockelman. 1997. "Travel Demand and the 3Ds: Density, Diversity and Design," *Transportation Research D*, 2, 199-219.

Cervero, Robert and Jin Murakami. 2010. "Effects of built environments on vehicle miles traveled: evidence from 370 US urbanized areas", *Environmental and Planning A*, 42, 400-418.

Cirilli, Andrea. 2010. "Long term urban trajectories in Italy: cities do matter, albeit to different extents", *Review of Economics and Statistics for Regional Studies*, 3/2010, 7-47.

Cirilli, Andrea and Paolo Veneri. 2009. "Urban structure and mobility patterns: towards a taxonomy of the Italian urban systems", *Review of Economics and Statistics for Regional Studies*, 1/2009, 25-61.

Coleman, Alice M. 1985. *Utopia on Trial: Vision and Reality in Planned Housing*. London: Hillary Shipman.

Cutler, David M., Edward L. Glaeser, and Jacob L. Vigdor. 1999. "The Rise and Decline of the American Ghetto," *Journal of Political Economy*, 107, 455-506.

Delgado, Manuel. 1999. *El animal Público*. Barcelona: Editorial Anagrama.

Deurloo, Marinus C. and Sako Musterd. 1998. "Ethnic Clusters in Amsterdam, 1994-1996: A Micro-area Analysis," *Urban Studies*, 35(3), 385-396.

Dieleman, Frans M., Martin Dijst, and Guillaime Burghouwt. 2002. "Urban form and travel behaviour: Micro-level household attributes and residential context," *Urban Studies*, 39, 507-522.

Dubois-Taine, Geneviève and Yves Chalas, eds., 1997. *La ville émergente*. Paris: Editions de l'Aube.

Edwards J. L. 1977. "The effect of land-use on transportation energy consumption," in R. J. Burby and A. F. Bell (eds.), *Energy and the Community*, Cambridge, MA: Ballinger.

Elkin, Tim, Duncan McLaren, and Mayer Hillman. 1991. *Reviving the City: Towards Sustainable Development*, London: Friends of the Hearth.

Ewing, Reid and Robert Cervero. 2001. "Travel and the built environment," *Transportation Research Record*, 1780, 87-114.

Florida, Richard. 2002. *The rise of the creative class*. New York: Basic Books.

Frank, Lawrence D. and Gary Pivo. 1994. "Impacts of mixed land-use and density on the utilization of three modes of travel: single-occupant vehicle, transit, and walking," *Transportation Research Records*, 1466, 44-52.

Giuliano, Genevieve. 1989. "Relationships between Urban Form and Transportation: Implications for Long Range Planning", *Technical Reports*, School of Urban and Regional Planning, University of Southern California.

Giuliano, Genevieve and Dhiraj Narayan. 2003. "Another look at travel patterns and urban form: the US and Great Britain," *Urban Studies*, 40, 2295-2313.

Gordon, Peter and Harry W. Richardson. 1997. "Are Compact Cities a Desirable Planning Goal?," *Journal of the American Planning Association*, 63, 95-106.

Haines, Valerie A. 1986. "Energy and Urban Form: A Human Ecological Critique," *Urban Affairs Quarterly*, 21, 337-353.

Henry, Garbiñe. 2007. "Análisis de costes de la baja densidad. Una lectura desde la sostenibilidad," in F. Indovina (eds.), *La ciudad de baja densidad: lógicas, gestión y contención*, Barcelona: Diputació de Barcelona.

ISTAT and Sforzi, Fabio. 1997. *I sistemi locali del lavoro 1991*, Rome: ISTAT.

Jacobs, Jane. 1961. *The Death and Life of Great American Cities*. New York: Random house.

Levine, John. 1998. "Rethinking Accessibility and Jobs-Housing Balance," *Journal of the American Planning*, 64, 133-148.

Massey, Douglas S. and Nancy A. Denton. 1988. "Suburbanization and Segregation in U.S. Metropolitan Areas," *American Journal of Sociology*, 94, 592-626.

Massey, Douglas S. and Nancy A. Denton. 1993. *American Apartheid: Segregation and the making of the Underclass.* Cambridge, MA: Harvard University Press.

Ministero delle Infrastrutture e dei Trasporti. 2005. *Conto Nazionale dei Trasporti e delle Infrastrutture*. Rome: Istituto Poligrafico e Zecca dello Stato.

Muñiz, Ivan and Anna Galindo. 2005. "Urban form and the ecological footprint of commuting. The case of Barcelona," *Ecological Economics*, 55, 499-514.

Muñiz, Ivan., Miguel Ángel García, and Daniel Calatayud. 2006. "SPRAWL. Definición, causas y efectos". *Document de Treball* No.06.03, Departament d'Economia Aplicada, Universitat Autònoma de Barcelona.

Newman, Oscar. 1972. *Defensible Space*, New York: Macmillan.

Newman, Peter W. and Jeffrey R. Kenworthy. 1989. "Gasoline Consumption and Cities," *Journal of the American Planning Association*, 55, 342-346.

Pouyanne, Guillaume. 2006. "Land use diversity and daily mobility: the case of Bordeaux," *Scienze Regionali*, 5, 5-23.

Sassen, Saskia. (2006), *Cities in a world economy*, Thousand Oaks, CA: SAGE.

Schwanen, Tim, Martin Dijst and Frans M. Dieleman. 2001. "Leisure trips of senior citizens: determinants of modal choice," *Tijdschrift voor Economische en Sociale Geografie*, 92, 347-360.

Secchi, Bernardo. 2005. *La città nel ventesimo secolo*. Rome: Laterza.

Snellen, Danielle, Aloys Borgers, and Harry Timmermans. 2002. "Urban form, road network type, and mode choice for frequently conducted activities: a multilevel analysis using quasi-experimental design data," *Environment and Planning A*, 34, 1207-1220.

Travisi, Chiara M., Roberto Camagni, and Peter Nijkamp. 2010. "Impacts of urban sprawl and commuting: a modelling study for Italy," *Journal of Transport Geography*, 18(3), 382-392.

Trilla, Carme. 2001. "La política d'habitatge en una perspectiva europea comparada," *Col·lecció Estudis Socials*, No. 9, Fundació "la Caixa", Barcelona.

Tsai, Yu-Hsin. 2005. "Quantifying urban form: compactness versus 'sprawl'," *Urban Studies*, 42(1), 141-161.

Tsai, Yu-Hsin. 2001. *Travel-efficient urban form: a nationwide study on small metropolitan areas* Ph.D. dissertation, University of Michigan.

Vance, Colin and Ralf Hedel. 2008. “On the Link Between Urban Form and Automobile Use: Evidence from German Survey Data,” *Land Economics*, 84(1), 51-65.

Veneri, Paolo. 2010. “Urban Polycentricity and the Costs of Commuting. Evidence from Italian Metropolitan Areas,” *Growth and Change*, 41(3), 403-429.