XXX CONFERENZA ITALIANA DI SCIENZE REGIONALI

URBAN POLYCENTRICITY AND THE SOCIAL COSTS OF COMMUTING: EVIDENCE FROM ITALIAN METROPOLITAN AREAS

Paolo VENERI[◊]

[◊] Dipartimento di Economia – Università Politecnica delle Marche, Piazza Martelli 8, 60121, Ancona.
E-mail: p.veneri@univpm.it

SOMMARIO

Polycentricity at the metropolitan scale is perhaps the model of spatial organization that needs to be investigated more thoroughly as regards its effects on travel. The aim of this paper is to test the role of polycentricity – as well as other spatial characteristics, such as compactness, functional diversification and size – on the social costs of commuting. The degree of urban polycentricity has been measured by adopting a dynamic functional approach based on commuting flows and on social network analysis tools. On the other hand, the social impact of mobility has been measured with per-capita CO_2 emissions as external cost and with average time spent travelling as private cost. The analysis is carried out using a database of 82 Italian metropolitan areas. The results show that cities with a higher degree of functional polycentricity are more virtuous both in terms of private and external costs of mobility, while the degree of compactness is associated with lower environmental costs but with higher private costs. Both bigger cities and southern cities are generally less virtuous if compared with those of the centre and the north. The effect of functional diversification turns out to be statistically insignificant.

Key words: polycentricity, commuting costs, urban structure
JEL: Q56, R14, R4

1 INTRODUCTION

The spatial organization of cities and its effects on welfare, economic growth and environmental sustainability has been the subject of increasing attention among economists and other social scientists during the last two decades. In this debate, one of the most relevant topics regards the relation between characteristics of urban spatial organization – i.e. polycentricity, dispersion, size and mixing use – and mobility patterns (Ewing and Cervero, 2001). Mobility yields relevant social costs that include a private component (i.e. fuel and time spent travelling) and an external one (i.e. negative environmental externalities, like global warming and pollution). While the former directly affects the commuters' utility, the latter affects the welfare of the whole society and it is not considered in the individual's travel decisions.

Among the spatial characteristics of cities, the degree of polycentricity is perhaps the one for which most effort must still be made to shed some light on its economic effects and externalities, especially those generated by travel behaviour (Schwanen et al., 2002). The relevance of polycentricity arises from the fact that for more than ten years, polycentric spatial organization has become a normative concept rather than only a positive one. Polycentricity is now considered a planning tool to enhance cities' competitiveness, social cohesion and environmental sustainability (Davoudi, 2003). However, these hypotheses have not yet been empirically investigated enough. Moreover, polycentricity itself needs to be better defined and measured, especially at the metropolitan level. Most of the attempts to measure urban polycentricity in the literature are based on static and morphological approaches, which mainly consider the spatial distribution of employment or of population within metropolitan areas (MAs), without focusing on the functions that each node can play within each MA.

The aim of this paper is to test whether a high degree of urban polycentricity is virtuous in terms of the social costs of mobility and thus can be considered as a desirable planning goal. Trying to answer this question, other relevant characteristics of urban spatial organization have also been considered as potential determinants of the social costs of mobility. More in depth, the role of urban size, dispersion and functional diversity have been assessed.

The analysis of polycentricity at a metropolitan level requires a previous definition and the identification of sub-centres. From a morphological perspective, urban sub-centres are usually identified with employment density thresholds. In this paper an attempt is made to identified sub-centres after having defined them from a functional perspective rather than from a morphological one. In this way, urban sub-centres are

defined as places with central functions that organize the territory around them. Their identification is hence carried out using dynamic approaches based on social network tools of analysis with which it is possible to catch the functions played by urban nodes and their hierarchic ranking.

In section 2, a review of the literature on the relationship between urban structure and mobility patterns is carried out, with particular attention on the role of polycentricity. Section 3 defines the concept of polycentricity and proposes two indicators – for reasons of robustness – to measure it suitably. Section 4 reviews the commuting patterns in the Italian metropolitan areas and proposes two indicators to measure, respectively, external and private costs related to mobility. The former has been measured by focusing on CO_2 emissions, while the latter has been approximated by focusing on the time spent travelling. In section 5 the causal links between characteristics of urban spatial structure and social costs of mobility are explained and then tested empirically with an econometric cross-section analysis. Section 6 concludes.

2 LITERATURE: A STILL OPEN DEBATE

The role of urban structure is now recognised as an important factor in facilitating travel, since it provides the framework for the location of houses and firms (Hickman and Banister, 2007). The characteristics of spatial organization that are supposed to be the most relevant in shaping commuting patterns at a metropolitan level are basically polycentricity, dispersion, mixing use and size (Tsai, 2001).

2.1 Polycentricity and commuting

Polycentricity is perhaps the characteristic on which knowledge is less consolidated among scholars, regarding its effects on commuting patterns (Aguilera, 2004; Levine, 1992; Schwanen et al. 2002). Some authors (Gordon and Wong, 1985; Tsai, 2001) argue that polycentricity has virtuous effects on mobility patterns. This has been put forward for several reasons.

Firstly, polycentric metropolitan organization favours the proximity between work and house places - the so called 'co-location hypothesis' (Gordon and Wong, 1985 - p. 666), reducing the distance travelled (Handy, 1996). Distances can be reduced also because of the lower rent near sub-centres if compared with monocentric areas (Cervero

and Wu, 1997), encouraging housing near the place of work. However, increasing frictions in residence mobility can in part compensate these effects.

Secondly, polycentric areas can favour the competitiveness of mass transit (Breheny, 1995; Susilo and Maat, 2007), reducing the use of less-sustainable private means of transport (e. g. cars, motorbikes, etc.). Sub-centres, in fact, assure a minimum dimensional scale for the supply of a competitive public transport system. Moreover, the use of mass transit usually increases when mobility follows a cross-commuting pattern, which is typical of polycentric metropolitan areas (Susilo and Maat, 2007 - p. 606).

Thirdly, polycentricity can also influence the time spent travelling. Polycentric urban structures are thought to reduce the excessive congestion that characterizes monocentric areas, especially those of big dimension (Parr, 2004 - pp. 235-236). Diseconomies of congestion can be avoided through the distribution of population, employment and urban functions in several sub-centres, without renouncing the advantages of agglomeration. In other words, polycentricity can be interpreted as a fair compromise between the need for safe urban compactness and the need to lighten congestion, while the city is growing.

Despite the above mentioned arguments that make polycentricity a potentially desirable planning goal, only a few empirical analysis have been carried out to corroborate such hypotheses. What is more, the available empirical works show quite contrasting results, so that the relation between polycentricity and the costs of mobility still remains unclear. In a work on the metropolitan area of San Francisco, for example, Cervero and Wu (1998) find that decentralization of employment in several sub-centres is associated with an increase in commuting distances and in car drivers. Other scholars find similar results, even for European cases (Aguilera, 2005; Aguilera and Mignon, 2004; Levinson and Kumar, 1994; Næss, 2007). Schwanen et al. (2004), in an analysis of Dutch urban system, show that polycentric cities - if compared with monocentric ones - are associated with longer commutes, both in terms of time and distance.

On the other hand, other studies show that decentralization of employment tends to reduce commuting time, both in Europe (Alpkokin et al., 2005; Owens, 1986) and in United States (Gordon et al., 1991; Tsai, 2001). Even regarding the share of mass transit users, contrasting results can be found. In particular, several studies show that the progressive transformation of cities from monocentric to polycentric is associated with a decrease of public transport users (Schwanen et al., 2002; Næss, 2007; Cervero and Wu, 1998), while others show the contrary (Bento et al., 2005).

These contrasting results are at least partially due to the way in which the concept of polycentricity is defined and measured. In almost all the cases, polycentricity is

intended to be the result of a mere process of decentralisation from the CBD to the emergent sub-centres. In this perspective, a sub-centre is simply defined as a place with an employment density that is higher than the surrounding territory. This interpretation can be sound for North-American cities, while it is less appropriated for European ones, where urban areas formed mostly through a process of coalescence rather than decentralization (García López and Muñiz, 2005; Calafati, 2002). As a consequence, the analysis of urban polycentricity in European cities must take into account a more complex definition of urban centres, which can be interpreted as high-hierarchy places that supply central functions to the surrounding territory. Hence, the simple density-based approach does not seem to be correct (Veneri, 2008).

In addition, the longitudinal dimension of most of the empirical analyses can play a significant role in explaining the ambiguity of the results. The fact that in the last twenty years an important phenomenon of decentralisation has occurred, in tandem with an increase of commuting distance travelled does not necessarily mean that polycentricity yields worse commuting patterns. Taking into account such a long time period, many other factors can explain differences in commuting patterns. Technological progress, expansion of circadian cycles, increase of car-drivers and changing preferences are only some examples of such factors. The relation between the degree of polycentricity and the costs of mobility can be better evaluated through a cross-sectional analysis of different areas with different urban structures, but at the same time *t*. This allows *ceteris paribus* reasoning.

2.2 The role of the other spatial characteristics

In addition to polycentricity, other spatial characteristics of cities can shape commuting patterns and their social costs. Firstly, urban dispersion is considered one of the most important spatial determinants of the increase in commuting distances (Banister, 1999), mass transit inefficiency (Ellison, 1995) and energy consumption (Newman and Kenworthy, 1989; Næss, 1995; Cirilli and Veneri, 2007). There is already quite a wide consensus among scholars over the disequilibria and externalities - especially the environmental ones - generated by low density settlements and scattered patterns of urban development (Calafati, 2003). On the other hand, the effects on private costs, like the time spent travelling, are still unclear.

Functional diversification represents another characteristic of urban spatial organization that can be important in shaping commuting patterns within cities. An urban area is functionally diversified if it presents a job-housing balance or, more

generally, a diverse or mixed land-use (Cervero, 1996; Camagni et al., 2002). Jane Jacobs (1961) was one of the major advocates of such a model of spatial organization, even for cities' economic prosperity and safety. The empirical literature shows that the higher the level of diversity is, the shorter is the distance travelled (Cervero, 1996) and the higher is the transit usage (Frank and Pivo, 1994). In an analysis of six Italian metropolitan areas, Travisi and Camagni (2005) show that the collective costs of mobility decrease in cities with higher density and mixed land-use.

Another key-factor in shaping commuting patterns is the generalised deregulation of house building that occurred in Europe during the last twenty years. This, together with changed individual preferences and the full diffusion of the car, combined to bring about less transit oriented cities and longer commuting distances. Newly built areas are often planned without taking enough into account the needs for an efficient mass transit service, yielding scattered and high land-consumption settlements. Hence, the rapidity of the house building process seems to be associated with less sustainable mobility patterns (Camagni et al., 2002). Cirilli and Veneri (2007) in an analysis of the major Italian Local Labour Systems show that the newer the house-stock, the higher the impact of mobility.

3 URBAN FUNCTIONAL POLYCENTRICITY: CONCEPT AND MEASURE

Polycentricity is emerging as an archetypal model of spatial organization of cities or metropolitan areas (Anas et al., 1998). Polycentric areas can be conceptualized according to two main dichotomies, depending on the perspective adopted. On the one hand, adopting a pure morphological approach, polycentric areas can be viewed as a middle way model of spatial organization between traditional compact cities and urban sprawl. They maintain the advantages related to compact cities, complying with the spontaneous tendencies to dispersion (Camagni et al., 2002 – p. 52). On the other hand, adopting a both functional and morphological approach, polycentric areas represent the alternative to monocentric areas (Meijers and Sandberg, 2008). Hence, polycentricity is considered as the natural evolution of monocentric spatial organization. However, polycentricity can be the result of two different territorial evolutions. The first consists in the decentralization processes from the Central Business District (CBD) to new emerging sub-centres. This pattern took place with particular intensity in U.S. cities. The second, that prevails in European cities, consists of a progressive integration of pre-existing self-contained centres in a single metropolitan area, through a coalescence (Calafati, 2002) or incorporation (Champion, 2001) process.

Using a traditional morphologic approach, an urban area can be defined polycentric if its employment is not concentrated in a single centre (Riguelle et al., 2007 – p. 195), but it is distributed in two or more centres. Adopting a functional approach, on the other hand, the focus is not only on the distribution of employment, but – more generally – on the spatial distribution of functions. With the functional approach, territorial units within an urban area must show two or more nodes or 'centres' with a higher hierarchical level. Given that, the definition of polycentricity at the urban level appears quite simple and should not be a matter of debate. Instead, the concept of sub-centre needs more attention. While from a morphological perspective a centre is simply a place with a higher employment density than the hinterland, from a functional point of view a centre is a place that carries out central functions and that organizes the surrounding territory. In the latter case, the focus is on the functions provided by sub-centres and on their hierarchic ranking. Thus, following the framework of the Central Places Theory (Christaller, 1933; Lösch, 1940), sub-centres represent the focal points of urban areas.

The first step to measure the degree of urban polycentricity consists in the identification of sub-centres. For this purpose, there are a lot of studies that use density-based approaches, especially in U.S. literature. Some of them use simple absolute cut-offs of employment density and of total employment for census tracts within metropolitan areas (Giuliano and Small, 1991; Cervero and Wu, 1998; Anderson and Bogart, 2001). Other more sophisticated studies use relative density based approaches, usually through the estimation of the local peaks of a density function, which often has a non-parametric specification (McDonald and Prater, 1994; Craig and Ng, 2001).

Another family of approaches to identify urban sub-centres is based on 'dynamic' indicators, which are built using flow data, such as commuting flows (Bourne, 1989). In a study of Spanish metropolitan areas, Burns et al. (2001) use a threshold of net entry flow of commuters (15%) above which an area can be thought of as a sub-centre. They also add an absolute population dimension cut-off of 10 000 residents, in a similar way to Giuliano and Small’s approach (1991). Dynamic approaches appear to be more appropriate for European urban areas, which are often the result of an integration process that involve pre-existing territorial units, that simply changed their hierarchical position and the way in which they relate with the surrounding territory. Looking at the relational aspects (flow data) rather than at simply static features (e.g. density) it is possible to better understand the capacity of a territorial unit to organize the territory.

In this work, sub-centres of Italian MAs have been identified using a social network analysis approach, following the methodology proposed in Veneri (2008). Some indicators of social network analysis, in fact, can be easily translated to urban

economics, allowing a mathematical characterisation of the relationships between cities (Boix, 2003).

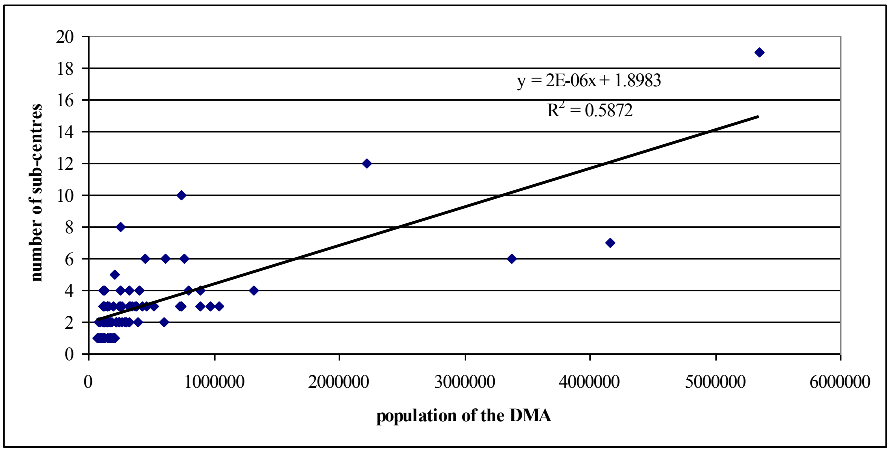
The above mentioned approach starts conceptualizing MAs as networks of municipalities – composed of nodes (municipalities) and links (flows of commuting) – and then it uses the in-degree index. More in depth, for each municipality within each metropolitan area, the in-degree index has been computed using commuting flows data in 2001. The in-degree index measures the number of links that go towards a given node (municipality) and it represents a simple, direct and stable measure of centrality among a given network's set of nodes (Costembader and Valente, 2003 – p. 291; Zemljič and Hlebec, 2005 – p. 82). Such an indicator can be calculated using the following formula:

$$I_j = \sum_{i=1}^{N} z_{ij} \qquad (1)$$

where I_j is the in-degree indicator for the municipality j of a given metropolitan area; z_{ij} is the number of links towards the municipality j from the N municipalities of the same metropolitan area under analysis.

Once having ranked all the municipalities by the value of the in-degree index, those belonging to the 95th percentile has been selected and considered as sub-centres, as in Veneri (2008). In this way, all municipalities that show a high attractiveness in terms of labour flows can be considered as 'central places', without considering any density-based measure. Then, the degree of urban polycentricity has been quantified on the basis of the assumption that – taking into account the size differences among MAs – the higher the number of sub-centres in a given MA, the higher its level of polycentricity.

Figure 1 Scatter plot with MAs' population and number of sub-centres



Source: Istat Census, 2001

Hence, a scatter-plot between the number of identified sub-centres and population has been drawn (Figure 1), together with a line that interpolates the two variables. Each point in the graph represents an MA with its number of sub-centres and residents. The distance between the line and each point can be interpreted as a direct measure of an MA's degree of polycentricity.

In order to add robustness to the measurement of polycentricity, another indicator has been applied – called Special Functional Polycentricity (P_{SF}) (Green, 2007). Again, this index employs a dynamic approach based on tools of social network analysis and it is computed using commuting flows. The P_{SF} index – whose values range from 0 to 1 – can be calculated as follows:

$$P_{SF}(N) = (1 - \frac{\sigma_{\partial}}{\sigma_{\max}}) \cdot \Delta \qquad (2)$$

where $\sigma_{ð}$ is the standard deviation of nodal in-degree within the MA N; $\sigma_{ð\max}$ is the standard deviation of the nodal in-degree of a 2-node network (n_1, n_2) derived from N where d_{n1} = 0 and d_{n2} = value of the node with highest value in N; Δ is the density of the network (Green, 2007 – p. 2085)[1]. Higher values indicate a higher degree of functional polycentricity.

4 THE SOCIAL COSTS OF COMMUTING IN THE ITALIAN METROPOLITAN AREAS

4.1 Mobility for working reasons in Italy

Before analysing the relationship between spatial characteristics and commuting costs it is worth exploring the patterns of mobility in Italy through simple descriptive statistics. The units of analysis are 82 Italian metropolitan areas, which are identified applying the functional algorithm based on the Federal Register's SMA methodology (Office of Management and Budget, 1990), with the adaptations of Clusa and Roca (1997). A

[1] Networks are metropolitan areas and nodes are municipalities. Original matrixes, containing the number of commuters from municipality *i* to municipality *j*, have been transformed into binary four nearest neighbour matrixes (with a minimum cut-off value of 5 commuters between municipality *i* and *j*).

complete mapping of Italian MAs using this approach can be found in Boix and Veneri (2008).

Within the 82 MAs that have been considered in this analysis, a great amount of people (almost eleven million) travel every day for working reasons. As regarding the mode choice, table 1 shows that the most used mean of transport is the private car (63.59 %). On the whole, private means of transport are much more used than public means. Among the latter, buses play a major role, followed by trains.

On average, distances travelled with public means of transport are longer than those with private means (Table 2). Moreover, it appears that the share of mass-transit users increases with average distances travelled. In other words, it seems that public transport becomes convenient when the distance to be travelled is longer.

Table 1 Modes of commuting within Italian MAs. Absolute and percentage values

Mode	Mode description	abs. Value	% value
1	Train	184,137	1.68
2	Tram	80,684	0.74
3	Underground	170,011	1.55
4	Urban bus or trolley bus	461,937	4.22
5	Extra urban bus or coach	153,504	1.40
6	School or business bus	67,744	0.62
	Public transport	*1,118,017*	*10.23*
7	Private car (driver)	6,952,851	63.59
8	Private car (passenger)	511,400	4.68
9	Motorbikes or scooter	689,287	6.30
10	Bike, foot or other means of transport	1,662,219	15.20
	Private transport	*9,815,757*	*89.77*
	Total transport	*10,933,774*	*100.00*

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

Table 2 Distances travelled by duration class (in minutes) and by mode class within MAs.

Time spent	Mode	Commuters	%	av. Km*
0 - 15	private	4,104,296	44.3	10.4
	public	119,007	1.3	13
15 - 30	private	2,781,277	30.0	15.5
	public	369,630	4.0	15.9
30 - 60	private	1,122,150	12.1	22.7
	public	474,610	5.1	21.4
> 60	private	145,815	1.6	27.9
	public	154,770	1.7	31.1
		9,271,555	100.0	

Source: Istat Census data (2001); Distances computed with GIS software.

Table 3 Distances and durations of travels by mode class within MAs.

Means of transport	commuters	% commuters	average duration (minutes)	av. distance travelled (kilometres)
Public transport	1,118,017	10.2	38	10.4
Motorized private transport	8,153,538	74.6	19	8.3
Bike, on foot, other	1,662,219	15.2	10	2.6
Total	10,933,774	100	22	7.1

Source: Istat Census data (2001); Distances computed with GIS software.

Another point to highlight is that, on average, travel duration with private means of transport is much shorter if compared with public transport (Table 3). This could be due to two different reasons. First, mass-transit users commute longer distances, hence they take more time to get to their destination. However, this factor alone can hardly explain all the difference in terms of time spent travelling. Thus, another factor could be the minor time efficiency of public means, probably due to the fact that reaching the bus or train station from the traveller's home takes a relevant amount of time, as well as reaching the destination once off the train. The relative speed of private means can also play a role.

4.2 The private and external costs of commuting

This analysis relies on verifying whether polycentric spatial organization influences the social costs of mobility within metropolitan areas. Two main components of the social costs of mobility have been considered in this analysis. The first regards the environmental externalities associated with commuting flows, such as pollution and CO_2 emissions. The impact of mobility in terms of CO_2 emissions have been measured with the Environmental Impact of Mobility (*EIM*) on the base of mode choice and distance travelled by commuters. The *EIM* index has been calculated as follows:

$$EIM_h = \frac{\sum_{i,j,k} f_{i,j,k} w_k d_{ij}}{\sum_{i,j,k} f_{i,j,k}} \qquad (3)$$

where $f_{i,j,k}$ is the number of commuters moving from municipality i to municipality j (within MA h), which use the k-th mean of transport; w_k is the amount of CO_2 emissions (in grams) per passenger per kilometre, as estimated by Amici della Terra and Trenitalia (2005)(see table 4); finally, d_{ij} is the distance between the two municipalities. The *EIM* index gives a measure of the average quantity of greenhouse gases of the type-commuter in each Italian MA.

Table 4 Per passenger per Kilometre CO_2 emissions by means of transport

Mean of tranport	gr CO2/pkm
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 and Trenitalia

The second component of the social impact of mobility regards the internal costs that directly affect commuters. Given their internal nature, these costs directly affect the commuters' utility, influencing their mode choice. However, they can be considered as social costs, since they are influenced by a systemic inefficiency (Kapp, 1950). Private commuting costs can embody ticket and fuel prices as well as time spent travelling. Given the limited availability of data, in this work we considered only the type traveller's average commuting time (*ACT*) for each MA. The *ACT* index has been calculated as in formula [4], using the Italian's National Statistics Institute's data of Commuting in 2001.

$$ACT_h = \frac{\sum_{i,j,k} f_{ijk} t_k}{\sum_{i,j} f_{ij}} \quad (4)$$

where $f_{i,j,k}$ is the number of commuters moving from municipality i to municipality j (within MA h), which spend a time k travelling; t_k is the duration class of the commute. For each of the four classes we considered the average value, as showed in table 5.

Table 5 – Time length of commuting and their average value

Time lenght classes (in minutes)	Time lenght considered (in minutes)
0 - 15	7.5
15 - 30	22.5
30 - 60	45
more than 60	75

Source: elaboration on Istat Commuting data (Istat, 2001)

5. THE SPATIAL DETERMINANTS OF THE SOCIAL COSTS OF COMMUTING

The aim of this paragraph is to test to what extent characteristics of urban spatial structure influence the external (*EIM*) and private (*ACT*) costs of mobility. The idea that has to be tested is that the social costs of commuting (*impact*) are a function of characteristics of spatial structure, as represented in formula (5).

$$impact = f\,(polycentricity, compactness, mixité, size, controls) \qquad (5)$$

The logical relations that have been estimated are graphically represented in figure 2, where left and right rectangles identify exogenous and dependent variables respectively. Urban spatial features can be grouped in four categories, as done in Tsai (2005). The first one is the MAs' degree of polycentricity. Sub-centres present a dimensional scale that facilitates the competitiveness of mass transit (Breheny, 1995). Hence, a polycentric structure can facilitate a more intense use of public transport systems, which in turn negatively affects the external costs of mobility through a minor impact in terms of CO_2 emissions (Amici della Terra and Trenitalia, 2005).

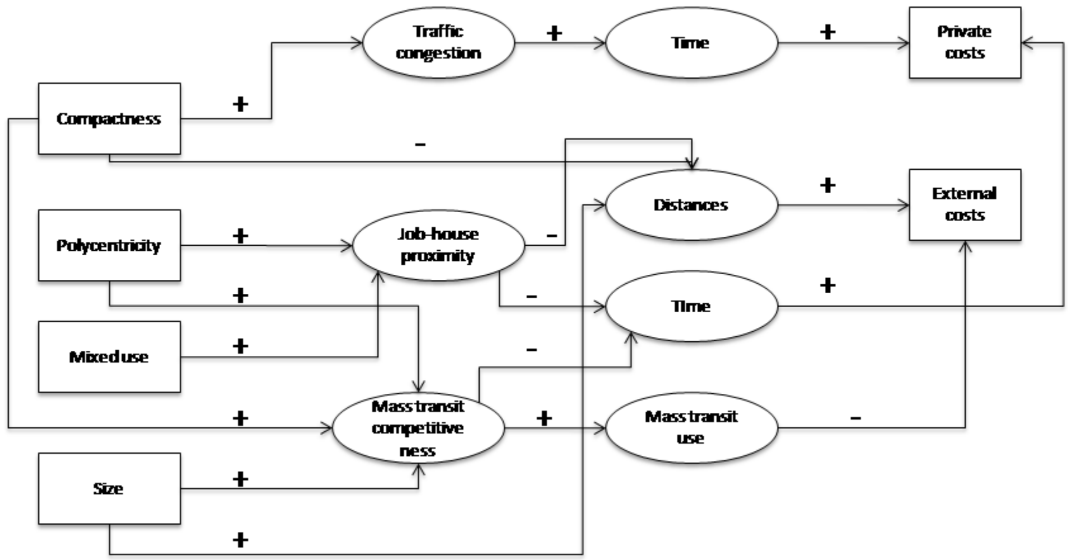
Polycentricity, according to the co-location hypothesis (Gordon and Wong, 1985), also increases job-house proximity. The presence of several sub-centres, in fact, increases the probability of finding a job near the place of residence. This, in turn, allows a reduction in distances and time spent travelling, with virtuous effect on the social costs of mobility.

Urban compactness is also relevant in shaping commuting patterns and its social costs. Compact cities, whose degree of compactness is usually measured with residential density, cause shorter travel time, thanks to a higher spatial concentration of houses and job places. Moreover, urban compactness enhances the competitiveness of a mass transit system (Ellison, 1995). On the other hand, the higher the cities' compactness, the higher their level of traffic congestion, which in turns causes an increase in the private costs of commuting.

Another variable of urban spatial structure that can influence commuting patterns is the functional diversification of the territory (*mixité*) (Camagni et al., 2002). More in depth, a mixed land use favours the proximity between places of living and working. Metropolitan areas with mixed land use are generally characterised by an adequate

equilibrium – within its territory – between residential and economic functions, integrating, rather than segregating them spatially. Thank to a reduction in the distance between jobs and homes, functional diversification reduces the length of travel and, as a consequence, the external (environmental) costs of commuting.

Figure 2: Urban spatial structure and costs of mobility: a qualitative model



The last urban spatial characteristic that affects travel behaviour is city-size (Handy, 1996). More in depth, the total city surface area influences the average distance that has to be travelled, as well as the amount of time spent travelling. Moreover, big cities are expected to present an advantage in supplying efficient mass-transit systems, since it is possible to reach minimum economies of scale that are necessary to justify big investments and expensive infrastructures.

Beyond the major spatial factors, a set of controls have been included in the analysis in order to take into account non-spatial determinants that can play a role in shaping commuting patterns. The inclusion of such elements permits a better interpretation of the empirical results and helps to avoid, or at least to reduce, problems of omitted variables.

The first element is a measure of the average age of the housing-stock, which has been computed through the number of houses built after 1982 over the total number of houses. The underlying idea departs from the fact that in the last decades the speed of house-construction has increased (Muñiz et al., 2006), but new settlements have been planned with not enough attention to the proximity to mass-transit service, in a general context of de-regulation and urban dispersion (Camagni et al., 2002). As a matter of

fact, cities with a higher share of new houses are expected to be less efficient in terms of the external costs of commuting.

The relative competitiveness of mass-transit service in comparison to private means of transport can also play a role in shaping the social costs of commuting, both private and external. High mass-transit competitiveness can boost the share of commuters that use these means of transport and can reduce the time spent travelling. Other controls that have been included in the analysis regard the geographical localization of metropolitan areas within Italy. As is well known, there are quite big economic, cultural and technological differences among Italian macro-regions. The use of territorial dummies allows these differences, although somewhat approximately, to be taken into account.

5.1 The empirical analysis

In order to test these hypotheses, a cross-section econometric model has been carried out using the above-mentioned 82 MAs as units of analysis. All the independent variables have been computed drawing on the Istat Population Census (1981,2001) and the Istat Industry and Services Census (2001). Dependent variables has been computed as explained in section 4 (formulas 3 and 4). Table 6 lists all the regressors, with a short description and measurement explanation.

Table 6 Variables used in the econometric model

Variable name	Underlying spatial dimension	Description
polyc_green	Functional polycentricity	Special Functional Polycentricity index (Green, 2007)
polyc_nsr	Functional polycentricity	"Relative sub-centre number" index of functional polycentricity (section 3)
gini_area_job	Spatial concentration of employment (morphological polycentricity)	sum, for each municipality within a MA, of the differences in absolute value between the area and the employment shares of that municipality over the whole MA
ldensity	Urban compactness (inverse measure)	log of the gross density (inhab./km^2)
gini_pop_job	Fuctional diversification - mixed land-use	sum, for each municipality within a MA, of the differences in absolute value between the population and the emloyment shares of that municipality over the whole MA
house_age	Age of the housing stock	Number of houses built after 1982 over the total number of houses in 2001
rel_pub_comp	Mass transit competitiveness	average km/h with mass transit over average km/h with private means of transport
area	Size	total MA's area (km$^{2)}$
dummy_centre	Geographic localization	MAs of Central Italy
dummy_south	Geographic localization	MAs of Southern Italy

Sources: elaboration on Istat Population Census (1981, 2001) and Industry and Services Census (2001)

As regarding polycentricity, an additional variable of morphological distribution of population and employment within urban territory has been included (*gini_area_job*).

More in depth, it has been calculated through the Gini index between the share of a municipality's *i* area and its share of employment, as suggested in Tsai (2005). The higher the variable, the more concentrated the employment within each MA. In the same way, the degree of mixed land-use (*gini_pop_job*) has been approximated with the Gini index between the shares of resident population and the shares of jobs in each municipality area within each MA. The higher the index, the less functionally diversified the MA.

Two cross sectional econometric models have been estimated. The first regards the external (environmental) costs (*EIM*), while the second uses as dependent variable the private costs (*ACT*). Coefficients of the former model have been estimated through a spatial lag model, in order to clean the residuals from spatial dependence problems[2]. This estimation is carried out with a maximum likelihood approach, weighting observation with a spatial matrix of proximity. The model 2, on the other hand, has been estimated through an OLS method with robust standard errors[3]. All the variables have been standardized with zero mean and unit variance so as to give a better interpretation of coefficients. Results are shown in table 7.

Regarding model 1, both the coefficients associated to the variables of functional polycentricity are negative and statistically significant. This result is confirmed by the coefficient relative to the *gini_area_job* variable, which tells us that the more concentrated the population within MAs, the lower the EIM indicator. These findings allow us to corroborate the hypothesis that a higher degree of polycentricity can reduce the external costs of commuting in terms of average CO_2 emissions per traveller. The effect of polycentricity on the average time-length is also negative, but not statistically significant. Hence, it is cannot be said that a higher degree of polycentricity makes the journey shorter. This result is in accord with Levinson (1998), for whom the change in urban structure does not affect travel times. However, the coefficient of the *gini_area_job* variable tells us that the more concentrated the population is, the longer the commutes.

[2] The spatial lag model has been carried out because of the spatial autocorrelation of residuals that emerged with the OLS estimator, as tested by Moran's *I* index. Robust LM test of spatial autocorrelation suggested using a spatial lag model, rather than a spatial error model (SEM). The residuals of the spatial lag, on the other hand, do not show spatial autocorrelation of residuals anymore, so that coefficients are consistent. The results are robust to the change of the weight matrix.

[3] There are not any problems of residual's spatial auto-correlation for model 2, since the Moran *I* is not significant, checking these results with different weighting matrixes.

Table 7 Estimation results

	Spatial lag models (ML)		Robust OLS	
dep. variable	EIM	EIM	ACT	ACT
polyc_green	-0.37 ***		-0.14	
	0.00		0.18	
polyc_nsr		-0.21 ***		-0.10
		0.00		0.10
gini_area_job	-0.22 ***	-0.25 ***	0.21 ***	0.20 **
	0.00	0.00	0.01	0.02
ldensity	-0.31 ***	-0.47 ***	0.56 ***	0.50 ***
	0.00	0.00	0.00	0.00
gini_pop_job	-0.11	-0.32 ***	0.22 *	0.14
	0.33	0.00	0.09	0.18
area	0.66 ***	0.59 ***	0.63 ***	0.61 ***
	0.00	0.00	0.00	0.00
house_age	0.04	-0.03	-0.08	-0.11 *
	0.64	0.72	0.17	0.06
rel_public_comp	-0.07	-0.08	-0.12 **	-0.12 **
	0.31	0.20	0.05	0.05
dummy_centre	0.26	0.26	-0.10	-0.11
	0.18	0.19	0.54	0.48
dummy_south	0.70 ***	0.95 ***	-0.08	0.00
	0.01	0.00	0.76	0.98
_cons	-0.32 **	-0.40 ***	0.06	0.04
	0.03	0.00	0.68	0.77
rho	0.22	0.24		
	0.04	0.02		
n. obs.	82	82	82	82
Adj. R2	0.694	0.691	0.753	0.755
lik	-66.86	-67.12	-53.64	-53.3
aic	157.73	158.24	127.3	126.6
bic	186.61	187.12	151.36	150.67

Source: our elaboration on Istat Census data (2001)

Estimation results show that urban compactness is an important factor in explaining commuting costs. A higher density causes more sustainable mobility patterns in terms of CO_2 emissions, but less sustainable patterns in terms of time spent commuting. The effect of density on commuting time is in accord with the results of Glaeser and Kahn (2004) and Levinson and Kumar (1997) for U.S. MAs. Following these authors, this result is due, at least in part, to a congestion effect that arises in high density cities. Hence, a trade-off between external and internal costs comes out and the net effect of density is still unknown.

Regarding urban functional diversity, its effects on mobility costs remain unclear. Despite the fact that the coefficients of the mixing-use variable (*gini_pop_job*) are negative for the external costs' model, their statistical significance is lacking for one of the two specifications. Thus, it cannot be stressed enough that functional diversification

has an effect on the external costs of commuting. The same results appear for private costs specifications, in which coefficients are always insignificant, though in this case the sign of the relationship is positive.

Urban size is probably the most important factor that determines social costs of mobility. As was expected, higher dimension is associated with higher social costs, both in terms of CO_2 emissions and time spent travelling. This results can be explained by the longer distances that have to be travelled, on average, in larger metropolitan areas, which affect both time and emissions.

As regarding the other factors of control, it appears that the age of the housing stock does not have a statistically significant effect. Coefficients of the dummy variable relative to the MAs' geographic localization are also insignificant, except for the south MAs for the external costs specifications. Southern cities, in fact, show a higher impact in terms of CO_2 emission. This can be due to longer distances or to the scarce use of public means of transport. On the other hand, a higher relative competitiveness of a mass transit system is associated with shorter commuting times, as the coefficient of the *rel_public_comp* variable shows.

Finally, in the spatial lag model the spatial parameter (*rho*) is positive and significant, showing that a proximity effect works. In other words, neighbouring MAs have similar characteristics that are not caught by the model's regressors, but that can be associated to other factors related to proximity (e.g. cultural and technological factors).

6. CONCLUDING REMARKS

Contemporary metropolitan areas are characterized by an increasing degree of polycentric spatial structure. The polycentric paradigm promotes this concept as a planning tool to enhance local competitiveness and sustainability. However, polycentricity is not yet a well-defined concept and its effects on competitiveness and sustainability still needs to be investigated from a positive perspective, even before a normative one.

The contribution of this work relies firstly on the formal definition of polycentricity at the metropolitan scale and on its quantitative measurement for comparative analysis. Secondly, and more deeply, it sheds some light on the relationship between the degree of urban polycentricity and the social costs of commuting.

The concept of polycentricity, after having been defined from a functional perspective, has been measured with apposite indicators based on tools of social

network analysis. A novel indicator of polycentricity has been introduced, but another one has been also computed for reasons of robustness.

In carrying out an analysis on 82 Italian urban areas, the results show that polycentricity is a sustainable model of urban spatial structure, especially from an environmental perspective, since it allows a reduction of CO_2 emissions due to commuting. The results are robust to two different measures of polycentricity and they are also in accord with morphological indicators of population distribution within urban areas. However, the degree of polycentricity seems not to influence the private costs of commuting, such as the time spent travelling.

Considering other characteristics of urban spatial structure, it appears that urban dispersion causes higher external costs, but smaller private costs. Hence, a trade-off seems to emerge between the need to contain collective costs of mobility (such as pollution and greenhouse gases) and the necessity to accomplish individual preferences towards low-density living styles.

References

Aguilera, A. (2005). Growth in commuting distances in French polycentric metropolitan areas: Paris, Lyon and Marseille. *Urban Studies* 42, 1537-1547.

Aguilera, A. and Mignot, D. (2004). Urban Sprawl, Polycentrism and Commuting. A Comparison of Seven French Urban Areas. *Urban Public Economics Review* 001, 93-113.

Alpkokin, P., Hayashi, Y., Black, J. and Gercek, H. (2005). Polycentric Employment Growth and Impacts on Urban Commuting Patterns: case study of Istambul. *Journal of Eastern Asia for Transportation Studies* 6, 3835-3850.

Amici della Terra e Trenitalia (2005). I costi ambientali e sociali della mobilità in Italia. Quinto rapporto: Amici della Terra.

Anas, A., Arnott, R. and Small, K. A. (1998). Urban Spatial Structure. *Journal of Economic Literature* XXXVI, 1426-1464.

Anderson, N. B. and Bogart, W. T. (2001). The Structure of Sprawl. Identifying and Characterizing Employment Centers in Polycentric Metropolitan Areas *American Journal of Economics and Sociology* 60, 147-169.

Banister, D. (1999). Planning More to Travel Less. *Town Planning Review* 3.

Bento, A. M., Cropper, M. L., Mobarak, A. M. and Vinha, K. (2005). The Effects of Urban Spatial Structure on Travel Demand in the United States. *The Review of Economics and Statistics* 87, 466-478.

Boix, R. and Veneri, P. (2008). Identification of Metropolitan Areas in Spain and Italy. *Paper presented at the 48th Congress of the European Regional Science Association.* Liverpool - 27 – 31 August 2008.

Bourne, L. S. (1989). Are New Urban Forms Emerging? Empirical Tests for Canadian Urban Areas. *The Canadian Geographer* 33, 312-327.

Breheny, M. J. (1995). The compact city and transport energy consumption. *Transactions of the Institute of British Geographers, New Series* 20, 81-101.

Burns, M. C., Boix, M. and Roca, J. (2001). Contrasting Indications of Polycentrism within Spain's Metropolitan Urban Regions. In *Paper for the Eight European Estate Society Conference.* Alicante.

Calafati, A. G. (2002). Sistemi locali: esercizi di identificazione. In *Il capitale nello sviluppo locale e regionale*(Eds, Malfi, L. and Martellato, D.). Milano: Franco Angeli.

Calafati, A. G. (2003). Economia della Città Dispersa. *Economia Italiana* 1.

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

Cervero, R. (1996). Mixed Land Use and Commuting: Evidence from the American Housing Survey. *Transport Research A* 30, 361-377.

Cervero, R. and Wu, K.-l. (1997). Polycentrism, Commuting and Residential Location in the San Francisco Bay area. *Environmental and Planning A* 29, 865-886.

Cervero, R. and Wu, K.-l. (1998). Sub-centring and Commuting: Evidence from the San Francisco Bay Area, 1980-90. *Urban Studies* 35, 1059-1076.

Champion, A. G. (2001). A Changing Demographic Regime and Evolving Polycentric Urban Regions: Consequences for the Size, Composition and Distribution of City Populations. *Urban Studies* 38, 657-677.

Christaller, W. (1933). *Die zentralen Orte in Suddeutschland.* Jena: Gustav Fischer Verlag.

Cirilli, A. and Veneri, P. (2007). The impact of commuting-to-work mobility in the Italian urban systems. *Paper presented at the 47th Congress of the European Regional Science Association,* Paris 29th August - 2th September.

Costembader, E. and Valente, T. W. (2003). The stability of centrality measures when networks are sampled. *Social Networks* 25, 283-307.

Craig, S. G. and Ng, P. T. (2001). Using Quantile Smoothing Splines to Identify Employment Subcenters in a Multicentric Urban Area. *Journal of Urban Economics* 49, 100-120.

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

Ellison, R. (1995). Melbourne's Public Transport Service. *Urban Future* 20.

Ewing, R. and Cervero, R. (2001). Travel and the Built Environment: A Synthesis. *Transportation Research Record* 1780, 87-114.

Frank, L. D. and Pivo, G. (1994). Impacts of mixed use and density on the utilization of three modes of travel: single occupant vehicle, transit and walking. *Transportation Research Record* 1466, 44-52.

García López, M. A. and Muñiz, I. (2005). Employment decentralisation: polycentric compaction or sprawl? The case of the Barcelona Metropolitan Region 1986-1996. *Document de Treball - Department d'Economia Aplicada, Universitat Autònoma de Barcelona* 5-11.

Giuliano, G. and Small, K. A. (1991). Subcenters in the Los Angeles Region. *Regional Science and Urban Economics* 21, 163-182.

Glaeser, E. and Kahn, M. E. (2004). Sprawl and Urban Growth. In *Handbook of Regional and Urban Economics*, Vol. 4 (Eds, Henderson, V. and Thisse, J. F.). Amsterdam: North Holland, 2482-2527.

Gordon, P., Richardson, H. V. and Jung, M.-J. (1991). The Commuting Paradox: Evidence from the Top Twenty. *Journal of the American Planning Association* 57, 416-420.

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

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

Handy, S. (1996). Methodologies for exploring the link between urban form and travel behaviour. *Transportation Research D: Transport and Environment* 1, 151-165.

Hickman, R. and Banister, D. (2007). Transport and reduced energy consumption: what role can urban planning play? In *Transport Studies Unit (Ref. 1026).* Oxford: Oxford University Centre for the Environment.

Jacobs, J. (1961). *The Death and Life of Great American Cities.* New York: Random House.

Levine, J. C. (1992). Decentralization of Jobs and Emerging Suburban Commute. *Transportation Research Record* 1364, 71-80.

Levinson, D. (1998). Accessibility and the journey to work. *Journal of Transport Geography* 6, 11-21.

Levinson, D. and Kumar, A. (1994). The rational locator: why travel times have remained stable. *Journal of the American Planning Association* 60, 319-332.

Levinson, D. and Kumar, A. (1997). Density and the Journey to Work. *Growth and Change* 28, 147-172.

Lösch, A. (1954). *The economics of location.* New Haven: Yale University Press.

McDonald, J. F. and Prather, P. J. (1994). Suburban Employment Centres: The Case of Chicago. *Urban Studies* 31, 201-218.

Meijers, E. and Sandberg, S. (2008). Reducing Regional Disparities by Means of Polycentric Development: Panacea or Placebo. *Scienze Regionali* 7, 71-96.

Muñiz, I., García López, M. A. and Calatayud, D. (2006). SPRAWL. Definición, causas y efectos. *Document de Treball - Department d'Economia Aplicada, Universitat Autònoma de Barcelona*.

Næss, P. (1995). *Urban Form and Energy Use for Transport. A Nordic Experience.* Oslo: Nth.

Næss, P. (2007). The impacts of job and household decentralization on commuting distances and travel modes. *Informationen zur Raumentwicklung* Heft 2/3, 149-168.

Newman, P. W. G. and Kenworthy, J. R. (1989). Gasoline Consumption and Cities. *Journal of the American Planning Association* 55, 24-37.

Office of Management and Budget (1990). Revised standards for defining metropolitan areas in the 1990s. *Federal Register* 55, 12154-12160.

Owens, S. (1986). *Energy, Planning and Urban Form.* London: Pion.

Parr, J. (2004). The Polycentric Urban Region: A Closer Inspection. *Regional Studies* 38, 231-240.

Riguelle, F., Thomas, I. and Verhetsel, A. (2007). Measuring Urban Polycentrism: a European Case Study and its Implications. *Journal of Economic Geography* 7, 193-215.

Schwanen, T., Dieleman, F. M. and Dijst, M. (2004). The impact of metropolitan structure on commute behavior in the Netherlands: a multilevel approach. *Growth and Change* 35, 304-333.

Schwanen, T., Dijst, M. and Dieleman, F. M. (2002). A microlevel analysis of residential context and travel time. *Environment and Planning A* 34, 1487-1507.

Susilo, Y. O. and Maat, K. (2007). The influence of built environment to the trends in commuting journeys in Netherlands. *Transportation* 34, 589-609.

Travisi, C. M. and Camagni, R. (2005). Sustainability of Urban Sprawl: Environmental-Economic Indicators for the Analysis of Mobility Impact in Italy. *Nota di Lavoro - Fondazione Enrico Mattei* 102.

Tsai, Y.-H. (2001). Travel-efficient urban form: a nationwide study on small metropolitan areas. In *Dissertation.* Ann Arbor, MI: University of Michigan.

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

Veneri, P. (2008). Polycentricity in the Italian Metropolitan Areas: a Dynamic Approach. *Paper presented at the XXIX Italian Conference of Regional Science.* Bari - 24-26th September 2008.

Zemljič, B. and Hlebec, V. (2005). Reliability of measures of centrality and prominence. *Social Networks* 27, 73-88.