"Sub-Centres and mobility patterns: A study on Social and Environmental Costs due to Commuting in the Barcelona Metropolitan Region"

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ABSTRACT:
The literature over the last decades has reinforced the idea that the urban spatial structure generates important positive economic, environmental and social effects. Starting from previous contributions to this field of research, this paper tries to examine these effects by focusing on the urban spatial structure by means of analyzing sub-centre influence what entails a new perspective of empirical analysis (intra-metropolitan scale) compared to the current literature studies based on inter-urban areas or inter-metropolitan scale.
Therefore, the aim of this paper is to determine whether urban sub-centres exert an influence on the social and environmental costs due to resident-to-work commuting in the Barcelona Metropolitan Region, and if so, how it is this relationship to define future sustainable policies. The issue is addressed through an analysis of the social costs by means of average distance spent travelling by commuters and its evolution from 1991 to 2001. Then, by a study of the environmental externalities (costs) in terms of per capita CO2 emissions associated with a given pattern of commuting (mode of commuting and distance travelled) in 2001 due to the lack of data in 1991. The ultimate aim of this work is to determine if sub-centres matter for the location and efficiency of the public and private transport. This point is studied in this case, through an analysis of share and trip times for public and private transport.
The results show that sub-centres are virtuous to reduce the social and environmental costs of commuting as well as to exert a strong influence on the location of public (positive) and private (negative) transport and in a less extent to its efficiency. In addition, sociodemographic characteristics and land use balance are also playing a role to decrease the aforementioned costs. Thus, planning a metropolitan area by taking into account sub-centres entails a more sustainable mobility pattern because they are remarkably able to prevent and reduce the private and external costs due to mobility.

KEYWORDS:
Urban spatial structure, sub-centres, polycentrism, commuting social and environmental costs

JEL CODES: R0, R11, R12 & R14

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1. INTRODUCTION

The urban spatial structure of cities and its relationship to the urban environment has recently been the subject of empirical, theoretical and policy research. This interest is a result that economic, social and environmental problems have become a worldwide concern for economists, as it witnessed by the development of many theories and policies aimed at driving the economy towards a sustainable urban development. This it becomes more and more significant even whether the object of study and discussion is cities and their spatial configuration. For instance, (Camagni et al. 1998:104) pointed out that "*in the context of sustainable city policy it should be recognized that cities are not passive spatial units victimized by anonymous global environmental developments, but may plan an active role in producing sustainable development in a multiplicity of relevant fields, such as housing, employment or environmental quality*". In an attempt to give more light about what is the most sustainable spatial organization of cities, the specialized literature has suggested to the best of our knowledge two distinct concepts to achieve it. The former is the polycentric city: the literature over the last few years has reinforced the idea that polycentric spatial structure generates important economic, environmental and social effects. From the environmental perspective, studies by (Anderson et al., 1996; Khan, 2000; Camagni et al. 2002; Muñiz and Galindo, 2005; Travisi and Camagni, 2006; Travisi et al., 2006; Cirilli and Veneri, 2010a and; Veneri, 2010) emphasize the close relationship that has been established between spatial structure and environmental sustainability, whether in terms of land consumed or in energy efficiency and CO_2 emissions. Studies such as (Evans, 1976; Camagni et al. 2002 and; Dura-Guimera, 2003) point out the importance of spatial structure in issues relation to social justice and territorial segregation. From the economic point of view, empirical works such as those by (Meijers and Burger, 2010 and; Fallah et al. 2011) highlight the influence of spatial structure on labour productivity; (Camagni and Salone, 1993) associate it with economic competitiveness and (Lee and Gordon, 2007, 2011; and García-López and Muñiz, 2012) link it with economic growth. The latter is the compact city: promote dense development focused around urban centers (oriented to downtown or to the central city) of employment and local services to reduce the need to travel long distances and to make cities more vibrant, a reaction against sprawl induced by the universal use of private automobiles. However, the benefits of promoting a compact city are still uncertainty. Although, there are some studies that show its advantages, for instance (Breheny, 1995) other such as (Gordon and Richardson, 1997; Echenique et al. 2012 and; Gaigné et al., 2012) prospect that it is not a desirable goal due to the negative externalities that generates or that there no significant positive benefits. In that sense, Gaigné's work, pointed out that policy-makers should pay more attention to the various implications of urban compactness due to the increasing-density policy affects prices, wages and land rents which could reshape the urban system and entailing a higher level of negative externalities such as social inequity, congestion and pollution.

In this debate, one of the most relevant topics is about the relationship between the urban spatial structure –i.e, monocentric city, polycentric city (sub-centres) and scatteration configuration- and mobility patterns. This is a consequence of that the environmental, economic and social problems associated with urban mobility patterns represent the core of the debate on the possible influence of urban spatial structure on mobility patterns. This issue has been analyzed by several studies such as (Commins and Nolan, 2011; Dubin, 1991; Giuliano and Small, 1993; Gordon et al., 1988, 1989; Gordon and Richardson, 1997; Hamilton, 1982, 1989; Handy, 1996; Imai, 1982; Levinson and Kumar, 1994, 1997; Levinson, 1998; Murphy and Killen, 2011; Murphy, 2012; Niedzielski, 2006; Sasaki and Mun, 1996; Small and Song, 1992; Sohn, 2005; Song, 1992a, 1992b and; White, 1976, 1988).

Mobility behavior-patterns yield prominent social costs (i.e. fuel, distance and time spent travelling) and external aspects (i.e. negatives environmental externalities such as pollution and CO_2 emissions). The social costs directly exert an influence on commuter's utility and it has been studied widely in the literature (Aguilera and Mignot, 2004; Aguilera 2005; Bento et al., 2005; Cervero and Wu, 1998; Cervero and Murakami, 2010; Cirilli and Veneri, 2010b, 2010c; Frank and Pivo, 1994; Gordon et al., 1989; Kockelman, 1995; Levinson and Kumar, 1994, 1997; Loo and Chow, 2011; Melo et al., 2012; Modarres, 2011; Schwanen et al, 2001, 2002, 2003, 2004; Shearmur, 2006; Sultana, 2002; Tkocz and Kristensen, 1994; Vega and Reynolds-Feighan, 2008 and; Watts, 2009). The external (environmental) costs affect the welfare of the population (society) and it is not considered in the individual's travel decisions (Breheny, 1995; Camagni et al., 2002; Cirilli and Veneri, 2010a; Kahn, 2000; Muñiz and Galindo, 2005; Travisi and Camagni, 2005; Travisi et al., 2006, 2010 and; Veneri, 2010).

Thus, the urban spatial structure and polycentricity is probably, more than promoting compact city policies, for which most effort the researchers have done to shed some light on its social and economic effects and externalities, especially generated by mobility patterns (or travel behavior). This it may be explained by the considerably interest of urban planners and policy-makers for polycentricity since it has become one of the key components of the integrated spatial development strategy promoted by the European Spatial Development Perspective (ESDP). In fact, now polycentric spatial structures are considered a planning tool to enhance cities', metropolitan areas' and mega city-regions' competitiveness, social cohesion and environmental sustainability. However, there is a lack of empirical work in the literature to test these hypothesis and the current studies due to the "fuzzy" notion of polycentricity which refers to different dimensions (morphological and functional) and different spatial scales (intra-urban, inter-urban and inter-regional) has achieved divergence results depending on the dimension and urban scale that they have taken into account.

In this sense, (Davoudi, 2003:979-980) pointed out this complex and confused reality:*"polycentricity means different things to different people. For example, urban planners use the concept as a strategic spatial tool; economic and human geographers use it to explain the changing spatial structure of cities, the European Union (EU) Commissioners and their counterparts in member states often promote the concept as a socio-economic policy goal aimed at achieving a balanced regional development; and civic leaders use the term for 'place-marketing', presenting the notion of polycentricity as synonymous with pluralism, multi-culturalism and dynamism, as well as a symbol of the 'post-modern' life style. It has become part of new vocabularies of inclusive politics. Furthermore, polycentricity means different things when applied to different spatial scales. With a few exceptions, the concept of polycentricity has traditionally been applied to the 'meso' level of urban agglomeration, focusing on intra-urban patterns of clustering of people and economic activity in places such as Los Angeles, Paris and London. More recently, the concept has also been used at the 'macro' level of inter-urban scale to denote the existence of multiple centres in one region. Examples from north-west of Europe, west coast of American and Kansai area in Japan are frequently mentioned as typical polycentric pattern of intraregional structures. A third, 'mega', level of polycentricity has been added to the debate by the EU's latest spatial policy framework, the European Spatial Development Perspective (ESDP). This uses the concept at intra-European scale and promotes polycentricity as an alternative to the core-periphery conceptualization of the European territory".*

As a result, the literature that has studied the relationship between urban spatial structure and mobility patterns or behavior presents this distinction in terms of spatial scale of analysis.

Thus the most relevant studies at intra-urban scale are (Alpkokin et al., 2005a, 2005b, 2008; Camagni et al., 2002; Cervero and Kockelman, 1997; Cervero and Wu, 1998; Giuliano and Small, 1993; Giuliano et al., 2012; Levinson and Kumar, 1994; Loo and Chow, 2011; Modarres, 2003, 2011; Muñiz and Galindo, 2005; Sasaki and Mun, 1996; Shearmur, 2006; Small and Song, 1992; Sohn, 2005; Song, 1992a, 1992b; Sultana, 2002; Vega and Reynolds-Feighan, 2008 and; Watts, 2009). At inter-urban scale are remarkably the works of (Aguilera and Mignot, 2004; Aguilera, 2005; Bento et al., 2005; Cervero and Murakami, 2010; Cirilli and Veneri, 2010a, 2010b, 2010c; Gordon et al., 1988, 1989; Hamilton 1982, 1989; Levinson and Kumar, 1997; Schwanen et al, 2001, 2002a, 2003, 2004; Susilo and Maat, 2007; Tkocz and Kristensen, 1994; Travisi and Camagni, 2005; Travisi et al., 2006, 2010; Veneri 2010 and; White, 1988) and, at inter-regional scale (Alpkokin et al., 2007 and; Melo et al., 2012).

In this context, the aim of this paper is to determine whether urban sub-centres exert an influence on the social and environmental costs due to resident-to-work commuting in the Barcelona Metropolitan Region, and if so, how it is this relationship to define future sustainable policies. The issue is addressed through an analysis of the social costs by means of average distance spent travelling by commuters and its evolution from 1991 to 2001. Then, by a study of the environmental externalities (costs) in terms of per capita CO2 emissions associated with a given pattern of commuting (mode of commuting and distance travelled) in 2001 due to the lack of data in 1991. To achieve both objectives, this paper has taken into account the distance to the central business district (CBD) and the distance to urban sub-centers (main variables to define the urban spatial structure). In addition, it has assessed the role of other relevant spatial variables and other non-spatial characteristics of the Barcelona Metropolitan Region. For instance, size (population density), land use mix (balance), employment-residents ratio and socioeconomic factor as a proxy of income, human capital and geographical variables respectively. The ultimate aim of this work is to determine if sub-centres matter for the location and efficiency of the public and private transport. This point is studied in this case, through an analysis of share and trip times for public and private transport

Therefore, starting from previous contributions to this field of research, this paper tries to examine these effects by focusing on the urban spatial structure by means of analyzing sub-centre influence what entails a new perspective of empirical analysis (intra-metropolitan scale) compared to the aforementioned current literature studies based on inter-urban or inter-regional scales. So, although the works of (Camagni et al., 2002 and; Veneri, 2010), examine what this paper has taken into account as a starting point, these works use an inter-urban scale of analysis, while the current paper contributes to present the effects of a polycentric urban spatial structure by means of sub-centre influence. The former study, analyses the social and environmental costs of commuting in the Milan Metropolitan Area by defining the urban structure only by the distance to the CBD and then by other spatial variables, so Camagni's et al., work do not define the spatial structure by a genuine polycentric spatial model (taking into account the urban sub-centres that are within the metropolitan area). The latter, also analyses the social and environmental costs of commuting and although, it takes at the first time a intra-metropolitan perspective by identifying sub-centres in Italian Metropolitan Areas by focusing on functional rather than morphological characteristics then, Veneri's work in order to do the analysis of spatial structure influence on private and externals costs due to mobility takes at inter-urban spatial scale (between Italian metro areas) and defining the degree of polycentricity by using the "relative sub-centre number" in each metro area.

This leads to the second main contribution of this work. As the spatial scale is the municipality level and this paper is testing whether the municipalities identified as urban subcentres exert an influence to reduce the social (private) and environmental (external) costs due to the mobility residence-to work, the results of this research could be useful in order to define future policies for the Barcelona Metropolitan Region that enhance sustainability by means of reduction of social and environmental costs due to commuting: proposing policies at local level and metro level oriented to achieve co-operation and cohesion between municipalities (CBD, sub-centres and the rest). For example, if sub-centres are virtuous to reduce social and environmental costs, then a housing and jobs policies between them and its surrounding municipalities, i.e. -increasing the supply of public transport between them- may reinforce this tendency towards lower costs due to mobility residence-to-work. In addition, that it also could entail a revisiting of the compact city concept: if sub-centres at intra-metropolitan scale are virtuous to reduce social and environmental costs, then promoting a set of compact cities formed by CBD and its surrounding sub-centres makes sense compared to the traditional concept of compact city which entails a reinforcement of monocentrism due to its policies are highly oriented to the central city or downtown. Finally, this paper contributes to conduct research to fill the lack of empirical research in these issues in the Barcelona Metropolitan Region. To the best of our knowledge at present, only the study of (Muñiz and Galindo, 2005) in which analyze the relationship between urban form and ecologic footprint is related to the influence of spatial structure on costs due to mobility.

However, the analysis of intra-metropolitan spatial scale requires a first step that is based on identifying the urban sub-centres that are within of this metropolitan area. To do so, is used the method to identify sub-centres proposed by the author of this work in (Masip, 2012a). This approach is suitable for identifying sub-centers that are within the bid-rent theoretical tradition based on the process of employment decentralization from a single and congested Central Business District (CBD) and also is suitable for the hierarchical and complex European urban systems where centers mostly emerged as a result of the integration or coalescence of pre-existing cities. In this way, Masip's approach takes into account the morphological and the functional characteristics of nodes (municipalities) according to the different dimensions that polycentricity is based on. In addition, the procedure is able to characterize the sub-centres that are "places to work" (employment sub-centers) and sub-centres that are "places to work and live" (urban sub-centers). That means distinguishing between those sub-centers that only attract workers (in-commuting flows) or retain their resident workers from those sub-centers that are able to attract flows and retain their resident employed population at the same time. In that sense, this brings to the current research more in-depth analysis about the influence of sub-centres on the costs of commuting according to its formation origin-nature.

The study is divided as follows. Section 2 presents a review of the literature on the relationship between urban spatial structure and mobility patterns by focusing on a) formation of the polycentric city, b) polycentricity and travel behavior and finally, c) the role of other spatial characteristics that exert an influence on commuting. Section 3 presents the study case, defines its urban structure and reviews the commuting patterns residence-to-work from 1991 to 2001. Section 4 is devoted to test empirically the relationships between urban spatial structure by means of sub-centre influence (according to its different nature) and other spatial and non-spatial characteristics with the social costs due to mobility by analyzing the average distance spent travelling by commuters and with the environmental costs in terms of per capita CO_2 emissions associated with a given mode of commuting. In addition, in this section the paper studies if sub-centres matter for the location and efficiency of the public and private transport. Section 5 sets out the main conclusions. Finally, in the end of the paper is presented an appendix with more information related to the empirical work.

2. LITERATURE REVIEW

In this section, is presented the still opened debate between urban spatial structure and mobility patterns. To do so, this section is divided into three subsections. Firstly, a) is explained the process towards the formation of polycentric city related to commuting patterns by taking the hypothesis that polycentric cities entail a more efficient pattern of mobility; then b) this issue is in-depth analyzed by focusing on the relationship between polycentricity and commuting distance-time and environmental externalities by taking into account the different spatial scales that polycentricity occurs; and finally c) are discussed the role of other spatial and non-spatial characteristics that also exert a significant influence on commuting.

2.1. From monocentric city to polycentric city: a commuting perspective

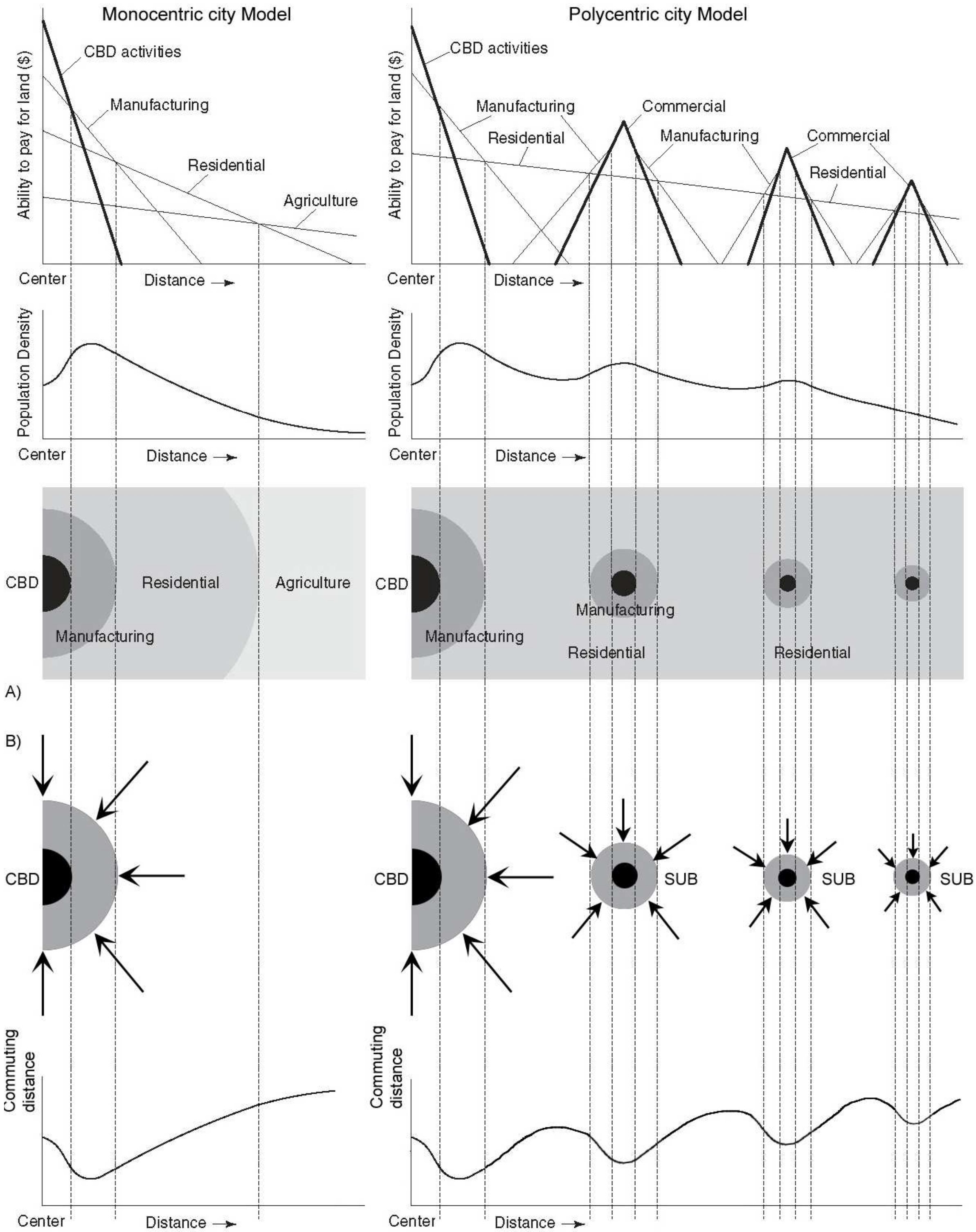
The discussion on the development of urban structure from monocentric to polycentric usually starts with the well-developed model of the Bid Rent curves centered on the Central Business District. According to the monocentric model studied by (Alonso, 1964; Muth, 1969; and; Mills, 1972), urban spatial structure is limited to just a point, the CBD (Central Business District), where most jobs are concentrated. One of the model's main assumptions is the existence of a compensatory mechanism whereby living further from the workplace (CBD) implies greater transportation costs, so the willingness to pay for each square meter of land decreases with greater distance to the CBD. When the bidding mechanism comes into play the land value is established, which gradually decreases as we move further from the CBD. In turn since densities are determined by land prices, they tend to follow the same spatial pattern. In a monocentric context, a structured territory is one in which density and the commuting patterns by means of distance can be reasonably well explained by the distance from the city center. Both predictions are clearly and easily comparable: the further from the CBD, the lower density and the longer the travel distance. Therefore, as it known three decades ago this model seemed to be capable of representing actual land value curves and density gradients, pivoted on the CBD as the most accessible point in an American city. (Clark, 2000:142) stated that, even in the 1960s, correlation coefficients greater than 0,90 are evidence that the models still closely fit the land use pattern in large cities: "*tests of the theory by examining population density gradients and land value gradients showed that the monocentric model was a good fit to empirical data in Chicago. Correlation coefficients greater than 0,90 suggested that the models were good fits even in 1960 and were even better fits in the mode defined cities of the 1940s and 1950s. Tests across cities confirmed the fits for densities and land values though they were clearly declining over time*".

With the spread of the city and the development of new nodes of accessibility, a new model was developed of the locational tradeoff between centrality and travel costs, based on the earlier Bid Rent Models. Empirical studies confirm that this modified polycentric model now fits the population and employment densities in U.S. cities more closely than the monocentric one. Despite the improvements brought about by including main transportation routes in the model, an increasing inability to explain intra-metropolitan patterns of density and commuting was detected back in the seventies and especially starting in the eighties. The estimate of density functions showed not only smaller gradients but also lower explanatory power, most likely due to the emergence of job density peaks on the periphery. Not only did the starting model seem functionally poor at predicting density, but mobility flows were also becoming apparently more random. This urban trend is explained by (Clark, 2000:143):*"the work on the urban structure of Los Angeles and Dallas/Ft. Worth provided a new picture of the relevance of a polycentric approach to the evolving urban structure of the late twentieth century. The empirical results showed that the number of centers had increased between 1970 and 1980,* *and that a modified polycentric model fits the population and employment densities more closely than a monocentric model. In addition the fit of the monocentric model has declined over time as the fit of the polycentric model has increased. Not only does the polycentric model fit better; the work-trip data for Southern California show that work trips are increasingly intracounty and more critically, these trips are shorter in the outlying counties. This implies that there are large numbers of jobs in the peripheral areas and that people are behaving rationally by seeking jobs in nearby locations when the jobs are available".* So, the emergence of these new nodes has created housing price gradients that far overshadow any residential gradient with respect to the CBD. This emphasize that the relative location of residential land-use was the critical factor in creating residential gradients. It is new urban nodes which are creating the price surface for the metropolitan region. The thesis is that there is a continuing and strengthening process of the movement of households further from the city center in search of amenities, and that decentralization is being followed at an accelerating rate by firms who wish to provide services to the dispersed population. In turn firms who wish to access the new suburban labor pools follow the population and the services.

In this scenario the new regional centres become less visible than the CBD but no less important job centers of the new urban structure. So, to explain this new spatial structure and solve the problems that the monocentric city model present in order to explain the population density and commuting pattern, the literature has develop theoretical models which include one of the most relevant stylized facts about the contemporary city: the existence of more than one employment center. Consequently, the new urban economic polycentric models offered theoretical alternatives to monocentricity without entailing a break with the starting model. The ideas of compensation and bidding were preserved, but the fundamental change consisted of allowing for a more subtle play between transportation costs and agglomeration economies, the latter having been missing from the basic monocentric model. Therefore polycentricity emerged as one of the possible equilibrium that, once achieved, should structure the system correctly: for example, proximity to subcentres should affect both density and commuting distance in the same way that the CBD used to, albeit on a smaller spatial scale. The following (Figure 1) presents schematically the transformation of old paradigm based on the monocentric city model to the new emerging one based on polycentricity as (Clark, 2000:152) has reviewed:*"the changes in commuting patterns are only the most visible manifestation of the changing structure of metropolitan areas whether in the United States or Europe. A new urban form has emerged in which decentralization will promote greater proximity between work and residence and reduced commuting. There is an alternative view in which decentralization is a force which deprives the low-income central-city residents of access to best jobs and adequate housing. In this new view, low densities are associated with economic inefficiency and environmental degradation from excessive automobile use"*

In this sense, the distance travelled in commutes between the home and workplaces is possibly the most widely used indicator to check the validity of the theoretical models on urban spatial structure. At first, the literature on wasteful commuting served to prove that the real distance travelled in these commutes was higher than the distance predicted by the monocentric model in its most extreme version (total concentration of employment in the CBD). Its theoretical framework is based on the pioneer study of (Hamilton, 1982) and then mainly by the successive works of (Hamilton 1989; White, 1988; Small and Song, 1992; Song 1992a, 1992b and; Giuliano and Small, 1993). Recently, has appeared in the literature works that are related to Hamilton's and White's works which aim is to achieve the most efficient commuting pattern in the knowledge economy. These studies have mainly carried out by (Niedzielski, 2006; Murphy and Killen, 2011 and; Loo and Chow, 2011).

Figure 1. Hypothetical monocentric and polycentric urban structures



Source: Own elaboration and adapted from (Clark, 2000)

In his pioneer work, (Hamilton, 1982) examines the ability of the monocentric model to predict the mean length of commute in urban areas taking a inter-urban scale of analysis (between urban areas in US). Hamilton's study compares actual mean commute with that which is predicted by monocentric models and finds that actual commuting distance is about eight times greater than that predicted by the model as well as that the volume of commuting which would result f people chose their houses and jobs at random, making no effort to economize on commuting entailing that this overpredicts actual commuting by about 25 percent. After establishing the commuting rules in a monocentric city model by taking into account a) centralized employment and b) decentralized employment (Hamilton, 1982:1038) achieve the following results: *"when some employment decentralizes from the CBD, the possibility arises for a reduction in the total volume of commuting, and a world populated by consumers who behave according to (1) subject to (2) will realize all of these potential savings. In other words, given the locations of jobs and workers' houses, there is no trade-off between commuting and the objectives specified in the utility function. But decentralization of employment also brings about another possibility which did not exist under complete centralization: -wasteful- commuting. Under the centralized-employment assumption, it is impossible to assign workers to houses in such a way that the aggregate commute exceeds the minimum. But with decentralized employment is clearly is possible, simply by violating the condition for commute minimization, that is, by having circumferential and reverse-flow commuting"*. In doing so, to prove that decentralization of employment has led a very large reduction in the required commute for a sample of U.S. cities[1] (Hamilton, 1982) firstly, calculates the required average commute (A)[2] and secondly, the mean distance jobs from the CBD due to the job decentralization (B)[3]. As a result is achieved (C) what is the mean required commute given a decentralization of jobs (C=A-B). The difference between the actual mean commute (D) and the minimized mean commute (C) is what Hamilton call "wasteful" commuting. (Hamilton, 1982:1040): *"all of this commuting could be eliminated by inducing people to swap either jobs or houses until all commute-reducing swaps have been carried out. In such an outcome, every household would be minimizing the sum of land rent plus commuting cost, if it is assumed land rent is determined as in the monocentric models"*.

However, Hamilton realize that whether average of actual commute (D) is about equal to the mean entry (A), so if all jobs which are located outside the CBDs of these cities were relocated in the CBDs, total commuting would not increase at all, then the decentralization of employment (the movement of jobs closer to people) has paradoxically resulted in no saving in total commuting. To solve this shortcoming and to prove the failure of the monocentric model, (Hamilton, 1982:1042) considered an alternative model: "*suppose that households are indifferent to commuting or, alternatively, that their preferences are lexicographic and that length of commute is sufficiently far down on the lexicon of preferences so as not to play a to role in the actual decision. This model implies that there will be no systematic relationship between the actual and –optimized- commute as calculated above, and that the best predictive model is one in which households are assumed to choose their homes and jobs sites at random and then commute between these randomly chosen sites"*. The results of this new Hamilton's model taking into account Boston city as example, show that the actual commute in somewhere between 72 and about 78 percent of the random commute, depending on whether the Boston number are badly biased. Therefore, Hamilton concludes that the standard

[1] Hamilton's work is focused on the following U.S. cities: Baltimore, Boston, Columbus, Denver, Houston, Milwaukee, Philadelphia, Phoenix, Pittsburgh, Rochester, Sacramento, San Antonio, San Diego, Wichita by then, extending the same analysis to the Japanese cities.

[2] The required average commute is calculated as follows: $A = \frac{1}{P}\int_0^{\bar{X}} xP(x)dx$, where (x) is distance from the CBD, P(x) is the number of people living distance (x) from the CBD, and P is the total population.

[3] The mean distance jobs is computed as follows: $B = \frac{1}{P}\int_0^{\bar{X}} xJ(x)dx$, where J(x) is the number of jobs at u. The logic is that displacement of a job from the CBD can save the worker a commute equal to the distance between the job and the CBD, if it is assumed workers obey the optimization rule.

monocentric models does a poor job of predicting commuting behavior in American cities and that it is not clear that the trade-off between commuting and land rent plays any significant role at all in location decisions.

After Hamilton's work in which is showed that average minimum commuting distance was only 1.1 miles, but the average distance actually commuted by workers in those cities was 8,7 miles, or nearly eight times as great and concluding that the monocentric urban model has little predictive value concerning commuting behavior and that actual commuting behavior could be predicting just as well using an assumption that commuting is random, some critics appeared in the literature related to that.

The most remarkable critic work is the study of (White, 1988) in which calculating again a new estimates of the average minimum commuting journey length in a sample of U.S. cities, using a 'more reasonable interpretation' of what urban models would predict concerning location behavior by workers and firms in comparison with Hamilton's study interpretation. In this sense (White, 1988) finds that only around 11 percent of the actual amount of commuting in urban areas is wasteful taking into account the Hamilton's sample cities.

What White's study criticizes from Hamilton's work are the predictions of the monocentric city model concerning commuting that (Hamilton, 1982) has taken into account in order to measure the "wasteful" commuting. (White, 1988:1103) states: "*Hamilton's measure of wasteful commuting actually includes three separate factors leading to extra commuting. These are (1) differences between the spatial distributions of jobs and residences around the CBD, which are caused by concentrations of employment at suburban subcenters; (2) the fact that the actual road network is not ubiquitous, so that commuting journeys do not proceed along straight-line routes; and (3) the existence of commuting trips that could be shortened if workers trade jobs or residences, thereby reducing the total amount of commuting in the metropolitan area. (This latter will be referred to as –cross-commuting-). Of these three sources of extra commuting, only the third should be counted in determining the amount of wasteful commuting because only cross-commuting can be eliminated if workers trade jobs or houses given the fixed spatial pattern of workplaces and residences. But Hamilton's own method includes all three*".

Therefore, (White, 1988) tries to propose a new method of calculating the average minimum commuting journey length using an assignment model that enables to separate out the amount of extra commuting actually due to cross-commuting from that due to the first and second factors of the three that Hamilton's work have considered. By taking into account the 1980 Census of Population and dividing metropolitan areas into political jurisdictions, White constructed a matrix of the number of workers who commute from any residential location to any workplace location in the metropolitan area but excluding the workers who live in the standard metropolitan statistical area but work outside it and workers who live outside the area but work in it. Then, White also constructs a matrix of actual commuting times[4] in order to figure for the average minimum commuting time in the metropolitan area that corrects for

[4] (White, 1988) used commuting times rather than commuting distance to measure work-place-residence separation for convenience reasons, since the census does not give distance data, and because time spent commuting is a better measure than distance of the cost of commuting, since it is workers' time that is scarce and is economized on. The commuting time matrix that (White, 1988) constructs has the following form: $\bar{t} = \sum_i \sum_j t_{ij} n_{ij}/N$, where its elements are denoted by t_{ij}; average actual commuting time for workers in the metropolitan area, denoted by $\bar{t}$, is the weighted sum of the matrix of commuting times, with weights equals to the proportion of workers in the metropolitan area commuting from jurisdiction (i) to (j).

cross-commuting but not for extra commuting due to the differing spatial patterns of jobs and housing or due to the actual road network. To solve it, (White, 1988) assume that the actual spatial patterns of jobs and housing are represented by the numbers of jobs and residences located in each jurisdiction, which are assumed to be fixed. In addition, (White, 1988) assumes that the actual road network is represented by the matrix of actual average commuting times between jurisdictions, and they are also assumed to be fixed. With this conditions, (White, 1988) determines the average minimum commuting time figure by solving for the assignment of workers to jobs that minimizes the total time spent commuting by all workers in the metropolitan area[5].

Consequently, according to (White, 1988:1105): *"the difference between the average actual time spent commuting, $\bar{t}$ and the average minimum time spent commuting, $\bar{\pi}$, is cross-commuting, which could be eliminated if workers trade residence or jobs. This corresponds exactly to Hamilton's definition of wasteful commuting, except that our procedure has eliminated the actual road network and the differing spatial patterns of jobs and housing as additional contributors to the measured amount of wasteful commuting. The proportion of commuting that is wasteful in these calculations is expected to be smaller than that found by Hamilton because it eliminates these two additional sources of extra commuting"*.

White were right and the results suggested that there is little waste in commuting behavior by urban workers: the average commuting journey length is 22,5 minutes, the average minimum commuting journey length is 20,0 minutes, and the average proportion of commuting that is wasteful is 0,11. The number of minutes added to the average commuting journey by cross-commuting is 2,5. (White, 1988:1107) explains in this way: *"Hamilton's results for the proportion of commuting that is wasteful is 0,87 or eight time the results obtained here. Since both sets of figures for wasteful commuting include commuting that could be eliminated if workers trade jobs or residence, a comparison of Hamilton's results with mine suggests that the influence of the actual road network and of the differing spatial patterns of jobs and housing, which add to Hamilton's calculations of waste in commuting but not to the results presented here, is much more important than the influence of cross-commuting in explaining Hamilton's results. If these factors are eliminated, then the amount of waste in the urban commuting pattern falls to a small proportion of actual commuting"*. In conclusion, White's results suggest that monocentric urban models are in better shape than Hamilton's gloomy diagnosis would imply but that further research is still needed to explain why some urban workers voluntarily choose "wasteful" commuting trips.

In front of the revision of his work, (Hamilton, 1989:1497) tries to reply White's critics: *"in my original paper, I estimated that almost 90 percent of commuting was wasteful; in her note, White estimates that only about 10 percent is wasteful. There are three possible sources of this discrepancy: (1) bias in my estimates; (2) bias in White's estimates and (3) the distinction between time and distance as a measure of length to commute.*

(Hamilton, 1989:1498) didn't consider the first point of discrepancy. Referring with the second one, Hamilton explains that the in White's estimation technique there is bias due to it

[5] (White, 1998:1105): the optimization problem thus solves for a new matrix of worker-to-job assignments that minimizes the total time spent commuting by all workers in the metropolitan area is calculated as follows: $\min Z = \sum_i \sum_j t_{ij} n_{ij}^*$, where the elements of the matrix are denoted by n_{ij}^* and the optimization problem is subject to the constrains $\sum_i n_{ij}^* = M_j$, $\sum_j n_{ij}^* = N_i$ and $n_{ij}^* > 0$. According to (White, 1988) the solution matrix is then used to solve for the minimum average commuting time in the metropolitan area, which is denoted by $\bar{\pi}$. It is $\bar{\pi} = \sum_i \sum_j t_{ij} n_{ij}^* / N$.

reassigns people to homes and jobs, satisfying the appropriate constraints, so as to minimize the mean commuting time. The crucial assumption in White's approach is that the (t_{ij}) are themselves free of waste (see White's approach). If we consider the diagonal (t_{ii}) , Hamilton pointed out that in order to accept White's estimates of (π), we must believe that the within-jurisdiction commutes are all optimal; other-wise, the (t_{ii}) are the wrong weights to use in the optimal-commute equation. By taking as example Boston, (Hamilton, 1989:1499) states: "*consider data from Boston... . For these commutes, we must simply assume optimality. This assumption works against finding waste in two ways. First, of course, the assignment algorithm cannot even attempt to reassign people who both live and work in the same jurisdiction. Second, having moved workers into the jurisdiction in which they work, the algorithm understates the commute saving because it incorrectly assumes that* (t_{ii}), *is an optimum"* and he concludes*: "in general, the bigger the jurisdiction, the more suspect is the assumption that* (t_{ii}) *is optimal (for small jurisdictions, origins and destinations are, of necessity, close together). The assumption (that the* t_{ij} *are themselves optimal) is particularly weak for the central cities and for large suburbs. To a more degree the assumption is weak when (i) and (j) are adjacent. Only when (i) and (j) are fairly remote from one another (when the between-jurisdiction distance is large relative to the within-jurisdiction distance) is the assumption fairly innocuous. So, actual* (t_{ij}) *are upward-biased estimates of the optimal* (π_{ij}), *with the bias being largest when i=j and when the jurisdiction is large. The bias then declines as (i) and (j) become more remote from one another.*

Referring to the third point of discussion, (Hamilton, 1989) states that part of the explanation for the two sets of findings (Hamilton, 1982 and White, 1988) surely is that commuting involves more wasted miles than minutes. (Whites, 1988) argues that time is the more appropriate metric, given the magnitudes involved, at the margin, time is more important to the commuter than the out-of-pocket cost of distance. (Hamilton, 1989) in his turn, argues that the time and distance measures would of course be identical if time spent in commuting were proportional to distance. To prove it, he estimates a model[6] that it seems to be a better approximation. By estimation this model, in the U.S. sample cities used before[7], (Hamilton, 1989) estimates (d_{ij}) for the Boston census jurisdictions and then as White proceed he calculate both the actual commute $\bar{d}$ and the optimum commute $\bar{\theta}$. The results that (Hamilton, 1989) achieved, were $\bar{d} = 9{,}11$ and $\bar{\theta}$=4,82. So, according to (Hamilton, 1989:1500): "*on the basis of this calculation, the required commute is 53 percent of the actual. Like White's calculation, this approach is unable to find any wasteful within-jurisdiction commuting; on this score it is subject to the same bias as hers. Aside from measurement errors, the difference between my Boston finding and hers should be solely attribute to the difference between time and distance".*

The diversity in this debate about "wasteful" commuting is tried to be solved by the study carried out of (Small and Song, 1992). Small and Song's work clarify the conceptual issues and provides new and more reliable empirical evidence. Firstly, they tried to clarify the theoretical notion of types of required commute. (Small and Song, 1992:889) state: "*urban is described by geographical distributions of work and residential sites, which we call a pattern*

[6] The equation is estimated as follows: $t = \alpha_0 + \alpha_1 + \alpha_2 d^2$, where (d) is distance, (α_0) and (α_1) are positive and (α_2) is negative. The term (α_2) reflects the fact that longer commutes are generally higher-speed, and (α_0) is the fixed time cost of a trip. If (α_0) and (α_2) are large, it is possible that neither White's nor my estimate is badly biased and that collectively we have discovered that it is possible (through reassignment) to save a lot of miles but nit much time.

[7] It has been used in (Hamilton, 1982)

of cities. When workers select their jobs and residences from these distributions, they presumably pay some attention to commuting cost. The lowest possible average commuting cost consistent with the pattern of sites is the average required commute for that pattern, any commuting cost beyond that amount represents excess commuting" and continue: "*models of housing or job selection in which utility is deterministic typically predict that aggregate commuting costs are minimized for whatever pattern of sites prevails. That is, they predict that the average actual commute equals the average required commute. In particular the standard monocentric models of urban economics predict zero excess commuting as do extensions to account for ring or point subcenters"*.

Therefore, the debate over "wasteful" (excess) commuting according to (Small and Song, 1992) has confused two patterns of urban form: (1) that predicted by a monocentric model with dispersed employment and (2) that defined by the actual distributions of workplace and residence sites. (Hamilton, 1982) defines wasteful commuting using the second pattern but calculates it using the first. (White, 1988) both defines and calculates it using the second but discusses it as though she were testing monocentricity.

To prove that, (Small and Song, 1992) estimates a monocentric and zonal models in Los Angeles-Long Beach metropolitan statistical areas by using journey-to-work data from 1980 census. By estimating the monocentric pattern, Small and Song, used two exponential density functions, one for employment and one for worker residence. Taking these estimated functions to represent smoothly varying distributions, as in Hamilton's original calculations[8], Small and Song, find that the average job is 14,77 miles from the center and the average worker lives 16,93 miles from the center. According to (Small and Song, 1992:892): "*the difference, 2,16 is the average required commute for the monocentric model, it accounts for just over one-fifth of the average actual commute of 10 miles. These results[9] verify Hamilton's finding that the standard monocentric model with dispersed employment greatly underpredicts commuting distances. To the extent that Hamilton's paper is intended to show that this model is hopeless for analyzing commuting distances, there can be no doubt that he is right"*. Then, in order to estimate the zonal model and to minimize aggregate commuting cost subject to the actual location of jobs and residences, Small and Song use the linear programming calculation[10] proposed by (White, 1988) and also used by (Hamilton, 1989). The results that (Small and Song, 1992:897) achieved prove that White's finding of very little excess commuting is due mainly to the bias from using large zones: "*our Los Angeles data yield relatively little excess commuting (33 percent of actual commuting time) when aggregated, like hers, to large jurisdictions, but far more (66 percent) when smaller zones are used. The reason is that most of the excess commuting takes place within jurisdictions of the*

[8] (Small and Song, 1992) take the same procedure that in (Hamilton, 1982), see notes 2 and 3, except that Small and Song use resident workers instead of population to measure residential density.

[9] Other significant results based on distance are: actual commute (10,03) and excess commute (78,5 percent). Results based on time are similar in proportion: employment average location from CBD (30,23 minutes), resident workers location from CBD (33,82 minutes), required commute (3,59 minutes), actual commute (22,06 minutes) and finally excess commute (83,7 percent)

[10] Small and Song explains the model that they used in the following way: let (n_{ij}) the number of commuters from zone (i) to zone (j), and let the (c_{ij}) be the corresponding network commuting cost (either time or distance). The travel flows satisfy $\sum_j n_{ij} = N_i$, $\sum_i n_{ij} = E_j$, $n_{ij} \geq 0$, for every (i) and (j), where (N_i) is the number of commuters living in zone (i) and (E_j) is the number working in zone (j). The actual average commuting cost is $\bar{c} = \frac{1}{N}\sum_i \sum_j c_{ij} n_{ij}$, where $N \equiv \sum_i N_i \equiv \sum_j E_j$ is the number of commuters in the study area. The linear program fins flows (n_{ij}^*) to replace (n_{ij}) in this expression so as the minimize the average commuting cost subject to constrains (1). The required commute is then $\bar{c^*} = (\frac{1}{N}) \sum_i \sum_j c_{ij} n_{ij}^*$, is the lowest average commuting cost attainable by allowing workers to swap houses or jobs.

size available to White. Once aggregation bias is removed, the excess commuting relative to actual density patterns is about two-thirds of the actual commute".

In conclusion (Small and Song, 1992) states that if excess commuting is measured relative to the predictions of the monocentric model with exponentially declining employment and residential density functions, as in (Hamilton, 1982), it is greater still: about four-fifths of the actual commute in the Los Angeles metropolitan area. This verifies Hamilton's original argument that the monocentric model is very poor at explaining commuting.

The study of (Small and Song, 1992) highly influenced the literature on excess "wasteful" commuting depending on the urban structure that it is taking into account: monocentric or polycentric. After their study, other studies try to continue to examine that uncertainty relationship between urban structure and commuting behavior. The works of (Song, 1992a and 1992b) are good remarkable to show this effort. The study of (Song, 1992a) tests the existence of polycentricity and determines its effect on the spatial structure and the estimate of excess commuting at the time that it also examines the behavioral validity regarding the trade-off assumption. By using 1980 small-zone journey-to-work data for the Los Angeles region, (Song, 1992a) estimate a monocentric and polycentric density functions[11] for both employment and resident workers, and perform hypothesis tests on fit of the monocentric model in explaining the spatial distributions and the existence of polycentricity[12]. Then, his study, determines the effect of polycentricity on the estimate of excess commuting by estimating the average minimum commutes required by the monocentric model and the polycentric model[13]. Finally, Song's work examines the behavioral validity that households make attempts to economize on commuting in their location studies.

The empirical results that (Song, 1992a) presents are highly remarkable. Firstly, a) referring the monocentric density functions of resident workers and employment (Song, 1992a) the results show that the density gradient of employment is greater than that of resident workers, implying that resident workers are more dispersed than the employment. According to (Song,

[11] (Song 1992a) use a negative exponential density (the most commonly used model in the literature) to estimate the monocentric city. This function is calculated as follows: $D_m = D_o e^{-g r_m} e^{u_m}$, where ($D_m$) is the worker residence or employment density at distance (r_m) to the single urban center; (M) is the total number of zones in an urban area; (e^{u_m}) is a multiplicative error term associated with zone (m^{-1}); (D_0) and (g) are parameters to be estimated from data by ordinary least square after taking logarithm of the equation. Theoretically, (D_0) is the density extrapolated to the urban center, and (g) is the density gradients measuring the percentage fall off for an unit increase in distance from the CBD. For estimating the polycentric model, (Song, 1992a) consider that the natural extension of the monocentric models is to assume that access to all employment centers is of primary importance in location decisions, and specify that resident workers and employment are functions of distances to all employment centers. So, the polycentric function that (Song, 1992a) estimates is: $D_m = \sum_{n=1}^{N} A_n \, e^{-b_n r_m} + v_m$, where (N) is the number of employment centers in an urban area; (r_m) is the distance from center (n) to zone (m); (v_m) is the error term associated with zone (m); (A_n) and (b_n) are parameters to be estimated for each employment center (n). The specification of polycentric model that (Song, 1992a) used, assumes that the density at any location is the vertical summation of the negative exponential density functions, each reflecting the influence of a center on that location.

[12] To explain the spatial distribution and the existence of polycentricity, the first step is identifying the subcenters. To do so, (Small, 1992a:16) uses the approach suggested by Giuliano and Small, because it incorporates adjacent high-density zones and restricts attention to centers large enough to exert potentially significant influences on the overall urban structure in a metropolitan area. In order to have a manageable number of employment centers in the density function estimation, the criteria that (Small, 1992a) uses is $\bar{D} = 15$, and $\bar{E} = 35.000$, that entails identifying 7 subcenters, 5 locate in Los Angeles county and 2 in Orange county.

[13] This is carried out by using two methods to estimate excess commute. One uses estimated monocentric density gradients, which (Song, 1992a) called Hamilton's calculation and the other uses a linear assignment model, called by (Song, 1992a) as White's calculation.

1992a:14): "*the gradient estimates show that both resident worker and employment distributions were quite flat in 1980 in Los Angeles region; resident worker density falls off at 4,6 percent and employment density falls off at 5.0 percent by one mile increase in distance from the CBD". This results suggest that the degrees of employment decentralization and resident worker suburbanization are close, implying a general balance between housing and jobs over the distance from the CBD".*

Secondly, b) referring with polycentric density estimates, the results suggest the existence of polycentricity in the Los Angeles region, although 2 of the 7 identified subcentres are not statically significant. In addition, according to (Song, 1992a:20) the polycentric model, explains statically better the distributions of resident workers and employment what it entails a rejecting of the monocentric model and what indicates that the overall access to major employment centers is much more important in location choices than the access to the central business district[14]: "*performing F-tests to the unrestricted (polycentric) model, I find that the F-statistic has values of 27.68 for resident worker distribution and 25,11 for employment distribution. These resulting tests, with (10,1112) degrees of freedom, indicate that the null hypothesis (monocentric model) is soundly rejected at a significance level of 0,0001".*

Then, c) in terms of monocentric required commuted, the main Song's findings are according to Hamilton's original finding and then it shows that the assumption of radial transportation network considerably underpredicts the minimum commuted required by the monocentric model. Therefore, (Song, 1992a:20) exposes: "*I find that the average worker lives at 25,02 miles from the center and the average job locates 24,00 from the center. The difference, C=1,02 miles, is the average minimum commute required by the monocentric model. It accounts for only about one-tenth of the average actual commute of 10,81 miles, i.e., 90,56 percent of actual commute is excess"* and "t*o determine the effect of actual road network on the estimate of excess commuting, I also calculate the minimum commuted required by the monocentric model by applying White's calculation… showing that the minimum required commute is 1,99 miles and about 81 percent of the average actual commute is excess*".

Finally, d) when is calculated the polycentric required commute, Song's study finds that the polycentric model has a minimum average required commute of 4,35 miles. According to (Song, 1992a:23): "*this result indicates that the polycentric required commute is considerably larger than required by the monocentric model". The latter requires 1,02 miles by Hamilton's calculation and 1,99 miles by White's calculation. Comparing with the monocentric excess commutes of 90,6 percent and 81,6 percent, the polycentric model has a much smaller amount of excess commute, with less than 60 percent of the actual commute being excess. Hence, it explains the observed commuting patterns much better than the monocentric model".*

Therefore, as a conclusion, (Song, 1992a:24) findings have two implications: "*Firstly, the polycentric model requires more urban commuting than the monocentric model. Put differently, polycentricity has a positive effect on the estimate of minimum required urban commute. As Song's study depicts, the monocentric density gradients are quite similar for*

[14] When (Song, 1992a) estimates a polycentric density function by means of resident workers, the t-values and impact of some identified subcentres are higher in comparison with CBD's t-value and impact: LA Airport (2,15 and 2789,6), West Hollywood (4,86 and 311,1) and Santa Ana (2,82) compared to Downtown LA (CBD) (1,87 and 58,1). The same happens when is computed employment. The impact that each center has on the overall distributions of employment and resident workers according to (Song, 1992a) is computed as follows: $IMPACT_n = \widehat{A_n} \sum_{m=1}^{M} S_m e^{-b_n r_m}$, where ($S_m$) is the area of the zone (m); ($\widehat{A_n}$) and (b_n) are the estimated intercept and density gradient. $IMPACT_n$ is positively related to ($\widehat{A_n}$), and negatively related to (b_n)

employment and resident worker distributions, indicating that the degrees of employment decentralization and resident worker suburbanization are close. This general balance between housing and jobs, in turn, requires a smaller amount of minimum commuting than the polycentric model. Hence, it is the decentralization of employment rather than the polycentric structure that makes it possible to reduce urban commuting. Secondly, b) households do make attempts to economize on commuting. Like the standard monocentric model, the polycentric model assumes that accessibility to workplace is the primary determinant of the residential location choices. Since it is shown earlier that the polycentric model is superior to the monocentric model in explaining the spatial structure, the trade-off assumption expects that the polycentric model is also superior to the monocentric model in explaining the actual urban commute. The findings that the polycentric model explains much better both and the actual commuting distance and the actual distribution patterns, therefore, supports the assumption in the standard urban model regarding the commuting behavior.

The in-depth analysis of the previous works, suggested that a polycentric distribution of employment and people shortens commuting distances because people locate within or close to their employment subcentre. In the theoretical literature these assumption is called the "co-location hypothesis". So, most polycentric urban models are indeed based on the premise that people tend to locate within or close to their employment subcentre (Sasaki, 1990 and; Sasaki and Mun, 1996) and consequently, the emergence of a polycentric model, either spontaneous or planned by large agents (private or public), is an answer to the non-sustainable growth of commuting distances –and costs- that characterize the monocentric city. The relationship between polycentric models and commuting distance-time and environmental externalities will be explained in detail in the following Section 2.2. However, as the co-location hypothesis is behind of the relationship between polycentricity and commuting we try to explain more about it by using the relevant study of Sasaki and Mun.

The basic idea explained by urban theoretical models is that at an early stage of urban growth, where the number of firms is fewer, firms tend to locate around the center of a region in order to benefit from agglomeration economies. Therefore the area outside a business district is used for household residence, i.e., the formation of monocentric city. In a monocentric city, however as the number of firms increases, the industrial district area is expanded and the average commuting distance increases. At a later stage, other business districts are naturally formed around subcentres and the average transport cost for commuting might be lower. This dynamic process of polycentric formation city is explained by (Sasaki and Mun, 1996:257) in which present an optimizing model of urban land development in order to determine the location of new firms and households in subcenters in order to maximize the net rental revenue from land over the planning horizon.

Sasaki and Mun's by taking their assumptions[15] describe the process to polycentric city formation in which due to the correct location of the subcenters (distribution of the

[15] Sasaki and Mun's model suppose at the beginning of the period (t=0) that no firms or households exist in this city. Also assume the location of the centre of the central business district (CBD) is prespecified as 0, and the fringes of other business districts (second business district, SBD) closer to the city centre are specified as C and –C; i.e. firms entering the city are located in one of the three business districts. The CBD expands symmetrically around 0 while an SBD develops outward from the fringe C (and –C). Residential districts are formed in the areas between the CBD and the SBDs, and outside the SBDs. It is assumed that in this city, the business district areas never shrink and a residential area can be converted to business use as the city grows. Finally, Sasaki and Mun's model assume that land use is symmetrical with respect to the city centre, thus the land-use pattern on the left side is the same as that on the right side of the city.

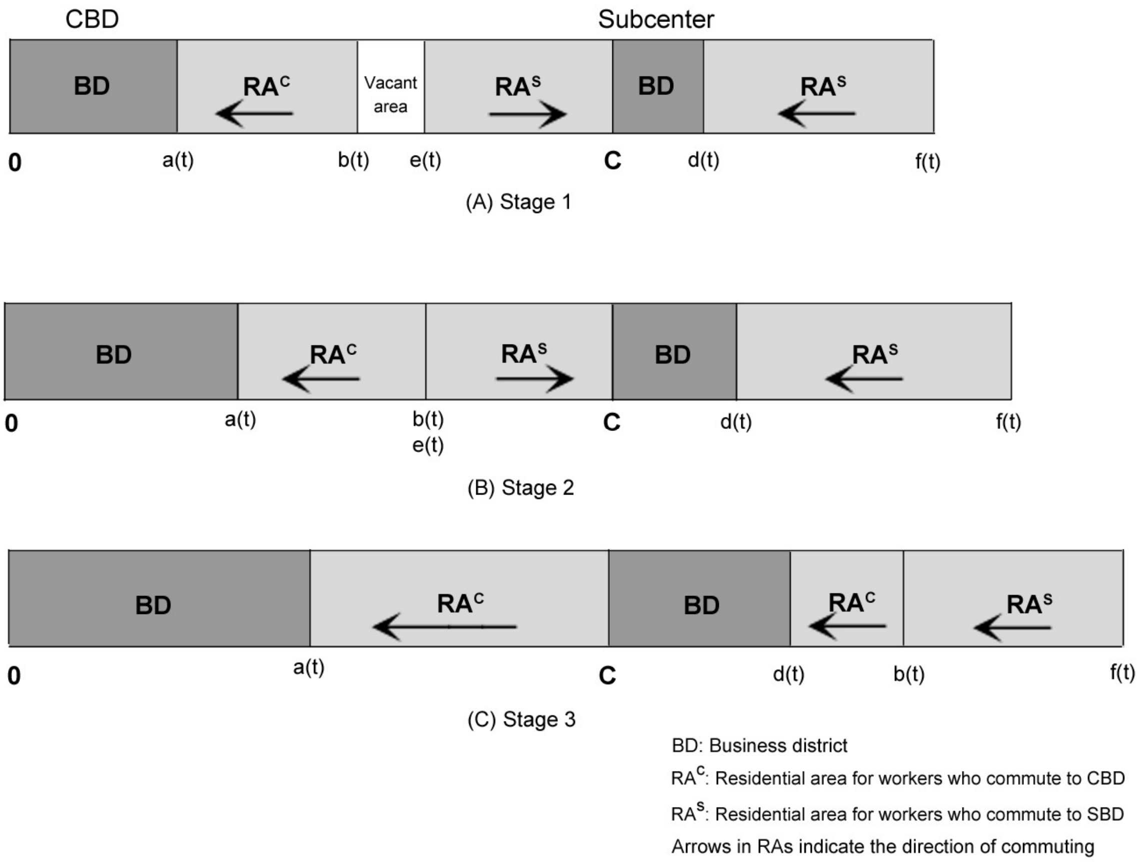
decentralized employment) entails that people commute shorter. Basically, the multicentre city proposed by Sasaki and Mun's is based on three stage as (Figure 2) depict.

In the first stage, (Sasaki and Mun, 1996:260) state: "*in the early stages of urban development, when the size of a city is not very huge, the residential districts are formed symmetrically around the CBD and the SBDs, and there is vacant land between the two residential districts, i.e., [b(t), e(t)] and [-e(t),-b(t)]. The land use pattern of stage 1 continues until the vacant land between b(t) and e(t) is completed developed*". (Figure 2a)

Then in a second stage: "*when a city continues to grow even after all vacant land between the CBD and a SBD is used up, the residences of workers who will be employed by new firms in the SBD cannot be increased any more on the left side of the SBD. Thus, the residential district for such workers has to be expanded on the right side of the SBD. In this situation, if new firms are located in the CBD, then the location b(t)(=e(t)) will move toward the right, and the residences of some employees in the SBD will be moved to the area on the right side of the SBD, whereby the city boundary f(t) will move outward*". (Figure 2b)

Finally, in the last stage, (Sasaki and Mun, 1996:260) explain that: "*If the CBD continues to expand even after the right-side fringe of the residential district for the CBD workers, b(t), coincides with the left-side fringe of the SBD, C, some CBD workers will reside on the right side of the SBD. Residences of SBD workers will be moved to the outside of the CBD workers' residences*". (Figure 2c)

Figure 2. Polycentric city formation, commuting and land-use patterns



Source: Re-elaboration and adapted from (Sasaki and Mun, 1996)

By analyzing the three stages of polycentric city formation proposed by (Sasaki and Mun, 1996) the main significant issue is the optimal subcentre location (C) from the city center (CBD). Sasaki and Mun's polycentric city formation model supports the co-location hypothesis (Figure 1) in which polycentric structure by means of subcentre location shortens commuting distance between resident area and job. Therefore, as it depicts (Figure 1b and Figure 2) as we move away from subcentre (and CBD) the average commuting distance is increasing. As a result, people locate within or close to their employment subcentre (or close to the CBD). In this sense (Sasaki and Mun, 1996) explain that the optimal location of a subcentre is such that the increase in the communication cost is just offset by the decrease in the commuting cost. So, there is a close relationship between location and optimal location of a subcentre and the commuting cost (distance) and communication cost: a) the higher the commuting cost, the more likely it is that an SBD will be formed according to (Sasaki and Mun, 1996:272): "*this is because the average commuting distance is shortened by forming the SBD, hence the average commuting cost is lowered"* and b) the lower the communication cost, the more likely it is that an SBD will be formed, "*this is because the average communication cost is hardly increased by SBD formation*".

However, other studies doubts if commuting patterns (distance and time) is sensitive to urban structure by means of local imbalances between employment and residential sties. (Giuliano and Small, 1993), starting from the aforementioned studies in this paper, analyze this presumption by finding the commuting pattern for the Los Angeles region in 1980 which would minimize average commuting time or distance, given the actual spatial distributions of job and housing locations. Their findings suggest that the amount of commuting required by these distributions is less than actual commuting, and that variation in required commuting across jobs locations only weakly explain variations in actual commuting. Consequently, they, conclude that other factors must be more important to location decisions than commuting costs, and that jobs-housing balance will have only a minor effect on commuting.

To carry out the study, their used 1980 journey-to-work data coded to geographical units known as transportation analysis zones, defined by the Southern California Association of Governments (SCAG) including 1146 zones. Using this data, they examine the required and actual commutes (time and distance) by computing White's approach (White, 1988) at sub-area Los Angeles county spatial scale and at subcentre level[16]. Resulting from computing White's approach they verify the findings of most other such studies. (Giuliano and Small, 1993:1492): "*a large fraction of commuting cannot be explained by the geographical imbalance in current locations of housing and jobs*" and "*as expected, the required commute tends to be higher where the ratio of resident workers to jobs is low. Only in central LA County, however, is the jobs-housing imbalance so great as to increase required commuting time above the 5-7 minutes range".*[17] Then, in the subcentre level of analysis based on examining the effect of employment concentration by means of dividing job sites into those located in employment centres and those located outside employment centres, Giuliano and

[16] To identify subcentres at Los Angeles Region, (Giuliano and Small, 1993) use their approach based on cut-off. They identify 32 employment subcentres by defining them as the largest set of contiguous zones, each with gross employment density of at least 10 per acre, that contains at least 10.000 employees.

[17] The 8 analyzed subarea in Los Angeles region are: (1) Central LA County, (2) South LA County, (3) North-west LA County, (4) North-east LA County, (5) Orange County, (6) Riverside County, (7) San Bernardino County and (8) Ventura County. (Giuliano and Small, 1993) examine for each county: resident workers per job, required (minutes), actual (minutes) and excess (percentage). According to that, the results are: Central LA County (0,78; 12,63; 25,30 and 50,1); South LA County (1,01; 6,61; 23,61 and 72,0); North-west LA County (1,27; 5,16; 20,04 and 74,3); Orange County (1,08; 6,95; 21,25 and 67,3); Riverside County (1,14; 5,34; 17,89 and 70,2); San Bernardino County (1,23; 5,75; 17,52 and 67,2) and Ventura County (1,31; 5,50; 16,07; and 65,8)

Small expect that employment centres must draw workers from surrounding areas, thus requiring longer commuter trips than would be the case for employment that is distributed in concert with population. The results are according to what they expected. When the employment subcentres are aggregated at 8 subarea level: "*employment centres clearly require longer commutes, ranging from 9 to 20 minutes, than do zones outside centres, where required commutes are only 3-6 minutes. Actual commutes, however, are only slightly longer to centres than to non-centres in most sub-areas –in fact, they are shorter in two of the outer counties. Overall, required commutes are more than three times longer to centres than elsewhere, whereas actual commutes are just 23 per cent longer to centres than elsewhere*" (Giuliano and Small, 1993:1492).

When the employment subcentres are analyzed isolated, then according to what Giuliano and Small, 1993:1493) find "*actual commutes are much longer than required commutes in most cases, and show far less variation across the region. The important exception is the downtown Los Angeles employment centre where the actual commute is only 4,0 minutes longer than required by its concentration of jobs (469.000 in a 20-sq-miarea)*". As a result, Giuliano and Small's results suggest that the polycentric pattern of employment centres along with the dispersal of many jobs outside centres altogether, creates the potential for shorter commutes than those required of people working in the CBD. However, Giuliano and Small (Op. Cit) state: "*commuters are taking little advantage of this potential, choosing instead to commute only a few minutes less than downtown workers. At the same time, given the size of the region, commutes are clearly much shorter than they would be if workers chose randomly among all available housing locations. One must conclude that commuting costs affect residential location choices somewhat, but are far from the sole consideration*".

To prove this point, Giuliano and Small's study computed the shortest average commute that could be achieved by people working within that sub-area regardless of the effect on other sub-areas' commutes and they found that this lowered the required commutes in comparison with what they achieved previously (see note 17) by only a minute and with the exceptional case of central LA County, where it lowered it by 4,0 minutes. Therefore, this corroborates that the structure of job and residential distributions does not account for the amount of commuting we observe. (Giuliano and Small, 1993:1495) explain in this way: "*this indicates that there are enough residents living in or near central LA County so that its jobs could be filled with an average commute of only 8,6 minutes. The average commute to its 12 employment centres (including downtown Los Angeles) falls more than 6 minutes, to 12,3 minutes, using this calculation. Hence the long required commutes to these jobs centres result not only from insufficient nearby housing, but also from the existence of jobs outside the Central LA sub-area that absorb many of the workers who live in that housing*".

Finally, Giuliano and Small's work try to examine the relationship between actual commuting time and various measures of jobs-housing balance[18]. After testing 6 different types of regressions analysis they conclude that: "*jobs-housing balance, whether measured by the ratio of resident workers per jobs in a broad sub-area or by the required commuting time, has a statistically significant but not very large influence on actual commuting times*" Giuliano and Small, 1993:1498).

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[18] One measure that (Giuliano and Small, 1993:1498) used is the required commute to that zone, which automatically takes account of the surrounding area through the working of the linear programming algorithm. Another measure that they used is the worker-jobs ratio, computed alternately for the entire sub-area in which the zone is located and for a smaller area.

The analyzed literature until this point related to excess commuting linked with the transformation process from monocentricity to polycentricity has been used to evaluate the efficiency with which urban residents travel to work at the city or regional scale. Armed with the explained findings, often indicating potential for reductions in commuting, the specialized studies of the literature propose solutions for a more sustainable commuting patterns primarily focusing on multicenter structure, where jobs and housing are balanced, although is questioned by some authors, such as the aforementioned study of (Giuliano and Small, 1993). In this context, the studied and mentioned works related to the concept of commuting efficiency has been used to evaluate the relationships between the journey to work, urban structure and land use at intra-urban and inter-urban scale. However, recently has appeared in the literature, studies that used different approaches, for example, based on spatial disaggregation or using new measures for defining commuting efficiency in order to find out the relationships between commuting and spatial structure. These are the cases of the studies carried out by (Niedzielski, 2006, Murphy and Killen, 2011 and; Loo and Chow, 2011).

The work of (Niedzielski, 2006:2486) develops an alternative method to commuting efficiency and spatial structure assessments based on spatial disaggregation applied to journey-to-work data for the cities of Warsaw, Poznán, Lódz and Kraków in Poland. Its study is a criticism to standard analyses of regional efficiency statistic: "*regional measures of excess commuting provide limited information, summarizing commuting efficiency and the jobs-housing balance for the urban region as a whole"* and *"consideration of zonal commuting efficiency allow analysis of the relationship between the journey to work and urban structure in a greater spatial detail, the spatially disaggregated commuting efficiency approach can answer basic questions as 'How far on average each zone send (or receive) workers? Or 'Do workers from one urban area commute more efficiently than workers from another part of town?"*. According to the literature there are two outputs from the application of linear programming to the optimization of work travel: trip length and the optimized journey-to-work matrix. The former is used to calculate regional efficiency metrics as we have just explained in (Song and Small, 1992). The latter is the building block of the spatially disaggregated framework for the analysis of intrametropolitan differences. This is the case of Niedzielski's work.

To do so, Niedzielski's spatially disaggregated approach to commuting efficiency uses two steps. First, linear programming is used to estimate the regional minimum and maximum commute flow matrices as the theoretical framework suggest. Secondly, by using the equation that he proposes, the zonal average trips lengths[19] and zonal commuting efficiency metrics[20] are calculated.

[19] In terms of origin-specific, Niedzielski's study uses: (1) Minimum $O_i^{\overline{MIN}} = \frac{\sum_j X_{ij}^{MIN} C_{ij}}{O_i}$, (2) Observed $O_i^{\overline{OBS}} = \frac{\sum_j X_{ij}^{OBS} C_{ij}}{O_i}$ and, (3) Maximum $O_i^{\overline{MAX}} = \frac{\sum_j X_{ij}^{MAX} C_{ij}}{O_i}$. In terms of destination-specific, Niedzielski's study applies: (4) Minimum $D_j^{\overline{MIN}} = \frac{\sum_i X_{ij}^{MIN} C_{ij}}{D_j}$, (5) Observed $D_j^{\overline{OBS}} = \frac{\sum_i X_{ij}^{OBS} C_{ij}}{D_j}$ and (6) Maximum $D_j^{\overline{MAX}} = \frac{\sum_i X_{ij}^{MAX} C_{ij}}{D_j}$, where the ($X_{ij}^{MAX}$) is the theoretical maximum journey-to-work, (X_{ij}^{OBS}) is the observed work travel matrix, (X_{ij}^{MIN}) is the theoretical minimum spatial interaction matrix and (C_{ij}) is the cost matrix.

[20] Niedzielski's study proposes the next commuting efficiency metrics: related to origin-specific (1) Excess commuting $E_i^O = \left(\frac{O_i^{\overline{OBS}} - O_i^{\overline{MIN}}}{O_i^{\overline{OBS}}}\right)100$, (2) capacity used $C_i^O = \left(\frac{O_i^{\overline{OBS}} - O_i^{\overline{MIN}}}{O_i^{\overline{MAX}} - O_i^{\overline{MIN}}}\right)100$; and related to destination-specific, (3) deficit commuting $E_i^D = \left(\frac{D_j^{\overline{MAX}} - D_j^{\overline{OBS}}}{D_j^{\overline{MAX}}}\right)100$, and (4) capacity remaining $C_i^D = \left(\frac{D_j^{\overline{MAX}} - D_j^{\overline{OBS}}}{D_j^{\overline{MAX}} - D_j^{\overline{MIN}}}\right)100$.

Hence, (Niedzielski, 2006:2488) states: "*it is now possible to investigate the lengths of work trips for workers leaving their homes and the distance of workers attracted to employers. For workers, commuting cost is a major factor in the process of matching home and job location. Thus, excess commuting measures the savings possible, if journey-to-work lengths are reduced. For employers the importance of the commute distance of employees is vastly overshadowed by the need to attract an appropriate workforce. Therefore, deficit commuting is proposed as a measure that reduces the importance of commuting efficiency in the process of matching workers and jobs*" and continues defining that "*the value of calculating deficit commuting is the line segment between* $D_j^{\overline{MAX}} - D_j^{\overline{OBS}}$ *, the unused portion of the commuting capacity or the commuting deficit from the maximum worker travel pattern. While the scenario of short-distance trips-where employment demand is satisfied by workers residing n proximity to the job site- is ideal, the traditional excess commuting definition of deviation from the minimum trip length penalizes employment location for their success in attracting workers. Large deviation from the optimal is considered inefficient based on the standard definition, but from the destination perspective this may be seen as efficient due to agglomeration effects. The positive effects of clustering may produce longer work trips than necessary but this is a desired side effect of the clustered location of economic activity. Therefore, as* $D_j^{\overline{MAX}} - D_j^{\overline{OBS}}$*increases relative to maximum average commute,*$D_j^{\overline{MAX}}$*, employers are able to satisfy their demand for workers as well as approach the most efficient work travel pattern. Applying this concept to the sub-regional level, the degree to which workers attracted by employers deviate from the maximum amount of travel is valuable approach in benchmarking the trade-off between commuting distance and worker-attraction success. Moreover, this new definition of deficit commuting is consistent with the concepts of growth pole effects and economies of scale and agglomeration economies*".

The results that Niedzielski's study achieves in the first step suggest that efficiency is higher in larger cities than in smaller cities due to more commuting possibilities. Then, by using the intrametropolitan framework that his work proposed, the results suggest that commuting efficiency is higher for peripheral locations than for centrally located sites and higher for job-poor areas than job-rich areas: "*workers travelling from homes located in job-rich areas make the shortest minimum commute, whereas workers living in housing-rich areas make the longest minimum commutes. However, the lowest commuting efficiency is found for job-rich areas and the highest for housing-rich areas. Employers in job-poor areas attract workers with the shortest minimum commutes, whereas those in job-rich attract employees with the longest minimum trip lengths. Commuting efficiency is higher in job-poor areas and lower in job-rich areas*". (Niedzielski, 2006:2496)

On its turn, (Murphy and Killen, 2011) revisit the notion of random commuting within the excess commuting framework[21] in order to argue that the average random commute, is a more appropriate basis for measuring the efficiency of urban commuting patterns and its study propose two new measures of commuting efficiency based on measuring the collective commuting economy of individuals for the journey to work: commuting economy normalized and commuting economy taking as a study case Greater Dublin Area from 1991 to 2001 and different modes of transport. To do so, Murphy and Killen's study differs from (Hamilton, 1982) in the basis that they develop a specific conceptual framework for measuring the efficiency of regional commuting patterns using random commuting (T_{rand}). Murphy and

[21] For knowing more about excess commuting, see the following complementary literature: (Frost et al., 1998; Horner and Murray; 2002, 2003; Horner, 2002, 2004, 2007; Yang, 2005; Horner and Medford, 2007; Charron, 2007; Ma and Banister, 2006, 2007; O'Kelly and Niedzielski, 2008 and 2009).

Killen develop this framework starting from other scholars studies such as (White, 1988, Giuliano and Small, 1993) in which define and use the concept of (T_{min}) which represent the lower limit towards which (T_{act}) will tend as the cost to individual of consuming zonal separation become more and punitive and (T_{max}) the limit towards which (T_{act}) will tend as the reward to individuals of consuming separation increases by then defining another concept which represents a situation where individuals are behaving in such a way as to be insensitive to zonal separation: "*where individuals are insensitive to separation, the result travel pattern will in effect be random-that is, similar to the situation emerging when a trip origins are assigned to destinations at random. We refer to the average trip cost associated with this solution as* T_{rand}" and they continue emphasing the contribution of this new value: "*the value of this scale is that it offers a more complete framework against which value of* T_{act} *can be measured and interpreted. Intuitively, we expect that for any given city region,* T_{act} *will lie between* T_{rand} *and* T_{min}*, ... As stated already* T_{min} *and* T_{max} *are a function of the geography of trips origins and destinations, that is of land use geography. On the other hand,* T_{rand} *relates solely to a particular type of behavior –namely, one where separation is of no importance".* (Murphy and Killen, 2011:1260)

Hence, to compare actual commuting, they use a pattern of random commuting where cost is considered unimportant in determining the behavior of individuals for the journey to work than with a pattern of commute minimization where it is considered extremely punitive or commute maximization where it is considered extremely rewarding. So, the pattern of random commuting that they use[22], represent the extent to which individuals are economizing on commuting costs and can be thought as the collective commuting economy of workers. In this sense, (Murphy and Killen, 2001:1261) point out that: *"(C_e) measure is independent of (T_{min} and T_{act}) it demonstrates the extent to which actual behavior is reacting to the cost of consuming the separation that exist between residences and workplaces in the urban region. Therefore, (T_{min}) and (T_{max}) represent the greatest extent to which (T_{act})can depart from (T_{rand}) in a downward and upward direction respectively. In particular, where (T_{act}) is less than (T_{rand}), as is generally expected to be that case, the statistic represents the extent to which (T_{act}) is below (T_{rand}) relative to the theoretical extent to which this could happen as determined by land use geography, -i.e.* T_{min}*-, In order words, we propose a revised commuting range using (T_{rand}) as the upper limit on commuting cost".* In this sense, Murphy and Killen's study develop what they called *normalized commuting economy*[23], a measure that allows them to determine the extent to which collective behavior is tending toward commuting economy while talking account of the theoretical extent to which it is possible within the constrains set by and use geography. To determine the value of T_{rand}, Murphy and Killen's study use a random simulation algorithm know as the *hit-and-run algorithm* based on a specific type of Markov chain Monte Carlo sample method which due to its iteratively proceeds by taking step of random length in randomly chosen direction is possible to generate a large number of trip matrices from a specified solution space[24].

By using the data derived from a Dublin Transportation Office (DTO) for 1991 to 2001 and broken down by private and public transport in order to draw conclusions concerning the

[22] $C_E = \left(1 - \frac{T_{act}}{T_{rand}}\right) * 100$, gives the extent to which T_{act} is falling below (positive) or above (negative) T_{rand} –i.e. the extent to which collective behavior as expressed by the actual trip pattern is departing from random behavior and reacting to the consumption of zonal separation.

[23] $NC_E = \left(\frac{T_{rand} - T_{act}}{T_{rand} - T_{min}}\right) * 100$

[24] In Murphy and Killen's study, the solution space is specified by the fixed distribution of origins (residences) and destinations (workplaces) in the study area. (Murphy and Killen, 2011:1262).

evolving roles of both modes, Murphy and Killen's work achieve the following results (Op.cit:1266-1270): a) there has been a significant increased in the efficiency of commuting patterns. The C_e measure shows that actual commuting was 15,4 per cent further away from random commuting in 2001 than in 1991 which suggests that the cost of separation between residences and workplaces was playing an increasing role in determining. The NC_e value support this assertion: they show that normalized commuting economy was 15,6 percent greater in 2001 than in 1991: "*undoubtedly, this was facilitated by the decentralization of employment functions over the period as evidenced by the reduction of T_{min}. Regardless of which measure is utilized, the results demonstrate clearly that commuting behavior has moved towards achieving greater commuting economies over the period",* b) greater commuting economies can be achieved in urban structures with a higher degree of residential and employment intermixing than in cities that are more monocentric form: "*we expected that cities with a greater intermixing of land uses would display more efficient spatial interaction, at least for the journey to work"* and c) the commuting economy of public transport users has improved at greater rates than for private transport users, so in policy terms: "*this implies that the movement towards a greater intermixing of residential and employment functions has increased the role played by public transport in servicing a greater range of trip possibilities".*

Finally, the work of (Loo and Chow, 2011) analyses the structural effects on the distribution of employment and the commuting patterns due to an infrastructure project. By using data of homes and employment locations and commuting cost, obtained from the Travel Characteristics Survey (TCS) and starting from the theoretical framework of excess commuting which different indicators of minimum and excess commuting are compared (Hamilton, 1982; White, 1988 and; Horner, 2002)[25], Loo and Chow's study aims to examine the impact of the Hong Kong International Airport relocation on the jobs-housing balance of the city under two scenarios: a) the first, shows the actual situation after the airport was relocated to a suburban area entailing decentralization or polycentric development; and b) the second, shows the situation with hypothetical and relatively monocentric city structure.

The findings according to (Loo and Chow, 2011:1691) suggest that: "*the polycentric patterns offer shorter commuting opportunities for workers in the city as a whole. Workers living in the suburban and rural areas would benefit most. Should the city rely strongly on the city center for job provisions under the 'irreversible' trend of population decentralization, workers in the city would have to travel longer distances for jobs and produce more transport emissions. The airport relocation in Hong Kong has partially redressed the jobs-housing imbalance caused by population decentralization*".

Until now, we try to understand how the transformation from a monocentric city model to polycentric city model influence on commuting by means of excess commuting (distance and time) presenting that most studies in the literature are agreed with the statement that polycentric spatial structures are able to shorten commuting distance and times. However

[25] The approach that Loo and Chow's study use is: $T_r = \frac{1}{W}\sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij}X_{ij}$, subject to: (1) $\sum_{j=1}^{m} X_{ij} = D_j$, (2) $\sum_{j=1}^{m} X_{ij} = O_j$, and (3) $X_{ij} \geq 0$; where n=number of origin zones (home location); m=number of destination zones (job location); C_{ij}=travel costs between zone (i) to zone (j); W=total number of workers; O_i=number of workers living in zone (i); D_j= total jobs in zone (j). Constraint (1) ensures that no jobs demand is left unfulfilled, constraint (2) ensures that all jobs are taken up and constraint (3) ensures that there is no negative commuting trip between zones. Then, for estimate the actual commuting above the minimum commuting (excess commuting), (Loo and Chow, 2011:1686) use the following equation: $E = \frac{(T_a - T_r)}{T_a} * 100$, where ($T_a$) is the actual commuting; and (T_r) is the minimum commuting.

would be interesting studying this relationship inversely: *are commuting patterns influence on spatial structure?* before continuing with an in-depth analysis in the following Section 2.2, in this way, the work of (Sohn, 2005) in which explores urban spatial structure based on commuting patterns and to examine how well commuting patterns reflect the corresponding urban spatial structure, especially in the case of the monocentric cities due to the lack of empirical resources of the used method to analyze the cases of polycentric cities.

To do so, (Sohn, 2005) uses an analytical model to explain commuting patterns in the Seoul Metropolitan Region from 1987 to 1995 is derived from the gravity model that after log-linearization is estimated by using a two-step regression process[26]. Then the dominant marginal commuting flow patter obtained from the previous model is examined and compared to the corresponding urban spatial structure by constructing an urban density function[27] and draw the urban density curve corresponding to the function. This comparison is made between the urban spatial structure projected from commuting patterns and the urban density patterns and the urban density distributions of employment and employed residents. According to (Sohn, 2005:310) this it shows how well the urban spatial structure projected by commuting patterns reflects the urban spatial structure measured by urban density function entailing four different relationships: a) more dispersed urban spatial structure: both the locational coefficient and the density parameter have increased from their initial level, b) more concentrated urban spatial structure: both the locational coefficient and the density parameter have decreased compared to the initial level and c) and d) other combinations entail that commuting patterns may not reflect the corresponding urban spatial structure.

The findings that (Sohn, 2005:315) present revealing a) that the marginal tendency of commuting in the area is a sign of dispersion for both employment and employed residents: "*the trend of this tendency, however, showed that the distribution of employment has become less dispersed (between 1987 and 1995) and the distribution of employed residents has become more dispersed over the years"*, b) the urban density functions showed that density distribution became most concentrated in 1990 and less concentrated afterwards:*"as a result*

[26]According to (Sohn, 2005), in the first step the equation estimated is: $logT_{ij} = logk + \alpha_1 logO_i + \alpha_2 logD_j + \beta d_{ij}$, where ($T_{ij}$) is the total commuting flow form (i) to (j); (k) is the constant; ($O_1^{\alpha 1}$) is the number of commuting leaving (i); ($D_j^{\alpha 2}$) is the number of commuting arriving (j); and (d_{ij}) is the distance between (i) and (j) in km. If commuting behavior of people is rational (less commuting between farther places and more commuting between more jobs and residences), the model should be able to explain the whole of variation of commuting patterns. However, there is some unexplained variation or marginal tendency beyond what standard variables explain in the model. One way to explain this variation is to specify additional variables representing different commuting patterns and as a result urban spatial structure by using the next equation: $logT_{ij} = logk + \alpha_1 logO_i + \alpha_2 logD_j + \beta d_{ij} + \gamma_1 d_i^O + \gamma_2 d_j^D$, where ($d_i^O$) is the distance to origin (i) from the city center (km); and (d_j^D) is the distance to destination (j) from the city center (km). So, the two-step regression is based firstly by estimation the first explained equation and once the coefficient are estimated, they are used to predict flows and subsequently to obtain residuals. The second set of regressions, as (Sohn, 2005:310) explains: "*are based on runs on the residual only with the location variables. If there are temporal tendencies in commuting patterns, the residuals will be statically associated with the locational variables. Because, the locational variables reflect the distance from the city center, they increase as the zone is farther from the center, so: positive coefficient means more commuting flow in outer regions and negative coefficient reflects more commuting flow in the core. Hence, a positive coefficient of (d_i^O) means that a larger volume of (outgoing) commuting flow is expected if the origin of the commuting is farther from the city center. A negative coefficient for (d_j^D) means that a larger volume of (incoming) commuting flow is expected if the destination of commuting is near the city center. Combining these two reflects traditional inbound commuting. In light of urban spatial structure, this is more or less associated with monocentric urban form: concentration of economic activities near the city center*".

[27] Song's study uses the most common form of density function, this is the exponential form which in log-linear form is: $logD(d_i) = logD_0 + \gamma d_i$, where ($d_i$) is the distance from the center to zone (i); D(d_i) is the density at a distance; (D_0) is the density of the city center and (γ) is the percentage by which D(d_i) falls as (d_i) increases.

of the comparison between the spatial structures projected from the commuting patterns and the urban density distribution, it is found that the distribution of employment was consistent between the two distribution patterns while the distribution of employment was not. These results according to Sohn's study seem to show that commuters may not always consider trip distance minimization as the primary factor in deciding their residential location, workplaces or even commuting routes, and that employers tend to spatially gravitate towards local labor markets, so this may be explain the excess of commuting (distance and time) that occurs in the metropolitan areas.

Summarizing, in this section we have presented the theoretical framework based on the transformation of cities from monocentric to polycentric and how this change of its urban structure influence on the commuting efficiency (distance, time, excess commuting). As the analyzed studies show the relationship between urban structure and commuting pattern is a still open debate. Although, most studies claim that polycentricity compared to monocentricity, entails shortens commuting in distance and time, there are other studies that defend that a polycentric city model not necessary means a more efficient commuting pattern. In the following Section 2.2 this relationship is in-depth analyzed due to defines the theoretical framework core which the empirical work of this paper is based on.

2.2. Polycentricity: commuting distances-time and environmental externalities

Polycentricity and its effects on commuting patterns is one of the issues less consolidated among researchers in the literature, entailing that it is still open. For an extensive revision of the literature, see (Handy, 1996, Crane, 2000 and; Stead and Marshall, 2001). A first body of research investigates whether the polycentric distribution of people and jobs would be likely to reorganize mobility patterns in a more sustainable way. In this context, a key question is whether the development of polycentric structure and subcentres would be likely to favour the co-location of workers and jobs. This is known as the co-location hypothesis (Gordon and Wong, 1985; Gordon et al., 1986, 1988, 1989a, 1989b, 1991; Dubin, 1991, Levinson and Kumar, 1994; Levinson and Wu, 2005; Alpkokin et al., 2005a, 2005b, 2007, 2008; Veneri, 2010 and; Modarres, 2011), which proposes that polycentric distributions of jobs and households shorten commute distances (or time) because workers tend to locate close to their employment centre (see, Section 2.1). There are however, empirical studies that reach the opposite conclusion (Cervero and Wu, 1998; Schwanen et al., 2001, 2002, 2003, 2004; Aguilera and Mignot, 2004; Aguilera, 2005; Bento et al.; 2005 and; Melo et al., 2012).

A second body of research analyses if polycentric structure exerts an influence on modes of transport in favour of supply and the competitiveness of mass and public transport in order to achieve a reduction of the use of less sustainable private means of transport (Breheny, 1995; Modarres, 2003; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008 and; Commins and Nolan, 2011).

Finally, a third body of literature investigates the relationship between urban structure with the environmental externalities related to mobility patterns. In that sense, some studies have studied the relationship between different patterns of urban expansion and environmental costs (Camagni et al., 2002; Travisi and Camagni, 2005; Travisi et al., 2006, 2010 and; Cirilli and Veneri, 2010b, 2010c) or with CO_2 emissions (Veneri, 2010 and; Cirilli and Veneri, 2010a) and with the ecological footprint which not only account for direct CO_2 emissions but also for indirect emissions and occupied land (Muñiz and Galindo, 2005).

The work of (Gordon et al., 1988:419) by using data from Nationwide Personal Transportation Study (NPTS) surveys of 1977 and 1983-1984[28] reveal a remarkable increase in nonwork travel: *"the growth in nonwork travel does not appear to be closely associated with the growth in female employment or trips related to the children of working women. The most convincing explanation of the growth in nonwork travel is that the trip cost savings (less time and distance) experienced because of more efficient spatial settlement patterns have provided an incentive to undertake more trips. Another implication is that urban economics models and urban transport policies have overemphasized the journey to work, especially to the central business district (CBD)"* what is suitable with the aforementioned co-location hypothesis.

In that sense, Gordon's et al., study made the following two objections, a) growth of nonwork compared with work trips, its ubiquity over city classes (especially for outside-central city residents), and its close association with suburbanization: "*trips volumes for volumes for nonwork trips grew faster than those for work trips (or declined less) and that the growth was strongest for suburban-based trips"* (Gordon et al., 1988:420), b) much of the growth in nonwork trips has been outside central cities, with the implication that it is more difficult to implement congestion fees administratively in suburban areas focused on subcentres that generates huge volumes of trips: *"for example trips generation rates per employee in Los Angeles are 13,6 times larger for retail trade and 9,3 times larger for entertainment than for the FIRE sector (the most typical downtown activity). Many subcenters double as workplaces and as foci for nonwork activities so that attempts to divert nonwork trips can be critical to relied of congestions, especially because the proportion of nonwork to total trips is much higher at subcentres than in the CBD"* (Gordon et al., 1988:422).

The previous Gordon's et al., study shows in a way that the monocentric city becomes inefficient as urban growth continues because of increasing congestion close to the CBD. Although the exhaustion of CBD agglomeration economies is another major reason for the breakdown of monocentricity, these congestion costs are sufficient grounds alone for the emergence of the polycentric metropolitan region. In this sense, the work of (Gordon et al., 1989b) by analyzing theoretical models of polycentric city they state that polycentric cities imply shorter commuting times because of the assumption that households in choosing residential locations cluster around employment subcentres to minimize commuting trips.

By using data across the U.S. main cities in 1980 aggregated into 91SMSAs (Standard Metropolitan Statistical Area), Gordon's et al., 1989 study examine the relationship between commuting times and urban spatial structure. However, as they pointed out, apart from the number of major employment centres, commuting times are also influenced by: a) city size, b) metropolitan density, c) economic structure, d) income, e)carpooling and, f) public transit.

Referring with a) city size, (Gordon et al., 1989b:141) states: "*mean travel times may be longer in larger cities, even in cases where their spatial structure is polycentric. The only exception to this generalization would be if there was a critical city size at which cities switched from being monocentric to polycentric, at which point travel times would dramatically fall. The two obvious scale variables are urbanized area population and the urban land area. The latter is preferred because has a more direct effect on trip length (and hence on travel time) than population size.*

[28] The simple size rules of this data permits Gordon's study to use it into five level of Standard Metropolitan Statistical Area (SMSA) disaggregation: (1) below 250.000, (2) 250.000 to 500.000, (3) 500.000 to 1.000.000, (4) 1.000.000 to 3.000.000 and, (4) more than 3.000.000.

In terms of b) density, (Gordon et al., 1989b:140) point out: "*the priori relationship between residential densities and mean travel time is unclear. On the one hand, the impact of residential density on the length of work trips is ambiguous. In a monocentric city high densities imply shorter trips, and low densities mean longer trips. In a polycentric city, low densities could mean either shorter or longer trips depending upon whether workers choose homes around employment subcenters (or, alternatively, firms decentralize to locations close to the areas from which their labor forces are drawn) or whether cross-commuting across metropolitan areas in common. On the other hand, the effects of employment densities on commuting patterns also have to be considered. High commercial densities imply a heavy CBD concentration of office workers. The greater this concentration the more likely that traffic congestion will increase means travel times. Manufacturing tends to be predominantly located in suburban areas and high industrial densities imply subcentre clustering of manufacturing jobs*".

According to c) economic structure factor, (Gordon et al., 1989b:142) explain that: "*the hypothesis is that the spatial distributions of industry and commerce are different and that these differences influence mean commuting times. One possible hypothesis is that the higher the share of industrial employment the more suburbanized the distribution of jobs (because manufacturing is more decentralized than commerce), and that this offers more opportunities for economizing on commuting times. In addition, the more service-oriented, and especially the more office-oriented a city is, the stronger the tendency to economize on commuting times. The explanation is that office buildings, some of which can be very attractive, do not repel residents because of negative externalities to the same extent as factories, if at all*".

Referring with d) income influence, (Gordon et al., 1989b:143), state that the explanation is that that income net of commuting cost is larger for the rich, and that housing expenditures increase with income: "*the rich would consequently consume more housing space at any location, and since the marginal change in commuting cost is invariant with income, rents have to decline with distance for the locational equilibrium condition to hold. The rich therefore consume more housing space at lower land rents and live further out than the poor. Thus commuting times increases with income*" and more indeed in nonmonocentric spatial structures: *"in a nonmonocentric (dispersed or polycentric) city, the income effects may even be stronger because higher income households do not necessarily have to trade off commuting costs against housing space as is inevitable for locational equilibrium in the monocentric model: higher income households have the buying power to choose the sites they prefer and the housing space they desire in the nonmonocentric city"*.

In terms of e) carpooling and f) public transit, (Gordon et al., 1989b:145) point out that: "*the incidence of carpooling and mean travel times can be expected to be positively related due to carpools result in longer collection and delivery times because several passengers have more origin-destination diversity than has one passenger and second, in cities where work trips are longer carpooling may be a response to higher commuting costs"* and *"similar influences may operate on public and private transit, however income effect might be weaker for public transit time if public transit commuters have, on the average, lower incomes than automobile commuters and if the value of travel time increases with income"* respectively.

To analyze this aforementioned relationship, Gordon's et al., study run OLS regressions[29] with mean commuting time by automobile and public transit as dependent variables using the

[29] Gordon's et al., study also take into account 2SLS regressions but the differences were negligible

density, economic structure, urban size, polycentricity and income measures as independent variables, plus the addition of carpooling in the automobile commuting equations[30]. Focusing on automobile commuting times, Gordon's et al, regression obtain a good explanatory coefficient (adjusted R^2=0,87) and the main results that this study obtain are: a) commuting times are longer in spatially large cities, and the ULAND variable has the most potent effect, b) the negative sign of the INDEMP coefficient supports the hypothesis that worker housing is located close to industrial sites because negative externalities make these residential areas unattractive for higher income households, c) the sign on COMMEMP is negative, in line with the argument that the absence of negative externalities around office workplaces implies no offset to the desire for accessibility, but the coefficient is insignificant, d) INCOME and commuting time are negatively associated with the hypothesis that high-income households have a strong incentive to economize on commuting, e) AUTODR variable has a negative sign, mean commuting times tend to be longer where the incidence of carpooling is higher, d) RESDEN and commuting times are positively associated, and the relationship is statically significant: "*this support the argument that low-density metropolitan areas with their decentralized employment centres facilitate short work trips. It also highlights the limited value of the monocentric city model, because high densities imply short trips in a monocentric city unless congestion effects are strong"* e) COMMDEN and INDDEN have opposite effects. The former reveals that the congestion is developing around office zones (positive effect).The latter, support the hypothesis that manufacturing clustering permits commuting economies (negative effects), finally f) CITYEMP has a positive and highly significant, confirming the hypothesis that monocentricity adds to commuting times.

In terms of public transit travel time have similar results, although the lower explanatory power (drops to R^2=0,62) and some of the variables that were significant for automobile commuting times become insignificant. However according to (Gordon et al., 1989b:150) the signs on the coefficients are identical: *"the most stinking difference between the two types of transportation is that CITYEMP and INCOME become insignificant for public transit while INDEMP AND COMMEMP become significant. The weaker income effect is understandable in view of the lower incomes of public transit commuters, while the CITYEMP result may indicate that the speed of travel differential between monocentric and nonmonocentric cities may be narrower for public transit than for automobile commuting"*

Therefore the main conclusion that (Gordon et al., 1989b:150) present is: "*polycentric and dispersed metropolitan areas facilitate shorter commuting times as predicted by theory. The density results illustrate the need to discriminate among the types of density. Low residential densities and high industrial densities favor commuting economies, a finding consistent with the idea that the clustering of manufacturing activities, especially "clean" industries at decentralized employment centers, in low-density metropolitan areas implies a spatial structure conducive to residential site choices with shorter commuting times"* and *"the influence of other variables (city size, economic structure, income, and carpooling) is as expected. The similarity of the results for public transit users suggests that they are as sensitive as automobile commuters to the benefits from commuting economies"*.

[30] As a dependent variables Gordon's et al. study takes (1) T_{AUTO}=mean travel time by private automobile and (2) T_{PUBLIC}=mean travel time by public transport. As a independent variables, the aforementioned study takes: (1) RESIDENCE= residence density (total population/residential land), (2) COMMDEN=commercial density (commercial workers/commercial land), (3) INDDEN=industrial density (manufacturing workers/industrial land), (4) ULAND=total urban land, (5) CITYEMP=proportion of employment in largest city of SMASA(=1,00 in monocentric SMSA), (6) INCOME=median family earnings of SMSA workers, (7) INDEMP= proportion of workers in commercial employment and (7) AUTODR=proportion of workers driving alone.

The previous revision of (Gordon et al., 1989b) work reveals that the emergence of multiple centres of economic activity has implication for travel behavior in a metropolitan area (economize commuting)[31]. Polycentricity gives rise to the alternative hypothesis that households and economic activities periodically readjust spatially to accommodate growing travel demand within the constraints imposed by transportation capacity. In this sense, the study of (Dubin, 1991) and (Levinson and Kumar, 1994) have highly importance.

Dubin's work hypothesize that individuals with greater job and residential mobility will have shorter commutes, given decentralized firm location by taking into account time and distances measures in its estimations. (Dubin, 1991:15) starts to state the following meaningful hypothesis: firm decentralization will reduce total commuting only if one of the following conditions holds, a) "*the firm's employees are located in one portion of the city so that the firm can located nearer to them by suburbanizing";* b) *"the employees are willing to move in order to be near the new suburban location"* and, c) *"the firm can change employees and thereby employ people who live near the new location".*

To test empirically his hypothesis, Dubin's work adopts Hamilton's convention of using the hypothetical monocentric commute as a benchmark against which to compare actual commuting[32]: "*residential and job mobility determines the extent to which a worker can use a non-CBD employment location to shorten his commute. These in turn are functions of an individual's socioeconomic and job characteristics"* (Dubin, 1991:18). By estimating several regressions models[33]: a) actual commuting, b) optimal commute, commuting benefit, c) commuting cost, d) household responsibilities, e) residential disequilibrium, f) job disequilibrium and, g) hypothetical monocentric commute and by using data compiled from the Baltimore Travel Demand Set in 1989, Dubin's work constructs a final model[34] one taking into account distances and the another one considering times in order to measure the effects of firms suburbanization in commuting patterns.

[31] In that sense, (Gordon et al., 1989b) also reveal that there are other factor that exert influence on commuting patterns apart from urban spatial structure. This factors will be in-depth explained in the following Section 2.3

[32] Dubin's work uses the following expression: $\Delta D = HYP - ACTUAL$, where (ΔD) compares the length of the current commute (ACTUAL) to the distance (time) the worker would travel if he were employed in the CBD (HYP). As such it represents the reduction (or lengthening) of the worker's commute due to firm decentralization: "*if the commute is shorter in the presence of suburbanization, (ΔD) will be positive. The monocentric model predicts that should be the case. If worker commutes farther than he would if his job were located in the CBD, then suburbanization has lengthened his commute, and (ΔD) will be negative. (ΔD) is a disaggregate version of Hamilton's actual vs. monocentric commuting comparison".* (Dubin, 1991:18)

[33] In such models, Dubin's study uses the following independent and dependent variables: as independent, (1) $\Delta D(\Delta T)$, which is the distance (time) the worker would have to travel if he were employed in the CBD minus the actual commute, a measure of the benefit to the worker of firm decentralization, as dependents, (2) HYP, which is the hypothetical monocentric commutes (in miles or minutes), (3) ACTUAL, which is actual commute (in miles or minutes), (4) OPT, that is optimal commute (not directly observed), (5) HDEQ, that is residential location disequilibrium factor (not directly observed), (5) JDEQ, which is employment location disequilibrium factor (not directly observed), (6) BEN, which is the benefit of commuting and additional mile, (7) COST which is the cost of commuting an additional mile, (8) HR, that is the household responsibilities (not directly observed), (9) SEX, 0=male, and 1= female, (10) RACE, 0=white and 1=black, (11) MODE, which is transportation model (0=auto, 1=bus), (12) OWNRNT, that is residential tenure (0=own, 1=rent), (13) PCHILD, 0=no children under 12 and 1=otherwise, (13) NADULT, which means the number of household members older than 18, (14) L, which is length of time at current location (1=<6mos,, 2=7-12mos., 3=13-24mos., 4=>2yrs.), (15) TS, which is a dummy variable representing jobs skills that are highly transferable, (1=service or sales worker, 0=any other occupation), (16) TEN, that means job tenure, (17) F, which is the number of full-time workers in household, (18) JDIST, that means the distance of job from CBD, (19) Y, which measures the households income (annual income in hundreds of dollars) and finally (20) U_k which means random, unexplained disturbances.

[34] The dependent variable of these models are (see note 33): (1) Y, (2) MODE, (3) PCHILD, (4) NADULT, (5) F, (6) OWNRENT, (7) L, (8) RACE, (9) SEX, (10) TS, (11) JDIST, and (12) TEN.

According to (Dubin, 1991:22) *"the coefficients for SEX, TS, OWNRNT, MODE, and JDIST are expected to be positive. This means that women, workers with highly transferable job skills, renters, public transit user, and workers whose jobs are located far from the CBD are all expected to use firm suburbanization to shorten their commutes. RACE, NADULT, L, and TEN are expected to have negative coefficient, i.e., being black having more adults in the household, and having longer residential or job tenure should adversely affect a worker's ability to take advantage of firm suburbanization"* and continues "*coefficient signs for Y, PCHILD, and F cannot be determined. The tendencies of high-income workers to locate farther from the CBD and to have higher commuting costs (because of a high value of time) exert a positive influence on (ΔD). High job change cost exerts a negative influence, while the residential mobility effect is indeterminate. Regarding PCHILD, the tendency of households with children to live farther from the CBD plus the added housework due to children tend to increase (ΔD). The relationship between the presence of children and residential mobility is unknown. Finally, for F (the number of workers), increased household responsibilities increase (ΔD), while the difficulty of optimizing with respect to two or more work places reduces it"*. After estimating the two models, the regressions results that (Dubin, 1991:25) present are: a) the (ΔT) regressions fit better than the (ΔD) –adjusted R^2 is 0,243 compared to 0,179- , b) RACE indicates that white workers use firm suburbanization much more effectively than black workers (spend less commuting time), c) Income is significant and positive, indicating that commuting time increases, d) NADULT is significant supporting the hypothesis that household responsibilities influence the degree to which a worker uses firm decentralization to shorten the commute, e) the coefficient of TS shows that jobs mobility affects the degree to which workers take advantage of firm decentralization (higher jobs skills that are highly transferable, the higher commuting times), f) MODE is negative and significant, so firm decentralization and using public transport entails less commuting time and finally h) JDIST is significant and positive associated with commuting time, which shows that (ΔT) increases (although not ΔD) as jobs move farther away from the CBD: *"this suggest that workers with suburban jobs travel at higher speeds, which is consistent with the notion that these workers face less congestion"*.

Hence, the main findings that Dubin's present are: a) "*although workers travel slightly longer distances, they save substantial commuting time due to firm decentralization"* and b) *"more mobile individuals commute less as a result of firm decentralization. Individuals with extremely high nonwork demands on their time also use suburbanization successfully to shorten their commutes. Therefore, the labor force characteristics must be more carefully considered in urban location models"* (Dubin, 1991:28).

On its turn, Levinson and Kumar's work explore changes in travel patterns, including trip duration, distance and speed for Washington Metropolitan Region in 1968 and 1988. Its analysis shows that average trip time have remained stable or declined in this period for all trip purposes and all modes of travel, despite increased trip distances. This suggests that residents could fulfill their daily needs without having to spend more time per trip in 1988 Washington as compared with 1968 according to what Levinson and Kumar called "the rational locator", *the locators of households and workplaces have responded by periodic relocation over time to maintain constant commuting durations in the face of changing commuting requirements. The time economies are more easily realized in suburbs because of multiple employment centers there, which provide opportunities to reside close to workplaces.*

By using data that comes from detailed person travel surveys conducted by the Metropolitan Washington Council Governments (MWCOG) for 1968 and 1987-1988, Levinson and Kumar define three primary travel modes: transit, automobile and walking and seven trip purposes: home-to-work, work-to-home, home-to-other, other-to-home, other-to-work, work-to-other, and other-to-other. Then, its study carried out an analysis of the a) regional commuting patterns, b) travel times by area (center city, inner suburbs, and outer suburbs), c) travel time by the defined purposes, d) travel time by modes (transit, automobile and walking), e) travel time by gender, f) travel distance and finally, g) travel speed.

Referring with a) regional commuting analysis, (Levinson and Kumar, 1994:323) explain that the most significant increase in flows for work trips with both origin and destination ends in the outer suburb ring entailing a over 300 percent increase what reinforce the idea that outlying areas are gaining importance as employment centers and what suggest that may be they will be more significant in the future if there is enough housing stock in the inner rings of the metropolitan area: "*the increasing importance of outlying areas as employment centers supports the concept that as urban growth continues, the monocentric city become less efficient because congestion close to the CBD increases. The analysis also supports the hypothesis that suburbanization of jobs has promoted complementary land uses in suburbs that bring the ratio of jobs to resident workers into better balance at a more local level"*.

In terms of b) travel time areas, (Levinson and Kumar, 1994:323) show that: "*the fact that change in regional commuting time (3,9 percent) is smaller than for each of the three trip interchanges (5,5 percent, 30,3 percent, and 24,3 percent) supports the further point: even though outer suburban trips duration has increased, and the volume of suburb-to-suburb trips remain shorter than suburb-to-city trips, thus on average, commuters maintain 1968 commuting times in 1988. The shifting composition of trip origins and destinations has the end result of relatively constant overall travel times for trips originating in the metropolitan area. Only modest changes are seen in work trips by origin area, indicating that the changing locational composition works at both the metropolitan and sub-metropolitan levels"*

According to c) travel time by the defined purposes, (Levinson and Kumar, 1994:324-325) state that: *"the average travel time for home-to-work and work-to-home trips has remained remarkably stable over the analyzed period*[35]" and "*traditionally defined home-based other purposes –home-to-other and other-to-home- are expected to be shorter than work trips"*.

Referring with d) travel time by modes and e) travel time by gender (Levinson and Kumar, 1994:326) conclude that longer travel time by trips in a car with a driver and one passenger and; trips in a car with a driver and two or more passenger (carpool modes) than by trips as a driver with no passenger and that females are more likely to commuter shorter distances: "*the cumulative distribution of travel times for home-to-work trips by mode for 1988 shows that the proportion of trips in each five-minute band from 0-5 minutes to 85-90 minutes is shown. Of the seven modes shown, walk trips are consistently the shortest, followed by drive-alone and carpool trips. Transit trips were subdivided into three access modes: walk-to-transit, park-and-ride, and kiss-and-rise. Transit is consistently longer than other modes, while walk-to-transit trips are generally shorter than park-and-ride or kiss-and ride-trips"* and "*the share of work trips made by females increased from 39 percent to 46 percent between the*

[35] Levinson and Kumar's empirical analysis show that the average home-to-work travel time changed slightly, from 28,30 minutes in 1968 to 28,90 minutes in 1988, while the work-to-home time stayed the same, at 32,50 minutes. Then, by analyzing the cumulative distribution of travel times for home-to-work trips for 1968 and 1988 the results suggest that: the proportion of trips in each five-minute band from 0-5 minutes to 85-90 minutes is shown. What is more striking than the table of central tendencies is the cumulative distribution of travel times, which is almost identical for the two years for each five-minute period.

years 1968 and 1988 (…) and women whose trips continue to be shorter in distance than those by men had a slight drop in trip duration from 32,4 to 31.1 minutes while for men trip durations from 32,2 to 33,7 minutes" respectively. Finally, in terms of f) travel distance and finally and g) travel speed (Levinson and Kumar, 1994:327) point out that trip length increased markedly for all modes of transportation and all purposes, the only exceptions being the home-to-other and other-to home purposes by automobile: *"This finding would seem to indicate that the effect of decentralization is to increase trip lengths, but because of the higher speeds attainable on lateral and reverse radial commuting trips, travel times decrease"* and commuting speed have gone up for all modes by 20 to 30 percent respectively.

The conclusion that (Levinson and Kumar, 1994:329) reach on its study are: a) "*the hypothesis that a polycentric metropolitan area facilitates commuting economies as compared to a monocentric city is tested by analyzing travel-behavior data over a twenty-year period for a single metropolitan region that has changed from orientation around a dominant center towards polycentricity. The display of constancy in trip duration over the study period (and even back to 1957), despite increasing trip distances and worsening congestion, is the primary finding of this paper"* and b) which states a critic towards the conception that jobs-housing balance is not an effective solution for traffic congestion (see Giuliano's study in Section 2.1): "*urban patterns as shaped by entities called "locators" (households, business enterprises, and other organizations), which caused the suburbanization of urban population in the past. Constancy of travel times over the twenty-year period, while travel demand increases so sharply, is evidence of a feedback mechanism between these locators and travel times: "rational locators", including both individual households and firms, respond to changes in transportation supply by sitting themselves to reduce commuting times. Evidence about Locators' decisions bears on the issue of balance between jobs and housing. Because that balance is inherently defined by the spatial separation (measured in commuting time) of jobs and housing"*

In that sense, few years later, (Levinson and Wu, 2005) continue its previous work and re-test the rational located hypothesis again: travel times are stable taking as study cases the Washington metropolitan area but now from 1968 to 1994 and the Twin Cities of Minneapolis and Saint Paul Minnesota from 1990 to 2000. So, to do so, Levinson and Wu's study conduct two intra-metropolitan analyses to better understand the responses of individuals to changing travel environments. The former case is Washington DC metropolitan area that according to the literature is a classic monocentric city which developed a number of suburban activity centers. The used data comes from Washington DC Household Travel Surveys in the years 1968, 1987-1988 and 1994 and its study takes into account three transportation modes: a) drive-alone, b) driver and passenger, c) driver and two or more passengers and transit; and six different activities for the empirical analysis: home, work, work-related, shop, other and travel. The latter, Twin Cities tend to be bi-centric, though have also seen the emergence of significant suburban employment over the past three decades. In this case the data comes from the Travel Behaviour Inventories in 1990 and 2000, the transportation modes are the same as previously, but the purposes are different: work and other (home-related).

Referring with activity duration analysis, Levinson and Wu's study reaches on the following results: a) workers and non-workers, males and females spent less time at home in the Washington metropolitan area: "*the reduction for male workers is 38 minutes and for females workers it is 31 minutes. The male working time apparently increased by 27 minutes in 1994, for female workers it increased by 29 minutes. The amount of time spent at home declined by about the same as the amount of time increased at work*" and, b) the Twin cities data show similar patterns but different magnitudes: "*the increase in this decade for both men and women was approximately 10 minutes. As in Washington, people spent less time at home. For non-workers, the time is reduced by 50 minutes*" (Levinson and Wu, 2005:195).

Related to travel duration, the results are: a) for Washington's DC average commute home-to-work and work-to-home commutes are longer than trips for other purposes: "*the travel time for these purposed has remained constant over the six year 1988-1994 for the drive-alone mode. The average time for home-to-work trips stayed at 29,6 minutes for work-to-home trips, it remained at slightly over 33 minutes. However, for the modes with higher occupancy, the travel time for these two purposes increased"* and, b) for Twin Cities case: "*the average travel time of home-based work trips for drive-alone commuters increased from 22,6 minutes in 1990 to 27,2 minutes in 2000 and for other purposes, travel times show the same pattern as the home-based work trips"* (Levinson and Wu, 2005:196).

Hence in conclusion, (Levinson and Wu, 2005:199) point out that: a) Washington's DC average commuting times remain stable between 1968 and 1988 despite the increase in commuting and congestion: "*fixing the area for 1994 commuting times are statistically equal (though higher) (and for drive-alone commuters, identical). Nevertheless, considering the new larger metropolitan area, the commuting times in 1994 show a 10% increase over 1988. Overall, time spent travelling rose as well (by 5 min the in the same, 7 min in the larger area), thus continuing a trend from 1968 (time spent traveling between 1968 and 1988 increased from 72-95 min)*, b) in the Twin Cities, commuting times (and total travel time) rose between 1990 and 2000, but remain lower than the times in Washington DC: "*similarly, U.S. Census data for most metropolitan areas show higher times in 2000 than 1990, but most metropolitan areas either remained the same physical size or increases, raising the question of whether these rises are statistical artifacts due to changing geography. However, we would expect that a smaller metropolitan area is more likely to see an increase in travel times than a large one, and Washington remains larger than the Twin Cities"* so what it could lead to c) "*as most metropolitan areas are growing faster in space than in population, that may indicate an increasing willingness to trade-off time for space, or an inability to rationally relocate to compensate for rapidly rising congestion"*.

The work of (Alpkokin et al., 2008) which is an extension of his previous works (Alpkokin et al., 2005a, 2005b, 2007) explore by identifying sub-centres[36] in Istanbul metropolitan region

[36] The methodology proposed by (Alpkokin et al., 2008:4) uses a generalizable way to identify subcenters by taking into account gross employment. Its procedure is based on the following steps: a) first in order to identify subcentres Zipf's law of rank frequency distribution is applied, so logarithmic employment density is plotted against rank size, b) secondly, the number of major employment and their classification through breaks of gradient: the number of clusters depends on the size of the city, the degree of detail aimed at in the analysis, and also the sizes of tracts or zones, then c) as the data are plotted as a two-dimensional graph simple techniques of cluster analysis are appropriate. These are correlations between the variable and the rank using the Pearson coefficient, equals intervals, and similarities of Minkowski distance, or maximizing the Spearman rank correlation: "*data groups are search that each gives a best fit for linear correlation between logarithmic employment density and rank within themselves using the Pearson correlation coefficient. Once the main clusters are decided by Pearson coefficient further classification can be done, either by following equal interval scales or by dividing into sub-clusters proving distance similarities"*. In the case of (Alpkokin et al., 2008) is used an adapted Spearman rank correlation to find the cut off for clustering of 138 zones for 1997; finally d) after excluding the zones with zero employment and zones with very small employment that both gave a negative logarithm value, (Alpkokin et al., 2008) identify 123 zones for 1985 and 138 zones for 1997 were included into the analysis out of a total of 209 traffic zones. The rank correlation resulted in values of 5,1; 4,1 and 2,8 on the y-axis as logarithmic scale of employment density. However, we rounded and defined the zones

from 1985 and 1997, the impact of them (urban structure) on commuting patterns (trip lengths, employment destination zonal preference functions and mode shares).

The main findings that (Alpkokin et al., 2008:13) reach are: a) by examining the spatial extent of trips attracted to each major employment zone in 1997 using employment location-specific preference function and the trip length frequency distribution of those commuter journey to that employment zone, the results suggest that employment subcentres grasp a very high proportion of workers, range from 20 percent to 70 to 80 percent: "*employment zones Kcekmece and Pendik are outer suburbs capture a very high proportion of workers from very nearby residences (from 70% to 80% of all commuter trips) indicating a minimizing approach to the journey to work by these commuters. On the other hand, for zones Eminonu and Kadikoy only from 5% to 20% come from nearby residential opportunities. In between, zone Kadikoy is representative of zones capturing both local (and half), and wider metropolitan commuters"*, the CBD downtown has lost prominence: "*when examining the two time periods, the trip length frequency distribution for the old CBD zone were found to have a more flat distribution and a rather more stable shape during the 12 years"*, contrary to subcentres: *"subcentres as wing attraction nodes attract a considerable portion of their trips from close to each center, although they did attract trips from greater distances too in 1997 bringing about the noticeable fact that as the zone grows to accommodate more employment opportunities, the shorter trips attracted gained a higher share"* and finally, b) by analyzing commuting patterns by means of modal share and one-way average commuting time attracted by the employment zone, or type of center, the results shows that the average time has increased and that CBD's public share is still dominant but with less difference: "*the public transportation share is the highest for the old CBD of Istanbul with 58%. For the suburban clusters, there are rather mixed results. There is a low public transportation share with 39% for the western wing attraction zones (Kcekmece-4 and Kcekmece-7) but higher shares for other western suburb zones with 47% and 48% for zones (Kadikoy-6 and Pendik_1) respectively. Such a variation is mostly due to the income distribution –that is, there are higher income groups on the west side than the eastern side of Istanbul"*.

However, one of the most meaningful forward steps in the literature is the study carried out by (Veneri, 2010) which takes into account the influence of polycentricity on costs due commuting by defining urban spatial structure by means of functional indicators (functional dimension of polycentricity[37]) and by considering the relative percentage of subcentres[38] that

as: (cluster 1) logarithmic employment density is larger than 5; (cluster 2) between 5 and 4; (cluster 3) between 4 and 3; and (cluster 4) less than 3.

Note:
$R_i^{\alpha} x S_i = K$. When plotting the diagram for natural logarithms of size (S) and rank (R), a log-linear pattern is observed. When the slope equals -1 it is known as Zipf's law.

The Minkowski distance can be expressed as follows: $d(i,j) = \left[\sum_q \left|x_{i1} - x_{j1}\right|^q\right]^{\frac{1}{q}}$, is simplified for one dimension and becomes $d(i,j) = \left|x_i - x_j\right|$ where x is the logarithmic employment density on the y-axis.
The adapted Spearman rank correlation is expressed as follows: $r = 1 - 6\sum_{i=1}^{i=g}\sum_{j=1}^{j=n_i}(x_i - y_{ij})/N(N^2-1)$, where (N) is the total number samples; (x_i) common rank of all elements in (ith) nominal class; (y_{ij}) (ith) (Y) rank of the (jth) element; and (g) is the number of clusters.
[37] To quantify polycentricity within Italian Metropolitan Areas, Veneri's study uses the following indicator-called functional polycentricity-. The indicator ranges from 0 to 1 and can be calculated as follows: $P_{SF}(N) = \left(1 - \frac{\sigma_\partial}{\sigma_{\partial max}}\right) * \Delta$, where ($\sigma_б$) is the standard deviation of nodal in-degree within the MA N, ($\sigma_{бmax}$) is the standard deviation of the nodal in-degree of a two-node network (n1, n2) derived from N where $d_n1=0$ and d_{n2}= value of the node with the highest value in N, (Δ) is the density of network. Higher values indicate a higher

are within the analyzed Italian Metropolitan Areas. Veneri's study analyses the costs due to commuting by means of private costs (average commuting time) and by means of environmental costs (per capita CO_2 emissions). At this point, we only present the contribution of Veneri's study related to the private costs due to the latter is referring with the environmental externalities, issue that we will in-depth analyze at the end of this Section 2.2.

By taking into account 82 Italian Metropolitan Areas and using data from Isatat Population Census data in 2001 and from Italian Institute Statistics, Veneri's study examine the relationship between urban structure at inter-urban scale with the private component of the costs of mobility, approximated through the time spent on travelling by commuter[39]. According to (Veneri, 2010:415) "*this component can be conceptualized as an internal cost that directly affects commuters' utility and their consequent behavior in terms of mode choice. However, it could be also considered as a social cost because it is influenced by systemic inefficiency. Private costs can include fuel prices as well as time spent on travelling*".

To test the hypothesis that what is the extent that characteristics of urban spatial structure influence the private costs of mobility, Veneri's work testing that the average commuting time is a function of some characteristics of spatial structure divided into the following four categories: a) Metropolitan Areas' degree of polycentricity and polycentricity according to the co-location hypothesis, b) urban compactness, c) functional diversification of the territory and finally d) city size and then using a set of control variables: average age of housing-stock, the relative competitiveness of mass transit service in comparison to private means of transport, and finally socio-demographic variables: age structure of population and share of graduates.

Referring with a) Metropolitan Areas' degree of polycentricity and polycentricity according to the co-location hypothesis, (Veneri, 2010:416) states "*the presence of several subcentres increases the probability of finding a job near the place of residence. This, in turn, allows a reduction in the time spent on travelling, with a virtuous effect on commuting costs*". In terms of b) urban compactness (Veneri, 2010:416) explains "*compact cities, whose degree of compactness is usually measured with residential density, are expected to be associated with shorter distances, thanks to a higher spatial concentration of houses and job places as well as*

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degree of functional polycentricity. Indeed the (P_{SF}) index takes into account, according (Veneri, 2010:411) some features that have not been directly considered in the Veneri's method to identify subcentres (note 38) which based on the number of subcentres: the (P_{SF}) index considers the degree of hierarchy of the network through the first multiplicative factor and, at the same time, it considers the strength of the interaction by including the density of the network

[38] In order to identify the subcentres that are within the 82 analyzed Italian Metropolitan Areas, (Veneri, 2010) proposes the following functional approach: (1) the first step starts conceptualizing MAs as network of municipalities and then it uses the in-degree index to characterize the degree of centrality of each node. More in depth, for each municipality within each MA, the in-degree index (measures the number of links that go towards a given node-municipality) has been commuting flows data in 2001 as follows: $I_j = \sum_{i=1}^{N} Z_{IJ}$, where ($I_j$) is the in-degree indicator for the municipality (j) of a given metropolitan area; (Z_{ij}) is the link between municipality (i) and municipality (j), which is 0 or 1 depending on whether (i) is one of the four nearest neighbours of (j). Using a k-nearest-neighbour specification of the matrixes, the in-degree also takes into account the size of flows, then (2) all the municipalities are ranked on the basis of the value of the in-degree index, those belonging to the 95th percentile were selected and considered as sub-centres. In this way, according to (Veneri, 2010:410), the higher the number of subcentres in a given MA, the higher its level of polycentricity.

[39] The average commuting time for each analyzed Italian Metropolitan Area is calculated as follows: $ACT_h = \frac{\sum_{i,j,k} f_{ijk} t_k}{\sum_{i,j} f_{ij}}$, where ($f_{ijk}$) is the number of commuters moving from municipality (i) to municipality (j), within (MA h), who spend time (k) on travelling, (t_k) is the duration class of the commute. Average value in Veneri's work has been considered for each of the four next classes: from 0 to 15 minutes, from 15 to 30 minutes, from 30 to 60 minutes and more than 60 minutes.

urban compactness enhances the competitiveness of a mass transit system" and continues "*compactness can also be analyzed in terms of spatial concentration of jobs. For this purpose, the most applied measures is the Gini indexes between jobs and area share of each municipality within each MA. A higher concentration should be associated with shorter distances travelled, while the effects on travel duration could be ambiguous because of the congestion problems that may arise in highly concentrated areas.* According to c) functional diversification of the territory, (Veneri, 2010:417) points out "*a mixed land use favours the proximity between places of living and working. MAs with a high degree of functional diversification are generally characterized by an adequate equilibrium between residential and economic functions, integrating, rather than segregating them spatially. Thanks to a reduction in the distance between jobs and homes, functional diversification reduces the length of travel"* and continues "*the functional diversification has been approximated with a Gini index between jobs and population shares with each MA. The more even the distribution of jobs and population within given MA, the more diversified is its territory"*. Finally, d) in terms of city size, (Veneri, 2010:417) explains that "*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 because it is possible to reach minimum economies of scale that are necessary to justify big investments and expensive infrastructures*".

The control variables that Veneri's study uses, permits a better interpretation of the empirical results helping avoid problems of under-specification of the empirical model. In terms of using the average age of housing-stock, (Veneri, 2010:418) argues that "*the underlying idea is that in the last decades the speed of house-construction has increased, but new settlements have not been planned with enough attention to the proximity to mass transit service, so cities with a higher share of new houses are expected to be less efficient"* then referring with the relative competitiveness of mass transit service in comparison to private means of transport, argues that "*high mass transit competitiveness can boost the share of commuters who use these means of transport and can reduce the time spent travelling"*. Finally, in terms of socio-demographic, Veneri's study uses a population structure index and the share of graduates: *"a higher education level could be expected to be associated with a higher income and, as a consequence a higher number of car owners that can influence commuting mode choice"*.

To test the aforementioned hypothesis, Veneri's study uses a cross-section economic model taking into account the 82 Italian Metropolitan Areas as units of analysis and being estimated through OLS method with robust standard error[40]. The results that (Veneri, 2010:420-422)

[40] The dependent variable of the model that Veneri's study is estimating, is the average commuting time (ACT), see note (39). The independent variables are: (1) "POLY_GREEN" which is related to the functional polycentricity and computed as note (37) suggests, (2) "POLY-NSR" is related also to the functional polycentricity and based on the relative subcentre number that are within each metropolitan area, (3) "GINI_AREA_JOB" is referred to the spatial concentration of employment (morphological polycentricity) which is computed as 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, (4) "IDENSITY" is related to urban compactness (inverse measure) which is calculated as logarithm of the gross density (inhab./km^2), (5) "GINI_POP_JOB" is related to functional diversification-mixed land-use- which is estimated as sum, for each municipality within a MA, of the differences in absolute value between the population and the employment shares of that municipality over the whole MA, (6) "HOUSE_AGE" is referred to the age of housing stock that is estimated by computing the number of houses built after 1982 over the total number of houses in 2001, (6) "REL_PUB_COMP" is related to mass transit competitiveness which is computed as the average km/h with mass transit over average km/h with private means of transport, (7) "AREA" is related to size is measured as Total MA's area (km^2), (8) "DUMMY_CENTRE" and "DUMMY_SOUTH" are related to geographic localization and they are measured ad MAs of Central Italy and Southern Italy respectively, (9)

present are: a) the effect of polycentricity on the average time is negative, but not statically significant: "*hence, it cannot be said that a higher degree of polycentricity makes the journey shorter"* b) the more concentrated the population and the more urban form is compacted, the longer commutes: "*the coefficient of the gini_are_job variable is positive and the relation between density and commuting time is also positive"*, c) the urban functional diversity has a negative relationship with average commuting times but is statically insignificant (gini_pob_job), d) urban size has a positive significant relationship with commuting times: "*these results can be explained by the longer distances that on average have to be travelled in larger MAs, which affect both time and pollutant emissions"*, and finally, e) referring with control variables: age of the housing stock does not have a statically significant effect as well as in the cases of the used dummy variables, the relative competitiveness of public transport has a negative relationship which is associated with a shorter duration of commutes and finally, among socio-demographic variables, the share of graduates is associated with higher travel times and the age of working population has a positive relationship with average commuting time but it is statically insignificant.

Hence, the main conclusion according to (Veneri, 2010:423) is "*the degree of polycentricity does not seem to influence the time spent on travelling in a significant way and taking into account other characteristics of urban spatial structure, it comes out that urban dispersion is associated with smaller private costs. Hence, the analysis shows the need to satisfy housing preferences for low-density areas/neighbourhoods"*.

Another study that support the co-location hypothesis is the recently work carried out by (Modarres, 2011) which investigates the dynamics of commuting patterns using the 2005 American Community Survey Orange, Los Angeles and Ventura Counties in Southern California. Before explaining its contribution in-depth, this study its meaningful due to by using various analytical approaches, the Modarres' work illustrates that spatial/temporal patterns of employment should be utilized to develop a better understand of the spatial dynamics of commuting patterns and the main findings that it achieve are: a) counter to popular belief, not all resident of suburban locations suffer from long commutes, b) polycentric urban employment patterns may provide a better explanation of commuting patterns and c) the commuting pattern of low-income population may be the most challenging issue to resolve, given the decentralized nature of service employment.

In detail, Modarres' study uses data from American Community Survey (ACS) and County Business Pattern; both provided by US Census Bureau at Public Use Micro-Sample Area (PUMA) in 2005. Its study analyze the commuting times in comparison with other current studies based on average commute times and vehicle miles travelled, by focusing on the concept of travel-time ratio in connection with the polycentric urban form, taking into account in addition the mode of transportation and time of departure to work which plays a significant role in the commuting expediencies of individuals: *"similar to the travel-time ratio, which suggest that people are willing to face longer commutes for a higher number of work hours, time of departure could also play a role in people's willingness to drive longer. For example, for someone who commutes outside the peak morning and afternoon rush hours, slightly longer commutes may pose less of a problem, since the drive is free of traffic jams"* (Modarres, 2011:1197).

"DEMO_STRUCTURE" which is referred to the age of the population is measured as a population structure index, based on: people aged between 40 and 64 over people aged between 15 and 39, and finally (10) "GRADUATES" related to human capital that is estimated as the share of people with a degree.

By analyzing these commuting times indicators, (Modarres, 2011) point out the following two findings: a) the connection between the length of commute and the hour of departure for work suggest that people whose work hours do not fall within the traditional 9 to jobs are more likely to experience longer commutes "*those who live for work around 5:00 a.m. experience the longest average commute time, declining in duration until 9:00 a.m. After that, the average commute remains relatively low until 1:00 p.m. The commute time declines from 1:00 to 4:00 p.m. and increases afterwards until the end of the afternoon peak period*" and b) referring with the relationship between travel time to work and number of hours worked per week to the travel-time ratio the findings suggest that a significant number of full-time employees, regardless of their gender, experience average commute times that grow consistently with their total hours of work per week: "*note that as the number of working hours per week increases and approaches full-time employment (40 hours per week), the difference between men and women narrow. However, as the number of work hours per week, exceeds 40, the difference between men and women widens again. This is especially noticeable for weekly work hours exceeding 50*" (Modarres, 2011:1199).

Then, Modarres' work to understand the relationship between travel time to work, travel-time ratios and the urban structure, by using the aforementioned County Business Pattern data, (Modarres, 2011) identifies the locations of major employment centers in the region following the work of (Modarres, 2003) based on kringing analysis[41] which avoids the pitfalls of using either arbitrary employment cut-off points or the limitations posed by other cluster analysis methods. In order to test this relationship, its study carried out two sets of regressions analyses. The former, travel time to work is used as dependent variable. The latter, travel-time ratio is the explained variable. In both cases, the independent variables are: a) average personal income, b) population density, c) average hours worker per week, d) jobs-to-population ratio (as a surrogate for job-housing ratio), e) distance to the closest major employment center, f) percent non-Hispanic white commuters, g) percent minority commuters, h) total working population, i) working population density and finally j) average vehicle ridership. The set of regressions are estimated by stepwise analyses and the results shows that only: a) jobs to population ratio and b) average vehicle occupancy variables are statically significant[42] and the main finding according to (Modarres, 2011:1207) is that in both models, the negative sign of the jobs-to-population ratio suggests that as the ratio increases, the average time and travel-time ratio for an area drops, so conversely, as the average vehicle occupancy increases, the values for both travel time and travel-time ratio also increase: "*therefore, these findings suggest that as an area increases the proportion of its locally available jobs to the total number of residents the commuting experience improves*". These findings with the previous one leads to Modarres' study to purpose the following final remarks or statements oriented to policy-making: a) "*it seems both logical and efficient to enhance the current polycentric urban form through the creation of a locally focused and effective job-housing balance (job matching residents and cost of housing), which would require a planned decentralization of jobs and housing to particular employment centers.*

[41] This method is explained when (Modarres, 2003) work will be revised. This is in this Section 2.2, in the second body of literature research based on analyzing if polycentric structure exerts an influence on modes of transport in favour of supply and the competitiveness of mass and public transport in order to achieve a reduction of the use of less sustainable private means of transport.

[42] According to (Modarres, 2011:1206) in the first model which dependent variable is average travel time to work, the R-Square is 0,19, the unstandardized coefficient (B) and the t-value of jobs to population ratio is (-1,38) and (-3,33) and for average vehicle occupancy variable are (9,23) and (2,53) respectively. In the second model which dependent variable is travel time ratio, the R-Square is 0,27, the unstandardized coefficient (B) and the t-value of jobs to population ratio is (-0,01) and (-3,79) and for average vehicle occupancy variable are (0,06) and (3,52) respectively.

This would allow us to create multiple centers of 'scaled densities', where mixed-use development and the provision of various urban amenities could significantly improve the live of current and future residents" and b) *"public transit, is historically designed to deliver commuter to downtowns and the urban core, and transit-dependent populations are mostly low-income earners, especially in cities such as Los Angeles. Therefore, while a transit system to connect various employment centers may produce some positive results, a more clearly thought-through and efficient systems of transportation for reverse commuters (those who need to go from the center of a city to jobs in the periphery) may produce more equitable results. Serving those who depend on public transit for their livelihood and other daily activities appears to be a more responsible planning strategy than the optimistic attempt to shift a small percentage of commuters from their cars into expensive rail and other rapid transit operations (targeted at the middle-class working populations)".*

However, not all studies that exist in the literature as we mentioned before supports the co-location hypothesis. There are some studies that contrary to co-location hypothesis, employment decentralization has not been associated with shorter average commute distances. One of the most relevant works is the study carried out by (Cervero and Wu, 1998). In this study, is tested whether the co-location hypothesis holds using disaggregated data[43] for a single metropolitan area, the San Francisco Bay Area and is postulated that employment sub-centring[44] has failed to reduce average commute duration and distances in the analyzed metropolitan area. However, due to the data limitations, Cervero and Wu's study don't draw casual inferences on how sub-centring has directly affected commuting, although its study do empirically probe whether sub-centres has been parallel by reduction or constancies in commuting duration and distances. To do so, in its empirical analysis, is tested its hypothesis by taking into account a) shifts in commute distances and durations, b) shifts in modal splits, c) and shifts in commute VMT per employee. Referring with a) shifts in commute distances and durations, (Cervero and Wu, 1998:1067) states "*among all 22 employment centres, average one-way network commute increased 12 per cent (from 10,6 to 11,8 miles) and average one-way durations rose by 5 per cent, or by 1 minute and 18 seconds (from 27,7 to 29 minutes) during the 1980s. The greatest increased in average distances and durations were for workers at the two fastest-growing employment subcentres –Pleasanton and San*

[43] The disaggregated data that Cervero and Wu's study uses by taking into account journey-to-work statistics is: a) commuting impact, b) average one-way durations, c) average one-way distances; d) modal splits, e) average vehicle occupancy levels and f) VMT per employee. For computing this measures, (Cervero and Wu, 1998:1061) procedure in this way: (1) for each employment center, the total number of commute trips made from ay of the region's (1382) census tracts to the EC constituted an origin-destination (o-D) pair. All commutes for each O-D pair were loaded onto the shortest route of the network. Then, summing over all trips interchanges destined to an employment subcentre produced a commute distance total, and dividing this by the employment subcentre total yielded an average 'network' commute distance for that employment subcentre; (2) the calculation commute of VMT per employee is as follows: $VMT/employee_j = \left[\sum_i \sum_k \left(\frac{T_{ij}^k}{O^k}\right) D_{ij}^k\right]/E_j$, where (T) is the total person work trips; (D) the network distance, (E) employment, (O) average occupancy level, (i) residential census tract index (i=1,2,…1382); (j) employment centre index (j=1,2,…22); (k) commute mode index (drive-alone, vehicle pool, bus transit and cable car, light rail and heavy and commuter rail).

[44] To identify the subcentres, Cervero and Wu's study uses an approach based on size and density criteria for identifying subcentres in 1990. By using the following criteria, (1) 7 or more workers per gross acre; and (2) 9500 or more employees, Cervero and Wu's study identifies 22 employment subcentres and classifying them according density levels into four categories: (1) downtown San Francisco; (2) Oakland, Berkeley and Emeryville; (3) Silicon Valley and downtown San Jose; and (4) the rest of 16 employment subcentres. According to (Cervero and Wu, 1998:1063) to draw 1980-1990 comparison, the same 22 employment subcentres defined using 1990 employment data were identified as of 1980. In setting the boundaries of the 22 employment subcentres for 1980, Cervero and Wu's study use a minimum employment size and density thresholds for contiguous tracts were lowered to 8.600 workers and 4,5 employees per acre.

Ramon- both on the eastern periphery of the metropolitan area. These results suggest that the co-location hypothesis did not hold for the San Francisco Bay area during the 1980s decade of continuing job decentralization".

In terms of b) shifts in modal splits, (Cervero and Wu, 1998:1067) point out "*examining modal splits and shift across classes of employment subcentre, several distinctive patterns emerge. Commuting shares by single-occupant vehicle and mass transit, and to a lesser extent by walking and bicycling, are strongly associated with type of employment centres in both years – the core urban centres averaged relatively high transit, walking and bicycling shares and low drive-alone shares. Rates of ridesharing were fairly similar across employment subcentres classes"* and continues explaining that "*the only significant differences in modal split changes were with respect to mass transit and walking / cycling –with transit usage falling the most in core centres. So, In the Bay area, the biggest modal effect of job decentralisation, particularly when jobs relocate from core to suburban centres, has clearly been shifts from transit riding to drive-alone commuting. This is for spatial, not temporal reasons: that is, composition has been most affected by shifts of jobs from core areas well-served by transit to peripheral area that are not".*

Finally in terms of c) shifts in commute VMT per employee, (Cervero and Wu, 1998:1071) explain "*for all employment subcentres combined, average VMT per employee rose from 7,1 in 1980 to 8,7 in 1990, a 23 percent rise. This is direct product of average commute distances and drive-alone shares having increased and average vehicle occupancy levels and transit/ridesharing share having fallen during the 1980s. (A fairly minuscule contribution was the decline in walking and cycling modal shares in outlying centres, the very areas with the fastest employment growth). Average commute VMT rose in all 22 employment subcentres. The largest increases occurred at the suburban centres of Pleasanton, Vallejo and San Ramon"* and continues emphasing that *"the strongest contribution to aggregate increases in VMT per employee is thought to be increased commute distances, largely because the automobile was by far the predominant commuting mode in the region in both 1980 and 1990. Additionally, outlying centres experienced the fasted growth in average commute distances during the 1980s. Thus, while lengthening commutes cut across all employment subcentres and therefore affected the Bay area's workforce across the board, the majority of employees in all employment subcentres (except downtown San Francisco) commuted alone in both 1980 and 1990, meaning that modal shifts away from higher occupancy modes affected a smaller share of the workforce".*

Hence, the main conclusion according to (Cervero and Wu, 1998:1073) is "*employment decentralisation has failed to shorten average commute distances and durations, contrary to the co-location hypothesis".*

Following Cervero and Wu's study is important to examine the work carried out by (Schwanen et al., 2001) which explores the way in which monocentric and polycentric urban structures (by distinguishing four types: one monocentric and three polycentric) affect modal choice and travel distances for different purposes in the Netherlands. Schwanen's study throws some light on the co-location hypothesis which states that firms and households periodically changer their location in order to reduce commuting costs. Its analysis is based on data from the Dutch National Travel Survey (OVB), which allows to simultaneously examining the influence of personal attributes and of urban structure. To do so, Schwanen's study estimate two regression models taking as dependent variables a) modal choice (car driver, public transport and bicycle and walking) and b) distance travelled distinguishing different travel purposes: a) work, b) shopping and c) leisure and considering as independent variables factors related to a) personal-household attributes[45] and b) residential environment[46]. The main results of modal choice model that Schwanen's study uses are: a) "*uses of public transport increases along with the level of education*", b) "*higher income lowers the probability of walking and cycling for all trip purposes considered: when income rises, the use of public transport becomes less likely for shipping and, to a less extent, for work. Yet, for leisure activities, public transport tends to be used more frequently by higher-income households*", c) the relationship between modal choice and the type and age of the household varies according to the purpose of the trip: "*working couples use public transport relatively often but bike and walk infrequently for their journey to work. For shopping and leisure trips singles and couples use public transports more frequently than families, while the frequency of biking and walking varies more across the households' types"*, d) the influence of residential environment on modal choice remains strong for all trip purposes, being a more important factor for modal choice as the personal characteristics: "*For all three types (working, shopping and leisure) driving is most important in suburban locations, while public transport and slow cities (walking and biking) are more common in the core cities. This difference is clearly related to the density of land use in the core cities and the wider availability of public transport"* and finally, f) the clear influence of urban system on modal choice: "*in cross-commuting urban regions, the use of public transport is low both in central and suburban locations. That is because the public transport system is not geared to this pattern of travel behavior. Conversely, for commuting and shopping, people use public transport relatively often in urban system with a decentralized form of interaction, though biking and walking are also common for such trips. These slower modes of transport are also popular in urban systems with exchange commuting. The reason may be that most urban systems in these categories are located in the Randstad Holland. There, densities are higher and more activity places can be reached by cycling and walking"* (Schwanen et al., 2001:181)

Referring with the results of distance travelled model that Schwanen's study uses are: a) although distance travelled for work trips is impact by spatial structure, the models perform relatively poor: "*only for commuting trips do the type of urban regions and the level of urbanization of the municipality have a clear impact on distances travelled by three modes*", b) the importance of including personal attributes in the analysis of travel behavior: "*gender is a strong determinant of distance travelled by each of the three travel modes. In Netherlands,*

[45] According to (Schwanen et al., 2001:176) the personal-household attributes are operationalised in terms of the household type to which a person belongs. So, its study is based on taking into account the typology of households focusing on a combination of 3 characteristics: the size of the household, the presence of young children (<12 years old), and the number of adult members who participate in the labour market. Based on these characteristics, Schwanen's work use (1) 9 households types: a) family, one worker, b) family two workers, c) family no worker, d) couple one worker, e) couple two workers, f) couple no worker, g) single worker, h) single no worker and i) other households. Beside this typology, Schwanen's study also uses other characteristics of the household or its members: (2) annual household income (six classes), (3) car owners of the household (yes or no), (4) person's highest education (four classes) and (5) gender and age (10 classes).

[46] Schwanen's study use two criteria referring with residential environment characteristics: (1) the structure of the urban system and (2) the location and urbanization level of the municipality. The former is distinguished by four different types: a) central: "*just as in a monocentric system, commuter streams are predominantly oriented toward the central city*", b) decentral: "*the central city is not a magnet for commuters from other suburbs and from the central city*", c) cross-commuting: "*many suburban commuters work in other suburbs, and many inhabitants of the central city are locally employed. The suburban part and the central city part do not have many relation between them*" and finally d) exchange-commuting: "*many suburban commuters travel to the central city, while many central city residents work in the suburbs what is indicative of a qualitative spatial job mismatch between demand and supply*" (Schwanen et al., 2001:176). The latter, is distinguished by three level of urbanization: a) core cities, b) suburbs and finally, c) growth centres

women travel much shorter distances to work than men, regardless of which mode of transport they use", c) education is also strongly related to distance travelled by car or public transport: *the higher the level of education, the longer the commuting distances will be*" and the same for household's income which is positively related to the distance travelled to work by car and public transport, d) in terms of households type, "*two-worker families travel less than one-worker families and single workers walk or bike the shortest distance for work*", and finally e) car ownerships and age have a weaker relationship with distance travelled due to this relationship is captured maybe by other personal attributes. (Schwanen et al., 2001:185)

Hence, Schwanen's study reaches on opposite conclusions depending on what is taken into account, if modal choice or distance travelled: a) the former, deconcentration of urban land use to suburban location and new town almost certainly promotes the use of the private car for all purposes and this leads to less use of public transport, cycling and walking. However b) the latter, in cross-commuting urban systems the distance travelled to work is relatively small, situation that comes close to the co-location hypothesis, but this trend is not find in other polycentric structure such as in the exchange-commuting urban systems which longer commutes were observed according to (Schwanen et al., 2001:195).

The previous work of (Schwanen et al., 2001) is revised one year later by the same authors in (Schwanen et al., 2002) in which tries to explore in-depth the relationship between residential and environment context with travel time[47] compared to former Schwanen's study which focused on distance traveled and modal choice. By using also data from the 1998 Netherlands National Travel Survey, Schwanen's work considers travel time associated with trip purpose and transport mode. In short, the results that this study reaches are: a) sociodemographic factors and residential context influence daily travel time, b) gender, number of workers in the household, age and education all have a significant impact on travel time, c) travel time for car drivers tends to rise with the degree of urbanization of the residential environment and, finally d) in the polycentric metropolitan region of the Randstad, travel times by car are greater than in the monocentric regions of the country.

To test empirically, (Schwanen et al., 2002) carry out a descriptive analysis regarding travel times broken down by trip purpose (modal choice in relation to travel time and then relationship between travel time and household attributes and residential environment) and

[47] Although many studies have analyzed commuting times, the influence of the time spent working on the home-to-work- travel time has only been investigated indirectly. In the study of (Schwanen and Dijst, 2002) is proposed a concept called "travel-time ratio" in order to investigate the association between work duration and commuting. By describing the theoretical framework of the travel-time ratio and analyze realized travel-time ratio for work activities with data from 1998 Dutch National Travel Survey they conclude that a) workers, on average, spend 10,50 % of the time available for work and travel on commuting, which corresponds to 28 minutes (single trip) for an 8 hours workday and b) the travel-time ratio varies systematically with sociodemographic variables, and urban form is of rather limited importance in the explanation of travel-time ratio values. Hence, according to (Schwanen and Dijst, 2002:575) the travel time is defined as the ratio between travel time and the sum of travel time and activity duration: $t = T_t/T_t + T_a$, where (t) stands for the travel-time ratio, (T_t) indicates the travel time (round trip) and (T_a) denotes the activity duration. (Schwanen and Dijst, 2002:575) state: "*the duration of an activity and travel time are taken together in the denominator, since individuals make decisions about staying at or traveling to activity places within a given time budget".* The results that (Schwanen and Dijst, 2002) find after testing the relationship that are between travel-time ratios and commuting times vary with work duration are: (1) up to work durations of 4h, commuting time is constant and the travel-time ratio is declining, which may indicate that, up to a certain threshold, commuters are indifferent to commuting time, (2) from 4 to 8h, the travel-time ratio tends to be stable and commuting time rises monotonically with work duration, and finally (3) for workplace visits of 8h or move, both travel-time ratio and commuting time tend to decrease with work duration. (Schwanen and Dijst, 2002:581) "*These results indicate that commuting time is positively related to work duration within certain time-space constraints".*

multivariate analysis[48] which the dependent variable is total daily travel time (the sum of the duration of the trips)[49] and in which it takes into account personal and household and the residential environment attributes as independent variables[50].

Referring the results of the descriptive analysis, (Schwanen et al., 2002:1498) point out that: a) for all trip purposes travel time are lower in suburban and less urbanized areas than in cities: "*people living in the large and medium-sized cities as well as inhabitants of growth centres tend to spend a considerable amount of time on travel*" b) the fact that travel distance decreases and travel time increases with the degree of urbanization suggests that travel speed should decrease with the degree of urbanization: "*this seems to be the case for car trips. For example, congestion results in lower average speeds for cart trips for leisure within the three large cities. The same is true for intramunicipal car trips for shopping purposes in the medium-size and large cities in the Randstad*" and c) polycentric urban structure entails high travel times: "*travel time for the car driver mode tends to be higher in the Randstad than in the north, east, and south of the Netherlands, where monocentric urban areas prevail*".

Related to the results of the multivariate analyses (Schwanen et al., 2002:1501) state: a) "*in the large and medium-sized cities, use of the private car is strongly reduced in comparison with other residential environment*", b) "*the influence of gender is particularly strong, with men more than three times as likely as women to commute by car. In addition, individuals in two-earner households and single people have a higher propensity to travel by car*" c) "*more highly educated workers tend to spend more time commuting by car*", d) "*people commuting to work by train tend to be male, aged between 25 and 45 years, single or living in a two-earner couple, and highly educated what entail that sociodemographic attributes are the most important in the explanation of travel time*".

Hence, the main conclusion of Schwanen's work is: "*sociodemographic attributes*[51] *are generally more important than residential context characteristics in the explanation of travel time. Travel time is relatively high for men and increases with the number of workers in the household, age, and education level. However, the significance of car ownership and income for travel time is relatively small. We have shown that the impact of both attributes is only indirect; after correction for the overrepresentation of households with high car-ownership rates and high income, these variables became insignificant*" (Schwanen et al., 2002:1505).

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[48] As (Schwanen et al., 2002a:1499) explain the regression analysis in its study in order to avoid bias selectivity is carried out a distinction between two types of models: a) the participation model is used to estimate the probability that travel for an activity type is undertaken by a given mode and b) this probability was transformed and used in the substantial regression model for travel time to correct for the selectivity bias.

[49] According to (Schwanen et al., 2002a) the total daily travel time is segmented along two lines: trip purpose and transport mode. Three trip purposes are distinguished by Schwanen's study: work (excluding work-related travel), shopping and leisure. This trip purposes classification are the same that (Schwanen et al., 2001) used.

[50] The personal and household factors used as independent variables in this work are the same that (Schwanen et al., 2001) proposed (see note 45). However the residential environment attributes have changed in comparison with the mentioned work of the same authors. So, in the current work (Schwanen et al., 2002a) use a classification of residential environment that combine the followings factors: city size, residential density and land-use mix by defining whether the municipality of residence is located within or outside the Randstad and on its urbanization level. Hence, (1) municipalities within the Randstad are categorized into: a) three large cities (Amsterdam, Rotterdam, the Hague), b) medium-sized cities (including Utrecht), and c) growth centres and d) suburbs. On the hand, (2) municipalities located outside the Randstad are dichotomize into e) more urbanized and f) less urbanized areas.

[51] In the following Section 2.3 Role of other spatial and non-spatial characteristics these factors that highly influence on commuting pattern but they are not related to urban spatial structure will be analyzed in-depth

To find more evidence in their previous studies (Schwanen et al., 2001, 2002), the same authors test if the contention that commute times are lower in polycentric than in monocentric urban systems is a reality or not. So, (Schwanen et al., 2003) by using data as the previous mentioned studies from the 1998 Netherlands Nation Travel Survey examines a) the effect of urban form on car commute time while adequately controlling for differences in personal and household attributes by using a multilevel regression modeling, and b) the effect of the impact f polycentric urban forms by c) defining them more comprehensively than some previous studies about polycentrism.

To test empirically the relationship between commuting times and urban form, (Schwanen et al., 2003) use a multilevel regression modeling to avoid biased estimation results which takes account the characteristics of individuals within households, residential municipalities and urban systems[52]. The result of this multilevel regression model according to (Schwanen et al., 2003:425) explains: a) in terms of individual characteristics, the role within the households of them is particularly related to the time spent commuting: *"women generally drive less that men, but this gender difference depends on household type: women's role in the household determines where females work and how much they commute. (1) women responsible as they still are for the bulk of household maintenance duties such as child care, economize on commuting time by working relatively close to home and (2) women in two-person households commute the most of all females: they are probably more career oriented than working mothers"* b) referring with education at individual level is positively correlated with total daily car commute time (high level of education): *"this finding is consistent with research on spatial mobility showing that workers with a higher level of education have to search greater areas to find a suitable job because jobs requiring a higher level of education are more spatially dispersed"*, c) related to socioeconomics variables at the household level, the regression model show that they are also positively associated with commute time: *"as household income or car availability rises, daily total car commute time increases"*, e) age is only related to the amount of car commuting at the 90% confidence level according to

[52] In this study (Schwanen et al., 2003) the empirical model is quite similar as the model used before for the same authors in (Schwanen et al., 2001, 2002) but there are slight differences. In this current Schwanen's study, (a) commute time (logarithm) is the dependent variable and (b) the independent variables are measured at four levels of analysis: (1) the level 1 is based on the individual: gender (male, female), age and education (low, medium, high); (2) level 2 is based on the household: income, car ownership (zero cars or one car and two or more cars), a typology of households based on number of household members, number of workers, and presence of young children (one-person, two person with one worker, two person with two workers, family with children <12 with one or two workers); (3) the level 3 is based on the municipality in which household resides: the net residential density of municipality, defined as the number of dwellings per square kilometers is used by Schwanen's work as an indicator of the degree of urbanization of a residential environment and finally (4) level 4 is based on the urban system in which the municipality is located: a) centralized: these regions resemble monocentric systems in which morning peak commute flows are predominantly oriented toward the core city, b) decentralized: much employment is located in the suburban parts of the system, these attract many morning peak commuters from the central city and other suburban municipalities, c) cross commuting: many suburban commuters work in other suburbs and many central-city commuters are locally employed, there are high levels of self-containment. This structure according to (Schwanen et al., 2003) may most closely resemble the archetypal polycentric region consisting of relatively independent, self-contained development nodes and d) exchange commuting: these systems feature reciprocal relationships between the suburbs and the core city: many suburban commuters work in the central city, while many central-city residents work in the suburbs, the self-containment levels are low. (Schwanen et al., 2003) state: *"we can formulate the expectations that guided the empirical analysis presented: (1) Because of the concentration of employment in the urban core, commute time are expected to be higher in the centralized systems. In exchange systems, they will be relatively high too, because of the limited job-residence balance and (2) In cross commuting systems, commute times by car will be relatively low. The decentralized system will exhibit average commute times"*. Finally e) is taking into account the natural logarithm of the size of the urban system (DUS).

regression model results: *"all else being equal, older workers tend to commute by car more than younger people",* f) at the macrolevel, the types of analyzed urban systems differ significantly: the centralized (monocentric) and cross commuting systems (archetypal polycentric system), with shorter commute times and the decentralized and exchange commuting systems, with longer commute durations: *"the fact that cross commuting structure have lower travel times than exchange systems is consistent. However, the relatively low commute times for the centralized systems and the high values for the decentralized systems are unexpected. In addition none of the three polycentric systems has a lower value than the centralized systems. Thus we find only (very) partial empirical support for the claim that the rise of polycentrism within DUS has led to more efficient travel time expenditure patterns".*

Hence, the main contributions of Schwanen's study are: a) only a small but nonetheless statistically significant proportion of the variation in car commute times can be attributed to differences in urban spatial context and as a result, sociodemographic variables are more important than urban form in the explanation of car commute times, b) descentralization has not result in more efficient car commute patterns in the Netherlands (people living in decentralized and exchange commuting regions spend more time on commuting by car than people in monocentric and/or cross commuting regions) and as a result; c) Schwanen's study results are not consistent with the expectations expressed on the basis of the literature that polycentrism is associated with lower commute times: *"the more monocentric urban regions in the Netherlands and the (small number of) cross commuting regions have relatively low commute times by car"* (Schwanen et al., 2003:426).

This main conclusion has been studied in-depth one year later by the work carried out by the same authors in (Schwanen et al., 2004). In this case, not only has the impact of monocentrism versus polycentrism been analyzed, but the influence of metropolitan density and size has also been considered, together with the ratio of employment to population and the growth of the population and employment. So, to examine the extent to which this relationship between commute behavior and metropolitan structure is the case for the Netherlands, Schwanen's study uses a multilevel analysis which is conducted with the binary choice between commuting as an auto driver (1), and commuting by any other means of transportation (0). The dependent variables of these multilevel regressions models are: mode choice, commute distance and time and, the independent variables are related to a) worker, b) household, c) residential municipality and d) metropolitan region[53].

[53] Referring with the first level of independent variables related to worker level, Schwanen's study uses: a) autoavailability index, which measures the ratio of the number of autos to the number of household members with a valid driver's license; set to zero if person has no driver's license, b) personal income, which measures a worker's annual net income, c) education which is classified into three sublevels: low, medium and high, d) age computed as the logarithm of years, e) gender (male or female). In terms of household level, the used independent variables are related to the household type: a) single worker, b)two-worker couple, c) one-worker couple, d) two-worker family (youngest child <12yr.), e) one-worker family (youngest child <12yr.), f) single-parent family (youngest child <12yr.) and g) other household. Referring with the third level of variables based on residential municipalities characteristics (Schwanen et al., 2004) use: a) population density, which is measured as number of residents per square km, b) residential density which is computed as number of residences per square km, c) employment density which measures the number of jobs per square km, d) area municipality which is measured as size of municipality in square km, e) core city which is the main settlement within metropolitan region and finally, f) growth center which is the settlement designed to accommodate population and employment relocating from the core cities; centerpiece of Netherlands national planning policy in the 1970s and 1980s. Finally, the fourth level based on metropolitan region are taken into account the following variables: a) DUS type: centralized, decentralized, self-contained and exchange-commuting, this classification is the same as in (Schwanen et al., 2001, 2002, 2003), b) area DUS (Daily Urban System) measured as the size in square km, c) number of residents computed as the logarithm, d) number of jobs

The results of Schwanen's mode choice model present are: a) "*the probability of driving an auto to work increases as the level of auto availability and/or personal income increases*", b) more highly educated workers are less likely to commute by automobile, which is consistent with (Schwanen et al., 2002): "*this may reflect that the fact that many highly educated people both live and work in more urbanized areas, where commuting by train is relatively fast and convenient*", c) women are less likely than men to drive an automobile to work but this difference is much smaller in households comprising children and one worker, d) the probability of commuting as an auto driver is lower in municipalities with a higher residential density as well as in those at a short distance from the most employment concentration situated in the core are of the daily urban system: "*automobile use may be less attractive in high-density zones and/or at short distances from the urban core of the region because of traffic congestion and parking problems and because of the supply of public transportation is usually greater there*", d) the ratio of jobs to residents in negatively correlated with the probability of commuting by automobile, indicating that fewer resident workers commute by auto in area with many jobs per resident, e) automobile use is greater for workers living in urban areas that experienced a substantial growth in the ratio of jobs to residents[54] and finally, e) the influence of a monocentric or polycentric structure on mode choice is limited: "*no statically significant effects were found for the sample as a whole*" (Schwanen et al., 2004:321).

The results of Schwanen's multivariate multilevel models estimated with total daily commute distance as an *auto driver* and total daily commute time as an *auto driver* are: a) the socioeconomic indicators of auto availability, personal income and education are all positively associated with both commute distance and commute time: "*both commute distance and commute time by automobile increase as the number of autos per driver, the monetary reward for paid employment, and the level of education attainment rise. The impact on distance is, however stronger*", b) age is related only to commute distance; older people tend to commute fewer kilometers than younger workers, c) the effects of household structure are small, all else being equal, single workers commute less than those with a partner and the difference pointed before related to gender, in commute time is smaller than for commute distance, d) at residential level, only the variable growth center is statically significant related to commute distance and commute time entailing that people living in growth centers tend to be commute more, e) the factors at metropolitan region level influence commute distance and commute time differently: 1) commute distance for driving to and from works tend to decrease as the number of jobs per hectare rise, commute distance tends to be longer in Daily Urban Systems that experience a strong growth in the number of jobs per resident and commute distance does not related to urban size meanwhile, 2) employment density has no impact on commute time, commute time is not dependent on the growth indicator and,

measured as logarithm of jobs, e) population density, which is measured as the number of residents per square km, f) employment density, which is measured as the number of jobs per square km, g) ratio of jobs to resident which is computed as number of jobs to population, h) growth of number of residents, which is calculated as the average annual growth (in %) of the number of resident in a DUS in the period 1994-1999, i) growth of number of jobs which is measured as the average growth (in %) of the number of residents in a DUS in the period 1994-1999 and finally j) growth of ratio of jobs to residents, which is computed as the average annual growth (in %) of the number of jobs per resident in a DUS in the period 1994-1999.

[54] (Schwanen et al., 2004:321) state: "*three explanations may be given for this result. First, a strong growth in the number of jobs serves as an indication of economic prosperity, this empirical result may indicate that auto use tends to be greater in more prosperous regions. Second, the growth in the number of jobs during the period of economic well-being was particularly strong in the upper segments of the labor markets. The people attracted to such employment are in general more likely to commute by auto. Third, the increase in the number of jobs differed across space; growth was relatively strong on the urban fringe and in suburban areas as well as along the highways. These employment locations are auto oriented and usually not well served by mass transit*".

commute time as an auto driver rises with the size (in square kilometers) of a Daily Urban System and finally f) although the impact on distance is greater, the distribution of employment relative to residences across metropolitan region –the monocentric or polycentric character of DUS- is the only dimension of metropolitan structure that influences both commute distance and time as an auto driver: *"workers living in decentralized and exchange-commuting regions commute longer measured in both time and distance than residents of centralized and self-contained DUSs"* (Schwanen et al., 2004:328).

Hence, according to (Schwanen et al., 2004:329) the main conclusions of its work are: a) socioeconomic status and gender are important explanatory factors, and that gender differences in commute behavior depend on household structure, b) in high-density environment and core cities, the probability of driving an auto to work is lower than elsewhere in metropolitan area, while commuting distance and commute time tend to be longer for auto drivers in growth centers, c) the probability of driving an auto to work falls as the number of jobs per resident rises, and commute distance by auto decreases as the number of jobs per hectare rises, and finally d) in majority of polycentric regions, commutes distances and commute times as an auto driver are significantly longer than in the monocentric-oriented, centralized DUSs: "*only in a one specific type of polycentric region –the self-contained region consisting of relatively independent nodes of development- are auto driver's commute distance and times equivalent to those of their counterparts in the monocentric DUSs. By large, polycentrism has not resulted in shorter commute distances and times for auto drivers in the Netherlands"*.

Other works that analyses if a polycentric distribution of employment and people shortens commuting because locate within or close to their employment subcentre (the co-location hypothesis) and reaches on the same conclusion as Cervero and Wu's study, is the research carried out by (Aguilera and Mignot, 2004 and; Aguilera, 2005). The former, Aguilera and Mignot's study analyses several urban areas with different size and different structure in terms of employment suburbanization from 1990 to 1999: a) three major French metropolitan areas: Paris, Lyon and Marseille-Aix and b) cities with different population rank: Bordeaux (800.000 inhabitants in 1999), Grenoble (500.000), Dijon and Saint-Etienne (300.000) in order to test the hypothesis: "*the presence of employment subcentres leads to a re-organization of mobility in the periphery which varies according to the type of subcentre, its location (in terms of distance to the city centre) and its size*" (Aguilera and Mignot, 2004:98). Hence, the aims of its study are: a) verifying the existence in the French urban areas, of a high spatial concentration of commutes due to a smaller number of municipalities. On this basis Aguilera and Mignot's study indentifies subcentres by using the approach proposed by (Aguilera, 2005), see note 55, and evaluates the evolution of the concentration of the commutes linked to the suburbanization processes of employment and population and b) determining whether workers locate in or close to their employment subcentre and to analyze the evolution of their location strategies through the evolution of commuting distances.

In that sense, according to the first objective, Aguilera and Mignot's work identifies the following subcentres in 1999: 25 in Paris, 11 in Lyon, 3 in Marseille-Aix, 3 in Bordeaux, 5 in Grenoble, 3 in Dijon and finally, 2 in Saint-Etienne what they are responsible for more than 80% of all jobs in the periphery and between 25% and 50% of all jobs in the urban area. Related to the second aim, the results that Aguilera and Mignot's study reaches on are: a) average commuting distances for workers living in the subcentres are shorter than for those living in the rest of the urban area: "*this result can be explained on the one hand by the number of people who live and work in the same subcentre which on average reaches 40%,* *and on the other hand by the fact that commuters living in suburban subcenters are mostly quite near their job. In fact they take advantage of the central job market (between one third and a half of them work in the city center), as well as the jobs located in other subcentres, mostly in suburban subcentres"* (Aguilera and Mignot, 2004:104), b) the majority of commuters in the city center work in a suburban subcentre expect in Paris where an important part of them works in outlying subcenters, c) so, the city center and the suburban subcentres constitute a sort of greater center where commuting distances are reduced: "*this greater center holds about 75% of the workers (expect Paris:50% and Marseille-Aix:66%), and 80% to 90% of the jobs (but 66% in Paris and Marseille-Aix)*" (Aguilera and Mignot, 2004:105), d) most jobs continue to be concentrated in the centre and subcentres, mainly in the suburban ones, while people live more and more in outlying centers but above all in the rest of the urban area what it entails the lengthening of the average commuting distances at the time that according to Aguilera and Mignot's study this reorganization of locations has the following consequences: "*a reduction of commutes in the direction of the city center, notable from suburban subcentres, due to a reduction of jobs in the center contrary to these subcentres at the time that the number of people living in the city center and working in a suburban subcentre has significantly increased", "a visible reduction of inter-municipality commutes, and notable of the number of intra-subcentres commutes", "a significantly increase of commutes towards centres, particularly to the suburban subcentres, from the rest of the urban area. These trips, generate long distances. There are also ever more people residing in the different subcentres but working in the rest of the urban area"* (Aguilera and Mignot, 2004:108), e) so, consequently: "*average commuting distance for people living in subcentres has been rising over the decade, so that the average attraction distance of the jobs located in subcentres" and "the reorganisation of people and jobs location therefore does not lead to better job-housing proximity in or around the subcentres, notably because the suburbanisation of the workers is produced outside the areas, but seemingly regardless of the employment centers, and also because the workers, living within the area, work there less and less"* (Aguilera and Mignot, 2004:109).

Hence, the main conclusion that Aguilera and Mignot's study presents is: subcentres are not be able to resist the growing distance between housing and places of work and to a general and diffused sprawl of residences beyond the subcentres: "*the workers, if they are less and less dependent on the city center including in urban areas where this center is large, are working more and more in the subcentres but also outside these subcentres. The average commuting distance in these subcentres has visibly risen between 1990 and 1999 even if on average they remain lower than those of the workers living outside these subcentres (and the city center)"* (Aguilera and Mignot, 2004:110).

The latter, (Aguilera, 2005), which is the most known within the literature, explores in-depth the three biggest French metropolitan areas over ten years (1990 to 1999) with the purpose to answer: a) are the people live in a subcentre also employed in this subcentre? And b) do the (other) people working in a subcentre live close to this subcentre? So, after using data taken from the 1990 and 1999 censuses which indicate the municipality of residence and the municipality of work and by identifying the subcentres[55] that are within each analyzed French

[55] Aguilera's work, defines a subcentre as "*areas that attract a major proportion of the commuters who work outside the central city"* (Aguilera, 2005:1540). To identify subcentres in Paris, Lyon and Marseille, Aguilera's study referred to the attractiveness of work trips evolving two phases: a) the first step, according to (Aguilera, 2005) identifies those suburban municipalities which are the most attractive to the non-resident workers –i.e. people working outside their municipality of residence. To do so, its study select the set of municipalities which in 1990 attracted 85 percent of these commuters, and finally b) the second step is based on given that the selected

Metropolitan Areas: Paris, Lyon and Marseille, Aguilera's study analyses the location of hobs held by people living in a subcentre, first in 1999 and secondly between 1990 and 1999 by then analyzing the location of people working within in assessing in both cases the impact of them in terms of commuting distances.

Referring with the former analysis, (Aguilera, 2005:1542-1543) point out: a) by examining the location of jobs held by people living in a subcentre, the subcentres in Paris, Lyon and Marseille concentrated 80 per cent of jobs and 70 percent of workers whose place residence was located outside the central city, but less than half of workers living in a subcentres have a job in the same subcentre and, b) by considering the jobs located in the subcentres (place of residence of people working in a subcentre) more than half are filled by non-residents: "*therefore have two types of spatial imbalance between jobs and inhabitants: on the one hand, the majority of people living in a subcentre work outside and, on the other hand, the majority of jobs concentrated within these subcentres are filled by non-residents. In other words, co-location is not the rule a majority of people"*. However, by analyzing c) the average distance to work (km) in relation to place of residence in 1999 for these French Metropolitan Areas, Aguilera's study emphasizes: "*people living in a subcentre have shorter commutes on average than those living outside, because the average commuting distance is very short for the 42 percent of those working in their subcentre of residence. Moreover, in closer-in subcentres, a large proportion of residents benefit from proximity to central-city jobs: the average commuting distance in then less for those living in closer-in subcentres compared with outlying subcentres where many residents work in a closer-in subcentre and therefore have longer commutes"*.

According to the latter empirical work, (Aguilera, 2005:1544-1545) states that: a) by analyzing the percentage change in the number of jobs and workers in each urban area (and at central city, subcentres and other municipalities level of analysis) there is an increment in jobs and decrease in working residents in the subcentres what it leads a creation of a growing job-housing imbalance: *"as a result, subcentres are beginning to specialize as employment areas because more jobs are being created there while more and more people are living in the suburbs but outside these subcentres"*; b) by analyzing the percentage increment in the commuting distance in relation to place of residence between 1990 an 1999, it explains the previous dynamic of jobs and worker residence in subcentres based on the changes in the distribution of people and jobs that have led to a rise in the number of commutes between the subcentres, but also from the subcentres to the other suburban municipalities and from the central city to the subcentres: "*these changes partly explain the growth in the average commuting distance that characterize the three urban areas: +14,4 percent in Paris, +13,8 percent in Lyon and +6,2 percent in Marseille. Moreover, commutes have become longer regardless of where people live: in the central city, in a subcentre or outside a subcentre.*

municipalities formed units of neighbouring or close municipalities, Aguilera's work uses a functional criterion to group these adjacent municipalities consisting of choosing the boundaries of each subcentre to maximize the intermunicipality commutes that took place within the subcentres. According to (Aguilera, 2005:1541) that means that a municipality (selected in the first step) is grouped with the (selected) municipalities that attracted that attracted the largest proportion of its working residents. By using this approach, Aguilera's study identifies 3 subcentres in Marseille, 11 in Lyon and 25 in Paris as well as they classify them according their location into: a) those located very close to the central city, designated as closer-in subcentres and b) those located further afield, which are referred to as outlying subcentres. (Aguilera, 2005: 1542) states "*this distinction is important because in France, the further people live from the central city, the longer their average commuting distance: we can expect to see outlying subcentres emerging, following the co-location hypothesis, to offer jobs to the growing number of people who live far from the central city and also far from closer-in subcentres"*.

However the average increase was less significant for central-city residents and outlying subcentre".

Hence, Aguilera's findings emphasize mainly two urban dynamics: a) although there are more jobs than working residents in all the subcentres, most people living in a subcentre work outside their subcentre of residence and in addition to this, the majority of jobs located in subcentres are filled by non-residents who generally live quite far from their employment subcentre, and, indeed, further in 1999 than in 1990 and b) results in terms of commuting patterns showed a growth in the number of commuting trips between the subcentres and also between the subcentres and the municipalities located outside, so the average commuting distance has increased regardless of where people live.

Another study that is agreed to Aguilera's findings is the work of (Bento et al., 2005). In this research, is examined the effects of urban form and public transit supply on the commute choice mode choice and annual vehicle miles traveled (VMT) of 114 urban areas in United States with data from the 1990 Nationwide Personal Transportation Survey. To do so, Bento's study estimates the following empirical models: a) a model of commuting mode choice in which is distinguished between –driving, walking, commuting by bus and commuting by rail- and a logit model to explain whether or not a worker drives to work and b) a model to explain the number of vehicles owned and another model for miles driven per vehicle taking into account the following measures to quantify urban form and transit supply[56]: a) road network, b) pattern of residential land use, c) balance of jobs versus housing and finally, d) public transit network (bus and rail).

The results of the first Bento's set of regressions models are: a) "*income, race and education all have statically significant effects on the probability that a commuter takes transit or walks to work. In both samples higher income workers are less likely to walk to work or take public transit than they are to drive. Whites are significantly less likely to ride the bus or train than are other groups. A 10% increase in years of schooling raises the probability of riding rail by*

[56] The urban form variables that Bento's study use in its regressions models are. In terms of a) road network, is used two variables: (1) city shape which theory suggests that trip distances should be longer in long, narrow cities than in circular cities with radial road networks. To measure it, is computed as the ratio of the minor to the major axis which ranges between 0 to 1, with 1 indicating a perfect circular city, and (2) road density which is measured for each urban area as miles of road are multiplied by average road width and divided by the size of the urbanized area (in square kilometers). Referring with b) pattern of residential land use, Bento's study uses (3) population centrality which is a measure less correlated with city area. This population centrality proposed by (Bento et al., 2005) is computed as follows: $PC = \frac{1}{N}\sum_{n=1}^{N}(\frac{\sum_{i=1}^{n} P_i}{\sum_{i=1}^{N} P_i} - \frac{\sum_{i=1}^{n} P_i d_i}{\sum_{i=1}^{N} P_i d_i})$, where i, i=1,…, N, indexes annuli around the CBD, d_i is the distance of annulus (i) from the CBD, and (P_i) is the population of annulus (i). In addition as this population centrality measure does not capture city size, Bento's study incorporates population density, and the size of urban area (land area) in square miles. In terms of c) distribution of employment, Bento's study takes into account the location of employment relative to population in a way that. is independent of the number or location of CBDs. To measure how evenly jobs are distributed relative to population, (4) Bento's study order ZIP codes in each city from the one having the smallest number of jobs to the one having the largest and plot the cumulative percentage of jobs (y-axis) against the cumulative percentage of population (x-axis) to obtain a Lorenz curve. Its balance measure is the area between the Lorenz curve and the 45-degree line, expressed as a proportion of the area under the 45-degree line. Larger values of this measure imply a less even distribution of jobs versus housing. Finally in terms of d) public transit network (bus and rail), Bento's study (5) measure the extent of the public network by the number of bus route miles supplied in 1993 divided by the number of rail route miles supplied in 1993 divided by the size of the urban area. In addition of the urban form and supply transit variables, Bento's study incorporates variables related to: (1) age of worker, (2) age squared, (3) indicator for female worker, (4) number of children aged from 5 to 21, (5) indicator for female workers with children, (6) logarithm of income, (7) years of education, (8) white household, (9) black household, (10) annual rainfall, (11) annual snowfall and (12) gasoline cost of driving per mile.

1,1 percentage points in both samples", b) "*a robust effect of urban form, as measured by population centrality and job-housing balance, is to increase the probability of walking or bicycling to work"*, c) "*the increment of rail (bus) supply as is increases the model share for rail (bus) in both samples*" and finally d) *"of all measures of urban form, population centrality and road density have the largest impact on whether a worker drives to work. Their effects, although are comparable in magnitude to the effects of income and education, are small in absolute terms"* (Bento et al., 2005:472).

Referring with the results of the second Bento's set of regressions models are: a) "*only population centrality has a significant impact on the odds of car ownerships: households in less sprawled cities (cities with more centralized population) are less likely to own one vehicle, two vehicles, or three or more vehicles"*, b) *"more circular cities reduce the odds of owing two or more vehicles, although the effects is only marginally significant. The effect of jobs-housing balance is by contrast, is never significantly different from 9 at conventional level, nor is that of road density"* and finally, c) *"the effects of all measures of urban form and transit supply on average household VMTs are striking"* (Bento et al., 2005:476)

Hence, the main findings according to (Bento et al., 2005:477) are: a) "*individual measures of urban form and public transit supply have a small but statically significant effect on travel demand. For example, a 10% increase in population centrality lowers the change that worker drives to work by 1 percentage point and the effects of 10% change in rail and bus miles supplied are approximately half as large"* and b) "*urban form and transit supply affect annual miles driven by influencing both the number of cars owned and the miles traveled per vehicle: in cities where the spatial distribution of population is more compact, households are less likely to own a car. The quantitative effect of these variables on annual average VMTs is small: a 10% increase in population centrality, through its effect on vehicle choice reduces annual VMTs by only 1,5%. Other measures of urban form and transit supply –jobs-housing balance, road density, city shape, and the supply of rail transit- all affect the average miles driven per vehicle but not the number of vehicles owned"*. As a result, although Bento's study point out the influence of urban spatial structure in travel demand, as it is lower, does not confirm at all co-location hypothesis.

Following the with line of the previous works, in which by studying the relationship between commuting patterns and distance travelled present a clear contradiction of the co-location hypothesis, the study carried out by (Melo et al.,2012) contributes to this open still debate in a meaningful way. To do so, Melo's study uses a new way: *explaining the observed spatial variation in the distance-decay of commute trips and testing the effects of urban structure and transport supply.* Before explaining this study in-depth, in short Melo's findings is that a) larger, less circular labour markets, with a less urbanized spatial structure and a greater jobs-housing balance are associated with a flatter distance-decay of commuting trips, b) similar effects are found for labour markets with a more specialized industrial structure and a greater availability of railway infrastructure and c) more monocentric and centralized spatial urban structures are associated with a steeper distance-decay gradient of commuting trips that could reflect a higher proportion of short distance commutes what are reasonable due to labour markets with this features will tend to have a higher proportion of medium and long distance commutes. Hence, Melo's study examines the relationship between how commuting patterns are affected by the spatial urban form and the supply of transport across labour markets in England and Wales focusing on the distance-decay gradient of commuting[57]. According to

[57] (Melo et al., 2012:721) emphasize that "by using *distance-decay of work trips to summarize commuting patterns instead of average commuting distances we believe this measure offers a more appropriate*

(Melo et al., 2012:717) "*this measures the relationship between work trips and the distance over which they occur. As a result, the magnitude of this parameter provides information on the degree to which distance is perceived by works as an obstacle to commuting. Small negative gradients indicate that distance is considered to be weak obstacle to commuting while large negative gradients indicate that distance is perceived as a strong obstacle to interaction".*

By using Travel-to-Work Areas (TTWA) as the unit of analysis[58], Melo's study tries to answer the following research question: how does the spatial structure of labour markets affect the distance-decay of commuting trips? By using a two-stage empirical approach: first, through an estimation of the distance-decay parameters of commuting trips across labour markets[59] and second, by an additional regression to test whether measures of urban spatial structure and transport supply affect the rate of distance-decay of commuting flows[60].

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representation of commuting patterns because it takes account of the relative distribution of work trips over distance".

[58] Apart from using Travel-to-Work Areas (TTWA), the data that Melo's uses come from the Annual Survey of Hours and Earning (ASHE) conducted by Office for National Statistics (ONS) which covers the data refers to employee's earnings, gender, age, working attachment, occupation, industry and, the location for both residences and workplaces. To calculate home-to-work distances, Melo's study matches the home and workplace postcode in the ASHR to the postcode data from the National Statistics Postcode Directory (NSPD) managed by the ONS.

[59] To identify the distance-decay gradient of commuting, Melo's study estimate the following gravity model: $T_{IJT} = cS_{it}^{\beta}S_{jt}^{6}f(d_{ijt}), i, j = 1, \ldots, N; t = 1, \ldots, T,$ where (T_{ijt}) is the number of commuting trips from residence place (i) to workplace (j) at time period (t); (c) is a constant; (S_{it}) is the mass of the origin and consists of the population at each origin, (S_{jt}) is the mass of the destination and consists of the employment at each destination. The parameter (β) and (Ϭ) determines the relationship between commuting flows and the origin (destination) size; it is hypothesized to positively influence the number of commuting trips between any two areas. The cost of travelling from origin (i) to (destination (j) is expressed as a function of distance between (i) and (j), $f(d_{ijt})$, where (d_{ijt}) is the (Euclidean) commuting distance between (i) and (j) in km. The distance-decay parameter can be interpreted as reflecting the extent to which distance represents an obstacle to job-worker interaction across space. High values indicate that distance constitutes a strong deterrent to interaction, where small values suggest that distance imposes a less restrictive force on interaction. According to (Melo et al., 2012:723) "*by the same token, higher values suggest that commuting trips decay faster and tend to take place within smaller spatial scales, whereas smaller distance-decay gradients suggest that interactions decay more gradually and tend to take place within wider spatial scales".* To dominate the empirical application of the above equation, Melo's study uses the following gravity equation and then use ordinary least squares (OLS) to estimate the model: $\ln T_{ijt} = \ln c + \beta \ln S_{it} + 6 \ln S_{jt} + \alpha \ln d_{ijt} + 6_t + \omega_i + \varphi_j + \varepsilon_{ijt}, i, j = 1, \ldots, N; t = 1, \ldots T;$ where (6_t) controls for time-specific unobserved effects, (ω_i) and (φ_j) consist of origin and destination fixed effects that control for origin-and destination-specific unobserved heterogeneity, and (ε_{ijt}) is the error.

[60] The factors that Melo's study uses to explain distance-decay are organized in: a) spatial urban structure and b) supply of transport infrastructure. The distance-decay parameters obtained from the gravity models are regressed on these factors. The regression model estimated is given below: $|\alpha_i| = c + \sum_k b_k X_{ik} + \varepsilon_i,$ where $|\alpha_i|$ is the absolute value of the distance-decay gradient obtained for TTWA i, X_{ik} are the (k) explanatory variables describing the spatial structure and transport supply of TTWA I, and (ε_i) is the error term. Melo's study, to account for differences in the precision of the distance-decay estimates (α_i) resulting from varying sample sizes, by performing a weighted least squares (WLS) regression with weights equal to the inverse of the variance of each individual estimate, Var(α_i). The variables in the regression model proposed by Melo's study are: (1) land area (area) measured by area in km^2; (2) employment (emp) measured by number of workers, (3) employment density (empden) measured by number of workers per square km, (4) circularity ratio (circ) computed as ratio of the area of the shape to the area of a circle with perimeter equal to that of the shape, (5) monocentricity (mono) computed as slope of the distribution of wards' employment with respect to the distance to the employment-weighted centroid of the TTWA, (6) urbanization (urban) measured as share of employment in urban wards, (7) jobs-housing imbalance (gini) measured as gini coefficient for the distributions of residents and employment at the ward level, (8) index of industrial specialization (hhi) computed as Hirschmann-Herfindahl Index, (9) rail network (rail) measured as railway length (km), (10) access to railway (railnd) measured as number of railway station and finally (11) road network (road) measured as road network length in km

The hypothesis that Melo's regression model takes referring with the spatial urban form and transport network variables (see note 60) are: a) "*larger areas are thought to have higher share of long travel-to-work journeys and hence a smaller distance-decay gradient*", b) "*a more monocentric and centralized distribution of employment entails a steeper decay of employment with increasing distance to the employment-weighted labour market centre*", c) "*the higher the degree of urbanization, the shorter the commute length will be and hence the steeper the distance-decay parameter"*, d) "*the greater divergence between the spatial distribution of households and employment is associated with a smaller distance-decay parameter because there will be more long commuting trips*", e) "*the extent that more specialized economic structures*[61] *require workers with specific skills, it may be more difficult to find such necessary skills within short distances, resulting in longer journeys to work and a flatter distance-decay gradient*" and finally, f) "*denser transport networks should be associated with a less steep distance-decay gradient as a result of a higher proportion of longer commutes*" (Melo et al., 2012:728).

The results of the second Melo's regression model (after estimated commuting gravity models for each of the 243 TTWA in England and Wales) are agreed to its previous hypothesis in generally (Melo et al., 2012: 734): a) the larger the land area of a given region the flatter the distance-decay parameter is, reflecting the fact that in larger areas the share of long commutes can be higher, b) circular-shaped areas are associated with steeper distance-decay gradient, reflecting that commutes will tend to be shorter in circular configurations than in long and narrow configurations, c) lower urbanization levels and increased jobs-housing imbalance are both associated with a flatter distance-decay of commuting trips: "*less urbanized spatial structures with an uneven distribution of jobs relative to households will tend to have higher proportions of longer commute lengths"*, d) the positive relationship between the degree of the monocentric arrangement of employment and the magnitude of the distance-decay of commuting trips according what it found by (Cervero and Wu, 1998; Schwanen et al., 2004 and; Aguilera, 2005), monocentric urban forms promote an increasing number of shorter commutes: "*we would expect to observe a higher distance-decay gradient of commuting trips. The findings indicate that an increase of 1 unit in the measure of monocentric urban form is associated with an increase in the size of the distance-decay gradient of 0,058 percentage points"*, e) a statically significant effect of localization economies on the magnitude of the distance-decay parameter in the way that the higher the degree of industrial specialization of a given local economy, the flatter the distance-decay gradient will tend to be: *"this can result from the increased difficulty of more specialized local economies to find an adequate supply of labour within reasonable distance, resulting in longer commuting trips and a flatter distance-decay"* and finally, f) an increased availability of a railway network is associated with a flatter distance-decay of commuting trips.

Hence, Melo's findings suggest that spatial urban structure plays a significant role in the explanation of the observed heterogeneity in the magnitude of the distance-decay gradient of commuting across labour markets what it contradicts the co-location hypothesis.

Another point in the literature that is still open is if polycentric structures exert an influence on modes of transport in favour of supply and the competitiveness of mass and public

[61] Melo's study uses Hirschmann-Herfindahl Index (HHI) which is computed as follows: $HHI_i = \sum_{o=1}^{O}(E_{io}/E_i)^2$, where ($E_{io}$) is the employment in industry (o) in TTWA (i), (E_i) is total employment in TTWA (i) and (O) is the number of industries. The index ranges from 0 (for perfect diversity) to 1 (perfect specialization).

transport[62] in order to achieve a reduction of the use of less sustainable private means of transport. In that sense, the study carried out by (Breheny, 1995) which explores if compact city case and the strength of decentralization can be substantially reduce transport energy consumption and hence pollution. Breheny's study argue that the development of polycentric cities, through market pressure, is the most effective way of dealing with energy-consumption problem by taking the following hypotheses: "*areas of high population density and large urban size will have lower rates of consumption on the grounds that (i) these areas have levels of accessibility and hence require shorter journeys and that (ii) they induce provision and use of public transport*" (Breheny, 1995:84). So, according to Breheny's study the cities with the highest densities were those with low car usage and high level of provision of public transport entailing obvious conclusion oriented to the need for stronger policies of urban containment and for investment in mass transport systems. The main Breheny's work contributions are: a) "*descentralization remains a power force, at least in the UK, and may be difficult to contain beyond existing levels of restraint*" and b) "*energy savings from urban containment are likely to be disappointingly low. Indeed, even modest savings could only be achieved through draconian policies of containment. Given the implicit expectations of politicians about the benefits of containment, realistic savings from this approach are likely to be trivial. It has been suggested that the levels of energy savings likely to result from even quite tough compact-city proposals could be achieved in other, much simpler and relatively immediate ways. The promotion of improved vehicle technology and the raising of fuel costs have been suggested as two ways.*" (Breheny, 1995:99)

In that sense, a meaningful study is the work carried out by (Modarres, 2003) in which focuses on the employment distribution and access to transit services. By using the 2001 census tract level economic activities and transit routes within the county, Modarres' study carries out a number of analyses to determine the location of major employment center (subcenters) in Los Angeles County and how these localities may be understood within the context of a transit service operation in a polycentric metropolitan area. Hence, Modarres' is important due to by taking a reality of polycentric distribution of urban functions, which is created by market dynamics and driven by differential land value and zoning policies, poses a challenge to creating equitable public transit services that meet the needs of its users without creating budgetary and efficiency dilemmas. To do so, (Modarres, 2003) first identify employment center/subcentres[63] and then the transit network[64] is assessed its relation to the previous identified employment subcenters.

[62] The study carried out by (Camagni et al., 2002) also investigates in this issue however in this work Camagni's work will be revised in the third body of the literature of this section 2.2 due to its main aim is to analyze whether urban form exert an influence on the social and environmental costs due to commuting

[63] In order to identify subcentres, Modarres' study use the following procedure: (1) The first step is based on: a) a total employee population map and superimposing the transit network is generated, then b) a centroid digital map of the census tract information for 2001 was constructed by using NNH clustering analysis taking into account a threshold of five points (which translated to five census tracts), and finally c) from the previous step (b) it resulted an identification of 124 first-order clusters and 18 second-order clusters. According to (Modarres, 2003:855) "*the 18 second-order clusters, which are most closely similar to the previous findings, contain 659 centroids (centers of census tracts) and 1,5 million employees. This is slightly higher than a third of total employment in the Los Angeles county data set and close to 40% of all census tracts. These results indicate that employment centres in Los Angeles continue to be diffused and contain a much smaller proportion of the employed population than would be otherwise expected"*. (2) The second step is based on: a) using Kriging function using the census tract centroids, weighted by the total number of employees and using a fine grid of smaller than half a kilometer to create a smooth surface of employment variation.

[64] Modarres' study defines transit accessibility by two different ways: (1) the level of service provided by existing routes and (2) the level of transit service available in each tract. The former, according to (Modarres, 2003) is performed by creating a spatial join between bus routes and the 2001 census tract business data: each

The results that Modarres' reaches are: a) while transit accessibility is relatively high for a majority of subcenters cluster, the general geography of jobs-housing balance suggest a high level of spatial mismatch in the region, especially for the low-income population, b) with the exception of a few locations, transit-rich areas are geographic spikes that converge on the downtown area and this creates a number of problems: "*while employment subcenters are adequately networked by the existing bus routes, the connection between employees and their place of work appears to be inadequate. This is especially true for connections that require a north-south movement*" and from the previous results, (Modarres, 2003:861) concludes: "*the 2001 employment geography in Los Angeles County suggest that not only have these employment subcenters become the essential nodes of a polycentric city, but also that their magnitude of employment attraction, compared to that reported by previous researchers, continues to grow. This means that these subcenters have become spatial nodes for attracting further economic growth. Given that many of these centers fall outside the neighborhoods where the employable population resides (especially low-income populations, which are more transit-dependent than other), it is crucial that transportation policymakers begin to view the geographies of employees and employment subcenters as the origin and destination of transit service operations*" and continues emphasizing the future role for subcentres: "*a reliable and intuitively acceptable methodology should be adopted for determining the subcentres on an annual basis: policy makers should annually asses the level of network efficiency for connecting the employed population to their places to work. This would require a full analysis of major and minor employment subcenters and designing an inter-regional, regional, and community-based transit service that efficiently serves that spatial arrangement: for example, subcenters would be connected with current buses and the local transit would connect residential corridors to the entire network and/or closest employment subcenters*".

Another relevant study, is the work carried out by (Susilo and Maat, 2007) which describe commuting trends in the Netherlands from 1995 to 2005 and examine the influence of urban form and travel accessibility (built environment) on commuting journeys over time on the basis of the from the Dutch National Travel Survey: changes in commuting participation, departure time, commuting time, commuting distance and modal split are analyzed by using a regression analysis and choice model in order to answer the following research questions. Firstly, a) who tends to commute outside the home municipality? Secondly, b) how far do they commute? Then, c) what is the preferred commuting mode? And finally, d) how long does the commuting journey take?. To do so, Susilo and Maat's study take into account a set of variables related to a) urban form, b) socio-demographic aspects of the area, c) local job opportunities, d) public transport and road network and finally, e) travel accessibility[65].

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bus route segment is assigned the number of employees in each tract. The latter, Modarres' study creates a spatial join between the census tract and the bus routes but this time each tract received information about the number of bus lines crossing it.

[65] The variables that Susilo and Maat's study takes into account and their descriptions are: (1) male, which is measured as dummy variable for male individuals, (2) younger than 25, which is computed as dummy variable for people younger than 25, (3) people aged 25-39, which is measured as dummy variable for people between the ages of 25 and 39, (4) people aged 40-64, which is calculated as dummy variable for people between the ages of 40 and 64, (5) people aged 65 or over, which is measured as dummy variable for people aged 65 or over, (6) dependent children, which is measured as the presence of children younger than 12, (7) number of household members, which is computed as the number of household members, (8) income, which is computed as personal income after taxes, (9) high education related to the individual has a university or polytechnic degree, (10) car availability, which is measured as the individual has a driving license and there is at least one car in the household, (11) population, which is measured as the number of inhabitants in the individual's home municipality, (12) very highly urbanized which is computed as home municipality has >2500 addresses per km^2, (13) highly urbanized, which is measured as home municipality has 1500<2500 addresses per km^2, (14) moderately urbanized, which is computed as home municipality has 1000<1500 addresses per km^2, (15) low

Referring with the first research question, (Susilo and Maat, 2007:596) by using binomial logit model reaches the following results: a) "*commuters who line in more populous and more urbanised areas tend to work inside their home municipalities in contrast with commuters who live in less populous and less urbanised areas"*, b) "*males tend to commute more than females outside their home municipality*", c) "*the presence of dependent children reduces the possibility of commuting outside the home municipality, although the influence is marginal*", d) "*younger workers tend to commute to locations outside their home municipality, while older workers tend to work in the municipalities in which they live*", e) "*job-housing balance reduces the likelihood that commuters will commute outside their home municipality*", f) "*higher job accessibility, denser transport network and access to a car also increase the chance of people working outside their home municipality*" and finally, g) "*the influence of accessibility has increased and the home location has become less important in influence the commute behavior: the coefficient of very highly urbanized area is -1,26 in 1995 with t-stats -15,90 and with -1,08 with t-stats -8,68 in 2005 and the coefficient of jobs accessibility is 0,46 in 1995 became 0,48 in 2005".*

Related to the second research question, (Susilo and Maat, 2007:599) by using a regression model point out: a) "*commuter's workplace (and commuting distance) is barely influenced by urban size or factors relation to travel accessibility, but rather by factors which have not been accounted for in this analysis, such as jobs suited to individual tastes and abilities*" and, b) "*commuters with higher incomes and higher levels of education tend to travel farther than other commuters and commuters who live in denser areas commute shorter distances than those who live in less dense areas*". In terms of to what the preferred commuting mode is, (Susilo and Maat, 2007:599) by estimating a multinomial logit model reaches on the following results: a) "*for commute longer distances, Dutch commuters tend to use public transport more than private cars*", b) "*the Dutch are fond of non-motorised modes of transportation (walking and cycling)*", c) "*females commuters tend to use public transport more than male commuters, but there are no gender differences in the propensity to use private cars and non-motorised modes in commuting*", d) "*the use of private cars is lowest among highly educated commuters*", e) "*commuters from more urbanised areas are more likely to use public transport than commuters from less urbanised areas*".

Finally, referring with how long the commuting journey takes, (Susilo and Maat, 2007:603) by estimating a regression model state: a) "*commuting distance shows a strong positive*

urbanized, which is computed as home municipality has 500<1000 addresses per km^2, (16) non-urbanised, which is measured as home municipality has <500 addresses per km^2, (17) located in RMA which means a home municipality is located in Randstad Metropolitan Area (RMA), (18) RMA main cities, which means home municipality is Amsterdam, The Hague, Rotterdam or Utrecht, (19) Job availability which is measured as number of jobs per 1000 inhabitants in home municipality, (20) Job accessibility by car, which is measured by number of jobs that can be reached by car within 30min, (21) Job accessibility by rail, which is measured by number of jobs that can be reached by rail within 30min, (22) Job accessibility, which is measured by number of jobs that can be reached by car or rail within 30 min, (23) Population accessibility, which is measured as number of individuals that can be reached by car or rail within 30 min, (24) Network density, which is measured as total land-use density for transportation network in home municipality, (25) Distance from train station, which is calculated as the average distance from the closest train station in home municipality (km), (26) Distance from metro station, which is measured as the average distance from the closest metro station in home municipality (km), (27) Distance from motorway access which is calculated as the average distance from the closest motorway access in home municipality (km), (28) Commuting by car which is computed as main mode of transport for commuting is car, (29) Commuting by train/bus/metro, which is computed as main mode of transport for commuting is train, bus or metro and finally (30) Commute by non-motorised mode, which means main mode of transport for commuting is walking, cycling or snorfiets (<50cc engine moped, which has usage characteristics similar to the bicycle).

association with total commuting time", b) "*although the average distance travelled by commuters from more urbanised areas was shorter, these commuters actually spend more time travelling: commuters from very highly urbanised areas travelled 2,34; 3,00 and 2,63 min longer than those non-urbanised areas in 1995, 2000 and 2005, respectively. So, commuters from the Randstad travelled longer than commuters from outside this area*", c) "*taking only the transportation-mode variables, with the same distances and conditions, car commuters travelled 1,5-2,0 min less and public-transport commuters travelled 16-18 min more than non-motorised commuters*" and finally d) "*overall, the time that commuters spent on commuting increased continuously from 1995 to 2005. However, while the influence of urban form on commuting time changed overtime, there is not any clear trend of the changes. The inclusion of built environment variables increased the models fitness (r^2-values) 0,57% in 1995, 0,33% in 2000 and 0,35% in 2005.*

Hence in conclusion, Susilo and Maat's study contribute to state the following points about the uncertainty relationship between built environment and journey parameters: a)"*as cities become more urbanised and compact, cross-commuting between municipalities, commuting distances, and car use for commuting are likely to decrease. Commuting time is likely to increase, however, because of the lower commuting speed. On the other hand, the use of public transport is likely to increase"*, b) "*the growth in transport-network density and accessibility will increase cross-commuting participation and reduce commuting distances. At the same time, this development will increase commuting time, as higher transport-network density tends to 'invite' higher numbers of private cars into the area and to make networks more congested"*, c) "*interestingly, increasing travel accessibility does not have a significant influence on the commuter's choice of transport mode: commuting distance (i.e. location of workplace) and car availability are the factors upon which commuters are most likely to base their choice of transport mode"*, d) "*the development of large polycentric networks, as in the Randstad, offers a convenient environment for cross-commuting, which tends to increase traffic flow and congestion, while also increasing the use of public transport*" and finally, e) "*the commuting distance model shows that the commuter's workplace is barely influenced by factors relating to urban forms and travel accessibility and more by other factors, such as job market that reflect individual abilities and preferences and the job location distribution: this supports the argument that individual and other factors are more crucial in determining the travel behavior of commuters than the built environment*" (Susilo and Maat, 2007:606).

Finally, to conclude this point, (if polycentric structures exert an influence on modes of transport in favour of supply and the competitiveness of mass and public transport) it is worth mentioning the study carried out by (Vega and Reynolds-Feighan, 2008) and (Commins and Nolan, 2011). The former, identifies key employment subcentres[66] in the Dublin region by

[66] To identify subcentres in Great Dublin Area (GDA), Vega and Reynolds-Feighan's study use a two-phasing approach based on assessing whether these subcentres candidates are relevant for the analysis on the basis of their employment size and their employment self-containment ratio: "*in general, relevant employment subcentres are those that attract the largest number of commuters and, in particular, those that attract the largest number of commuters from other districts"* (Vega and Reynolds-Feighan, 2008:1753). The first step according to Vega and Reynolds-Feighan's study (1) is based on estimating a negative exponential employment density as a function of distance to the CBD in the log version by using weighted least squares: $D(x) = D_0 e^{-\beta x+\mu}$ to $ln\, D(x) = lnD_o - \beta x + \mu$, where (D) is the employment density measured as the total number of workers per hectare; (x) represents the distance in kilometers to the CBD; (D_o) is a positive constant; and (β) and (μ) are the density gradient and the random error term respectively. Resulting from analyzing the residuals, Vega and Reynolds-Feighan's study identifies 126 employment subcentres candidates. In the second step (2) these employment subcentres candidates according to Reynolds-Feighan's methodology are assessed on the basis of the number of commuters they attract (employment size) and their self-containment ratio: "*the idea is to concentrate on employment subcentres that attract most traffic from other districts in the city with commuting*

using data from the 2002 Census of Population modified with travel-specific data by the Dublin Transport Office and to characterize them in terms of their composition by industrial and socioeconomic groups[67], its study illustrate the differences and similarities in travel behavior in the context of the choice of travel-to work mode across employment destinations. To test empirically, the linkages between the distribution of employment and the modal choice in the Great Dublin Region (a comparative analysis of travel mode choice across employment subcentres), Vega and Reynolds-Feighan's study model the choice of mode of transport[68] in the context of the journey to work.

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trips usually made by non-local residents who use motorised modes of travel in their journey to work" (Vega and Reynolds-Feighan, 2008:1754). By using GIS tools, Vega and Reynolds-Feighan's study identifies the those districts (from the 128 identified candidates to subcentres) that lie above the upper quartile of a measure of the total number of commuters to each potential subcentres candidate and below the lower quartile of the ratio of self-containment at each district. Resulting from this second step, Vega and Reynolds-Feighan's identified at the end 4 subcentres: two main subcentres in the west Dublin (Blanchardstown and Clondalkin-Tallagt), Dublin airport and a cluster districts along the two main roads (national N11 and the coast train line to the south).

[67]After identified the subcentres, Vega and Reynolds-Feighan's study classify them into industrial groups: a) manufacturing industries, b) construction, c) commerce, d) transport, storage and communications, e) public administration and defence, and f) education, health and social work and into socio-economic groups: a) employer and managers, b) higher professionals, c) lower professional, d) non-manual, e) manual skilled, f) semi-skilled and g) unskilled. In terms of the former classification, (Vega and Reynolds-Feighan, 2008:1756) point out "*some industrial groups seem to follow a predominant spatial location pattern in the region. Transport, storage and communications industries are mainly clustered around Dublin airport, while manufacturing industries show higher concentration patterns in the western subcentres. Education, health and social-work-related industries are mainly present in the N11 and the CBD, which coincide with the location of two of the main third-level educational institutions in the country.* Referring with the latter classification, (Vega and Reynolds-Feighan, 2008:1758) state: "*CBD and the N11 show a very similar profile in terms of the socioeconomic make-up of their commuters, with a very low proportion of manual skilled, semi-skilled and un-skilled commuters present and the highest proportion of higher and lower professionals recorded in the region. Manual skilled and semi-skilled classified commuters are found in large proportions in the western suburban employment subcentres and around Dublin airport".*

[68] Vega and Reynolds-Feighan's study estimate a binary logit model for the choice of mode of travel-to work. The logit model according to its study is obtained by assuming that each ($\mathcal{E}_{nj}$) is an independently and identically distributed extreme value. The probability of choosing alternative is: $P_{ni} = e^{V_{ni}} / \sum_j e^{V_{nj}}$, and regarding the travel mode decision for the journey to work, the choice between the private car and public transport is modeled. In Vega and Reynolds-Feighan's study, due to lack of data on slow mode commuting (walking and cycling) are not included, so the availability of private car and public transport is taken into account and probability are computed accordingly. According to (Vega and Reynolds-Feighan, 2008) the systematic part of the utility function for each of the two choice alternatives, car and public transport, is given by the following expressions: (1)$V_{car} = \beta_1 * TravelTime_{car} + \beta_2 * TravelCost_{car} + \gamma_1 * Gender + \gamma_2 * NumberCars + \gamma_3 * Age2 + \gamma_4 * Age3 + \gamma_5 * SEG1 + \gamma_6 * SEG3 + \gamma_7 Subce1 + \gamma_8 Subcentre2 + \gamma_9 Subcentre3 + \gamma_{10} CBD + \gamma_{11} Emp\_density$, and (2) $V_{PT} = \alpha_0 + \beta_3 * TravelTime_{car} + \beta_4 * TravelCost_{car}$, where all the coefficients for the characteristics of the decision-maker are normalized to zero for the public transport alternative and the constant is normalized to zero for the car alternative. The attributes of the alternative and the characteristics of the decision-maker included in this Vega and Reynolds-Feighan's model are those typically used for modelling travel mode choice: (1) attributes of the alternatives and (2) socioeconomic and land use characteristics. Concretely the independent variables are: a) total travel time for car and public transport in hour, which is measured as the in-vehicle travel time for car provided by the DTO, b) total travel costs for car and public transport in euro, which is calculated as the travel costs for car and public transport fares provided by the DTO, c) gender (female commute=1), d) age group 2 which is computed as the individuals between 35 and 54 years old (reference category: individuals between 15 and 34 years old), e) age group 3, which is measured as individuals over 55 years old (reference category: individuals between 15 and 34 years old), f) socioeconomic group1, which is computed as education and employment status (socioeconomic group as defined by CSO) and as employers, managers and professionals (reference category: non-manual), g) socioeconomic group 3, which is calculated as education and employment status (socioeconomic group as defined by CSO) and as manual skilled, semi-skilled and unskilled (reference category: non-manual), h) number of cars, which is calculated as car availability for use in the household, i) employment subcentre, which is computed as dummy variable for each identified employment subcentre –i.e. Blanchardstown, CBD, Clondalkin-Tallaght and N11 (reference category: airport) and finally, j) employment

The results that Vega and Reynolds-Feighan's empirical model (and also taking into account the elasticities with respect to travel times and costs across the identified employment subcentres) reaches are: a) "*results for the socioeconomic characteristics of the commuters show that older commuters are more likely to use the private car than those under 35 years old*", b) "*the number of available cars in the household, shows a positive effect on car choice possibilities*", c) "*gender effects are found for car use, with small negative marginal effects for female commuters, who are found to be less likely to use the private car in their journey to work*", d) "*commuters classified as employers, managers and professionals and those classified as part of socioeconomic group 3-i.e. manual skilled, semi-skilled and unskilled occupations- are more likely to drive to work than those classified within the non-manual socioeconomic group2*", e) "*the largest numbers of socioeconomic group 3, commuters are found in suburban employment subcentres, which have a limited supply of public transport from areas other than the city center. For these suburban subcentres, it is frequently the case that no travel mode is available other than the private car*", f) "*in terms of employment destinations show that commuters to the CBD and the N11 employment subcentre area less likely to use the private car than those commuting to more distant suburban areas in the west of the region and in terms of employment density, estimation results show small negative marginal effects on the choice probability for car use*" and finally, g) by analyzing the elasticities with respect to travel times and costs, significant differences are revealed in the public transport choice probabilities for the CBD compared with suburban employment subcentres: "*in general, elasticities are remarkably low by international standards for car use and significantly greater for public transport, particularly with respect to travel times. Differences in travel mode choice probabilities between central and suburban employment locations reflect the relatively poor provision of public transport to non-central employment sub-centres, making it difficult to commuters to switch modes of travel-to-work from the private car to public transport at those employment destinations"* (Vega and Reynolds-Feighan, 2008:1762-65).

Hence, in conclusion, (Vega and Reynolds-Feighan, 2008:1765) state "*in a polycentric city model, an increase in the number of employment subcentres due to lower transport costs, and the consequent switch from public transport to car use, enormously reduces the cost of employment suburbanization" and "results from this research are consistent with previous research on employment suburbanization in relation to the link between the emergence of new suburban employment subcentres, the importance of the private car as the main driver of decentralisation and the existence of poor provision of public transport to the new suburban job subcentres"*.

The latter study, carried out by (Commins and Nolan, 2011) explore the influence of travel and supply-side characteristics, as well as demographic and socioeconomic characteristics on the choice of mode of transport to work in the Greater Dublin Area over the period from 1996 to 2006 by using the latest data on the full population of working individuals from the 2006 Census of Population. To a certain point Commins and Nolan's study continue the previous study of (Vega and Reynolds-Feighan, 2008). To do so, Commins and Nolan's study use a conditional logit (CL) model[69] due to (Commins and Nolan, 2011:261) point out that: "*the CL*

density, which is measured as gross employment density computed as the total number of employed per hectare in each electoral district.

[69] In that sense, (Commins and Nolan, 2011) explain, assume each individual (i) faces choice between a set of J alternatives (j=1,2,…,J) with the attributes of the choices described by (Z_{ij}) and the characteristics of the individual described by (x_i). The mode is based on random utility framework in which each individual (i) aims to maximize their utility. The (unobserved) utility of each alternative is assumed to be a liner function of various

model extends the ML model to include variables that describe attributes of the choices (such as travel time) as well as variables that describe the attributes of the individuals (such as age or gender)" at the time that the independent variables that are included, are related to individuals, socioeconomic group of the individuals and transport supply variables[70]. Commins and Nolan's work estimate two specifications of the model: a) CL model of choice between three alternatives (walk/cycle, bus/train, car driver/car passenger/motorcycle) and b) CL model of choice between seven alternatives (walk, cycle, bus, train, car driver, car passenger, motorcycle).

The results and main findings that (Commins and Nolan, 2011:265) reach on estimating the previous models are: a) "*those working in the city centre are significantly more likely to walk or cycle, or take public transport to work, indicating the effect of public transport availability and city centre parking restrictions*", b) "*the existence of park-and-ride facilities and quality bus corridors in an individual's electoral districts is associated with a significantly increased probability of travelling by public transport*" and finally, c) "*the significance of gender, household type and marital status in determining choice of mode of transport to work highlights the importance of household or family interactions in determining modal choice: while women are significantly less likely to walk or cycle to work, they are significantly more likely to take public transport*"

Finally the third point of this Section 2.2, reviews the body of literature investigates the relationship between the spatial urban structures with the environmental externalities related to mobility patterns. In that sense, some studies have studied the relationship between different patterns of urban expansion and environmental costs (Camagni et al., 2002; Travisi and Camagni, 2005; Travisi et al., 2006, 2010 and; Cirilli and Veneri, 2010b, 2010c).

The first study carried out by (Camagni et al., 2002) examines for Milan Metropolitan Area, whether different patterns of urban expansion could be associated with specific environmental costs –in particular, for land consumption and mobility generation. Camagni's work defines a)

independent variables and an error term: $U_{ij}^{*} = x_i'\alpha_j + z_{ij}\beta + \varepsilon_{ij}$, where (U_{ij}^{*}) is the unobserved utility individual (i) derived from alternative (j), (x_i) is the vector of individual-specific independent variables, (αj) is the vector of estimated parameters for individual-specific variables, (z_{ij}) is the vector of alternative-specific parameters and $(\mathcal{E}_{ij})$ is the error term.

[70] The independent variables that Commins and Nolan's take into account are: a) age 25-39 (=1 if aged 25-29), b) age 30-34 (=1 if aged 30-34), c) age 35-39 (=1 if aged 35-39), d) age 40-44 (=1 if aged 40-44), e) age 45-49 (=1 if aged 45-49), f) age 50-54 (=1 if aged 50-54), g) age 55-59 (=1 if aged 55-59), h) age 60-64 (=1 if aged 60-64), i) age more than 65 (=1 if aged more than 65 years) and the reference category=aged 15-24 years, j) female (=1 if female) with reference category=male, k) lone parent with at least one resident child under 19 (=1 if it is true), l) lone parent with resident children but none under 19 (=1 if it is true), m), couple with at least one resident children under 19 (=1 if it is true), n) couple with no resident children (=1 if it is true), o) other households (=1 if it is true) and the reference category=single households, p) ever married (=1 if it is true) with reference category=single, r) third level (=1 if highest level of education completed is third level) and the reference category=less than third level, s) employers or manager (=1 if it is), t) higher professional (=1 if it is), u) lower professional (=1 if it is) and the reference category=all other socioeconomic groups, v) commerce, (=1 if it works), w) public administration (=1 if it works), x) health, education, social (=1 if it works) with reference category=all other industrial groups, y) working in city centre (=1 if it works) with reference category=works elsewhere, z) rail available (=1 if lives and works in a (electoral division) ED where 100 per cent of addresses are within 2km of a rail station) with reference category=does not live and work in such an ED, aa) park and ride, (=1 if lives in an ED with park and ride facilities) with reference category=does not live in an ED with park and ride, ab) QBC, quality bus corridor (=1 if lives in an ED with QBC) with reference category=does not live in an ED with QBC and finally ac) Household card, which is measured as predicted number of households cars per household member.

different typologies of urban expansion[71] and an impact index weighting differently journey-to-work with reference to mode and time length at the municipality level to study the environmental costs due to mobility patterns; then, b) its study focuses on the components of the mobility impact by means of modal choice and trip time: the relative competitiveness of the public and private transport modes.

To test it empirically, (Camagni et al., 2002:206) take the following hypothesis: "*the working hypothesis is that within a relatively homogenous area (in terms of income level and general socio-economic conditions), such as the province of Milano, the local differences in the mobility patterns (time and mode) can, at least to a certain extent, be attributed to the form in which urban growth has occurred"* and estimate a regression models which the dependent variable is: a mobility impact index (an indicator of environmental cost of mobility)[72] and the independent variables are a combination of factors related to a) geographical variables, b) socio-economic variables, c) morphology and finally d) accessibility and transport[73]. Hence,

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[71] By using maps drawn up by Centre Studi PIM on land consumption in the Milano area in 1991, Camagni's work analyze the patterns of residential development over the period 1981-1991 in each of the 186 communes within the province and by taking a descriptive/intuitive approach its study distinguish five types of urban expansion: (1) infilling: "*characterized by situations in which the building growth occurs through the infilling of free spaces remaining within the existing urban area*", (2) extension: "*occurs in immediately adjacent urban fringe*", (3) "*is development which follows the main axes of the metropolitan transport infrastructure*", (4) "*characterize the new scattered development lots*" and finally (5) "*concerns new lots of considerable size and independent of the existing built up urban area*" (Camagni et al., 2002:204). Then, Camagni's study by identify all the combinations among these types of urban area and by eliminating and re-assigning the least significant combinations a selection of 10 prevalent typologies are defined, typologies that its study use in the empirical work. These 10 prevalent typologies are: (1) pure infilling (T1/T1), (2) infilling-extension (T1/T2), (3) infilling-sprawl (T1/T4), (4) pure extension (T2/T2), (5) extension-linear development (T2/T3), (6) extension-sprawl (T2/T4), (7) pure linear development (T3/T3), (8) linear development-sprawl (T3/T4), (9) pure sprawl (T4/T4) and finally, (10) large scale projects (T5/T5).

[72] To construct the dependent variable, Camagni's study use the only data available on a homogenous basis at the local (commune) level, that is the journey-to-work data recorded in the 1991 Census for each active resident, disaggregated by mode (6 categories: walking or other soft means, bus, car (driver), motorcycle, car (passenger), train, and tram or underground) and within each mode by the time taken: 30, 31-60 and over 60 minutes. So, from this data on travel modes and the time of length of commuter trips, Camagni's study defines an indicator of the environmental costs of mobility. To do so, as environmental impact of a trip depends on the combination of mode and time, (Camagni et al., 2002:207) define a weighted index of impact for the 18 combinations of mode and time as follows: (1) the first step is assigning arbitrarily the value 1 to the 45 minutes trip by car in the matrix of weights for time and mode and then assuming: a) "*for any given mode, the impact of a trip per unit of time decreases with the trip length (to take into account the higher pollution produced by a vehicle with catalytic converter at the start of the trip, the greater fluidity of traffic outside the urban area, the lower number of stops for trains on longer journeys, etc*" and, b) "*for any given duration, the weight of the various modes –put conventionally at 1.00 per passenger x minute the weight of the trip by car- is, respectively: 1/3 for motorcycle and bus; 1/5 for rail trips; zero for pedestrians or bicycle trips and transported passengers (this is justified by considering that the possible lengthening of a journey due to the presence of the passenger is already absorbed by the length of the journey travelled by the driver)*" and, (2) the second step is based on using the above values, the commuters recorded in the Census were transformed into 'equivalent impact commuters' EIC. At this point, having two values for each commune- 'real' commuters and EICs- by comparing the two values, Camagni's work arrive at an 'impact intensity index' (or quality index) for each commune, measuring the average impact that can be assigned to every commuter trip made. To use it in the empirical analysis, Camagni's work normalized the mobility impact value for each commune to the man value for the province. According to (Camagni et al., 2002:207) "*the advantage of this index of mobility impact over other, more direct indices of environmental damage (emissions, congestion) resides in the fact that it refers to the mobility demand generated in each municipality (as a consequence of its settlement structure) and not to the mobility effects on each place, which could well derive from trips originating in other municipalities"*.

[73] Apart from the dependent variable: mobility impact, which is measured as the ratio between the EIC and the number of commuters recorded in the Census, Camagni's work takes into account the following independent variables: 1) distance from Milan, which is measured as the distance (km) between the centroid of a commune

the first set of regression models that Camagni use; try to answer the first point mentioned before. To do so, its study estimates a model which the dependent variable is the mobility impact and the independents: a) distance from Milan, b) net density (in logarithm form), c) growth rate of residents, d) age (in logarithm form), e) ratio of employment to residents (in logarithm form) and finally, f) the dummy variables of sprawl, extension/linear and infilling/extension by using OLS (ordinary least square) and (WLS) weighted least squares (WLS) being the difference between them in terms of results no significant.

The main results that Camagni's work reaches are five: a) "*a significant inverse relationship was found between the index measuring the mobility impact and net population density (density of the built up are). Together with the size of the urban areas in terms of absolute population, density appears to have mainly an indirect effect on the mobility impact, through its influence on the average trip time of public transport and hence on the modal split of commuter trips in favour of public transport*", b) "*a significant relationship also exists with the variables representing demographic growth rate and the average age of housing. In both cases, the impact index increased with the dynamism of the communes concerned, so high values were associated with communes with a rapid growth of population over the ten year period 1981-1991 and also those with never housing, i.e. areas of recent expansion*", c) "*the coefficient relating to the distance from the centre of Milan is small in terms of absolute values (0,006 points per km), but is significantly less than zero, indicating the greater autonomy of the town in the most external parts of the province and a spatial structure of settlements similar to that of a self-contained industrial district*", d) "*the analysis of the relative coefficient of the dummy variables makes it possible to establish the following ranking (in increasing order of impact): infill-extension, extension-linear development, sprawl and large-scale projects*" and finally, e) "*the role of the employment/residents ratio which can be considered as indicator of the level of functional diversification –integration-segregation, the 'functional mix' of each commune, has a significant and negative relationship, indicating that the mobility impact was higher when the proportion of employment was lower, i.e. in areas of specialized residential nature"* (Camagni et al., 2002:209).

Then to test empirically, the second research question (casual relationship between the physical structure of urban development and the social costs), Camagni's study takes the following two hypotheses: a) "*settlements of relatively compact structure entails a greater competitiveness of public transport (in terms of journey to work time) so, a greater use of public transport and as a result lower mobility impact*" and, b) "*settlements of relatively compact structure entails a greater efficiency of both public and private transport, so lower*

and the centroid of Milan, 2) age, which is calculated as the average age of building (years), 3) growth rate of residents, which is measured as the percent growth rate of population between 1981 and 1991, 4) gross and net density, which are calculated as the density (inhabitants/km^2) over the whole land area (km^2) and over the built up area respectively, 5) emp, which means the total employment, 6) emp/res, which is the ratio between employment and number of residents, 7) competitiveness public transport, which is the relative competitiveness of public transport, calculated as the ratio between the average time taken for trips made with private transport and the average time for trips made by public vehicles, 8) share public transport, which measures the market share of public transport, for example the percentage of all trips made by public transport, 9) built up area, which is calculated as the total area (km^2) classified as built up area by Corine Land Cover, 10) public time, which is measured as average trip time (minutes) for public transport trips, 11) private time, which is measured as average trip time (minutes) for private transport trips and finally 12) dummies for typology of urban expansion: from the 10 typologies (see note 71), Camagni's study has reduced into 4 groups to include them into the regression analysis: a) infilling/extension, b) extension/linear, c) sprawl and finally d) large-scale projects.

commuting time and as a result, lower mobility impact" (Camagni et al., 2002:210) what leads to test two sets of regression models[74].

The former set of empirical models is related to the relative competitiveness of the public and private transport, the dependents variables are: a) competitiveness of public transport, b) share of public transport and c) mobility impact and; the independent variables are: a) net density, growth rate of residents (in logarithm form) and, ratio of employment to residents, b) competitiveness of public transport, gross density, growth rate of residents, built up area and, ratio of employment to residents, and finally c) growth rate of residents, ratio of employment to residents (in logarithm form), share of public transport, age (in logarithm form) and distance from Milan, respectively. The latter set of empirical models is related to the absolute efficiency of the public and private transport, the dependents variables are: a) public time and b) private time and the independent variables for both models are: distance from Milan, age, growth rate of residents, net density (only for public time model) and finally employment.

Referring of the first set of models the findings that Camagni's study reaches are: a) "*the relative competitiveness of public transport depends significantly on the form of urban development, and in particular on residential density (as well as on the functional mix – employment to residents ratio- and the growth of residents)*", b) "*there is an evident connection between this competitiveness indicator and the model split: as it well known in the transportation literature (and close to common sense expectations), the share of public transport increases with its comparative efficiency vis-à-vis the other transport modes as well as with the gross density of the commune. On the contrary, the share of transport public decreases with growth rate of residents, built up area of the communes and the employment to resident ratio*", and finally c) "*the market share of public transport has a significant influence on the mobility impact: the higher the share of public transport, the lower the mobility impact. The same significant effect exert age, distance to Milan, and the functional mix of the communes on mobility impact and only growth rate of resident have a positive significant effect*" (Camagni et al., 2002:210).

Related to the second set of models the findings that Camagni's study reaches are: in terms of public time, a) "*decreases by about 10 min (20%) from the smallest communes to the largest ones*", b) "*decreases with the increase of net density*", c) "*increases with distance from Milan*", d) "*the unexpected significant positive sign of housing age, which in this context probably indicates a congestion effect*", and e) "*the expected significant positive sign of demographic growth variable*", and finally, in terms of private time, the results are: a) "*perfect indifference to demographic size and substantial indifference (no significant) to density*", and b) "*a negative relationship with the age of housing (also with distance to Milan and employment size) and positive relationship with the demographic growth, confirming the existence of a pattern of new urbanization which relies heavily on long trips by private car*" (Camagni et al., 2002:213).

Hence Camagni's work conclusions (and main contributions) are: a) urban density, demographic growth rates, age of the building stock and functional mix (economic-residential balance) exert a statically significant influence on mobility impact. Higher impacts are associated with diffused, sprawling development, more recent urbanization processes and residential specialization of the single municipalities, b) public transport is strongly influence, both in terms of efficiency (time) and competitiveness (market share) by the structural

[74] The detailed description of the variables: independents and dependents that Camagni's study use in this point are in-depth explained in previous note 73

organization of an urban area: the more dispersed and less structured the development, the lower its level of efficiency and competitiveness, and consequently, its share of the mobility market, and finally c) private transport appear to be correlated not so much to urban dimension or density as to the presence of recent housing development, indicating the emergence of new models of lifestyle and mobility.

This previous work carried out by (Camagni et al., 2002) exerts a meaningful influence on the literature. Later studies that focus on the same research question start from Camagni's empirical work and contribution. In that sense, the works of (Travisi and Camagni, 2005) and (Travisi et al., 2006, 2010)[75] extend the previous Camagni's empirical analysis to seven major Italian Metropolitan Areas: Bari, Florence, Naples, Padua, Perugia, Potenza and Turin in order to corroborate the previous tentative results for the Italian context. The novelty of Travisi and Camagni's and Travisi's work are threefold: a) their works explore the changes that have occurred due to the increased intensity of mobility from 1981 to 1991, b) using an econometric analysis of cross-section data, their works consider several metropolitan areas simultaneously and finally, c) their studies offer a structural interpretation of the causal chain in the explanation of the mobility impact intensity by using Casual Path Analysis.

To do so, firstly, Travisi's work borrow from Camagni's study the indicator of mobility impact that its work has proposed[76]. Secondly, (Travisi et al., 2010) estimate three different econometric multivariate models (two by using OLS -ordinary least squares- and one by using WLS –weighted least squares-) with cross-section data which the independent variable is the intensity of mobility impact factor expecting that four types of variables influences on it at local level: geographical-spatial, morphology-structural variables and variables measuring the accessibility and efficiency of private versus transport. For this reason, the independent variables that its study uses slightly vary from Camagni's independent variables work[77]. The aim of this empirical work according to (Travisi et al., 2010:388) is explore the existence of significant differences between: 1) pooled regression model 2) across single urban areas, 3)

[75] The work of (Travisi and Camagni, 2005) and (Travisi et al., 2006) are really similar with (Travisi et al., 2010), so in this work since now only the study of (Travisi et al., 2010) will be taken into account.

[76] The indicator of mobility impact according to (Camagni et al., 2002) is calculated as follows: $I_k = \sum_{ij} m_{ij}\, w_{ij} / \sum_{ij} m_{ij}$, where ($m_{ij}$) is the number of commuters moving within the (kth) municipality plus the number of commuters going outside the (kth) municipality for the (ith) travel mode and the (jth) trip time class, and (w_{ij}) is the weight assigned to the (ith) travel mode and the (jth) trip time class.

[77] The dependent variable is the same as (Camagni et al., 2002): mobility impact in 1991 which is defined as the average intensity of the impact of urban mobility at commune level and calculated as the ratio between the EIC (Equivalent Impact Commuters) and the number of commuters recorded in the Census. The independent variables related to (1) spatial characteristics are: a) distance, which is measured as the distance in kilometers between the centroid of a commune and the centroid of the capital of the province, b) rural, which is defined as the incidence of rural areas and measured as the rural area (km^2) over total land area (km^2), c) density which is defined gross density of the commune and which is calculated as the number of resident over the whole land area (km^2), d) poptot, which is defined as total number of residents, e) suptot, which is defined as total land area (km^2) f) north, which takes value 1 if the city is located in the North of Italy, the same for g) centre and h) south. In terms of independent variables referring are (2) structural features, Travisi's work takes into account: i) mixitie, which is calculated as ratio between the number of employments and residents of a commune (in logarithm form), j) growth, which is measure as growth rate of the population between 1981 and 1991, k) metro, which takes value 1 if the urban area is metropolitan, l) polyc, which takes value 1 if the urban area is polycentric. Related to (3) mobility independent variables, Travisi's study defines: m) compub, which is defined as the relative competitiveness of public transport and which is calculated as the ratio between the average time taken for trips made with private transport and the average time taken for trips made with public vehicles (the ratio is multiplied for 100 for computational reasons), n) sharepub, which is defined as market share of public transport and which is calculated as the percentage of all trips made by public transport and finally o) selfcont, which is defined as the degree of containment of urban mobility within a given urban settlement moving out the commune, and the number of commuters moving within and going outside the commune.

across cities located in the north, centre and south of Italy and 4) between metropolitan and polycentric urban areas in relation to the environmental costs due to mobility.

The results of these three models when is taken into account 1) pooled model show that: a) OLS and WLS models provide significant and robust results consistent with Travisi's study a priori expectations: "*distance to the center of commune, residential density, rural areas, 'functional mix' of the commune, self-containment, and the commune located in the south exert a negative significantly effect in the mobility impact. Meanwhile the recent growth areas, metropolitan areas and the north analyzed urban areas are positively significantly associated with the impact of urban mobility*" and, b) when are included variables measuring the share of trips with public transport and a proxy for the efficiency of private versus public transportation, the model has slightly higher explanatory power, and it shows that both variables are negatively and significantly correlated with the impact of urban mobility. (Travisi et al., 2010:388). The results when is taken into account 2) across single urban areas show that: a) the results confirmed the outcomes of the previous models (pooled models), even though the significance of coefficients is reduce due to the limited number of observations available for sub-samples on provinces, b) the major variations relate to the effects that the self-containment capacity and the proportion of agricultural land: "*coefficients get either a positive or a negative sign. For instance in terms of self-containment, Naples and Turin have negative and significant coefficients, whereas Perugia, Potenza, Florence and Bari have positive and highly significant coefficient not in conformity with our expectation. The same divergence occurs in agriculture land and the share of public transport*", c) the coefficients of distance, residential density and rural are statically significant and negative, however the functional mix variable (mixtie) is negative associated with the mobility impact but with a no statically significant way and finally, d) the most demographic growth areas have a positive significant effect related to the mobility impact. (Travisi et al., 2010:388)

The results of these three models related to 3) geographical location depict that: a) the differences between Italian geographical zones (north, centre and south) are focused on self-containment and share of public transport. In terms of self-containment, the north and the south areas exert a statically negative influence on mobility impact, whereas the centre part of Italy is associated with it in a statically positive way. Related to the share of public transport, only the north exerts a statically influence (negative) on impact of urban mobility and b) the other variables are statically significant and have the expected sign as the first model. In addition, the main result, taking into account 4) metropolitan and polycentric urban areas, according to (Travisi et al., 2010:389) is: apart from that all variables take on the expected sign and are significant, there are some differences in the elasticity of some explanatory factors: "*in particular, the effect of functional mix, growth rate and density is stronger for towns and cities belonging to a polycentric urban agglomeration, whereas the effect of distance and rural is stronger for metropolitan areas".*

Finally, the last novelty of Travisi's is presenting a conceptual casual chain in the explanation of the mobility impact intensity, in which the mobility impact is the result of the influence of three main territorial dimensions: structural, economic, and social. According to Travisi's study, the first dimension is defined by self-containment (which at the same time is defined by urban form and urban functional mix), the second dimension (economic) is represented by the competitiveness of public versus private transport (in terms of time efficiency) which is a result of the urban settlement's structural features (urban density, functional diversification etc…) and finally, the third dimension (social) is defined by the modal choice of the city inhabitants, depending on the competitiveness of the public versus private transport that, in its turn, is related to urban settlement features. To do so, Travisi's study uses the Generalised Least-Square (GLS) method to run the path analysis and find the causal effects between the third dimensions that influence on the impact of urban mobility[78]. Their findings are: a) "*the level of self-containment depends on the structural form of urban development, and in particular on its residential density, functional mix and proportion of farmland*", b) "*there is a positive correlation between the self-containment indicator and public transport competitiveness and between public transport competitiveness and travel modes preferenc*e" and finally, c) "*the causal path analysis (CPA) shows a negative and statically significant correlation between an increase in the use of public transport and the intensity of urban mobility*" (Travisi et al., 2010:391).

The last two mentioned studies that examine the relationship between different patterns of urban expansion and environmental costs due to mobility, are the works carried out by (Cirilli and Veneri, 2010b, 2010c) The former, is based on analyze Italian urban spatial organization in order to build a taxonomy of them: ranging from the most compact and transit-oriented Italian cities to the most dispersed and car-oriented ones. To do so, after defined them by a functional approach, Cirilli and Veneri's study proceed by a) use indicators to define the spatial organization of cities[79] as well as their patterns of mobility by then b) using a

[78] Travisi's study uses the following variables to capture the structural dimension: a) residential density, b) functional mix and c) rural, so they describe respectively, the urban form and function of a given urban area. Then, to synthesize the general territorial structural dimension, Travisi's select the self-containment. Finally, competitiveness of the public transport versus private transport (Compubb) is the economic element of the model and the share of public transport (sharepub) estimates individual preferences for public transport, so it is the social element of the causal path.

[79] Cirilli and Veneri's study take into account four dimension of urban form. The first (1) is related to the SIZE of urban area. Its study considers the a) population and b) land area in order to define the size of a city. The second (2) is referring with RESIDENTIAL DENSITY in order to measure the dispersion of cities. (Cirilli and Veneri, 2010b) take into account the following variables as proxies for urban dispersion: c) gross residential density, which is the residential population over total area (in km^2) and re-scaled in logarithm terms (ldensity), so the higher this variable, the more compact the system, d) residential structure which is defined as the share of population living in inhabited settlements and dispersed houses over population living in inhabited centres in 2001 (sprawl), so the higher is this variable according to Cirilli and Veneri's study, the more dispersed the system and finally e) rural share, that is the share of total agricultural farmer's area in 2000 over total area in 2001 (rural_share), so the higher it is, the less urbanized the system. The third dimension is related to (3) CONCENTRATION OF RESIDENTIAL AND ECONOMIC ACTIVITIES. To take into account this dimension, Cirilli and Veneri's define: f) pivot population share, which is the share of population living in the pivotal municipality over the total population of the system in 2001 (pivot_pop_share). The higher this variable, the larger the weight of the pivot on the system (which tends to be monocentric in that case, as opposed to either a more dispersed or polycentric system), g) pivot employment share, that is the share of employed people in the pivotal municipality over the total number of employed people in the system in 2001 (pivot_empl_share), so the higher it is, the larger the weight of the pivot on the system, h) population concentration which is calculated as Gini concentration index as follows: $gini\_area\_pop = \sum_{i=1}^{n} |A_i - P_i|$, where ($A_i$) and ($P_i$) represent, respectively, the area and population shares in 2001 of the (i-th) municipality over the whole urban system, whereas (n) is the number of municipalities in that system, so the higher is this variable, the more concentrated the population distribution over the territory of the system, i) employment concentration, which is measured as Gini concentration index as follows: $gini\_area\_empl = \sum_{i=1}^{n} |A_i - E_i|$, where ($A_i$) and ($E_i$) represent, respectively, the area and employment shares in 2001 of the (i-th) municipality over the whole urban system, so the higher this variable, the more concentrated the employment distribution over territory of the system. Finally, the last dimension is related to the degree of (4) CLUSTERING. In that sense, Cirilli and Veneri's study define j) the relative functional specialization of the pivot which is measured as the difference in absolute value between the pivot employment and population shares over the whole system in 2001 as follows: $pivot_{mix} = \sum_{i=1}^{n} |E_p - P_p|$, where ($E_p$) and ($P_p$) are respectively, the employment and population shares of the pivotal municipality in 2001, so a positive value implies a higher proportion of productive activities in the pivot relative to the rest of the system and viceversa, a negative value implies a higher proportion of residential activities in the pivot relative of the rest of the system, meanwhile, a zero value implies the same proportion of productive and residential

multivariate statistical analysis in order to find the relation that exist between them (cities' structure and mobility patterns) to achieve the mentioned Italian cities taxonomy[80].

The results of Cirilli and Veneri's work are: giving a classification of the Italian urban system according to its level of environmental costs due to mobility. Its study range from the less sustainable urban system (very dispersed) to the most sustainable (very compact). The specific characteristics of each identified urban system group are: a) very dispersed urban systems: "*in this group residential density is the lowest, while the rural share and the share of houses built after 1982 are the highest, as well as the residential structure is the most scattered. Accordingly, the intensity of private motorized commuting is the highest, whereas the functional diversity of the pivot is the lowest. Cities belonging to this group are characterized by a high degree of urban sprawl and mobility is largely dependent upon the automobile*", b) dispersed urban systems: "*in this cluster cities have similar features –albeit less accentuated- as cities in the first group. In particular, cities in this group are less*

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activities in the two territorial scale. In addition, apart from the dimensions of urban form, Cirilli and Veneri's study take into account (5) the urban dynamics of the systems and (6) mobility patterns characteristics. The former, is defined through k) house age, which is the share of houses built after 1982 over total houses in 2001 (house_age), so the higher it is, the more rapid the urbanization process in the last decades and l) population variation, that is measured as the relative population variation in the 1981-2001 period as (Camagni et al., 2002; Travisi and Camagni, 2005 and, Travisi et al., 2006) has proposed, so the higher it is, the more dynamics the urban system. The latter, is defined by m) public transport share, which is the share of commuters-to-work that use public means of transport over the total of commuters-to-work in 2001 (public_share), n) weighted average public commuting time, which is the average commuting time (in 2001) when public means of transport are used-time are weighted by the number of commuters, which is calculated as $average\_pu\_time = \sum_{i=1}^{n}\sum_{j=1}^{4} t_j pu_{ij} / \sum_{i=1}^{n}\sum_{j=1}^{4} pu_{ij}$, where ($pu_{ij}$) are the public transport users in the (i-th) municipality whose commuting time is (j), while (t_j) is the commuting time in minutes (the 4 value are the number of time categories) that have been taking into account, o) weighted average private commuting time, that is the average commuting time (in 2001) when private means of transport are used-time are weighted by the number of commuters, which is computed as follows: $average\_pr\_time = \sum_{i=1}^{n}\sum_{j=1}^{4} t_j pr_{ij} / \sum_{i=1}^{n}\sum_{j=1}^{4} pr_{ij}$, where ($pr_{ij}$) are the private transport users in the (i-th) municipality whose commuting time is (j), while (t_j) is the commuting time in minutes, p) normalized average public transport time, which is the weighted average commuting time (in 2001) when public means of transport are use normalized by the logarithm of the total area of the system (public_time), r) normalized average private transport time (private_time) calculated as p), and finally, s) private transport intensity, which is the share of commuters-to-work that use motorized private means of transports over the total employment of the system (priv_intensity), the higher it is, less sustainable mobility.

[80] To do so, (1) the first step that Cirilli and Veneri's study define is based on carrying out a factor analysis taking into account: a) six variables belongs to urban form: ldensity, sprawl, rural_share, house_age, pivot_mix, gini_area_pop) along with b) three variables pertaining to mobility patterns: public_share, public_time and priv_intensity and not taking into account variables that are duplicated: i.e. gini_are_empl is not included because is really similar to gini_area_pop. By selecting one of the factor outcomes of the factor analysis the next step (2) according to Cirilli and Veneri's study is computation the factor scores, which allows us to draft a ranking of Italian cities. The factor scores are computed according to (Cirilli and Veneri, 2010b:24) as a linear combination –for each urban system- of the relevant variables where the combination coefficient are the factor loadings: factor_score = 0,6140*public_share + 0,7903*public_time - 0,4202*sprawl - 0,3615*house_age + 0,8467*ldensity - 0,6565*rural_share_- 0,4881*priv_intensity - 0,1616*pivot_mix + 0,1691*gini_area_pop. Hence the higher the factor value, the more compact, densely inhabited, congested and concentrated cities, where the use of public means of transport is more intense and by contrast, the lowest values entails those systems are likely to be more dispersed, more rural, more dynamic in terms of new houses building, with a higher intensity of private motorized commuters and with a less functionally diversified pivot. Finally, the last step (3) of Cirilli and Veneri's work is based on using cluster analysis to grouping together those systems that present a similar degree of urban compactness and public means of transport orientation. To do so, is carried out according to (Cirilli and Veneri, 2010b:26) a cluster analysis following a hierarchical agglomerative approach and the urban system has been divided into five different clusters: (1) very dispersed, (2) dispersed, (3) dispersed/compact, (4) compact and finally (5) very compact which the results are agreed to the results of the factor analysis: the systems that are within the cluster: very compact (the most compact one) are the systems that have the highest value (rank) of the factor value obtained in step (2).

congested and population is more evenly distributed within them, which perhaps explain the even lower share of public transport users. Moreover, pivot municipalities concentrate on average quite a small population share, but are relatively diversified in functional terms", c) the urban systems grouped in compact and very compact are the contrary of the first and the second one: "*show the highest residential density as well as the least dispersed residential structure. As regarding mobility patterns, in such systems congestion is highest and the incidence of private motorized commuters is the lowest, whereas the use of the public means of transport is the most intense*" and finally the last group of urban systems is made up of in-between features of the others clusters: "*they do not stand out either for their compactness (and public-oriented mobility) or for their dispersion (and private motorized-oriented mobility. Furthermore, they have been the most dynamic in terms of population variation in 1981-2001 and are characterized by pivots whose population share over the whole system is fairly low on average, although population distribution over the system is fairly concentrated. These findings, taken together, may actually suggest that these systems are organized in a polycentric way, though it has not been possible*" (Cirilli and Veneri, 2010b:33).

Starting from the study of (Cirilli and Veneri, 2010b) and borrowing from the work of (Camagni et al., 2002) the idea of constructing an index to measure the impact of urban mobility, serves to the study of (Cirilli and Veneri, 2010c) to continue investigating the relationship between the impact of mobility and the different patterns of urban expansion. In this case the analysis is carried out by taking into account a functional dimension of what a city is (the Italian Local Labour Systems which contains a municipality at least 50.000 inhabitants in 2001[81]) and focusing on the two majors aspects of urbanization: a) the degree of urban sprawl and b) the degree of functional diversity, 'functional-mix' concept. To do so, Cirilli and Veneri's study a) firstly, construct a indicator to measure the impact of mobility that help to quantify indirectly the costs of commuting-to-work mobility[82] (with particularly regard to environmental costs due to air and noise pollution and congestion), and b) secondly, carrying out the estimation (Ordinary Least Squares and Spatial Lag Model) of a cross-section econometric model by using as a dependent variable, the impact-equivalent commuters (EIC) proposed and used by (Camagni et al., 2002) but changed in terms of calculation in Cirilli and Veneri's and as independents variables, factors that are related to 1) intensity-based sprawl, 2) spatial-structure sprawl, 3) urban dynamics and finally 4) mobility patterns[83].

[81] The Italian urban systems that Cirilli and Veneri's take into account are: Genova, Milano, Roma, Venezia, Napoli, Torino, Firenze, Bologna, Taranto, Palermo, Bari, Cagliari, Catania, Padova, Bergamo, Verona and Busto Arsizio.

[82] The impact factor proposed by (Camagni, 2002) is: $IEC_h = \sum_{i,j,k} f_{ijk} w_{ij} \,/\, \sum_{i,j,k} f_{ijk}$, where ($f_{ijk}$) indicates the flow of commuters in the (k-th) municipality of the (h-th) urban system that use the (i-th) transport mode and whose commuting duration is the (j-th), whereas (w_{ij}) represents the weight attached to the combination of the (i-th) transport mode and (j-th) commuting duration. In particular in (Cirilli and Veneri, 2010c) use a different weights in comparison with (Camagni et al., 2002) because the Camagni's weight overestimate the commuting times and tends to overwhelm the negative influence of a more intense use of public means of transport (commuting times are disproportionately longer when public means of transport are used): "*for a given distance commuting time is 15 minutes when a private car is used, while it is 30 minutes when a bus is used. Suppose two people use that car, while twenty people use the bus (but in peak hours the number is likely to be higher). In the computation of the IEC indicator as Camagni's study proposes, this means that private transport entails 15 minute-commuting, while public transport entails 600 minute-commuting, although the bus users in this example travel in the same vehicle. As a result, regardless of the lower weight attached to the bus vs. car mode of transport, the time weighting in this case tends to prevail and the public transport contribution to the impact, is clearly overestimated*" (Cirilli and Veneri, 2010c:12). To solve this issue, Cirilli and Veneri's study proposes changes the vector of weightings: 0,20 for train, tram and underground; 0,33 for bus and coach; 1,00 for private car (driver); 0,00 for private car (passenger) and on foot or other; and finally 0,33 for motorbike.

[83] The independent variables used in Cirilli and Veneri's work according to its distinction, are: (1) residential density in 2001, LDENSITY, which is measured as the logarithm of population over total area, (2) residential

The results that (Cirilli and Veneri, 2010c:19) present when the econometric model is estimated by OLS are: a) "*the explanatory variables, indeed, all show the expected signs: more compact (ldensity) and mono-centric cities (pivot_empl_share) are characterized by a lower impact intensity of mobility, whereas the latter proves to be higher in those urban systems that are less functionally diversified (gini_pop_empl) and have experienced rapid processes of urbanization in the 1981-2001 period (house_age)*", b) "*as regards to control variables, the territorial dummies that are related to Northern and Southern cities impact tends to be lower relative to the other cities*" and finally c) "*the model seems to account for 50% of total variance*". Finally, the results that (Cirilli and Veneri, 2010c:24) present are when the econometric model is dealt with spatial autocorrelation are: a) "*in this case all the territorial dummies becomes non-significant and two of the main regressors are no longer statically different from zero (i.e. rual_share, variable that accounts for share of farm land and gini_pop_empl, related to functional diversified cities)*" and, b) "*the square R indicator now much lower (25,4%), while the signs and the significance of the coefficients of all the other independent variables seem to be confirmed*".

Then, another relevant issue in the literature related to urban spatial structure and environmental externalities due to commuting is analyzing its costs by means of CO_2 emissions. In this sense, the studies of (Veneri, 2010; and Cirilli and Veneri, 2010a) contribute to solve this point. The former, takes into account the influence of polycentricity on costs due commuting by defining urban spatial structure by means of functional indicators (functional dimension of polycentricity) and by considering the relative percentage of subcentres that are within the analyzed Italian Metropolitan Areas. Veneri's study analyses the costs due to commuting by means of private costs (average commuting time) and by means of environmental costs (per capita CO_2 emissions). Previously, the first aim of Veneri's study has been revised (see, pages 33-36) and in order to analyze the second one, (Veneri, 2010) use the same independent variables (see, note 40) in the econometric model but changing its dependent variable (see, note 39) and its estimation method.

Hence, by taking into account 82 Italian Metropolitan Areas and using data from Isatat Population Census data in 2001 and from Italian Institute Statistics, Veneri's study examine the relationship between urban structure at inter-urban scale with the external effects of the costs of mobility, approximated in terms of CO_2 emissions, which is measured through the

structure in 2001, SPRAWL, which is calculated as the population in dispersed house and inhabited settlement over population in inhabited centres, (3) share of rural area, RURAL_SHARE, which is calculated as the total agricultural farms' area (2000) over total area (2001), (4) functional diversity for the pivotal municipality in 2001, PIVOT_MIX, which is calculated as the difference in absolute value between the employment and the population share of the pivot over the whole urban system, (5) monocentricity of the system in 2001, PIVOT_EMPL_SHARE, which is calculated as pivot share of total employment of the system, (6) functional diversity of the system in 2001, GINI_POP_EMPL, which is calculated as the sum, for each municipality within a urban system, of the differences in absolute value between the population and the employment shares of that municipality over the whole urban system, (7) population concentration in 2001, GINI_AREA_POP, which is calculated as sum, for each municipality within a urban system, of the differences in absolute value between the area and the population shares of that municipality over the whole urban system, (8) employment concentration in 2001, GINI_AREA_EMPL, which is measured as the sum, for each municipality within a urban system, of the differences in absolute value between the area and the employment shares of that municipality over the whole urban system, (9) HOUSE_AGE, which is computed as the proportion of houses built after 1982 over the total number of houses in 2001, (10) POP_VAR_81_01, which is calculated as relative population variation in the 1981-2001 period, (11) PUBLIC_SHARE, which is computed as the proportion of commuters that use public means of transport over the total number of commuters in 2001, (12) PRIV_INTENSITY, which is the proportion of commuters that use private means of transport over the total employment in 2001.

Environmental Impact of Mobility (EIM) index[84], on the basis of mode choice and distance travelled by commuters.

To test the hypothesis that what is the extent that characteristics of urban spatial structure influence the external costs of mobility, Veneri's work testing that the capita CO_2 emissions associated with a given pattern of commuting (mode of commuting and distance travelled), so by using its EIM proposed index, is a function of some characteristics of spatial structure divided into the following four categories: a) Metropolitan Areas' degree of polycentricity and polycentricity according to the co-location hypothesis, b) urban compactness, c) functional diversification of the territory and finally d) city size and then using a set of control variables: average age of housing-stock, the relative competitiveness of mass transit service in comparison to private means of transport, and finally socio-demographic variables: age structure of population and share of graduates.

Referring with a) Metropolitan Areas' degree of polycentricity, (Veneri, 2010:416) states that: "*subcentres present dimensional scale that facilitates the competitiveness of mass transit. Hence, a polycentric structure can facilitate a more intense use of public transport systems and this in turn negatively affects the external costs of mobility through a minor impact of CO_2 emissions*". In terms of b) urban compactness (Veneri, 2010:416) explains "*urban compactness enhances the competitiveness of a mass transit system"*. According to c) functional diversification of the territory, (Veneri, 2010:417) points out "*thanks to reduction in the distance between jobs and home, functional diversification reduces the length of travel and, as a consequence, the emissions of CO_2 and of other pollutants*". Finally, d) in terms of city size, (Veneri, 2010:417) explains that "*big cities are expected to present an advantage in supplying efficient mass transit systems because it is possible to reach minimum economies of scale that are necessary to justify big investments and expensive infrastructures"*.

The control variables that Veneri's study uses, permits a better interpretation of the empirical results helping avoid problems of under-specification of the empirical model. In terms of using the average age of housing-stock, (Veneri, 2010:418) argues that "*the underlying idea is that in the last decades the speed of house-construction has increased, but new settlements have not been planned with enough attention to the proximity to mass transit service, so cities with a higher share of new houses are expected to be less efficient in terms of external costs of commuting"* then referring with the relative competitiveness of mass transit service in comparison to private means of transport, argues that "*high mass transit competitiveness can boost the share of commuters who use these means of transport and can reduce the per capita (commuter) CO_2 emissions"*. Finally, in terms of socio-demographic, Veneri's study uses a population structure index and the share of graduates:*"a higher education level could be*

[84] The Environmental Impact of Mobility (EIM) index according to (Veneri, 2010) is calculated as follows: $EIM_h = \sum_{i,j,k} f_{i,j,k} w_k d_{ij} / \sum_{i,j,k} f_{i,j,k}$, where ($f_{ijk}$) is the number of commuters moving from municipality (i) to municipality (j) within (Metropolitan Area h), who use the (k-th) means of transport, (w_k) is the amount of CO_2 emissions (in grams) per passenger per kilometer and finally, (d_{ij}) is the road 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. To do so, a) the means of transport that Veneri's work considers are: (1) train, (2) tram, (3) underground, (4) urban bus or trolley bus, (5) extra urban bus or coach, (6) school of business bus, (7) private car –driver-, (8) private car –passenger-, (9) motorbike or scooter and finally (10) bike, foot or other means of transport; and b) the kilometer CO_2 emissions by means of transport that Veneri's work use are: a) train, 35 grCO_2/pkm; b) tram, 32 grCO_2/pkm; c) underground, 21,3 grCO_2/pkm; d) urban bus, 72 grCO_2/pkm; e) extra-urban bus, 26 grCO_2/pkm; f) school or company bus 31 grCO_2/pkm; g) car, 105 grCO_2/pkm; h) motorbike, 80 grCO_2/pkm and finally i) bike, on foot, other, 0 grCO_2/pkm.

expected to be associated with a higher income and, as a consequence a higher number of car owners that can influence commuting mode choice, so higher external costs of commuting".

To test the aforementioned hypothesis, Veneri's study uses a cross-section economic model taking into account the 82 Italian Metropolitan Areas as units of analysis and being estimated through spatial lag models (ML) in order to clean the residuals from spatial dependence. The results that (Veneri, 2010:420-422) present are: a) the coefficient associated to the variables of functional polycentricity are negative and statically 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 the MAs, the lower the EIM indicator. These findings corroborate the hypothesis that a higher degree of polycentricity is associated with lower external costs of commuting in terms of average CO_2 emissions per traveler"*, b) estimation results show that urban compactness is an important factor in explaining external costs: "*a higher density is associated with more sustainable mobility patterns in terms of CO_2 emissions*", c) as regards urban functional diversity, its influence on external costs remains unclear: "*although the coefficients of the mixed land-use variable (gini_pop_job) are negative for the external costs model, they lose statistical significance in one of the two specifications*", d) urban size entails the most prominent influence on environmental costs due to mobility: "*as was expected, larger size is associated with higher CO_2 emissions, so these results can be explained by the longer distances that on average have to be travelled in larger MAs, which affect pollutant emissions*". Finally, referring with the control variables that Veneri's study use in its econometric models the results shows that: e) age of housing stock does not have a statically significant effect, although it is negative associated with environmental costs, f) coefficient of the dummy variables in relation to the MA" geographic localization are also insignificant, expect for the Southern MAs that is positive statically associated with respect the external costs: "*southern cities show a higher impact in terms of CO_2*", g) a higher relative competitiveness of mass transit system is associated with lower environmental costs but it is not statically significant, h) among socio-demographic, the share of graduates is associated with a higher level of CO_2 emissions in a statically significant way but the age of the working population, on the other hand, although exert a negative influence on the external costs of mobility is not significant, and finally i) the spatial parameter of the spatial lag model is positive and significant, showing that a proximity effect exists: "*so neighbouring MAs have similar characteristics which are not taken on by the model's regressors, but which can be associated to other factors related to proximity (e.g. cultural and technological factors).*

Hence the main contribution of Veneri's work to the relation between urban spatial structure and environmental costs due to mobility by means of CO_2 emissions are: "*the analysis on 82 Italian Metropolitan Areas shows that polycentricity is a sustainable model of urban spatial structure, especially from an environmental perspective because it is associated with a reduction in CO_2 emissions due to commuting, whereas it comes out that urban dispersion is associated with higher external costs*" (Veneri, 2010:423).

In its turn, the work carried out by (Cirilli and Veneri, 2010a) starting from the previous study of (Veneri, 2010) also try to investigate whether and to what extent the spatial configuration of area affects its level of environmental externalities. In Cirilli and Veneri's study compared to Veneri's work (82 Italian Metropolitan Areas) the unit of analysis is the 111 largest Italian urban areas identified as Local Labour Systems (a functional delimitation of cities) whose central municipality has at least 50.000 inhabitants in 2001. To do so, Cirilli and Veneri's study a) borrow from Veneri's work, how measuring the external effects: its study uses the same indicator, the Environmental Impact of Mobility (EIM) index proposed by (Veneri, 2010)[85] on the basis of mode choice and distance travelled by commuters to approximate the CO_2 emissions caused by workers and b) extend the Veneri's study to take into account the PM_{10} (particulate matter <10μm) and NO_x (nitrogen oxides) emissions also as the case of CO_2 emissions on the basis of mode choice and distance travelled by commuters[86].

To test the hypothesis that what is the extent that characteristics of urban spatial structure influence the external costs of mobility, Cirilli and Veneri's work testing that the capita CO_2 emissions and PM_{10}-NO_x emissions associated with a given pattern of commuting (mode of commuting and distance travelled), so by using its EIM index proposed by (Veneri, 2010) and PM_{10}-NO_x index, are a function of some characteristics of spatial structure divided into the following four categories: a) intensity-based and spatial-based structure perspective, b) urban compactness, c) functional diversification of the territory and finally d) city size and then using a set of control variables: average age of housing-stock, accessibility, congestion, and finally socio-demographic variables: age structure of population and the spatial distribution of human capital. As Cirilli and Veneri's work use the same independent variables as Veneri's work with only the exceptions of the accessibility and congestion control variables, the expected hypothesis for these 'borrowed' independent variables are the same that (Veneri, 2010) pointed out (see pages 68 and 69) and in the cases of accessibility and congestion are expected that the higher is the accessibility and congestion, the lower and the higher are the both analyzed environmental costs (CO_2 and PM_{10}-NO_x) due to mobility respectively.

To test empirically the aims of its work, Cirilli and Veneri's study uses a cross-section economic model taking into account the 111 Italian Urban Areas as units of analysis and being estimated through Ordinary Least Squares (OLS) and two-stage least square (2SLS) estimation where the four main spatial structure variables –those related to density, concentration, degree of monocentricity and functional diversity- are instrumented by corresponding variables referred to the past (according to Cirilli and Veneri's study to 1951 data)[87]. The results that (Cirilli and Veneri, 2010a:24-27) present when as dependent variable

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[85] Cirilli and Veneri's work uses the same analytical expression of EIM, the same classification of transport modes, and the same values to measure per passenger per kilometer CO_2 emissions proposed and used by (Veneri, 2010). To see details about it, see page 67, note 84.

[86] PM_{10}-NO_x index according to (Cirilli and Veneri, 2010a) is calculated as follows: $pc\_PM_{10}NO_x = \sum_i \sum_j \sum_k f_{ijk} w_k d_{ij} / \sum_i \sum_j \sum_k f_{ijk}$, where ($f_{ijk}$) is the number of commuters moving from municipality (i) to municipality (j) within (Urban Area h), who use the (k-th) means of transport, (w_k) is the amount of PM_{10}-NO_x emissions (in grams) per passenger per kilometer and finally, (d_{ij}) is the road distance between the two municipalities. The PM_{10}-NO_x index gives a measure of the average quantity of particular matter and nitrogen oxides emissions of the type-commuter in each of the 111 Italian urban areas. To do so, a) the means of transport that Cirilli Veneri's work considers are: (1) train, (2) tram, (3) underground, (4) urban bus or trolley bus, (5) extra urban bus or coach, (6) school of business bus, (7) private car –driver-, (8) private car –passenger-, (9) motorbike or scooter and finally (10) bike, foot or other means of transport; and b) the kilometer PM_{10}-NO_x emissions by means of transport that Cirilli and Veneri's work use are: a) train, 0,25 cent*euro/pkm; b) tram, 0,19 cent*euro/pkm; c) underground, 0,13 cent*euro/pkm; d) urban bus, 5,69 cent*euro/pkm; e) extra-urban bus, 5,77 cent*euro/pkm f) school or company bus, 3,11 cent*euro/pkm ; g) car, 8,2 cent*euro/pkm; h) motorbike, 2,17 cent*euro/pkm and finally i) bike, on foot, other, 0 cent*euro/pkm.

[87] Cirilli and Veneri's study defines the following independent variables: (1) DENSITY, related to the compactness of the built environment, which is measured as residential density (population over total area) in 2001, (2) PIVOT_EMPL_SHARE, related to the degree of monocentricity, which is calculated as the central municipality's share of total employment of the urban area in 2001, (3) GINI_AREA_EMPL, related to employment concentration, which is measured as the sum, for each municipality within a urban area, of the differences in absolute value between the area and the employment share of that municipality over the whole UA in 2001, (4) GINI_POP_EMPL, related to functional diversity, which is measured as the sum, for each municipality within a urban area, of the differences in absolute value between the population and the employment shares of that municipality over the whole urban area in 2001, (5) HOUSE_AGE, related to recent urban dynamics which is calculated as proportion of houses built after 1982 over the total number of houses in

is the CO_2 emissions as environmental costs are: a) the only two variables that do not seem to play a significant role in the explanation of CO2 emissions are those used to control for UA's functional diversity and the age of their housing stock, b) 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, c) densely inhabited UAs appear to be more sustainable in terms of per commuter CO_2 emissions, even after controlling for accessibility and socio-demographics, d) monocentric UAs as well as UAs with an even spatial distribution of employment, generate higher levels of polluting emissions, e) the larger the city, the higher the level of per commuter CO_2 emissions: "*larger UAs commuters travel longer distances, thereby offsetting the beneficial effect due to a more intense use of public means of transport*", f) the accessibility of urban areas is associated, with lower level of CO_2 emissions: "*more accessible areas commuters are able to reach their workplaces more rapidly and with a wide set of options among transport means*", g) traffic congestions implies longer journeys and therefore generate higher levels of emissions, h) referring with sociodemographic characteristics, a high concentration of skilled workers in the central municipality entails more environmental costs: "*more educated people tend to travel longer distances, graduates are likely to obtain better jobs (and better pay), this developing a preferences for larger houses in the outskirts, which in turn implies longer commutes*". Finally, the results that (Cirilli and Veneri, 2010a:24-27) present when as dependent variable is the PM_{10}-NO_x emissions reach on the same conclusions as CO_2 emission empirical models. Hence, Cirilli and Veneri's work findings corroborate and they are in the line with the previous works such as (Veneri, 2010 and Travisi et al., 2010).

Finally, the last point in the literature, that investigates the relationship between urban spatial structure and environmental costs due to commuting, is on the basis of ecological print which not only accounts for direct CO_2 emissions but also for indirect emissions and occupied land. In that sense, the study carried out by (Muñiz and Galindo, 2005) is the most remarkable one, in which seeks to contribute to a deeper understanding on the global environmental effects of transport by explaining how an appropriate urban form can reduce it by a causality analysis where the ecological footprint of commuting is taken as dependent variable[88] and the independent variables are related to urban form and socio-economic characteristics[89] in the Barcelona Metropolitan Region from 1986 to 1996.

2001, (6) EMPL, referring with size of the urban area, which is computed as the number of employed people in 2001, (7) DEMO_STR, related to age of population which is computed as population structure index: people aged between 40 and 65 over people aged between 15 and 39, (8) GRAD_DISTR, related to spatial distribution of human capital which is computed as central municipality's share of total graduates of the urban area in 2001, (9) ACCESSIBILITY, which is computed as endowment of transport infrastructures and finally (10) ACCIDENTS, related to congestion, which is computed as the share of traffic accidents over the total number of commuters in 2001.

[88] Muñiz and Galindo's study use the following equation for calculate the annual ecological footprint of the required mobility in municipality (i): $E.F._i = \sum_z \left[\left[\sum_j EC_z EL_z D_{ij} Trip_{ij,z}\right] + L_z\right]$, where (E.F.$_i$) is the annual ecological footprint of trips made by municipality (i) residents, (EC_z) is the energy consumption of mode of transport (z) per kilometer and passenger (G_j/km); (EL_z) is the ecological land per (G_j) in mode of transport z (ha/G_j); (D_{ij}) is the network distance between municipalities (i) and (j); ($Trip_{ij,z}$) are the annual trips made by residents from the municipality (i) towards municipality (j) made by mode of transport (z); (L_z) is the land area corresponding to the infrastructure space used by mode of transport z (ha).

[89] The independent variables that (Muñiz and Galindo, 2005:508) take into account are: (1) DEN, which is net population density, calculated as the municipal population divided by hectares of residential land, (2) DC, which is distance to the center, calculated as the distance to the center (km) consists of the network distance from the geographical center of each municipality towards the center of Barcelona (CBD), (3) DA, which is distance to the transport axis, and it is calculated as the distance (km) from the geographical center of each municipality to the nearest transport axis, (4) INC, which is the average household income, and it is calculated as the average declared income per municipality and finally (5) JOB, which is job ratio and it is calculated as the per capita employment in each municipality, that is the ratio the number of jobs and residents. According to Muñiz and

To test empirically the influence changes of each considered variable on ecological footprint of commuting, Muñiz and Galindo's study use three different types of regressions models: a) the dependent variable is the per capita ecological footprint; b) the dependent variable is average distance and c) the dependent variable is the proportion of trips made by car; at the time that each type of regression model is based on five distinct variations according to including different independent variables: 1) net residential density, 2) distance to the center and distance to transport axis, 3) average income and job ratio, 4) net residential density, average income and job ratio and finally 5) distance to the center, distance to transport axis, average income and job ratio. The results that (Muñiz and Galindo, 2005:509-511) present are: a) the explanatory capacity of density and accessibility measures have a similar effect: "*while density mainly affects the proportion of trips made by car, accessibility variables have a higher impact on trip distance*" so, as ecological footprint calculated as Muñiz and Galindo's study have proposed is on the basis of incorporating both (modal split and trip distance), these factors also exert an influence on ecological footprint, both are statically significant and are virtuous to reduce it, and accessibility (distance to the center-CBD and distance to transport axis) is as important as population density, b) urban form variables influence increasingly the ecological impact of transport over time: "*1996 estimation has a higher goodness of fit than the correspondent does for 1986*", c) average household income has a statically significant positive effect on the value of footprint associated to model choice: "*job ratio variable exerts a negative effect on eco-footprint, confirming the assumption that proximity to jobs reduces the transport impact. Comparing the results for 1986 and 1996, the estimated coefficient of job ratio has significantly increased, which seems to indicate that the tendency towards the job ratio dispersion among municipalities with a low job ratio towards municipalities with a high job ratio*" and finally d) "*although urban form variables determine the ecological footprint of commuting in a larger extent than socio-economic variables, it is also clear that changes over time in the job ratio and income spatial distribution are raising their relevance in explaining eco-footprint differentials*".

Hence, the main contribution of the study carried out by (Muñiz and Galindo, 2005:511) is that measures of urban form typically used (net population density and accessibility –distance to the center and distance to transport axis-) have a greater capacity to explain municipal ecological footprints variability than other factors, such as average income and the job ratio: "*the authors conclude that urban form exercises a clear effect on the ecological footprint of transport: municipalities with low-density levels located in the outer periphery have a higher per capita ecological footprint of commuting than denser central areas and the control variables estimates show that ecological footprint also increased with income and decreases with job ratio, which recently is becoming a more important determinant*".

2.3. Role of other spatial and non-spatial characteristics

As we could observed in the previous section, in addition to urban spatial structure defined by means of degree of polycentricity or subcentres that are within metropolitan areas, other spatial and non-spatial characteristics of cities can influence on commuting patterns and on their social (commuting distance and time) and environmental effects. First, a) urban dispersion defined by means of density (low densities are related to urban dispersion) is considered one of the most important spatial determinants concerning the increase in

Galindo's study this ratio basically refers to the dimension of the economic sector in reference to the inhabitants of one municipality: "*it gives us an idea of the potential for self-containment of the municipal labor market if all the municipality's active population worked there*" (Muñiz and Galindo, 2005:508).

commuting distances and time but according to literature contribution its effects are still unclear. For example (Glaeser and Kahn, 2004; and Gordon et al., 1989) observe that higher densities are associated with higher travel times and (Levinson and Kumar, 1997) find a negative relationship between density and travel time when density is beyond a given threshold, after which the sign changes. Other remarkable studies (most of them, revised in the previous Section 2.2) that take into account density as explanatory factor of commuting patterns are the studies carried out by (Camagni et al., 2002; Schwanen, 2001; Giuliano and Narayan, 2003; Schwanen et al., 2004; Muñiz and Galindo, 2005; Bento et al., 2005; Travisi and Camagni, 2005; Travisi et al., 2006, 2010; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008; Veneri, 2010; Cirilli and Veneri, 2010a, 2010b, 2010c and; Melo et al., 2012).

Second, b) functional diversification is another characteristic of urban spatial organization that can be important in shaping commuting distances and time within cities and metropolitan areas. The literature has related this concept to b1) the notion of 'job-housing balance-imbalance' or to b2) a diverse or mixed land-use. The former has been studied widely by the most studies analyzed in the previous section (Giuliano and Small, 1993; Levinson and Kumar, 1994; Peng, 1997; Sultana, 2002; Modarres, 2003, 2011; Schwanen et al., 2004; Muñiz and Galindo, 2005; Bento et al., 2005; Camagni et al., 2002; Travisi and Camagni, 2005; Travisi et al., 2006, 2010; Veneri, 2010; Cirilli and Veneri, 2010a, 2010b, 2010c and; Melo et al., 2012) which most claim that the higher job-housing balance, the shorter the commuting distances but others find that it exerts a no significant influence on commuting patterns. The latter, the empirical literature shows that the level of diversity, the higher the transit usage (Frank and Pivo, 1994) and the shorter the distance travelled (Cervero, 1996, 2002; Cervero and Kockelman, 1997 and; Cervero and Murakami, 2010).

Third, c) city size, d) economic structure (concentration of industry, commerce and service activities) and e) accessibility are the other spatial characteristics that influence significantly to the length of distance and time spent by commuters. Studies such as (Gordon et al., 1989; Camagni et al., 2002; Schwanen et al., 2004; Travisi and Camagni, 2005; Travisi et al., 2006, 2010; Veneri, 2010; Cirilli and Veneri, 2010a, 2010b, 2010c and; Melo et al., 2012) show that the higher the city size, the higher the commuting distance or the works of (Gordon et al., 1989 and; Melo et al., 2012) and (Levinson, 1998; Muñiz and Galindo, 2005; Susilo and Maat, 2007; Cirilli and Veneri, 2010a and; Melo et al., 2012) that economic structure and accessibility of cities respectively are virtuous to economize commuting.

Fourth, there also are non-spatial characteristics related to the sociodemographic status of the individuals that shape clearly the commuting patterns of cities and metropolitan areas. These are the cases of f) income, g) education and h) demographic characteristics on the basis of h1) gender, h2) age and finally, h3) demographic growth of cities. According to the literature income and education are associated with higher distances and time spent by commuters such as presented in (Gordon et al., 1989; Dubin 1991; Kockelman, 1995; Giuliano and Narayan, 2003; Schwanen et al., 2003, 2004; Bento et al., 2005; Muñiz and Galindo, 2005; Shearmur, 2006; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008 and; Watts, 2009) and (Schwanen et al., 2001, 2002, 2003, 2004; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008, Veneri, 2010 and; Cirilli and Veneri, 2010a) respectively. Referring with demographic variables, the studies of (Dubin, 1991; Levinson and Kumar, 1994; Schwanen et al., 2001, 2002, 2003, 2004; Giuliano and Narayan, 2003; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008 and; Commins and Nolan, 2011) and (Tkocz and Kristensen, 1994; Schwanen et al., 2001, 2002, 2003, 2004; Bento et al., 2005; Shearmur, 2006; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008; Veneri, 2010; Cirilli and Veneri, 2010a and;

Commins and Nolan, 2011) show respectively that there are meaningful differences between the gender of individual as well as its age related to distance travelled being the women and the older people those spent less time and shorter distances to commute. Finally, the empirical literature also shows that the newer growth areas entails higher commuting distances and time due mainly to the lack of accessibility facilities for public transport, as it is studied by the works carried out by (Camagni et al., 2002; Schwanen et al., 2004; Travisi and Camagni, 2005; Travisi et al., 2006, 2010 and; Cirilli and Veneri, 2010c).

Then, another non-spatial characteristic are related to i) households in terms of i1) structure (number of workers, number of children, household incomes etc…) and i2) housing age. The former has studied by (Dubin, 1991; Clark et al., 2003; Schwanen et al., 2001, 2002, 2003, 2004; Susilo and Maat, 2007 and; Commins and Nolan, 2011) which show a clear tendency that the higher number of workers in a family, the less commuting time they spent and that single workers tends to commute by soft means of transport (walking and bicycle). The latter, studied by (Camagni et al, 2002; Veneri, 2010 and; Cirilli and Veneri, 2010a, 2010b, 2010c) show that the newer housing stock, the higher polluting emissions and time spent due to commuting. Finally, the supply of public and private transport also clearly shape in the commuting patterns of cities and metropolitan area, as it has been presented in (Gordon et al., 1989; Dubin, 1991; Camagni et al., 2002; Bento et al., 2005; Travisi and Camagni, 2005; Travisi et al., 2006, 2010; Susilo and Maat, 2007; Veneri, 2010 and; Cirilli and Veneri, 2010b, 2010c).

Hence, in order to give in-depth analysis of the spatial and non-spatial characteristics that exert an influence on commuting patterns, in this section is revised in detail each mentioned variable through a prominent study different from the just analyzed works in Section 2.2. In front of what (Glaeser and Khan, 2004:2511) pointed out: "*by using the micro data from the 1995 National Personal Transportation Survey to study differences in one way commuting times (in minutes) as a function of distance to work and residential bloc density. We find that average commute time rise with population density. The effect of density is actually less on car commuters than on non-car commuters. It is also true that that across cities, there is a strong positive relationship between average commute times and the logarithm of population density*", the work of (Levinson and Kumar, 1997) found the opposite result, a negative relationship between density and travel time. Levinson and Kumar's study point out that the conflicting findings between researches indicate a difficulty in determining whether density increases or reduces total commuting time and distance and its study give the following reasons: "*in part is due to multiple measurements of density: local vs. metropolitan and residential vs. employment, in part is the ambiguity about what a 'density' measurement is really measuring: is local density really capturing the number of people per unit area, the level of congestion, or the distance from the center(s) of the region (and implicitly the distance to other people), is metropolitan density really just capturing city size?*" (Levinson and Kumar, 1997:148)

To answer these questions (Levinson and Kumar, 1997:149) claim what its study understood as density at metropolitan and local level: a) "*at the metropolitan level, average density is principally a surrogate for city size. Aside from its accessibility benefits, increased density brings about costs that are undesirable (less space per person, more expensive construction, higher land costs, congestion). Thus densification, like polycentricity, is primarily a market response to contain or reduce otherwise high interaction costs (journey to work times, firm to firm interactions, non-work travel) found as cities increase population, rather than a cause of those travel times*" and b) "*within the city, density remains largely a measure of distance from* *the center(s) of the region. Clearly the higher the density is (and the closer to the center of the region) the more possible destinations that can be reached in the same distance*" and then by using that data come from Nationwide Personal Transportation Survey (NPTS) in 1990/1991 and estimating three different types of regression models (two of them at inter-urban scale at one at intra-urban scale), Levinson and Kumar's work test if them (metropolitan and local density) and other factors (growth rate, transportation network structure, income, gender and age)[90] exert and influence on a) commuting time, b) speed, and finally c) distances.

The hypotheses that Levinson and Kumar's study takes related to metropolitan density and local residential density are: a) "historically, density was increased, both uniformally and particularly in downtown. More recently, multiple centers were spawned. This suggest that density (or polycentricity), rather being a cause of higher travel times, may be more properly viewed as a response which finds a positive association of average commuting duration with density (or the number of centers), may found what historically explains the density, rather than viceversa" and conclude "*if metropolitan density is positively associated with high commuting times, it is the density which is a consequence of trying to reduce otherwise higher interaction costs (in times past) in a city, which without increasing density would spread over a larger space, and not the other way around. Density, after controlling for city size, would be associated with shorter distances and slower speeds*" (Levinson and Kumar, 1997:151), and in terms of local residential density three hypothesis are taken b) "*density is negatively associated with trip speed for all modes of travel*", c) density is negative associated with commuting distance: "*city centers typically have high job to housing ratios. Therefore due to high job accessibility in high density residential neighbourhoods we expect this relationship*" and finally c) "*we expect that higher densities will reduce automobile travel time up to a point, and above that level, auto times will rise because the speed reduction outweights the density reduction*" (Levinson and Kumar, 1997:154)

The results in the first type of regression model (automobile commuters: nationally) that (Levinson and Kumar, 1997:162) estimate are[91]: a) the results for trip distance and speed are

[90] Apart from metropolitan and local residential density, Levinson and Kumar's study take into account other independent variables. Related to (1) GROWRATE, (Levinson and Kumar, 1997:157) point out: "*a growing city may provide greater opportunities for households and economic establishments to relocate, resulting in shorter time and distance commutes. Alternatively, a growing city may have difficulty providing adequate transportation infrastructure in a timely fashion resulting in longer commutes*". Referring to (2) transportation technology, Levinson and Kumar's study by take into account RAILCITY (takes the value of 1 for those cities with a heavy rail system and 0 otherwise) and FREECITY (computed as the total share of automobile travel). Related to the former, (Levinson and Kumar, 1997:157) state "*the presence of heavy rail will be positively associated with distance and speed for transit user and negatively associated with speed for auto commuters*" and related to the latter point out: "*freeway-orientation will be positively associated with auto speeds, and this will have trips of longer distances to take advantage of them*". In terms of c) income (measured as the ratio of household income for an individual to median metropolitan income in their city), INCRATIO, (Levinson and Kumar, 1997:158) explain that "*high income households may lead to shorter travel times in the polycentric urban model. However, in the monocentric city, travel distances have typically been found to be longer for high income persons, who more often live in the suburbs, so the degree to which income is related to travel time is thus a function of urban structure and extent of decentralization*". Finally, related to d) gender and age, Levinson and Kumar's work define the following variables: MALE (taking the value of 1 if the individual is male), AGExx-yy (series of dummy variables representing cohorts from 16-20, 20-30 to 70+) and ADULT (if the individual is between the ages of 18 and 65) and take the following hypothesis: "men commute longer than women and we also expect working age adults to have longer commutes than those below 20 or above 65, as full-time jobs are typically farther afield than part-time" (Levinson and Kumar, 1997:159).

[91] The results of the other independent variables are: c) the number of edge cities, representing the degree of polycentricity was not statically significant, d) the rate of growth, a measure of urban disequilibrium, was positively associated with travel time and distance though not speed: "*this corroborates the idea that high rates*

as Levinson and Kumar hypothesized, higher density areas have slower speeds and shorter distances and time remain unclear: "*generally travel time is positively associated with density above 10,000 ppsm and negatively associated with density below that 7,500 ppsm. Densities above 10,000 ppsm and particularly over 50,000 ppsm are observed in older central cities, for instance New York, where diseconomies resulting from congestion may exceed the advantage of higher accessibility. Below the 7,500 ppsm threshold, higher residential density areas offer the advantage of better accessibility without as severe a penalty in slower speeds, resulting in lower commuting time"* and b) the urbanized area population density is positively associated with distance and not statically significant against time or speed.

In comparison with the first type, by taking into account transit commuters at national scale, the results that the model estimated by (Levinson and Kumar, 1997:164) finds that: a) in contrast to auto commuters, transit users display a negative relationship between travel time and density both above and below the 10,000 ppsm density threshold and b) density is positively related to metropolitan population, and bigger cities may be better served by transit facilities: "*metropolitan density, principally a surrogate for city size, is positively associated with time, distance and speed*"[92].

The third type of regression model estimated by (Levinson and Kumar, 1997:166) is related to automobile commuters at city by city scale due to eliminate the inter-metropolitan variation. The findings that its study reaches are: a) residential density is clearly negatively associated with speed in most cities at both high and low density levels as well as density is negatively correlated with commuting distances in almost all cases where significant, b) however, the majority of cities show no significant relationship between commuting time and density: "*where it was significant, the tendency was the higher the density the lower the time for low density areas. For high density areas, only 5 of 18 cases were significant, and they were split 3negative, 2 positive, suggesting the need for more research*". Finally, when the regression model is used in New York city study case, (Levinson and Kumar, 1997:167) point out: a) "*for New York's auto commuters, the higher the density the lower the speed, but for transit, just the opposite is true. Rail transit does not suffer the same congestion problems as the automobile, and the higher density provides a higher frequency of direct routes at least to 10,000 ppsm. Above that threshold, the effect of density on speed is insignificant. These results differ from the national results for transit, possibly due to New York's exceptional dependence on rail*" and, b) "*for auto commuters density is negatively related to distance in New York, this is true for transit commuters there too. This supports the national findings. Finally, time: for auto commuters in New York, density is negatively related to time up to 10,000 ppsm, and positively related above that value; however for the transit commuter, density is negatively related to time at all densities*".

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of change couple with relocation costs may prevent individuals from achieving their preferred bundle of housing and travel choices", e) the presence of heavy rail is positively associated with auto commuting time and distance and negatively associated with speed and, the proportion of travel on freeways is positively associated with both distance and speed, and not associated with time, suggesting the higher speeds are used to make longer distance commutes, but not so far as to increase duration and finally f) socio-economic and demographic hypotheses are corroborated: "*having a relatively high income, being a male a middle aged adult was positively associated with travel distance, speed and time"* (Levinson and Kumar, 1997:162).

[92] The results of the other independent variables are: c) the number of edge cities is not statically significant as well as in the cases of growth rate and gender, d) the presence of heavy rail, is positively associated with time but distance and speed is not significant and finally e) income is associated with higher distances and speed, but the results for time are not statically significant: "*the question of whether high income persons who live and work in the suburbs have shorter commutes than similarly situated lower income persons remains outstanding"* (Levinson and Kumar, 1997:164).

Hence, the main contributions of Levinson and Kumar's study are: a) while distance and speed are both negatively associated with density, auto travel time is negatively related to density below 10,000 ppsm and positively related above 10,000 ppsm (due to congestion), b) while density is an important explanatory variable, it is likely to be much less important policy instrument to influence commuting behaviour: "*creating additional high density areas may not increase the number of people with certain commuting and lifestyle preferences*" and finally c) referring with the other variables that Levinson and Kumar's took into account the results support the hypotheses presented before (Levinson and Kumar, 1997:169).

Referring with the second main spatial characteristic mentioned before: the functional diversification on the basis of job-housing balance-imbalance the work of (Sultana, 2002) shows a remarkable analysis about how it influence on commuting patterns. In this sense, its study examines commuting patterns in the Atlanta metropolitan area to determine the extent to which commuting flow volume is the result of an imbalance between the location of home and workplace by using the data provided by the 1990 U.S. Census of Transportation Planning Package.

To do so, Sultana's work states that: a) there may be a relationship between J/H imbalances[93] and mean travel time (MTT): "*an area which is job-rich (imbalanced) will have longer MTT compare to a balanced area for workers because such an area will draw more workers outside that area, but employed residents will have shorter commuting times because they should be able to find hobs nearby. In a housing-rich area (imbalanced), workers employed there will have shorter MTTs because they will attract fewer workers from outside the area. However, the employed residents of these areas will have long MTTs because these residents will have access to fewer job opportunities and will be forced to seek jobs at more distant locations. Individuals working or living in an area with proximity to ample housing and jobs (balanced) will have shorter MTTs because they will have greater opportunities to work and live nearby*" (Sultana, 2002:731) and b) there will be negative effect on commuting times if

[93] The criterion that is used in Sultana's study is based on two points. Firstly, according to Sultana's work, the J/H ratio is calculated as the total number of jobs to total housing units (total employment/total housing units) in an area. After it has been calculated, Sultana's study relies on that a J/H ratio above 1,50 suggests that there is an insufficient supply of available housing to meet the needs of the local work force (job-rich), and a J/H ratio below 0,75 suggests that area has an insufficient supply of jobs for local employed residents (housing-rich). Secondly, (Sultana, 2002), calculates the housing price index (HPI) as an indicator of balance: "*the index is the comparison of the quantify of housing units demanded at an affordable price compared to the quantify of housing units available at the same price level. The index compares prices for which households can afford (or are willing to pay) with the available supply of housing units at a affordable price. The HPI this includes workers' income and housing price in the analysis of residential location in the job and housing markets*" (Sultana, 2002:735). In addition, Sultana's work uses occupation as proxy for worker's income to compare housing affordability and local job opportunities. The occupational status of workers according to Sultana's study is classified into: high-status professionals, moderate-status workers and low-status workers and they are used to examine whether MTTs are longer if there is an imbalance between the location of jobs for specific groups and the location of houses suitable for members of those groups. In order to apply this criterion, Sultana's work uses a 7-mile buffer zones of each TAZs to identify imbalanced areas. The relationship between MTTs and the J/H ratio by place of residence and by place of work by estimating a simple regression is: "*as the J/G ratio increases, the MTT of workers increased by place of work, but decreased by place of residence. In other words, the job-rich buffer areas had longer MTTs for workers employed there and shorter MTTs for residents living there. Housing-rich areas had longer MTT for residents, whereas the MTT was shorter for workers employed there, which is consistent with the hypotheses"* and when this is applied in its study case, Atlanta metropolitan area then: *"a clear pattern show that the central part of the metropolitan Atlanta is predominantly job-rich and has higher MTTs for workers than the areas of balanced J/R ratio. Employed residents in the central part of the Atlanta metropolitan have significantly shorter MTTs to work. In contrast, suburban areas in Atlanta are predominantly residential (housing-rich) in which employed residents have longer MTTs compared to areas of balanced J/H ratios"* (Sultana, 2002:737).

housing affordability does not match the local housing price and if the occupational status of employed residents does not match local jobs opportunities: "*MTT will be greater if there is an imbalance between worker earnings and the cost of local housing, as well as the occupational levels of local residents and local job opportunities. In general, high-status professional workers (executive administrative, managerial and professional) will locate in higher-quality, more expensive housing, while moderate-status workers (technician, sales, administrative supportive jobs and low-status workers*" (Sultana, 2002:732) and takes the following hypotheses: 1) if an area is job-rich, the MTT will be longer for its workers compared to a balanced area, while the MTT will be shorter for the employed residents of that areas, 2) if an area is housing-rich, the MTT will be longer for its employed residents compared to a balanced area, while the MTT will be shorter for the workers of that areas, 3) the MTT will be higher for workers if the local housing price range does not match the affordability range of local workers, 4) the MTT will be higher for both workers and residents in an area if the locations of jobs for specific occupational groups do not match the location of houses suitable for members of those groups and finally 5) the racial status of workers is independent of commuting time.

To test it empirically, the relationships between J/H imbalance and commuting time and the determinants of causes of longer commuting, Sultana's study uses two different empirical methods: a) analysis of variance (ANOVA)[94] and regression analysis[95] respectively. The results of the former analysis are: a) the mean travel time is highest for the workers who are employed in job-rich areas and lowest for workers employed in housing-rich areas: "*the MTT for workers employed in job-rich areas is 29,05 minutes and the MTT for workers employed in housing-rich areas is 21,23 minutes. In contrast, the MTT is higher for employed residents that live in housing-rich areas (28,46 minutes) and lowest (24,04 minutes) for those employed*

[94] The dependent variables are: (a) MTT_PR which is calculated as one-way commuting time by employed residents for each seven-mile buffer zone, and (b) MTT_PW which is computed as one-way mean commuting time by workers for each seven-mile buffer zone. The independent variables that Sultana's work uses are: (1) JHR_DM1, which is more housing than jobs (housing-rich) and it is calculated as if J/H ration is 0,75-1,50=0 and if J/H ration is <0,75=1, (2) JHU_DM2, which is more jobs than housing (job-rich) and it is calculated as if J/H ration is 0,75-1,50=0 and if J/H ration is <1,50, (3) HPI_DM1 which is affordability of workers higher than median housing price and it is calculated as if HPI=3,5-5,5=0 and if HPI is <3,5=1, (4) HPI_DM2 which is housing affordability of workers lower than housing price and it is calculated as if HPI=3,5-5,5=0 and if HPI is >5,5=1, (5) RK1_DM1 which is more professional-status employed residents than professionals status occupations and it is calculated as if RK1 ratio is 0,90-1,10=0 and if RK1 ratio is <0,90=1, (6) RK2_DM2 which is more professional-status occupations than professional status employed residents and it is computed as if RK1 ratio is 0,90-1,10=0 and if RK1 ratio is >1,10=1, (7) RK2_MD1 which is more moderate-status employed residents than moderate-status occupations and it is calculated as if RK2 ratio is 0,90-1,10 and if RK2 ratio is <0,90=1, (8) RK2_DM2 which is more moderate-status occupations than moderate-status employed residents, and it is calculated as if RK2 ratio is 0,90-1,10=0 and if RK2 ratio is >1,10=1, (9) RK3_DM1 which is more low-status employed residents than low-status employed residents and it is calculated as if RK3 ratio is 0,90-1,10=0 and if RK3 ratio is <0,90=1, (10) RK3_DM2 which is more low-status occupations than low-status employed residents and it is calculated as if RK3 ratio is 0,90-1,10=0 and if RK3 ratio is >1,10=1, (11) BLACK_DM1 which is more black employed residents than Black workers and it is computed as Black workers ratio is 0,90-1,10=0 and if Black workers ratio is <0,90=1, (12) BLACK_DM2 which is more Black workers than Black employed residents, and it is calculated as if Black workers ratio is 0,90-1,10=0 and if Black workers ratio is >1,10=1 and finally (13) PTM50K which is calculated as percentage of workers who earn than $50,000 per year.

[95] The regression analysis carried out by Sultana's study use as dependent variable the one-way mean commuting time by workers for each 7-mile buffer zone (MTT_PW) and as independent variables: imbalanced J/H ratio, imbalances between housing affordability of workers and local housing prices, imbalances between employed residents' skills and local job opportunities, and imbalances between the location of the workplaces for Blacks and their residents, JHR_DM1, JHR_DM2, HPR_DM1, HPR_DM2, BLACK_DM1, BLACK_DM2 and PTM50K.

residents who are live in job-rich areas" (Sultana, 2002:741), b) job-rich areas in Atlanta tend to have longer commuting times (3,78 minutes longer) than balanced J/H ratio areas for workers because these areas draw workers from outside of that area due to unavailability of adequate housing stock and employed residents living in housing-rich areas in Atlanta have longer commuting times (2,06 minutes longer) than balanced J/H ratio areas since these residents have to go father to find jobs, c) employed residents who live in job-rich areas and workers who are working in housing-rich areas tend to have the shortest commuting times: "*in the first case, employed residents do not have to travel farther to find jobs, and in the second situation workers have many housing choices and reside close to their workplaces*" (Sultana, 2002:742), d) lower housing prices compared to the affordability range for workers is associated with an increase in commuting times, e) workers tend to have longer travel times in areas in which the occupation status of workers and employed residents are not balanced compared to balanced areas, and finally f) workers have longer commuting times in areas where there are more Black workers or more Black residents compared to areas in which Black workers and residents are not balanced. Then, the results of the latter analysis are: a) there is a positive relationship between job-rich areas (more jobs than housing) and the workers MTT, b) Sultana's model predicts that the average commuting time of workers is 3,5 minutes longer in buffer areas where the J/H ratio is above 1,5 (more jobs than housing) than that of the areas where the J/H ratio is balanced, while controlling for the other variables, c) lower housing prices compared to a balanced housing affordability for workers has a statically significant relationship with mean commuting time: "*the model predicts that MTT is expected to be 1,06 minutes longer in buffer areas where median housing price is below the affordability level of workers compared to areas where housing prices are balanced with workers' affordability levels*" (Sultana, 2002:746), d) the less expensive housing in an area compared to the affordability level of workers, the more likely those employees will not be able to reside close to their workplace: "*they have to live farther from their workplaces to find better housing, adding to greater commuting times*" and high-income workers have longer mean travel times, finally e) the J/H imbalance between the residential location of Blacks and their workplace does not add extra commuting time.

Hence, the main contribution of Sultana's work is that Job-Housing imbalance is the most significant factor explaining long commuting times at the time that its previous explained findings do not support the hypothesis that a balanced J/H ratio will always result in reduced commuting times: "*in many cases the imbalance between the cost of housing affordability of workers is also an important factor in shaping the residential location choices of workers in an employment area, even though the area has a balanced J/H ratio*" (Sultana, 2002:747).

Then, in terms of the functional diversification on the basis of diverse or mixed land-use the work of (Frank and Pivo, 1994) presents a prominent explanation of how it influence on commuting patterns. In its study, debates the difference that are exist in terms of impact between mixed land-use and density (population and employment) on the use of the single-occupant vehicle (SOV), transit, and walking for both work trips and shopping trips. To do so, Frank and Pivo's study estimate a set of regressions models related to three different travel mode choices taking into account both work and shopping trips in which the dependent variables are: a) percent of trips originating in census tracts made by SOV, b) percent of trips ending in census tracts made by SOV, c) percent of trips originating in census tracts made by transit, d) percent of trips ending in census tracts made by carpool, e) percent of trips originating in census tracts made by walking and finally, e) percent of trips originating in census tracts made by walking. The independent variables that Frank and Pivo's work use are related to a) urban form factors and b) non-urban form characteristics of cities[96]. Hence, the hypotheses that its study try to test are: 1) population density, employment density, and land-use mix are related to mode choice, 2) population density, employment density, and land-use mix are related to mode choice when non-urban-form factors are controlled, 3) a stronger relationship exists between mode choice and urban-form features at both trips ends than at one trip end and finally, 4) the relationship between population and employment density, land-use mix, and mode choice is nonlinear.

Related to the first hypothesis Frank and Pivo's study states that: a) "*the findings indicate that employment density and land-use mix both significantly related to percent SOV use, percent transit use, and percent walking*", b) "*population density is not significantly related to percent SOV use*", c) "*Percent SOV use had a negative relationship and transit use and walking had a positive relationship with density and mix, which is intuitively correct, so these findings confirm the hypothesis that urban form and mode choice are significantly related*", in addition, Frank and Pivo realize that d) "*the strongest linear relationships for work trips is between employment density and transit and walking (0,59 and 0,43 respectively) however, significant association were found between percent walking and population and land-use mix (0,34 and 0,21 correspondingly)*", and finally e) "*land-use mix was not found to be significantly correlated with these three mode choice variables for shopping trips*" (Frank and Pivo, 1994:49). In terms of the second hypothesis, the results suggest: a) "the percentage of transit and walking (for both work trips and shopping trips) had the highest relationships with the urban-form variables", b) "urban form factors were consistently negatively associated with percent SOV use and were positively associated with percent transit use and walking", c) "percent transit use appeared to be highly related to employment density for both work and shopping", d) employment density at trip origins and destinations for work trips and percent transit use was found to be the strongest relationship between an urban-form and mode choice variable and population density has the greatest effect on walking trips for both work and

[96] The independent variables that are related to urban form factors are based on population density, employment density and land-use mix. (Frank and Pivo, 1994:46) define the following variables: (1) gross population density, which is measured as the entire population or number of residents within a designated area, which is census tract. The average gross population density according to Frank and Pivo's study is taken into account at trip origins and destinations, (2) gross employment density, which is calculated as the number of employees within also a census tract and it is also taken into account at trips origins and destinations and finally (3) land-use mix which according to (Frank and Pivo, 1994:48) "*mixed-use developments are those with a variety of offices, shops and restaurants, banks, and other activities intermingled amongst one another*". To measure it, Frank and Pivo's study uses the entropy index to describe the evenness of the distribution of built square footage among seven land-use categories. The entropy index is based on the following equation as (Frank and Pivo, 1994:48) present: $Level\ of\ land\ use\ mix\ (entropy\ value) = -[single\ familiy * log_{10}(single\ family)] + [multifamily * log_{10}(multifamily)] + [retail\ and\ services * log_{10}(retail\ and\ services)] + [office * log_{10}(office)] + [entertainment * log_{10}(entertainment)] + [institutional * log_{10}(institutional)] + [industrial/manufacturing * log_{10}(industrial/manufacturing)]$ and "*this equation resulted in the development of a normalized value between a minimum of 0 and a maximum of 0,845 (the logarithm of K or the number of categories which is seven in this case) assigned to each census tract"*. The independent variables related non-urban from (control variables) are on the basis of the following characteristics, as (Frank and Pivo, 1994) define: (4) proportion of survey households per census tract with one adult less than 35 years old, (5) proportion of survey households per census tract with one adult between 35 and 64 years old, (6) proportion of survey households per census tract with one adult over 65 years of age or older, (7) proportion of survey participants per census tract that have a driver's license, (8) proportion of trips ends per census tract made by survey participants that are employed outside the home, (9) proportion of trips ends per census tracts made by survey participants with a buspass, (10) proportion of trips ends per census tract made by survey participants that have access to less than one vehicle, (11) mean number of vehicles available for survey participants ending trips in each census, and finally (12) mean age of survey participants endings trips in each census tract.

shopping" and finally, e) "mixing of uses had the weakest relationship with mode choice, having the greatest effect on walking for work trips".

Then related to the hypothesis related to if stronger relationships exists between mode choice and urban-form characteristics when they are measured at both trips ends than at one trip end, Frank and Pivo's study reaches on the following results: a) "*employment density at trip origins and destinations had the greatest degree of explanatory power over variation in mode choice for transit use for both work trips and shopping trips and for SOV use for work trips*", b) "*employment density at trip origins and destinations had the greatest degree of explanatory power over variation in mode choice for walking for both work trips and shopping trips*", c) land-use mix at trip origins and destinations had the greatest degree of explanatory power variation in mode choice for walking for work trips, and finally as result of this findings Frank and Pivo's work states d) "*although they are not universal, the finding from this analysis suggest that average urban-form measures rather than measures taken at the origin or destination have the strongest ability to predict variations in mode choice for SOV use, transit use, and walking*" (Frank and Pivo, 1994:51). Finally, in terms of the last hypothesis that Frank and Pivo's study state: the relationship between population density, employment density and mode choice is non-linear, as a result of its empirical work, its study find: a) the results are consistent with the hypothesis and employment density and mode choice for SOV use, transit use and walking for work trips has a nonlinear relationship what this lead to significant policy implications "*policies that call for an increase in employment density to encourage transit use and walking and to discourage SOV use for work trips will not cost-effective unless certain density thresholds are reached"* and b) this nonlinear relationship also exists between population density and mode choice for SOV use, transit use and walking for shopping trips.

Hence, the main contribution of Frank and Pivo's work related to land-use mix is: "*the relationship between mode choice and land-use mix can be measured at the census tract scale; however, the relationships are relatively weak. Only the relationship between average land-use mix at origins and destinations and percent walking for work trips was significant enough to remain in a regression model when non-urban form factors were controlled*" (Frank and Pivo, 1994:52).

Other prominent works of related to this issue are the studies carried out by (Cervero, 1996, 2002). The former, (Cervero, 1996) investigates how mixed land-uses influence the commuting choices of residents from large metropolitan areas using data from the 1985 American Housing Survey through an empirical analysis that examines the effects of mixed-use levels as well as other features of the built environment like residential densities on three measures of transportation demand: a) commuting mode choice, b) commuting distance and c) household vehicle ownership levels. To do so, the effects of land-use environment on mode choice are modeled in Cervero's study by using binomial logit analysis, meanwhile for the analyses of the commuting distance and household vehicle ownership level its study estimates multiple regression models[97]. The hypotheses that (Cervero, 1996:363) test are: a) mixed-use

[97] The independent variables used for Cervero's study in all the three mentioned empirical models are related to (1) land-use variables and (2) control variables. The former set of independent variables are defined by: a) single-family detached housing within 300 feet of unit (0=no, 1=yes), b) low-rise multi-family buildings or single-family attached units within 300 feet of unit (0=no, 1=yes), c) mid-rise multi-family buildings within 300 feet of unit (0=no, 1=yes), d) high-rise multi-family buildings within 300 feet of unit (0=no, 1=yes), e) commercial or other non-residential buildings within 300 feet of unit (0=no, 1=yes), and finally f) grocery or drug store between 300 feet and 1 mile of unit (0=no, 1=yes). The latter set of variables (control variables) are defined by: g) residence in the central city of the MSA (0=no, 1=yes), h) number of private automobiles

neighborhoods induce higher shares of non-auto commuting among residents, b) mixed-use neighborhoods exert their strongest influence on non-motorized commuting, specially walk and bike travel to work, c) mixed-uses only have a positive influence on transit-riding, walking, and bicycling to work if they are close by, i.e. within several blocks of a residence, d) non-residential uses, such as grocery and drug stores that lie between several blocks and a mile or so of a residence, induce auto-commuting and trip-chaining and finally e) mixed-use neighborhoods are associated with shorter commutes and lower vehicle ownership rates.

The results of estimating the binomial logit model for predicting the probability of commuting by private automobile, either alone or with a passenger as Cervero's study propose show the following findings. In terms of private automobile, a) hypotheses on how mixed uses influence commuting choices are confirmed: "*having retail or other non-residential uses within 300 feet of one's residence lowers the probability of auto-commuting, whereas having a grocery or drug store beyond 300 feet but within a 1 mile radius increases the odds, controlling for the influence of other factors, including density. This probability reflects the tendency for mixed uses in one's immediate neighborhood to encourage commuting by foot or transit, assuming home-to-work distances, are not too long*" and b) neighborhood density exerts a much stronger influence on auto-commuting than the level of land-use mixture: "*for workers with a single automobile in their household, the odds of auto-commuting are 0,78-0,80 if they live in a low-density neighborhood versus 0,29-0,34 if they live in an area with mid-rise and high-rise apartments. Having commercial and other activities within 300 feet lowers the probability of auto-commuting by only 2-5%. The presence of mixed uses lowers auto-commuting slightly more in high-density than low-density neighborhoods*" (Cervero, 1996:369). Related to transit transport, c) the findings are consistent with the two previous results referring with auto-commuting model, however the influence of land-use environment in this case (transit transport) is fairly weak. Finally, in terms of walking/bicycling commute model d) the results show that this model is the best-fitting model predicted in comparison with the two previous models, e) all the variables are consistent with the hypothesis that Cervero's study predict and finally f) the presence of mixed-uses have in this case a fairly strong and significant influence on non-motorized commuting: "*having commercial and other non-residential activities in the immediate vicinity of one's residence induces people to walk or bicycle to work, holding factors such as trip distance and vehicle ownership level constant*" at the time that exert a similar influence as density factor (in auto-commuting model that it does not occur): "*the probability of walking or biking to work is virtually identical for someone living in a low-density, mixed-use neighborhood as in a neighborhood of high-rise residential towers*" (Cervero, 1996:372). The another type of regression model estimated by (Cervero, 1996:369) is related to vehicle ownership and commute distance models, the main findings of these Cervero's empirical work are: a) vehicle ownership levels decline with neighborhood density and the presence of non-residential land-uses in the area and rise with household income and size as well as with commuting distance, and b) commuting distances tend to be shorter for those living in dense, mixed-use neighborhoods.

Hence, the contributions of Cervero's study are, on the one hand neighborhood densities have a stronger influence than mixed land-uses on all commuting mode choices, except for walking and bicycling and b) neighborhood density and mixed land-uses tended to reduce vehicle ownerships rates and are associated with shorter commutes, controlling for other factors such

available in household, i) annual household income, j) four-lane highway, railroad, or airport within 300 feet of unit (0=no, 1=yes), k) public transportation adequate in neighborhood (0=no, 1=yes) and finally l) distance from home to work, one way in miles. According to (Cervero, 1996:365) "*the first four land-use variables represent overall neighborhood density and the remaining two land-use variables the levels of mixture*".

as household income (see, note 93): "*in combination, the effects of reducing auto-commuting, commute distances, and vehicle ownership rates suggest that moderate-to-high density, mixed-use neighborhoods average less vehicle-miles-traveled (VMT) per capita than lower density, exclusively residential ones*" (Cervero, 1996:376).

Then, related to the spatial variable of accessibility, the work of (Levinson, 1998) gives to know remarkable contributions. Consistent with the standard model of urban economics, is expected that people living in area with relatively high accessibility to jobs is associated with shorter trips, as is working in an area of relatively high housing accessibility. So, Levinson's study argues that the relative location of houses and firms, measured using accessibility[98], is an important determinant of commuting duration and by using the household travel survey conducted in the Washington DC metropolitan area in 1987/1988, its study examines the influence of jobs and housing accessibility on commuting duration. The general hypothesis that Levinson's work test is that individuals that residing in areas of high job accessibility are likely to have shorter commutes, while those whose job opportunities are located farther away will have longer commutes, given a fixed number of competing workers in the labor market: "*individuals living in an area of relatively high accessibility to houses should have longer commutes as more job opportunities will be absorbed by other residents. Similarly those working in an area of high accessibility to houses should have shorter commutes, while those working near many competing workers will have to travel farther to find housing and will have longer commutes. Even with the trend toward polycentric cites, distance from the center of the region is still an important indicator of relative job and housing accessibility, houses near the center of the region have relatively high accessibility to jobs and thus should have shorter commutes*" (Levinson, 1998:16).

From this hypothesis, Levinson's study elaborates a set of independent variables related to geographical factors[99]. In addition, its study takes into account demographic and socioeconomic factors and a set of dummy variables[100] related to age in order to predict

[98] (Levinson, 1998:13) "*an accessibility measure derived from the gravity model can be used to measure jobs-housing balance more powerfully than using the number of jobs and houses in a smaller sub-regional geography. Accessibility is the product of two measures, a temporal element and a spatial element reflecting the distribution of the activity under question: the higher the accessibility of jobs, the more jobs which are available in a given commuting time. The accessibility measure weights the available destinations by a measure of time. The higher the travel time is, the lower the weight*". To measure it, Levinson's study uses the following equations: (1)$A_{iEm} = \sum_{j=1}^{J}(E_j * f(c_{ijm}))$ and (2) $A_{iRm} = \sum_{j=1}^{J}(R_j * f(c_{ijm}))$, where ($A_{iEm}$) is the accessibility to jobs (employment) from zone (i) by mode (m), (A_{iRm}) is the accessibility to houses (residences) from zone (i) by mode (m), (E_j) is the number of jobs (employment) in zone (j), (R_j) is the number of houses (residences) in zone (j) and f(c_{ijm}) is the function of cost/time between zones (i) and (j) according to equation (3) and (4) which show the impedance function for a work-trip gravity model estimated for metropolitan areas. According to (Levinson, 1998:14) "*the dependent variable in the estimation of these equations was the number of trips divided by the number of opportunities, to which a natural log transformation served as independent variables. Each five minute travel time cohort was a separate observation. It should be noted that this aggregate method for estimating friction factors helps ensure higher R^2 values than would be obtained from a more disaggregate approach because of the central limit theorem*". So, the equations (3) and (4) are as follows: $f(c_{ija}) = \exp(-0{,}97 - 0{,}08c_{ija})$ and $f(c_{ijt}) = \exp(-1{,}91 - 0{,}08c_{ijt} + 0{,}265c_{ijt}^{0,5})$, where ($C_{ija}$) is the peak hour auto travel time between zones (i) and (j) and, (C_{ijt}) is the peak hour transit travel time between zones (i) and (j).

[99] The independent variables that Levinson's work takes into account related to geographic factors are: (1) the distance between the home and the center of the region (D_{it}), (2) the distance between the workplace and the center (D_{jt}), (3) the accessibility to jobs from the home (A_{iem}), (4) accessibility to other houses from the home (A_{irm}), (5) accessibility to other jobs from the workplace (A_{jEm}) and finally (6) the accessibility to houses from the workplace (A_{jRm}).

[100] The control variables that Levinson's work considers are: (1) gender which is measured as male (1 if individual is a male), (2) age which is divided into seven different cohorts of age: age 10, age20… until age 70

commuting duration (dependent variable of the regression models in transit commuting and auto-commuting separately). As a result of estimating these two sets of regressions models by using OLS (ordinary least squares), Levinson's study reach on the following results in terms of auto-commuting and transit commuting: a) all geographic variables (see note, 96) are borne out for auto-commuters: "*while the relationships for distance from the center of the region for jobs and houses is supported for transit commuters, excepting origin jobs accessibility (A_{iEt}), the accessibility hypothesis is not supported for transit commuters: for transit commuters, housing accessibility (A_{iRt} and A_{jRt})is not statically significant, while location of a workplace in an area with many jobs (A_{jEt}) is negatively associated with commuting duration"* and this, is explained by Levinson in this way: "*transit commuters is more efficient in the high density central areas, as the high density enables more routes and higher frequency of service. This is unlike auto-commuting where high density is a diseconomy due to congestion. The high density is reflected in our variables as high accessibility for jobs and for housing at either trip-end"*, b) the transit models have a higher explanatory power than the auto-models (0,38 and 0,17 respectively) and finally, c) the demographic and socioeconomic features are not as effective as the accessibility variables in explaining commuting duration: "*relative to the suppressed age cohort 30-40, teen workers as well as older workers tended to have shorter commutes. Males tended to have longer commutes than females when using the automobile, though for transit users the commutes were indistinguishable. Home ownership was significant only for transit commuters, being associated with shorter Durant commutes than apartment dwellers and taking the number of children and household size together, it can be seen that each additional child is associated with a net one minute reduction in transit commutes, and a net one minute longer auto-commute*" (Levinson, 1998:18).

After, this empirical analysis, Levinson's work examines how accessibility in the journey-to work can explain indirectly job-housing balance. (Levinson, 1998:18) argues that "*in an area with a high proportion of housing relative to jobs (the housing accessibility is greater than jobs accessibility after correcting for the number of workers per household), improving balance, that is increasing the proportion of jobs, will reduce the average commute for individuals living there, though increase the expected commuting duration for the smaller number of individuals living there, though increase the expected commuting duration for the smaller number of individuals working in that area. Similarly, in a place with a high proportion of jobs relative to houses, improving balance by increasing the proportion of houses, will reduce the average commute for individuals working there, but increase the expected commuting duration for the fewer individuals living in the area*" and to test it, its study conduct an analysis of the point elasticity of travel time with respect to a one percent increase in accessibility, pivoting off the mean values of accessibility and travel time. The results that Levinson's work reaches are: "*a increase 1% in origin jobs accessibility (opportunities) for auto commuters will decrease commutes by 0,22%. Likewise a 1% increase in origin housing accessibility (competing workers) increases commutes by 0,19%. The similarity of these two values confirms that additional competing workers can be seen as the equivalent to a reduction in available jobs*" what it entails: "*on the one hand, bringing workers closer (increasing destination housing accessibility) is associated with shorter commuters for its employees and on the other, continued suburbanization of housing concomitant with a re-concentration of jobs in downtown, increases commute lengths*" (Levinson, 1998:20).

(1 if the individual aged is in this cohort, otherwise, 0), (3) household size, which is measured as the number of persons in the household, (4) dwelling unit type and finally (5) vehicle ownership, which is calculated as the number of vehicles per licensed driver.

Hence the main contributions of Levinson's work are: a) clearly the urban structure as measured by jobs and housing accessibility is an important (17-38% of the variation in travel time to work of individual can be explained by it), but it is not the only element and what is more important b) according to co-location hypothesis (see, previous Sections 2.1 and 2.2), Levinson's findings suggest that: "*the data from this research suggest, given the present amount and location of jobs and housing, that is the suburbanization of jobs creating a polycentric or dispersed urban form (which serves to balance jobs and housing) rather than the further suburbanization of houses (which creates additional imbalance), which keeps commutes from getting longer. This leads inexorably to the conclusion that all other things being equal, in an auto dominate transportation system, policies favoring a properly defined jobs/housing balance will, at the margins, reduce commuting duration, while policies preventing balance will increase that duration*" (Levinson, 1998:20). In that sense, the works carried out by (Baum-Snow, 2007a, 2007b; García-López, 2012 and; Giuliano et al., 2012) give more insights about the influence of accessibility and transportation on urban systems and metropolitan areas (in terms of suburbanization, population growth, growth of subcentres, etc…) but as their aim is not related to commuting patterns are not analyzed in this work.

In that sense, the works of (Cervero and Kockelman, 1997 and; Cervero and Murakami, 2010) give new insights related to the influence that not only density, diversity (land-use mix) and accessibility but also design on the commuting patterns (travelled distance and time). The former, tests the propositions that compact neighborhoods (the role of density), mixed land uses (diversity factor) and pedestrian-friendly designs (design characteristic) 'degenerate' vehicle trips and encourage residents to walk, bike, or take transit as substitutes for automobile travel, particularly for non-work purposes. To do so, (Cervero and Kockelman, 1997:200) take the following hypotheses: a) higher densities, richly mixed land uses and pedestrian-friendly designs are thought to lower the rates of vehicular travel (i.e. trip degeneration), expressed as daily personal vehicle miles traveled per household, b) these three dimensions are thought to be positively associated with the choices of share-ride, transit, and non-motorized modes, c) these dimensions also are associated with higher occupancy level for personal vehicle travel (higher incidence of non-single occupant vehicle, non-SOV, travel) and finally d) density, diversity and design are postulated to increase non-personal-vehicle (non-PV) and non-SOV travel for both work and non-work trips. Hence: "*in the case of non-work trips, more compact settings with neighborhood retail outlets and pleasant walking environments are thought to induce more foot and bicycle travel and short-hop transit trips, especially for purposes like personal-business travel (where there is less of a need for a car to haul purchases)*" and *"in the case of work trips, pedestrian-friendly environments and the presence of convenience stores near residences are expected to induce commute trips via transit and non-motorized modes"*. Then, to test them empirically, Cervero and Kockelman's study carries out a statistical analysis using independent variables[101] that, individually and

[101] The independent variables that Cervero and Kockelman's study uses are related to (a) density, (b) diversity and, (c) design. Related to density, the specific variables are: (1) population density which is measured as population per developed acre, (2) employment density which is calculated as employment per developed acre, (3) accessibility to jobs which is calculated as a gravity model from, for zone i, $Accessibility\ Index = \sum_i (jobs)_j exp[\lambda\ t_{ij}]$, where i=origin (residential), j=destination traffic analysis zone, t_{ij}=travel time between zones i and j, and λ=empirically derived impedance coefficient. The accessibility index according to Cervero and Kockelman's study serves as a proxy of relative proximity and compactness of land uses. Related to diversity, the specific variables are: (4) dissimilarity index, which is calculated as the proportion of dissimilar land uses among hectare grid cells within a tract. For each tract is computed as $[\sum_j^k \sum_i^8 (X_i/8)]/K$, where K=number of actively developed hectare grid-cells in tract, and X_i=1 if land-use category of neighboring hectare grid-cell differs from hectare grid-cell j (0 otherwise), (5) entropy which is calculated as mean entropy for land-use categories among hectare grid cell within a tract. For each tract, computed as $(\sum_k [\sum_j P_{jk} \ln(p_{jk})]/\ln(J))/K$,

collectively, capture these three dimensions (density, diversity and design) of the built environment for 50 neighborhoods in the San Francisco Area; a set of control variables related to sociodemographic status of the trip-maker, household of the trip-maker, transportation supply and distance factor; and finally the following dependent variables: 1) daily personal vehicle miles traveled per household (all trips, and non-work trips), 2) proportion of total home-based trips by non-personal vehicle and non-single-occupant vehicle, 3) proportion of non-work home-based trips by non-personal vehicle and non-single-occupant vehicle, 4) proportion of personal business home-based trips by non-personal vehicle and finally, 5) proportion of work home-based trips by non-personal vehicle.

The results of these empirical models estimated by Cervero and Kockelman's study present the following points: a) intensity and pedestrian factors have positive signs and both factors reveal neighborhoods that are denser and more pedestrian-oriented in their designs are associated with choosing share-ride, transit, and non-motorized modes for non-work travel, b) non-SOV travel increased with the spatial inter-mixing of land uses (statically positive sign by the dissimilarity index), c) intensity and walking quality factors have emerged as strong predictors of non-personal vehicle travel and for non-personal vehicle for personal business trips, and finally, d) when the elasticities between different indicators of travel demand and measures of the three mentioned dimensions of the built environment has been calculated, then densities exert the strongest influence on personal business trips, diversity have a modest

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where p_{jk}= is the proportion of land-use category j within a half-mile radius of the developed area surrounding hectare grid-cell k; j=number of land-use categories; and K=number of actively developed hectares in tract. The mean entropy ranges between 0 (homogeneity, wherein all land uses are of a single type) and 1 (heterogeneity, wherein developed area is evenly distributed among all land use categories), (6) vertical mixture, which is calculated as the proportion of commercial/retail parcels with more than one land-use category on the site, (7) per developed acre intensities of land uses classified as: residential, commercial, office, industrial, institutional, parks and recreation, (8) activity center mixture, which is calculated as: entropy commercial land-use categories computed across all activity centers within a zone; proportion of activity centres with more than one category of commercial-retail uses; proportion of activity centers with stores classified as: convenience, auto-oriented, entertainment/recreational; offices, institutional, supermarkets, and service-oriented, (9) commercial intensities, which as measured as per developed acres rates of: convenience stores; retail services, supermarkets, eateries, entertainment and recreational uses, auto-oriented services and; mixed parcels and finally (10) proximities to commercial-retail uses which are classified into: proportion of developed acres within 1/4 miles of convenience store, retail-services use; and proportion of residential acres within 1/4 miles of convenience store and retail-service use. Related to design, the specific variables are: (11) streets which are classified into: predominant pattern, proportion of intersections, per developed acres rate of freeway miles within or abutting tract; number of freeway underand over-passes; number of blocks; number of dead ends and cul-de-sacs and averages of arterial speed limits and street widths, (12) pedestrian and cycling provisions, which are classified into proportion of blocks with sidewalks, planting strips, street trees, overhead street lights, bicycle lanes and mid-block crossings and finally (13) site design which are classified into proportion of commercial-retail and service parcels with off-street parking, off-street parking between the store and curb; on-street front or side parking; and on-site drive-ins or drive-throughs. Finally, (Cervero and Kockelman, 1997) uses a set of control variables on the basis of (d) sociodemographic of trip-maker, (e) household of trip-maker, (f) transportation supply and services and (g) distance. Related to socio-demographics of the trip-maker, the specific variables are: (14) age, (15) gender (male status), (16) employment (full-time or part-time status; professional occupation), (17) race and ethnicity (racial-ethnic category), and (18) possession of driver's license. Related to household of trip-maker, the specific variables are: (19) size (number of members, number of persons under 5 years, number of persons 5 years of age and over), (20) vehicle ownership which is calculated as number of automobiles, trucks, vans and motorcycles per household, (21) income and (22) housing tenure (own or rent). Related to transportation supply and services, the specific variables are: (23) transit service intensity which is computed as route miles of peak-hour revenue service divided by developed area of tract, (24) distance to nearest freeway-on ram, nearest commuter rail station, nearest light rail station and nearest ferry landing, (25) proportion of commercial-retail parcels with paid on-street parking and paid off-street parking. Related to distance, the specific variables are: (26) Euclidean distance between centroids of trip's origin and destination traffic analysis zones and (27) Euclidean distance to downtown San Francisco, downtown Oakland and downtown San Jose.

impact on travel demand, though it is significant and in the case of person vehicle miles traveled per household its influence is stronger than density but lower than neighborhood characteristics (design) of the area.

The latter, offers additional insight into the question of how much urban form, in particular urban densities, accessibility, and land-use mix influence VMT (vehicle miles travelled) by taking into account a national scope using data from 370 urbanized areas in the United States. Cervero and Murakami's study test this mentioned relationship by defining the dependent variables as VMT per capita and by using the following key built-environment predictors: density, destination accessibility, diversity and design forming what Cervero and Murakami's study defines as 4 Ds (dimensions) of the built environment. So, its key research question is whether built-environment variables influence VMT per capita controlling for other predictors and is so, what is the relative magnitude. To do so, (Cervero and Murakami, 2010) use a structure equation modeling (SEM) in order to build and estimate a path model that accounts for possible two-way relationships among variables, thus statically controlling for possible endogeneity problems[102].

The results that (Cervero and Murakami, 2010:409-412) present when is estimated SEM are: a) the strongest predictors are population densities, automobile commuting modal shares, and roadway density, followed by household income: "*the direct effects of population density are quite high, yielding an elasticity estimate well above that found in most previous studies; high automobile-commuting shares are, as expected, also strongly associated with high VMT/cap, with the highest elasticity in the southern region of the USA (elasticity=0,602+0,027=0,629); high provisions of road infrastructure are also associated with high VMT/cap, as in the control variable, household income*", b) the direct influences of local retail density and accessibility on VMT/cap are fairly modest, as in the effect of urban area size, c) the other key non-residential land-use variables such us basic-job density and accessibility have no

[102] As independent variable Cervero and Murakami's study uses (1) VMT/CAP which is computed as vehicle miles of travel per capita, 2003, daily vehicle miles per person; then its study also uses other travel variables, (2) AUTOCOM% which is the percent of commute trips by private automobile; mean estimate, 2000, (3) RAILPAXMI/CAP, which is rail passenger miles per capita, for 2003. Then, the independent variables related to Transportation-supply are: (4) ROADDEN, which is roadway infrastructure density in 2003, directional miles of roadway per square mile of urbanized land area, (5) RAILDEN, which is urban passenger rail infrastructure density, 2003; one-way directional fixed-guideway track miles per 10.000 square miles of urbanized land area. In terms of built-environment, Cervero and Murakami's study uses the following ones: (6) POPDEN which is population density in 2003 and calculated as persons per square mile in thousands, (7) BASICJOBDEN, which is basic employment density, 2003, mean number of basic (export-industry) jobs per square mile, (8) LOCRETDEN which is local-serving retail employment density in 2003 and is calculated as mean number of local-serving (retail, service, and trade) jobs per square mile –a proxy for intensity of retail/shopping activities, (9) BASICJOBACC, which is basic-employment accessibility index and is measured as mean estimate in 2003, mean number of basic-industry jobs within 30 minutes travel time on highway networks across 500 m grid cells of urbanized area, weighted by number of households in grid cells, (10) LOCRETACC, which is local retail accessibility index, and is measured as mean estimate in 2003, proxy for accessibility to retail activities, computed as mean number of local retail/service/trade jobs within 30 minutes travel time on highway networks across 500 m grid cells of urbanized area, weighted by number of households in grid cells. Related to urbanized area control variables, the used variables are: (11) URBANAREA, which is urbanized area, measured in square miles in 2003, and (12) HHINC which is household income, calculated as median in 2000, in 1000US$. Finally (Cervero and Murakami, 2010) use variables related to interactive factors: (13) AUTOCOM%_S, which is percent of commute trips by private automobile in South Region of USA, measured as mean estimate in 2000; averaged across 500 m gird cells of urbanized area, weighted by number of household in grid cells, (14) URBANAREA_N, which is urbanized area, measured as square miles in 2003, in Northeast Region of USA and finally (15) LOCRETACC_N, which is local retail accessibility index in Northeast Region of USA, measured as mean estimate in 2003, proxy for accessibility to retail activities, averaged over 500 m grid cells of urbanized area, weighted by number of households in grid cells.

statically significant direct effects on VMT/cap but operating indirectly through other variables, d) urban railway supply and riderships has a significant negative correlation with VMT/cap but weak and indirect.

Then, related to the direct and indirect effects of built-environment variables used by Cervero and Murakami's study on VMT/cap the results are: a) "*the direct elasticity between population density and VMT/cap among the 370 urbanized areas is fairly high: all else being equal, a 1% increase in population density is associated with a 0,6% decline in VMT/cap. However, this significant negative direct effect is offset by positive indirect effects, yielding a net, or total, elasticity of -0,381*", b) "*high population density lowers VMT/cap through its association with lower auto-commuting shares*", c) "*there is a tendency of urbanized areas with high population densities to consume less land area further lowers VMT/cap*", d) "*areas with higher population densities tend to also have higher road-infrastructure densities, a factor that induces travel*", and finally, d) the other direct and indirect effects of population density on VMT/cap are: "*via the influences of population density on local retail accessibility and urbanized area size cause that dense urban sets tend to enjoy relatively high retail accessibility which correlates with high VMT/cap, so this positive indirect effect is supplemented by a positive association between retail accessibility and urban-area size, which tends to increase VMT/cap further"* (Cervero and Murakami, 2010:412). Then related to indirect effects of basic-job density, e) "*basic employment prompts the formation of household, with the resulting higher densities associated with lower VMT/cap*", and finally f) "*the influence of basic-job density and VMT/cap is also possible through local-retail accessibility and density as well as urbanized area size, yielding a positive indirect effect of 0,086*" (Cervero and Murakami, 2010:413).

Hence, the main contribution of Cervero and Murakami's work is that its study presents the moderately strong negative elasticity between population density and vehicle miles traveled per capita, the positive association between neighborhood density and roadway provisions, as well as retail accessibility, moderated these effects and by extension this suggests according to (Cervero and Murakami, 2010:416) that the largest VMT reductions would come from creating compact communities which have below-average roadway provisions, more pedestrian/cycling infrastructure and, in-neighborhood retail activities which invite nonmotorized travel.

Related to the non-spatial characteristics that exert an influence on commuting patterns, the work carried out by (Kockelman, 1995) studies by using level data at three different levels: census tract, city and metropolitan area levels that leads to a three distinct empirical analysis, in order to examine what matters more in commuting patterns by means of mode choice whether density (in this case population density) or income.

The first analysis, based on the analysis of 108 San Francisco Bay Area (SFBA) census tracts by using data come from 1990 Census is conducted by estimating several different regressions models which the dependent variable that (Kockelman, 1995) uses is the percentage of workers not driving alone (%WNDA) and the dependent variables are mainly income and density[103]. Kockelman's study reaches on the following results: a) by regressing

[103] According to (Kockelman, 1995:852), the independent variable related to density is used in the model in the logarithm form. Then in other models, Kockelman's study use the independent variable called as "Destination Index, (DI)" which is constructed as a coarse proxy for transit level-of-service to and at the work location and the regional importance of that destination for employment (this encouraging densities of trip-making, which often leads to more transit service). Referring with Destination Index (DI), (Kockelman, 1995:853) state "*the DI*

%WNDA versus income, %WNDA versus population density and income versus population density: "*observing R^2 terms, it appears that density explains far more of the variation in commuters' modal choice than does income; moreover, the t-statistic for density from these is consistently several times larger than of income (0,795 and +0,891 versus 0,084 and -0,289 respectively)"*, b) when is regressing %WNDA versus density, income and a destination index[104], Kockelman's study finds that density and destination contribute far more significantly to mode choice (work trip) than does income: "*while density and destination variables are consistently highly significant, the t-statistic for income varies greatly. For the over-100 degrees of freedom entailed by the regression, the p-value is over 0,15 for the coefficients of the income variable in the first and the third regressions (indicating a lack of significance of the income variable in determining %WNDA). However, with t-statistic values well above 2,62, the density and destination variables are highly significant (under the normal linear regression model, these indicate p-values of less than 0,01)"* (Kockelman, 1995:853), and finally c) by regressing coefficients, Kockelman's study estimates elasticities of change in commuting behaviour with respect to predictor variables and its study finds that: "*density has a greater relative effect on %WNDA than does income, in other words, a doubling of density results in a substantially greater percent change in %WNDA than does a doubling of income*" (Kockelman, 1995:854). The second analysis that Kockelman's study carries out is focused on San Francisco Bay Area cities and the main results that achieve in this urban scale are: a) "*regressions at the city level of %WNDA versus density and income exhibited lower R-square values than those of the tract analysis"*, b) "*as in tract-level results, density is consistently a more significant variable for inclusion in the model than is income*" and, c) analysis the elasticities, Kockelman's study show that: "*the +0,35 elasticity with respect to density is in agreement with the results of the tract-level analysis (-0,25 is the elasticity related to income) performed previously*". (Kockelman, 1995:859) Finally, the third empirical work related to metropolitan areas scale that (Kockelman, 1995) conducts by using data from U.S. metropolitan statistical areas (MSAs)[105] shows that: a) "*elasticities are roughly the following %WUT with respect to freeway provision, -0,25; income, -0,37; and transit provision +1,0. The elasticity of %WUT with respect to density is difficult to gauge at this point, although it is probably over +0,3"* (Kockelman, 1995:861).

Hence, the main contribution of Kockelman's work is that its study point out that using a cross-sectional analysis, work-trip choice is significantly determined by population density

is constructed using the approximate percentage of workers (in tract groupings) commuting to various cities. Only significant percentages (i.e. those over 15%) were used. The percentages were multiplied by 10 if the destination was San Francisco, five if Oakland, and three if Berkeley, Palo Alto, or San Jose. The summation of these values yields the DI per tract grouping".

[104] In that case, the three models that Kockelman's study estimates are: (1) %WNDA versus income and density, (2) %WNDA versus income, density and destination index, and finally (3) %WNDA versus income, density and destination index in logarithm form. The R^2 square are: 0,695; 0,748 and 0,816 respectively and the t-values are: (1) -1,38 and +14,5; (2) -2,19; +8,06 and +4,69 and finally (3) -1,16; +10,7; and +3,50 respectively.

[105] In this case, Kockelman's study includes the following independent variables in its regression models: (1) freeway supply (in logarithm form) which is measured as lane-miles/capita and transit provision (in logarithm form) which is measured as seat-miles per capita. In addition the dependent variable used in the first and the second analysis is replaced by WUT, which is measured as the percentage of workers using transit (%WUT). The models that in this case, its study estimates are: (1) % WUT versus density, that entails a R^2 of 0,825 and a t-value of +17,9; (2) % WUT versus income (measured as average per-capita), that entails a R^2 of 0,007 and a t-value of +0,719; (3) % WUT (logarithm) versus transit (logarithm), freeway (logarithm) and income (logarithm), that entails a R^2 of 0,849 and a t-values of +17,2; -32,5 and -2,87 respectively and finally (4) % WUT (logarithm) versus density (logarithm and measured as persons per square mile of MSA) freeway (logarithm) and income (logarithm) that entails a R^2 of 0,584 and a t-values of +8,10; -1,32 and -1,81 correspondingly. (Kockelman, 1995:860)

(and/or the factors that commonly arise with density –such as land-use variables, see the aforementioned works of (Cervero, 1996, 2002) and (Frank and Pivo, 1994) more frequent transit service, and more congested roadways), not income. However, the following work carried out by (Watts, 2009) presents a different point of view about the influence that exerts socioeconomic variables on commuting patterns.

Watt's study uses an integrated spatial econometric model which utilizes a number of proxies of urban from and a range of socioeconomic variables, including occupational prestige, educational attainment and weekly hours of work in order to analyze the determinants of average commuting distances by occupation across the 52 Statistical Local Areas (SLAs) in the Sydney Metropolitan Area of New South Wales by using the Australian Bureau of Statistics (ABS) census journey-to-work in 2001. To do so, Watt's work uses two different types of empirical models according to the proxies that its study uses to define urban form, the former is related to minimum commute as a proxy of urban structure and the latter is related to job proximity variables as a factor to determine urban form. Then, its study estimate each type of empirical model by using a) OLS –ordinary least squares- and in order to deal with spatial dependent between adjacent Statistical Local Areas, by b) SAR –autoregressive model, c) SEM –spatial error model- and, d) SAC -spatial lag model with spatially correlated residuals-. The independent variables that (Watt, 2009) uses to explain the mean out-commuting distance by occupation across the Sydney metropolitan area are related to a) gender, b) occupation, c) range of socioeconomic variable and finally, d) the aforementioned urban form variables.[106]

[106] The independent variables that Watt's study uses are: (1) the jobs to resident employment ratio (JR) for each occupation, (2) job proximity (JP) which the job proximity of job seekers living in location (i) cas be written as: $Z_i = \sum_j \bar{x}_j f(C_{ij})/D_j$, where $f(C_{ij})$ denotes the impedance (decay) function, which is estimated as a negative exponential functional of travel time and the numerator measures the effective number of job opportunities in location (j) for residents of location (i) and $D_j = \sum_k P_k f(C_{kj})$, is the effective number of jobs seekers who can access location (j), where (P_k) is the number of job-seeking residents from location (k), that is the employed plus unemployed and again is weighted by the impedance function, f (C_{ij}), (3) job proximity incorporating unemployment rate (JPU) which according to (Watt, 2009:329) is defined by a simple iterative procedure for each SLA, so the resulting distribution of total unemployment across the nine major occupations is measured as the relative rates of unemployment by occupation equaled the relative rates of unemployment from the Labour Force Survey: $u_j^k/u_j^m = u^{-k}/u^{-m}$, where ($u_j^k$) denotes the estimated unemployment rate in the (kth) occupation in the (jth) SLA; (u^{-m}) denotes the unemployment rate in the (mth) occupation from the Labour Force Survey and the final allocation of unemployment satisfies the total constrain in each SLA, (4) the centroid distance of each area from Inner Sydney (SD), which is the dominant centre for employment in the commuting area. According to (Watt, 2009:325) "*within a predominantly monocentric urban area, this variable would be expected to attract a positive sign",* (5) the male share of resident's employment by occupation and SLA (MS) which is expected to be positive as (SD), (6) a variable that measure the socioeconomic status of the commuters (SS), (7) access to private motorised transport (MV) which would be expected to have a negative effect on the average commute, (8) two variables related to the share of employees who undertake less than 15 or 24 hours respectively (H15 and H24) which according to (Watts, 2009:326) is expected that exert a negative (reduce) the average commute due to its high implied relative direct and indirect cost, (9) the percentage of residents aged over 15 years who did not complete Year 10 schooling (D10) which is expected a negative coefficient, since this group is likely to have limited social network in addition to being reluctant to travel significant distance for relatively poor wages, (10) the percentage of the population who speak only English (SP), (11) the share of the population living in state housing (SH), (12) another household variable which is measured as the share of households who either own or are in the process of buying their own home (HO), which is expected that owner occupiers would be prepared to commute further, due to being less able to change residential location than private renters, (13) a composite variable to capture the lower mobility of both state housing tenants and owner-occupiers (HS=HO+SH) and finally, (14) a proxy for the relative wage (RW) which is created by dividing the estimated residents' wage by occupation which according to (Watts, 2009:326) is expected that local employment would be more attractive and hence commuting would be lower, the higher the relative wage.

The main results that (Watt, 2009:334) present are: a) "*all socioeconomic variables took their hypothesized sign in the reported results and common to all quadratic specifications were occupations status (SS), educational attainment (D10), and the housing variable, consisting of both public housing tenants and owner-occupiers, HS, which marginally outperformed, the other housing variables, SH and HO, treated separately. The distance from Inner Sydney (SD) is significant across all specifications, except those employment job proximity as the proxy for urban form*", b) so the expected signs are: the distance from Inner Sydney (+), job proximity (-), occupation status (+), educational attainment (-), access to private motorized transport (-), week workers hours (-), English speaker population (-), housing owners (+) and relative real wage (-). Hence, Watt's study contribute to understanding the determinants of travel patterns within metropolitan areas by showing that jobs to resident ratio is an inadequate proxy of urban from and that both minimum commute and measures of job proximity have superior explanatory power in concert with the mentioned socioeconomic variables related to occupational prestige, education attainment and weekly hours of work.

Finally, referring among studies that examine the relationship between demographic characteristics and commuting patterns, the studies carried out by (Tkocz and Kristensen, 1994 and, Shearmur, 2006) provide meaningful contributions. In its turn, Tkocz and Kristensen's study investigates for both monocentric and polycentric cities through analyzing the social determinants of commuting distances and the determinants of commuting distances arising from the spatial structure of urban centers. Hence, Tkocz and Kristensen's work analyses the relationship between commuting distances and distances between residences and centers, and then its parameters are respecified into functions of social variables. To do so, (Tkocz and Kristensen, 1994:2) estimated models in stages[107]. The starting point is developed on the basis of the relationship between commuting distances (the distances between a person's residence and his/her work place), and distances of residences to city center (distances between a person's residence and the center of the city in which the residence is located). Then the initial model is divided into: a) the study on the relationship between commuting distance and its sociological determinants, b) the analysis between commuting distances and distances of residences to city center and finally c) the combining involvement of these relationships by an expansion method.

The results of the step a), according to Tkocz and Kristensen's are[108]: a) the educational level influences the commuting distances for women, but not for men, b) at the higher ages the commuting distances decline significantly for women and the same tendency exist for men although is not significant at the 5 percent of level, c) bigger cities are characterized by longer commuting distances than smaller cities, d) car ownership is associated with longer commuting distances, and finally, e) single women are not significantly closer to their jobs than married women. The second step according to Tkocz and Kristensen's empirical analysis

[107] The variables that Tkocz and Kristensen's uses are: (1) POP, which is the number of inhabitants and LP when is calculated in the logarithm form, (2) SM, calculated as the share of manufactured labor force, (3) AGE and LAGE, where the latter denotes the logarithmic transformation of the former, (4) CH which means the number of children, (5) S, which is a dummy variable in order to identify the "status" of the head of the household (if is single=1, otherwise=0), (6) MY and WY, which are the annual income before tax for men and women respectively, (7) ED, which is the education level calculated according five levels (1 is the lowest and 5 is the highest), (7) DM and DF commuting distance (in kilometers) for men and women respectively, and finally (8) CAR which represents a car dummy (if the households have a car=1, otherwise=0).

[108] According to Tkocz and Kristensen's in this step the independent variables (see, note 102) that are included in the regressions models those dependent variables are DM and DF (commuting distance for men and for women) respectively are: (1) S, (2) ED, (3), CAR, (4) LAGE, and then (5) LP and (6) ICC which represent a dummy variable that indicates a intercity commuting.

shows that: a) when is taking into account a monocentric city model the results show both for men and women that the influence of residential distances to city center on commuting distances is clear: "*the positive and significant intercept values indicate that, as it could be expected all jobs are not in the exact center of the city*" (Tkocz and Kristensen, 1994:6) b) when is considered a polycentric city model, then the results[109] suggest that: "*more omen then men are employed in the city center and subcentres, while men to a greater degree are employed in the areas around those centers and at the periphery*" (Tkocz and Kristensen, 1994:9). Finally, the expansion model that (Tkocz and Kristensen, 1994) estimate[110] shows that: a) "the share of manufacturing variable does not influence significantly the distance pattern for men" and b) age influence the distance patterns differently for men and women: *"for women higher age are associated with smaller commuting distances, for men higher ages not only decrease their commuting distances but also makes them center-oriented* and *single men experience shorter commuting distances, single women do not"* (Tkocz and Kristensen, 1994:12).

Hence, (Tkocz and Kristensen, 1994:13) conclude that: a) "*the commuting distances are higher for persons who reside farther from city centers*", b) "*because men tend to work in the periphery, while women tend to work in the city centers, the women's distance patterns are closer to that for the monocentric Alonso-type of city than is the case for men's distance patterns*", c) "*men in general experience longer commuting distances than women due to married couples tend in their residential location choices to adjust to the wife's job*", d) "*women's commuting patterns seem to be more dependent on the city's structure than those of men, and are more influenced by changes in the city structure than men's and finally*", e) "*age clearly reduces the commuting distances for women and men*".

Then, the work carried out by (Shearmur, 2006) examines whether people travel different distances to access different types of job location, with particular attention to the different distances traveled by men and women. Shearmur's study uses as a point of reference the major employment subcentres (poles) in the Montreal region. Briefly, after controlling for a wide range of explanations that may account for travel distances, its study conclude that differences in commuting length between different places of work are, by and large, independent of possible explanatory factors such as residential locations, economic sector, occupation, income and participation in household earning –some places of work generate longer commutes than other and in the case of gender, men and women behave differently in relation of these places: women will travel farther to access jobs in centers where men will not, and despite their shorter average overall commutes, women travel farther than men to reach jobs in the CBD (Central Business District). So, Shearmur's study tries to response if a) people travel farther to the CBD than to other employment centers? And if b) they do travel farther to suburban centres than to jobs outside these centres. To do so, (Shearmur, 2006) estimates two empirical models through OLS (ordinary least squares) technique which the dependent variable is the travel-to-work distance and a set of independent variables related to a) occupation, sector and income, b) household responsibilities, c) mode of transport, d) spatial factors, and finally e) a set of dummy variables[111]. The results that Shearmur's study

[109] In the second stage, (Tkocz and Kristensen, 1994) use the following to models: (1) $Dm = 5{,}36 + 4{,}06CAR - 1{,}38t + 0{,}16t^2$ and (2) $Dw = 0{,}39 + (3{,}77 + 0{,}48CAR)t - 0{,}94t^2 + 0{,}62t^2$.

[110] The basic form of the expanded model that Tkocz and Kristensen's study estimate is: $D = (b_{00} + b_{01}LP + b_{02}SM + b_{03}S + b_{04}ED + b_{05}CAR + b_{06}LAGE + b_{07}ICC) + (b_{10} + b_{11}LP + b_{12}SM + b_{13}S + b_{14}ED + b_{15}CAR + b_{16}LAGE + b_{17}ICC)t + (b_{20} + b_{21}LP + b_{22}SM + b_{23}S + b_{24}ED + b_{25}CAR + b_{26}LAGE + b_{27}ICC)t^2 + (b_{30} + b_{31}LP + b_{32}SM + b_{33}S + b_{34}ED + b_{35}CAR + b_{36}LAGE + b_{37}ICC)t^3$

[111] The independent variables that Shearmur's study uses are: (1) distance of residence from the CBD and distance of work from the CBD and; according to (Shearmur, 2006:341) "*is expected that travel distance will*

reaches when the empirical model does not take into account job location effects are: a) the model explains 32,4% of the variance in travel distances, b) commuting distances increases as the population suburbanizes: "*for each kilometer a worker lives away from the CBD, he or she travels 340m farther to work. For each additional kilometer a job is located from the CBD, a worker travels 240m less from home*" (Shearmur, 2006:348), so according to Shearmur's study as travel-from-home increases faster with residential suburbanization than it decreases with employment suburbanization, this suggests that sprawl may lead to longer commutes, notwithstanding the parallel suburbanization of jobs, c) retail, education, and health and social services still exhibit the shortest travel-from-home distances, d) the percentage of household income earned by an individual has a positive effect on travel-from-home: "*the higher earners in a household travel farther to their jobs. A person earning 100% of household income tends to travel 660m farther to their job than a person earning close to 0%*" (Shearmur, 2006:350), e) the presence of young child in a household actually increases distance traveled to work by 290 m and finally, f) the distance traveled by women is, on average, 1,05 km less than distance traveled by men

Then, the empirical results of answering the question: does job location explain differences in travel-from-home distance?, (Shearmur, 2006:351) show that: a) the model accounts for 37,2% of the variance in travel distance, an increase of 4,8% compared with the controls alone (without job location effects), b) women travel farther to reach the CBD than they do to reach any other employment subcentres except for one of them what it could entail that CBD exerts no particular attraction on men; but it exerts a strong pull on women, c) there are clear differences between men and women in terms of distances traveled to jobs located within a pole against distances traveled to jobs located toward (but not within) a center: "*women systemically travel father to an employment center than toward it. This is in sharp contrast with men*" (Shearmur, 2006:353), so men are not particularly attracted to employment centers.

Hence, in terms of gender and commuting distances at intra-metropolitan scale, Shearmur's study contributes to understand that: a) men travel farther to all suburban employment centres than they do to the CBD. Women, by contrast, travel farther to reach jobs in the CBD than they do to reach jobs in all other centers and according to (Shearmur, 2006:354) "*this cannot be explained by differences in economic sector, occupation, or other variables often invoked to explain differences in travel behavior between men and women*" and b) different types of job location exert their attraction differently over men and women: "*if this attraction can be explained by milieu effects differ for men and women. The CBD "milieu" is more attractive to women, and suburban jobs centers are more attractive to men. Furthermore, all centers are more attractive to women than alternative (noncenter) locations*". (Shearmur, 2006:355)

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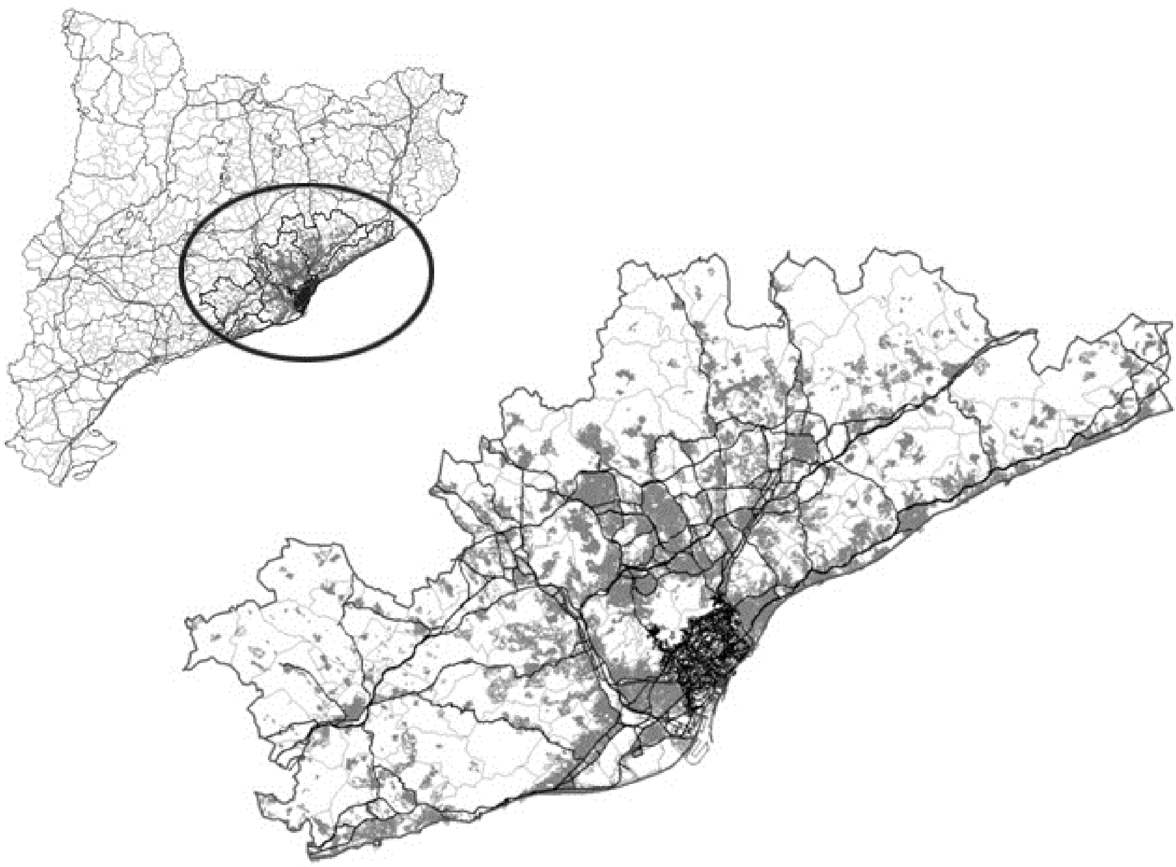
increase as residential location becomes more suburban and that travel distance will decrease as work location become more suburban", (2) residential zone, divided into four different residential areas and what is expected that travel distance to be greater from the outer suburbs, (3) economic sector and occupation, what takes into account the following sectors: primary, manufacturing traditional, manufacturing medium-tech, manufacturing high-tech, construction and utilities, transport and warehousing, wholesale, retail and personal services, communication services, FIRE, high-order services, education, health and social services and public administration and; the following occupations: administration and professionals, science and technical, management and senior professionals, sales and services, secretarial and clerical and clerc, and blue collar, (4) employment income, which according to the literature is expected that individuals will tend to travel farther to a better-paying job, (5) percentage contribution to household income, what is suggested according to (Shearmur, 2006:341) that: "*or the highest earner in a household who will tend to choose the residential location in order to facilitate his or her access to employment or that the earner of a household's secondary income will tend to find a job locally after the residential decision is made*", (6) presence of young child (under the age of 15) what is expected that the effect of this variable is negative, though its effect may be different for men and for women, and finally (7) gender, which, is expected that women will travel shorter distances to work than men.

3. STUDY CASE: BARCELONA METROPOLITAN REGION

The Barcelona Metropolitan Region (BMR) (Figure 3) was delimited in 1966 by the Esquema Director de l'Àrea Metropolitana. Composed of 164 municipalities, the region covers an area of 323,000 ha and has a radius of 55 km. Currently, the Barcelona Metropolitan Region (BMR) is the second most dense urban area, the fourth most populated and the eighth most extensive in Europe. It generates 12 percent of Spain's GDP and more than 20 percent of Spanish exports. With over 65 percent of Catalonia's population (4.390.413 inhabitants) and employment (1.822.000 jobs) in 2001, the BMR is the main urban agglomeration in Catalonia. The city of Barcelona (marked in dark in Figure 3) is the principle center in the region and the continuous built-up area surpasses its administrative limits, taking in 12 adjacent municipalities[112]. Five outlying municipalities (Mataró, Terrassa, Sabadell, Vilafranca del Penedès and Vilanova i la Geltrú) are medium sized towns that in the past accounted for a significant proportion of the services consumed by nearby towns. Today, these towns still have a high level of self-containment and a net balance of entries in journeys due to work or study. Since the 1980s, population and employment decentralization towards other cities have meant that many firms have moved towards the outskirts in search of access to main roads. Therefore, other cities have emerged as important nodes within the BMR, including Granollers, Martorell, Rubí, Sant Cugat del Vallès and Cerdanyola del Vallès.

Figure 3. The Barcelona Metropolitan Region within the Catalan territory



Source: Own Elaboration

[112] Badalona, Cornellà del Llobregat, Esplugues de Llobregat, L'Hospitalet de Llobregat, Montgat, El Prat de Llobregat, Sant Adrià del Besòs, Sant Boi de Llobregat, Sant Feliu de Llobregat, Sant Joan Despí, Sant Just Desvern and Santa Coloma de Gramanet.

3.1. Defining the urban spatial structure

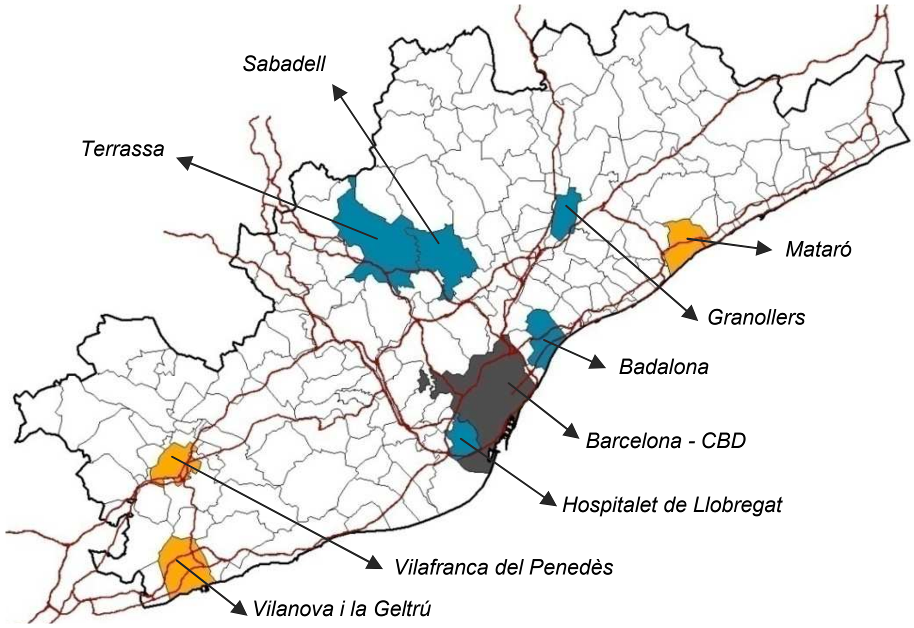
The procedure of defining the urban spatial structure at intra-metropolitan scale is based on identifying the subcentres that are within in. In this sense, during the last 20 years many empirical studies about polycentricity have been proposed methodological procedures to identify subcentres. In our case, we borrow the identification methodology proposed by the same author of this work in (Masip, 2012a). Its approach is suitable for identifying sub-centers that are within the bid-rent theoretical tradition based on the process of employment decentralization from a single and congested Central Business District (CBD) and also is suitable for the hierarchical and complex European urban systems where centers mostly emerged as a result of the integration or coalescence of pre-existing cities. In this way, Masip's approach takes into account the morphological and the functional characteristics of nodes (municipalities) according to the different dimensions that polycentricity is based on as the specialized literature suggests. In addition, the procedure is able to characterize the sub-centres that are "places to work" (employment sub-centers) and sub-centres that are "places to work and live" (urban sub-centers). That means distinguishing between those sub-centers that only attract workers (in-commuting flows) or retain their resident workers from those sub-centers that are able to attract flows and retain their resident employed population at the same time. According to Masip's work the former group of subcentres is characterized as emerging subcentres and the latter one as large subcentres. To identify them, Masip's procedure is based in three steps: a) first, it adopts a functional perspective in keeping with the European urban system paradigm by analyzing the commuting flows in a residence-to-work matrix, RW (resident workers) Entropy Information and the IF (in-commuting flows) Entropy Information has been calculated for all municipalities. These indicators proposed by (Masip, 2012a) approximate which municipalities are the most hierarchical and complex in terms of the local labor market (RW-resident workers) and attracting a substantial number of commuters (IF-incommuting flows)[113]. In other words, according to Masip's study the municipalities that best fit the European urban systems paradigm, then b) secondly, it identifies the positive residuals estimated from an exponential RW Entropy Information function and from an exponential IF Entropy Information function[114] and finally, c) the third step of Masip's

[113] To estimate the RW and IF Entropy Information, it is necessary according to (Masip, 2012a) to use the following two equations: $EI_{RW} = -\sum_{i=1}^{n}(RW_i \cdot [Ln(RW_i)])$ and $EI_{IF} = -\sum_{i=1}^{n}(IF_i \cdot [Ln(IF_i)])$, where $(RW_i \cdot [Ln(RW_i)])$ and $(IF_i \cdot [Ln(IF_i)])$ are the RW Entropy Information and IF Entropy Information for each municipality, and EI_{RW} and EI_{IF} are the RW Entropy Index and IF Entropy Index for the entire metropolitan area. The higher the RW Entropy Information and IF Entropy Information for municipality (i), the greater the weight of municipality (i) in terms of RW and IF relative to entire metropolitan area because RW_i and IF_i are the probability (proportion) of observing RW and IF in municipality (i). As a consequence, (Masip, 2012a:14) states that: "*the higher the RW (resident workers) Entropy Information is for a given municipality, the greater its functional urban hierarchy and complexity with respect to the local labor market. Thus, the greater the capacity a given municipality has to retain its labor force and be functionally autonomous from other urban nodes. For the same reason, the higher IF (in-commuting flows) Entropy Information is for a given municipality, the greater its capacity to attract workers and be an important employment node in the metropolitan area*". Thus, after the RW and IF Entropy Information are separately calculated, Masip's study observes two types of municipalities: (1) municipalities that have a higher value of RW and IF Entropy Information. Thus, these urban nodes have a hierarchical local labor market, meaning that they are able to retain their labor force and be attractive enough in residential terms to increase population. In addition, these nodes attract workers from a variety of other urban nodes in the metropolitan area and, (2) municipalities that have a higher value of RW or IF Entropy Information. Thus, these nodes are functionally hierarchical in terms of their local labor markets or have a higher capacity to attract workers. In other words, these nodes are important "places to work".

[114] These double exponential Employment Entropy Information functions as Masip's study suggests can be formulated as follows: $RW(EI)Inf_x = C + \beta Dist_{x-CBD}$ and $IF(EI)Inf_x = C + \beta Dist_{x-CBD}$, where $RW(EI)Inf_x$ and $IF(EI)Inf_x$ are the RW and IF Entropy Information in municipality (x), C is a constant that is assumed to be the RW and IF Entropy Information at the CBD and $Dist_{x\text{-}CBD}$ is the distance between the CBD and the municipality (x). Therefore (Masip, 2012a:15) points out that: "*the proposed procedure to identity sub-centers*

methodology consists of selecting the positive residuals of the two Employment Entropy functions: the municipalities that have positive residuals in these two Employment Entropy functions are defined as sub-centers and they are simultaneously categorized using the following criteria: 1) municipalities with both residuals in RW and IF Entropy Information are categorized as large subcentres and 2) ones with positive residuals in RW or IF Entropy Information are classified as emerging subcentres. After applying its approach to identify subcentres and compared to other density standard methodologies, (Masip, 2012a:26) present that: "*results suggest that compared to identifying sub-centers using standard density models, the municipalities identified as sub-centers using this new procedure are more dominant in the mobility flows, more self-contained, and their influence on the urban structure are more significant entailing a better explanation of employment density*" and its study identifies, 8, 11 and 12 subcentres in the Barcelona Metropolitan Region from 1991 to 2001 respectively.

Figure 4a. Sub-centres (large and emerging) identified by (Masip, 2012a) for the Barcelona Metropolitan Region in 1991



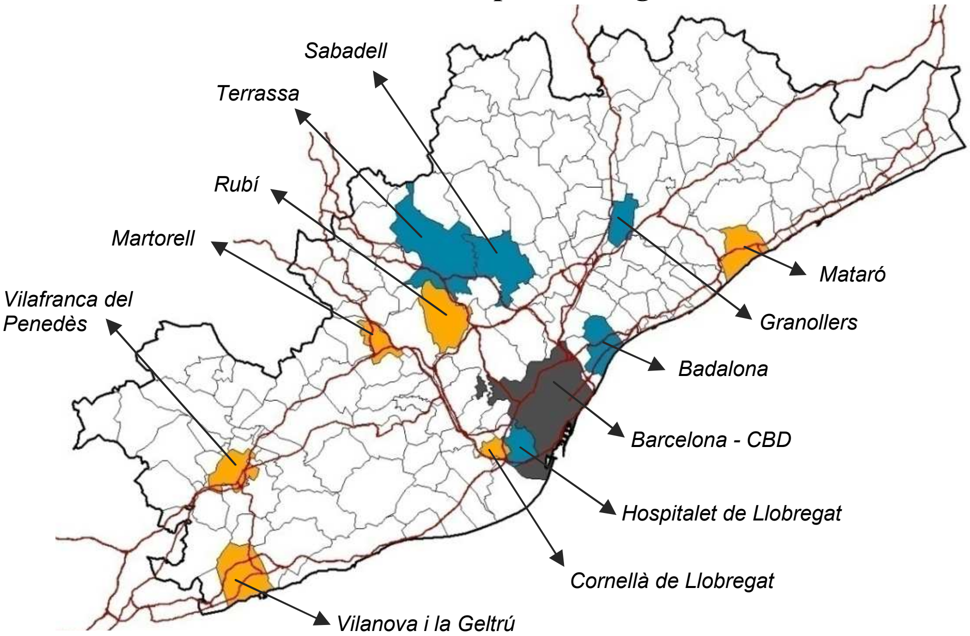
Source: (Masip, 2012a). Note: the emerging subcentres are marked in orange and the large ones in blue.

The following (Figures 4a, 4b and; 4c) show the subcentres that Masip's study has identified in the Barcelona Metropolitan Region from 1991 to 2001. In addition the Figures highlight the process of subcentres emergence linked to the infrastructure nodes (Martorell, Rubí) as well as in the north of the CBD-Barcelona (Sant Cugat del Vallès and Rubí). According to (Masip, 2012a:17) this process of emergence has been more significant from 1991 to 1996 than 1996 to 2001 (during the period of 1991 to 1996 there was an increment of three identified subcentres, meanwhile from 1996 to 2001 this increment it was only one subcentre) at the time that the subcentres identified as "emerging" are the subcentres that most increased their LTL (localised workplaces: resident workers and incommuting workers) in comparison with their LTL in 1991. These are the cases of Martorell (139,67%), Sant Cugat del Vallès

includes methodology employed by North American studies to identify sub-centers. By computing the RW and IF Entropy Informations for each municipality as function of the distance to the CBD, the procedure adopts a morphological methodology that is based on the bid-rent theoretical tradition".

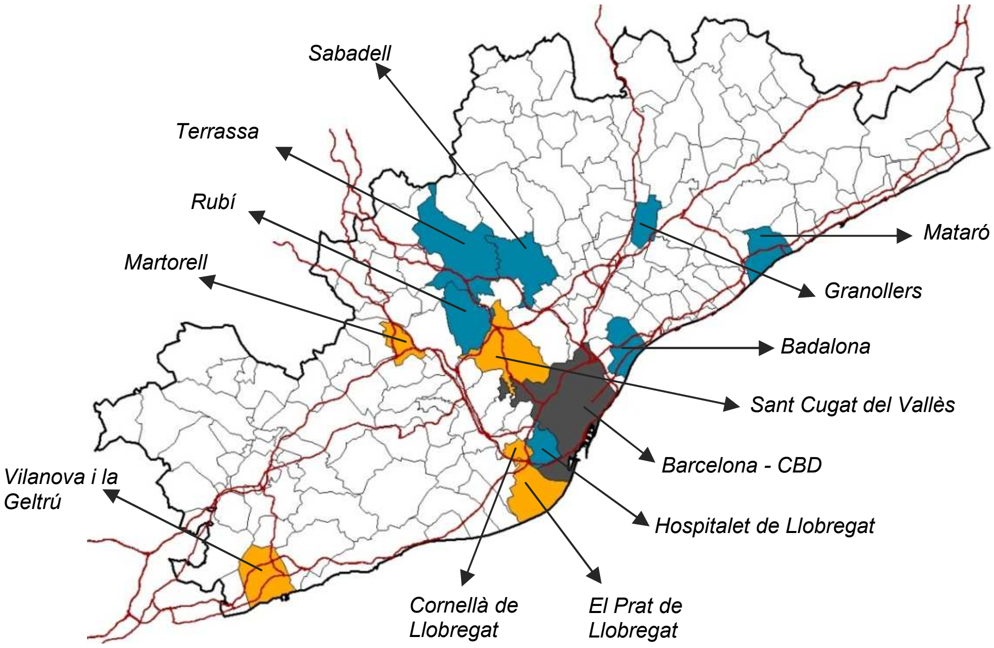
(86,04%), El Prat de Llobregat (38,11%). Otherwise, the "large-consolidated" subcentres have had a more constant LTL increment: for example Sabadell 10,19%, Terrassa 26,05%, Badalona 10,57%, L'Hospitalet de Llobregat 4,08%.

Figure 4b. Sub-centres (large and emerging) identified by (Masip, 2012a) for the Barcelona Metropolitan Region in 1996



Source: (Masip, 2012a). Note: the emerging subcentres are marked in orange and the large ones in blue.

Figure 4c. Sub-centres (large and emerging) identified by (Masip, 2012a) for the Barcelona Metropolitan Region in 2001



Source: (Masip, 2012a). Note: the emerging subcentres are marked in orange and the large ones in blue.

3.2. Descriptive analysis: commuting patterns in the Barcelona Metropolitan Region

Before analyzing the relationship between urban spatial structure and commuting costs, it is worth examining the patterns of mobility in Barcelona Metropolitan Region through simple descriptive statistics. The units of analysis are 164 municipalities (administrative units). Within these municipalities that have been considered in the analysis, a large considerably number of people (almost 1,8 million) travel every day for work. As regards the mode choice, (Table 1) shows that the most used means of transport is the private car (47,22% = 42,91% + 4,31%). On the whole, private means of transport are much more used than public means, 54,60% compared to 25,91%. In the latter, bus and underground play a major role (8,80% and 8,56% respectively), followed by trains and the combined transport of bus and underground what entails a percentage of 3,96% and 2,75% correspondingly. Finally, no motorized transport are less used than the two previous ones with a percentage of 19,49% but walking with a percentage of 16,61% is the second most used means after the private car (driver).

Table 1. Modes of commuting within the Barcelona Metropolitan Region in 2001: absolute and percentages values

Mode	Description	Total	% value
1	Private car (driver)	754.281	42,91%
2	Private car (passenger)	75.796	4,31%
3	Private car (driver) and public transport	33.927	1,93%
4	Private car (passenger) and public transport	13.466	0,77%
11	Motorcycle	82.247	4,68%
	Private transport	959.717	54,60%
5	Bus	154.617	8,80%
6	Underground	150.534	8,56%
7	Train	69.543	3,96%
8	Bus and underground	48.354	2,75%
9	Bus and train	11.401	0,65%
10	Train and underground	20.924	1,19%
	Public transport	455.373	25,91%
12	Walking	291.885	16,61%
13	Bicycle	8.167	0,46%
14	Others soft means	42.538	2,42%
	No motorized transport	342.590	19,49%
	TOTAL	1.757.680	100,00%

Source: Own Elaboration on INE (2001)

On average, commuters spent less than 30 minutes in their journey residence-to-work entailing that the 71,77% of workers spent less half hours to commute (Table 2). Moreover, it appears that the share of no motorized transport plays a prominent role in the lower range of commuting (less than 10 minutes) with a percentage of 9,53% compared to private transport 8,80% and to public transport with a no relevant share of 0,39%. The former increases its importance as commuters spent more time travelling until achieving medium-long trips: in the ranges of commuting time from 10 to 20 minutes and from 20 to 30 minutes, private transport is the most used means of transport with a percentage of 18,63% and 13,69% respectively. In the range from 30 to 45 minutes, although private transport is still the most used means of transport, it decreases its share until 8,27% and the difference in terms of mode choice between private and public transport has reduced significantly (from 13,69% and 8,07% to 8,27% and 7,03% correspondingly).

Table 2. Commuters by duration class (in minutes) and by mode class within the Barcelona Metropolitan Region

Time spent	Mode	Commuters	% value
Less than 10 minutes	Private transport	154.600	8,80%
	Public transport	6.770	0,39%
	No motorized transport	167.559	9,53%
	Total less than minutes	328.929	18,71%
From 10 to 20 minutes	Private transport	327.381	18,63%
	Public transport	66.547	3,79%
	No motorized transport	115.953	6,60%
	Total from 10 to 20 minutes	509.881	29,01%
From 20 to 30 minutes	Private transport	240.641	13,69%
	Public transport	141.852	8,07%
	No motorized transport	40.285	2,29%
	Total from 20 to 30 minutes	422.778	24,05%
From 30 to 45 minutes	Private transport	145.287	8,27%
	Public transport	123.603	7,03%
	No motorized transport	11.784	0,67%
	Total from 30 to 45 minutes	280.674	15,97%
From 45 to 60 minutes	Private transport	65.090	3,70%
	Public transport	77.416	4,40%
	No motorized transport	4.376	0,25%
	Total from 45 to 60 minutes	146.882	8,36%
From 60 to 90 minutes	Private transport	22.244	1,27%
	Public transport	34.578	1,97%
	No motorized transport	1.973	0,11%
	Total from 60 to 90 minutes	58.795	3,35%
More than 90 minutes	Private transport	4.474	0,25%
	Public transport	4.607	0,26%
	No motorized transport	660	0,04%
	Total more than 90 minutes	9.741	0,55%
	TOTAL	1.757.680	100,00%

Source: Own Elaboration on INE (2001)

The latter, becomes the most used means of transport for medium and long trips: from 45 minutes of travelling the percentage of public transport are the highest compared to private transport and no motorized transport (i.e. in the range of time from 45 to 60 minutes its percentage is 4,40% compared to the share of the other two means of transport: 3,70% and

0,25% correspondingly), although it also has a relevant presence in a relative short-medium trips (from 20 to 30 minutes and 30 to 45 minutes) entailing a percentage of 8,07% and 7,03% respectively. Finally, the general and obvious urban trend that commuters follow is that as spent time to commute increases there are more commuters that commuting until achieving the peak time of 20 minutes by then highly decreasing until 0,55% for trips with more than 90 minutes. Another clear statistic that shows this trend is for example that only 3,9% of the total commuters spent more than 60 minutes to commute from their homes to work.

Table 3. Duration of trips by mode class within the Barcelona Metropolitan Region

Means of transport	Commuters	% commuters	Average duration (minutes)
Private car (driver)	754.281	42,91%	24,14
Private car (passenger)	75.796	4,31%	23,78
Private car (driver) and public transport	33.927	1,93%	39,96
Private car (passenger) and public transport	13.466	0,77%	36,92
Bus	154.617	8,80%	31,86
Underground	150.534	8,56%	31,26
Train	69.543	3,96%	43,99
Bus and underground	48.354	2,75%	41,04
Bus and train	11.401	0,65%	52,21
Train and underground	20.924	1,19%	50,17
Motorcycle	82.247	4,68%	18,80
Walking	291.885	16,61%	13,77
Bicycle	8.167	0,46%	17,05
Others soft means	42.538	2,42%	26,85
Private transport	959.717	54,60%	24,39
Public transport	455.373	25,91%	35,84
No motorized transport	342.590	19,49%	15,47
TOTAL	1.757.680	100,00%	

Source: Own Elaboration on INE (2001)

Another point to highlight is that, on average, travel duration with no motorized transport and private transport is much shorter when compared to that with public transport (15,47 minutes, 24,39 minutes and 35,84 minutes respectively) as (Table 3) shows. This may be due to the following reasons. First, a) mass transit users commuter longer distances, hence it takes more time for them to get to their destination. However, this factor alone can hardly explain all the differences in terms of time spent travelling. Thus, b) another factor may be the minor time-efficiency of public means, probability due to the fact that it takes a relevant amount of time to reach the bus or train station from the commuter's home, as well as to reach the destination once off the train. Finally, taking into account specifically each means of transport, the ones that take shorter times are walking (13,77 minutes) and bicycle (17,05 minutes) followed by motorcycle (18,80 minutes) and private car as driver or passenger (around 24 minutes). As regards what we mentioned previously public transport on average are the modes of transport that takes more commuting time: underground (31,26 minutes) followed by bus and train.

If we analyze in-depth the commuting patterns at municipality scale, we are able to find out if the co-location hypothesis explained in the previous Section 2 is corroborated in the case of the Barcelona Metropolitan Region from 1991 to 2001. Are the people who live in a subcentre also employed in this subcentre? And do the (other) people working in a subcentre live close to this subcentre?. The following (Table 4) presents polycentric structure insofar as the subcentres retain and attract a great share of commuters: this share reached 26,90 per cent in 2001 and taking into account all centres (CBD and subcentres) this percentage reaches on 68,34% of all commuting trips. However, due to suburbanisation of both inhabitants and jobs from 1991 to 2001, the number and the proportion of the central-city residents working in Barcelona (CBD) have nevertheless significantly declined (from 33,38% to 27,96%), whilst the number of the central-city-to-subcentres and to-other municipalities commuters have remain stable (first case) or have slightly decreased (second case) and; the number of subcentres-to-other municipalities, subcentres-to-subcentres, other municipalities-to-other municipalities and other municipalities-to-subcentres commuters have increased significantly.

Table 4. Percentage of commuting trips between the central city, subcentres and the other municipalities from 1991 to 2001 in the Barcelona Metropolitan Region

Place of residence	Place of work	1991	1996	2001
Barcelona (CBD)	Barcelona (CBD)	33,38%	28,05%	27,96%
Barcelona (CBD)	Subcentres	2,94%	3,51%	2,95%
Barcelona (CBD)	Other municipalities	3,23%	3,63%	3,00%
Subcentres	Barcelona (CBD)	7,37%	7,05%	6,17%
Subcentres	Subcentres	17,98%	17,47%	18,10%
Subcentres	Other municipalities	4,22%	5,17%	5,19%
Other municipalities	Barcelona (CBD)	7,05%	7,95%	7,30%
Other municipalities	Subcentres	4,06%	5,51%	5,85%
Other municipalities	Other municipalities	19,77%	21,67%	23,47%

Source: Own Elaboration on IDESCAT (1991, 1996, 2001).

In 2001, more than half or almost half of workers living in a sub-centre have a job in the same sub-centre, a percentage of 53,99% in the case of large sub-centres and 44,66% in the case of emerging ones (Table 5). This proportion has decreased since 1991 in 2,29% and in 3,33% respectively at the time that subcentres have become more independent (more functionally autonomous) to the central city of Barcelona (CBD): in 2001, the workers living in a large sub-centres and having a job in Barcelona were 19,62% (4,47% less than in 1991) and in the case of the emerging sub-centres this percentage was 25,63% of the total workers living within (2,68% less than in 1991. According to (Masip, 2012a) this is not surprising due to, large sub-centres as Masip's study defines are the sub-centres that are most functionally autonomous and hierarchical in terms of local labour market in comparison with the emerging ones, so it is obvious that the formers could retain higher its resident workers (59,99% compared to 44,66%), with less interdependence with the central city (19,62% in front of 25,63%) and in a less extent to other sub-centres and municipalities (9,18% compared to 10,67% and 17,21% to 19,03% respectively). This latter case shows that more and more workers living in a subcentre both large and emerging have jobs in other subcentre or in other municipalities compared to have job in the central city: in 2001, the workers living in a large sub-centre and having a job in other sub-centre (large or emerging) and in other municipality were 9,18% and 17,21% respectively (3,50% and 3,26% more than in 1991 correspondingly) and in the case of the emerging ones these percentages were 10,67% and 19,03% (2,57% and 3,44% more since 1991). Hence, from 1991 to 2001, in the Barcelona Metropolitan Region more and more workers living in sub-centres have its job beyond the central city of Barcelona (CBD) at the time that the polycentric structure has become its main place to work: 63,17% of the workers living in a large sub-centre have a job in a sub-centre (the same or other) and in the case of the emerging ones this percentage is quite lower but still relevant, around 55,34%.

Table 5. Location of jobs held by people living in a subcentre from 1991 to 2001 in the Barcelona Metropolitan Region (percentages)

	1991		1996		2001	
	Large subcentre	Emerging subcentre	Large subcentre	Emerging subcentre	Large subcentre	Emerging subcentre
Barcelona (CBD)	24,09%	28,31%	22,64%	28,03%	19,62%	25,63%
Same subcentre	56,29%	47,99%	51,70%	43,48%	53,99%	44,66%
Other subcentre	5,68%	8,10%	8,40%	10,49%	9,18%	10,67%
Other municipality	13,95%	15,59%	17,26%	17,99%	17,21%	19,03%
Total	100%	100%	100%	100%	100%	100%

Source: Own Elaboration on IDESCAT (1991, 1996, 2001).

Table 6. Place of residence of people working in a subcentre from 1991 to 2001 in the Barcelona Metropolitan Region (percentages)

	1991		1996		2001	
	Large subcentre	Emerging subcentre	Large subcentre	Emerging subcentre	Large subcentre	Emerging subcentre
Barcelona (CBD)	10,78%	15,49%	11,67%	18,03%	9,19%	15,88%
Same subcentre	68,14%	51,99%	61,16%	40,57%	62,67%	40,77%
Other subcentre	5,91%	12,33%	7,80%	16,27%	8,27%	16,36%
Other municipality	15,17%	20,19%	19,37%	25,13%	19,87%	26,98%
Total	100%	100%	100%	100%	100%	100%

Source: Own Elaboration on IDESCAT (1991, 1996, 2001).

If now, we consider the jobs located in the sub-centres (Table 6), we note that less than half are filled by non-residents in the case of large sub-centres (37,33%) and more than half in the case of emerging ones (59,23%). In addition, in 2001, jobs are mainly held by people living in other municipalities (19,87% for large sub-centres and 26,98% in emerging ones) what shows that both types of sub-centres have become more and more attractive as place to work for other municipalities and people located their residence close to them. This urban dynamic, is quite more clear in the case of the emerging sub-centres, so more than quarter of their jobs are filled by residents in other municipalities (6,79% more since 1991) in comparison with large subcentres, around 20% (4,70% more than 1991). Again, this is not surprising due to the nature of subcentres as (Masip, 2012a) points out related to emerging ones, which its study stands out the emerging subcentres' capacity to attract work from the whole of the metropolitan area and being truly economic poles of jobs. This it also explain why emerging sub-centres could attract more workers from the central city of Barcelona (CBD) and from other sub-centres (large and emerging) in comparison with the large ones: in 2001, the people that have a job in a emerging subcentre and living in Barcelona and other subcentres were 15,88% and 16,36% respectively (0,39% and 4,04% more since 1991 correspondingly) and in the case of the large ones these percentages were 9,19% and 8,27% (1,59% less and 2,36% more than 1991). Hence, on the one hand, the majority of people living in a sub-centre work in the same subcentre (this is clear for the large subcentres and almost for the emerging ones) and; on the other hand, the majority of jobs concentrated within these subcentres are filled by residents (significantly again in the case of large subcentres) and by non-residents located in other municipalities. In other words, the co-location hypothesis is corroborated within the Barcelona Metropolitan Region from 1991 to 2001, because people mainly located their residences within or close to their subcentre.

Table 7. Evolution of the average trip distance (km) in relation of place of residence between 1991 to 2001 in the Barcelona Metropolitan Region

Barcelona Metropolitan Region: spatial units subdivisions	1991	1996	2001	Growth rate 1991-2001
Badalona	6,341	7,807	7,670	20,96%
Barcelona	3,267	3,764	2,871	-12,13%
Cornellà de Llobregat	9,278	8,825	7,675	-17,28%
Granollers	4,683	6,382	6,301	34,56%
Hospitalet de Llobregat (l')	7,450	7,477	6,240	-16,25%
Martorell	8,064	8,325	7,474	-7,31%
Mataró	3,499	5,037	5,372	53,52%
Prat de Llobregat (el)	4,842	6,342	6,815	40,74%
Rubí	7,360	7,766	7,326	-0,46%
Sabadell	4,960	5,220	4,836	-2,50%
Sant Cugat del Vallès	12,482	11,402	8,310	-33,43%
Terrassa	6,199	6,086	4,675	-24,57%
Vilanova i la Geltrú	5,345	8,178	9,743	82,28%
CBD (Barcelona)	3,267	3,764	2,871	-12,13%
Subcentres (all)	6,709	7,404	6,870	2,40%
Subcentres (large)	5,785	6,539	6,060	4,76%
Subcentres (emerging)	8,002	8,615	8,004	0,02%
Rest of the metropolitan region	10,434	12,240	11,272	8,04%
TOTAL AVERAGE RMB	10,114	11,832	10,899	7,76%

Source: Own Elaboration on IDESCAT (1991, 1996, 2001).

In addition, if we analyze as (Table 7) presents, the average trip distance in relation of place of residence for 1) centres (CBD and subcentres) individually and then 2) aggregated for: a) central city, b) subcentres (large and emerging), c) rest of the metropolitan region, we can draw the following conclusions. Firstly, people living in the central city of Barcelona (CBD) and in a subcentre have shorter commutes on average than those living outside: in 2001, people living in Barcelona and in subcentres on average commutes 2,871 km and 6,870 km respectively compared to people living in the rest of the metropolitan region, those takes the journey-to-work on average 11,272 km, so, four times more and almost twice more than if they were living in the CBD or in subcentres correspondingly. Secondly, although the central city of Barcelona is the only spatial subdivision that has decreased its average commuting distance (12,13% less since 1991), the most majority of subcentres have also decreased its average trip distance: these are the cases of Sant Cugat del Vallès (33,43% less than 1991) followed by Terrassa (-24,57%), Cornellà de Llobregat (-17,28%), L'Hospitalet de Llobregat (-16,25%), Martorell (-7,31%), and in a less extent, Sabadell (-2,50%) and Rubí (-0,46%). Thirdly, as the result, the central city and subcentres are virtuous to shorten commuting distance and as we could imagine as we could move away from the centres (people's whose place of residence are outside), the higher the commuting distance is, and so the higher the commuting costs are because of people commute more proportionally from their homes. Moreover, if we take into account instead of the place of residence, the place of work as the following (Table 8) shows, the conclusions that we obtain are the same: a) reaching to jobs it takes on average shorter distances if the jobs are located in centres (central city and subcentres) although that in the case of emerging subcentres this is less clear, and b) centres are useful to shorten trip distance, as we move away from the central city of Barcelona (CBD) and subcentres (people's whose of place of work are less close to them), the higher the commuting distance is, and so the higher the commuting costs are due to workers commute higher to reach on their jobs.

Table 8. Evolution of the average trip distance (km) in relation of place of work between 1991 to 2001 in the Barcelona Metropolitan Region

Barcelona Metropolitan Region: spatial units subdivisions	1991	1996	2001	Growth rate 1991-2001
Badalona	3,794	5,212	4,580	20,74%
Barcelona	5,537	6,164	5,230	-5,55%
Cornellà de Llobregat	6,872	7,971	6,352	-7,57%
Granollers	7,245	8,397	9,011	24,37%
Hospitalet de Llobregat (l')	6,195	6,772	5,216	-15,81%
Martorell	15,421	21,242	17,032	10,44%
Mataró	3,107	4,014	4,295	38,24%
Prat de Llobregat (el)	6,331	7,616	8,251	30,32%
Rubí	7,752	8,594	8,019	3,45%
Sabadell	4,539	5,043	4,442	-2,15%
Sant Cugat del Vallès	10,398	10,689	8,983	-13,61%
Terrassa	4,899	5,246	3,644	-25,61%
Vilanova i la Geltrú	3,121	3,875	4,346	39,28%
CBD (Barcelona)	5,537	6,164	5,230	-5,55%
Subcentres (all)	6,640	7,889	7,014	5,64%
Subcentres (large)	5,362	6,182	5,601	4,47%
Subcentres (emerging)	8,429	10,279	8,993	6,69%
Rest of the metropolitan region	7,017	7,700	7,303	4,08%
TOTAL AVERAGE RMB	6,979	7,705	7,269	4,15%

Source: Own Elaboration on IDESCAT (1991, 1996, 2001).

Finally, to give more details about the average commuting distance in the Barcelona Metropolitan Region, the following (Table 9) depict the average trip distance between: central city of Barcelona, subcentres and other municipalities. In this sense, it is possible to find more exactly in which direction, the average commuting distance has changed since 1991.

Table 9. Average distance (km) travelled by commuters in relation to place of residence and location of job from 1991 to 2001 in the Barcelona Metropolitan Region

Place of residence	Place of work	1991	1996	2001
Barcelona (CBD)	Barcelona (CBD)	0,00	0,00	0,00
Barcelona (CBD)	Subcentres	16,89	15,89	14,37
Barcelona (CBD)	Other municipalities	24,63	21,13	18,30
Subcentres	Barcelona (CBD)	22,29	13,01	12,35
Subcentres	Subcentres	3,22	2,68	2,42
Subcentres	Other municipalities	18,03	13,57	13,30
Other municipalities	Barcelona (CBD)	14,25	21,85	19,24
Other municipalities	Subcentres	8,12	14,72	13,55
Other municipalities	Other municipalities	2,85	4,91	4,83

Source: Own Elaboration on IDESCAT (1991, 1996, 2001). Note: the average distance of the central city of Barcelona (CBD) is zero for all analysed years due to we only take into account the trips and distances made by commuters between (inter) municipalities and not the trips that are within (intra) them.

As (Table 9) depicts, in 2001, people living in the CBD on average commute less if they have its job place in other subcentres (14,37 km) than in other municipalities (18,30 km). Residents of subcentres are able to have shorter commuting distances, if they work in other subcentres which entails on average only 2,42 km. In addition, they tend to have equal opportunities to commute to both CBD and other municipalities (the average distance travelled by commuters those living in subcentres to CBD is 12,35 km and, to other municipalities is 13,30 km) although in 1991 the workers that commute to CBD spent considerably more distance than if they do to other municipalities (22,29 km compared to 18,03 km). Finally, people living in other municipalities in 2001, spent more distance on average if they commute to the CBD (19,24 km) than if their place to work are in subcentres what entails on average 13,55 km. In addition, if people living in other municipalities have their place to work in other municipalities then, on average its trip distance it is only 4,83 km although has been increased 69,49% since 1991 (in 1991 was 2,85 km). These results suggest that the Barcelona Metropolitan Region since 1991 the polycentric structure of employment related to commuting patterns has strengthen: since 1991 people living in centres that means the central city of Barcelona (CBD) and subcentres (large and emerging) has highly decreased their average trip distances to reach on their places to work what is inversely for residents those living in other municipalities. Hence, a) since 1991 people living in CBD and commute to subcentres and to other municipalities have decreased a percentage of 14,91% and 25,68% respectively b) but this reduction is more clearly in subcentres which their residents travelled to CBD, to other subcentres and to other municipality commute a 44,57%, 24,75% and 26,26% less since 1991 correspondingly and finally, c) on contrary, people living in other municipalities commute a 35,03%, 66,73% and 69,49% more to commute to the central city of Barcelona (CBD), to other subcentres and to other municipalities since 1991 respectively.

4. EMPIRICAL FRAMEWORK: THE DETERMINANTS OF THE SOCIAL AND ENVIRONMENTAL COSTS OF COMMUTING

In this section, the paper tests empirically the relationships between urban spatial structure by means of sub-centre influence according to its different nature: all, large and emerging as it has proposed by (Masip, 2012a) and other spatial and non-spatial characteristics with the costs due to mobility residence-to-work. In addition, in this section is devoted to determine what factors matters for the location and efficiency of the public and private transport.

4.1. Research design

Starting from the mainly previous contributions of the literature (Camagni et al., 2002; Muñiz and Galindo, 2005, Travisi and Camagni, 2006; Travisi et al., 2010; Cirilli and Veneri, 2010a, 2010c and; Veneri, 2010), the social and environmental costs due to commuting are on the basis (associated with) of average commuting distance and time travelled by commuters and on the basis of CO_2 emissions per capita and ecological footprint. Borrowing from these previous studies and their contributions in this paper the private component (social) of the costs of mobility has been approximated through the distance spent on travelling per commuter. This component can be conceptualized as internal costs that directly affect commuters' utility and their consequent behaviour in terms of mode choice. Given the limited availability of data for the analyzed time period (from 1991 to 2001 in the Barcelona Metropolitan Region), only the typical commuter's average distance (DAC) for each municipality within the Barcelona Metropolitan Region has been considered in this work. The DAC index has been calculated as in (equation 1):

$$DAC_i = \frac{\sum_{i,j} f_{ij} * d_{ij}}{\sum_{i,j} f_{ij}} \qquad (1)$$

Where (f_{ij}) is the number of commuters moving from municipality (i) to municipality (j) within the Barcelona Metropolitan Region, who travelled a distance (d), (d_{ij}) is the distance between municipality (i) and municipality (j), so $\sum_{i,j} f_{ij}$ are the total resident employed population (RWP) within municipality (i) and finally, (DAC_i) is the average commuting distance for commuters living in that municipality (i).

On the other hand, the external effects of mobility have been approximated as it has been proposed by (Veneri, 2010) in terms of CO_2 emissions and measured through on the basis of mode choice and distance travelled by commuters. The Environmental Index (EI) proposed by Veneri's study is calculated as follows:

$$EI_i = \frac{\sum_{i,j,k} f_{ijk} * w_k * d_{ij}}{\sum_{i,j} f_{ij}} \qquad (2)$$

Where (f_{ij}) is the number of commuters moving from municipality (i) to municipality (j), who use the (k) means of transport; (w_k) is the amount of CO_2 emissions (in grams) per commuter per kilometer, see (Table 10) as it has borrowed and adapted from Veneri's work: CO_2 estimation made by (Amici della Terra, 2005);(d_{ij}) is the road distance between the two municipalities (i) and (j), $\sum_{i,j} f_{ij}$ are the total resident employed population (RWP) within municipality (i) and finally (EI_i) gives a measure of the average quantity of greenhouse gases of the type commuter in each municipality (i) within the Barcelona Metropolitan Region.

Table 10. Per commuter per kilometre CO_2 emissions by means of transport

Means of transport	grCO2 / pKm
Private car (driver)	105,00
Private car (passenger)	0,00
Private car (driver) and public transport	73,88
Private car (passenger) and public transport	42,77
Bus	72,00
Underground	21,30
Train	35,00
Bus and underground	46,65
Bus and train	53,50
Train and underground	28,15
Motorcycle	80,00
Walking	0,00
Bicycle	0,00
Others soft means	0,00

Source: Adapted from (Amici della Terra, 2005) and own elaboration on INE (2001. Note: in our case borrowing from Amici della Terra's estimation, it has been to adapted on the basis of INE's 14 combined means of transport.

Finally, to measure the concentration (location) and the efficiency of the means of transport (public and private), in this work is used: a) share of public and private transport and b) average public and private transport time. These transport indicators as formulated as follows:

$$Public\_share_i = \frac{\sum_{i,j} Pu_{ij}}{\sum_{i,j} f_{ij}} \qquad (3)$$

$$Private\_share_i = \frac{\sum_{i,j} Pr_{ij}}{\sum_{i,j} f_{ij}} \qquad (4)$$

Where ($Public\_share_i$) and ($Private\_share_i$) are the share of commuters-to-work of municipality (i) that use public / private means of transport over the total number of commuters-to-work ($\sum_{i,j} f_{ij}$), which are the total resident employed population (RWP) of the municipality (i) and finally, $\sum_{i,j} Pu_{ij}$ and $\sum_{i,j} Pr_{ij}$ are the number of trips made by public / private means of transport by the RWP in this municipality (i).

$$Average\_pu\_time_i = \frac{\sum_{i=1}^{n} \sum_{j=1}^{7} t_j pu_{ij}}{\sum_{i=1}^{n} \sum_{j}^{7} pu_{ij}} \qquad (5)$$

$$Average\_pr\_time_i = \frac{\sum_{i=1}^{n} \sum_{j=1}^{7} t_j pr_{ij}}{\sum_{i=1}^{n} \sum_{j}^{7} pr_{ij}} \qquad (6)$$

Where ($Average\_pu\_time_i$) and ($Average\_pr\_time_i$) are the average commuting time when public / private means of transport are used-, times are weighted by the number of commuter that uses public / private modes of transport. Hence, (pu_{ij}) and (pr_{ij}) are the public/ private transport users in the municipality (i) whose commuting time is (j) while (t_j) in both (equations 5 and 6) is the commuting time in minutes[115].

Table 11. Proportion of trips made by private, public and no motorized transport for the Barcelona Metropolitan Region in 2001

Barcelona Metropolitan Region: spatial units subdivisions	Private transport	Public transport	No motorized transport
Badalona	53,38%	28,05%	18,57%
Barcelona	36,81%	42,38%	20,81%
Cornellà de Llobregat	50,78%	29,60%	19,62%
Granollers	63,56%	10,39%	26,05%
Hospitalet de Llobregat (l')	43,54%	36,24%	20,22%
Martorell	69,45%	12,06%	18,48%
Mataró	58,95%	10,91%	30,14%
Prat de Llobregat (el)	53,82%	23,04%	23,15%
Rubí	69,85%	13,75%	16,40%
Sabadell	65,77%	15,55%	18,68%
Sant Cugat del Vallès	64,53%	20,35%	15,13%
Terrassa	68,24%	11,56%	20,21%
Vilanova i la Geltrú	55,50%	15,39%	29,11%
CBD (Barcelona)	36,81%	42,38%	20,81%
Subcentres (all)	59,78%	18,91%	21,31%
Subcentres (large)	60,47%	18,07%	21,47%
Subcentres (emerging)	58,81%	20,09%	21,10%
Rest of the metropolitan region	76,66%	8,11%	15,23%
TOTAL AVERAGE RMB	75,18%	9,11%	15,71%

Source: Own Elaboration on INE (2001).

Summarizing, these indicators formulated in the previous (equation 1 to 6) will be used as dependent variables in the following regressions models (Section 4.4) in order to examine the relationship between urban spatial structure and a) social (private) costs and b) environmental (external) costs due to mobility residence-to-work and then c) its influence on the location and d) efficiency of the public and private transport. However, in this point we can hypothesize that a) the higher the DAC index for a given municipality, the higher the social cost of commuting for people living in this municipality is: as the previous descriptive analysis showed, the average commuting distance for residents in centers (central city and sub-centres) are considerably lower in comparison with people living beyond them, so we expect that the social cost due to mobility that for people living in other municipalities is higher than people living in centres, b) the higher EI index for a given municipality, the higher the environmental costs of commuting is: due to the mass transit and no motorized transport imply lower environmental costs and they are highly concentrated in centres (central city and sub-centres)

[115] Commuting times, in INE (Instituto Nacional de Estadística), are classified into 7 categories: (1) less than 10 minutes, (2) from 10 to 20 minutes, (3) from 20 to 30 minutes, (4) from 30 to 45 minutes, (5) from 45 to 60 minutes, (6) from 60 to 90 minutes and finally (7) more than 90 minutes.

in comparison with other municipalities, as (Table 11) depicts, we expected that commuters that are living in them cause lower environmental costs (greenhouse emissions) in its journey-to-work. For instance, the average share of private transport (mode of transport that entail higher CO_2 emissions) among other municipalities in 2001 is around 76,66% compared to 36,81% in the central city of Barcelona and to 59,78% in subcentres, and finally c) the higher (lower) the average private time / public private time spent for commuters in its journey residence-to-work for a given municipality, the lower (higher) efficiency of the private / public transport in this given municipality is.

4.2. The spatial and non-spatial determinants of social and environmental costs due to mobility: independent variables and hypothesis

The aim of this section is to present the spatial and non spatial determinants and the hypothesis that this work has taken into account in order to examine its influence on the (1) social costs (DAC), on the (2) external costs (EI) of mobility, and on the factors that matters for the (3) location and (4) efficiency of the public and private means of transport. The hypothesis that has to be tested is that these commuting costs and transport location and efficiency are a function of some characteristics of spatial structure and non-spatial factors which can be grouped in the following categories:

The first one is polycentricity at intra-metropolitan scale, according to the co-location hypothesis (Gordon and Wong, 1985; Gordon et al., 1986, 1988, 1989a, 1989b, 1991; Dubin, 1991, Levinson and Kumar, 1994; Levinson and Wu, 2005; Alpkokin et al., 2005a, 2005b, 2007, 2008; Veneri, 2010 and; Modarres, 2011), which increases job-house proximity. In fact, the presence of several sub-centres increases the probability to finding a job near the place of residence. This, in turn, allows a reduction in the distance and time spent on travelling, with a virtuous effect on commuting costs. In addition, the degree of polycentricity presents a dimensional scale that facilitates the competitiveness of mass transit (Breheny, 1995; Modarres, 2003; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008 and; Commins and Nolan, 2011). Hence, a polycentric structure can facilitate a more intense use of public transport systems and this in turn negatively affects the external costs of mobility through a minor impact in terms of CO_2 emissions. In this study, is defined the polycentric structure of the metropolitan area by means of sub-centres and CBD (central business district). To examine their effects at inta-metropolitan scale as (García-López and Muñiz, 2012) has proposed is necessary to measure the agglomeration economies (urbanization economies -diversity- and localization economies –specialized services-) that these nodes exert in the metropolitan area. To do so, in our case we compute separately the (1) DISTANCE TO CBD and (2) DISTANCE TO THE NEAREST SUB-CENTRE[116] for each municipality of the metropolitan area[117]. In addition, in the case of (2) it also has taken into account the distance to the nearest (21) LARGE SUB-CENTRE and to the nearest (22) EMERGING SUB-CENTRE in order to give a more in-depth analysis related to the urban spatial structure effects. Hence, from a detailed point of view, because of the municipality of Barcelona (CBD) shows a diversified economic structure and, at the same time, a high degree of specialization

[116] As we see in following Section 4.4, in the case of sub-centres we use an inverted distance. Working with a direct distance for the case of the CBD (Barcelona) and an inverted distance for the case of the sub-centres implies that the spatial influence of the CBD is greater than that of the sub-centres. This assumption is common in most empirical studies (McDonald and Prather, 1994).

[117] These distances are in kilometers and they are computed by using a geographical information system (GIS) that compute the distance by road (not between centroid of each spatial unit) between each municipality to the central city of Barcelona (CBD) and to the nearest sub-centre which are identified in (Masip, 2012a).

in some economic sectors, its distance might capture urban spatial structure (metropolitan) urbanization economies, as well as urban spatial structure (metropolitan) localization economies. In the case of sub-centres, all subcentres (large and emerging) as it shown in (Figures 4a, 4b and 4c), resemble small CBDs and they might be related to both urban spatial structure (metropolitan) urbanization and localization economies. On the other side, by taking into account the characterization of sub-centres that (Masip, 2012a) has proposed: large-consolidated subcentres (places to work and live) and emerging ones (places to work), then emerging subcentres are smaller and more specialized and, as a result they might be more related to (urban spatial structure) localization economies with a metropolitan scope (but less than total sub-centres and less than large sub-centres). To test which type of sub-centres (and their related agglomeration economies) are more important, we estimate in the following Section 4.4. three specifications, one considering total sub-centres, and other two taking into account large and emerging ones respectively. As a result, we take the four following assumptions: (1) firstly, as we move away of the central city of Barcelona (CBD) and the sub-centres, the higher are the average distance travelled by commuters because the urbanization and localization economies are lower as we move away from these nodes, so CBD and sub-centres are virtuous to reduce the social costs due to commuting, (2) secondly, the same for the external costs, as we move away from the CBD and sub-centres, the higher the CO_2 emissions per commuter are due mainly to the higher concentration of public and soft means of transport that are located in these centers, so CBD and sub-centres are also virtuous to reduce the environmental costs due to mobility, then (3) related to location of means of transport we hypothesize that the higher the distance to the central city of Barcelona (CBD) and subcentres, the lower (higher) are the concentration (share) of public (private) means of transport and finally, (4) regarding with the efficiency of them (see, equations 5 and 6), measured as average public and private time when these means of transport are used, we expected that the efficiency of the public time decreases (more time spent by commuters that use these means of transport) as we move away from the CBD and subcentres due to the lower supply and facilities of mass transit (in terms of inter-municipalities commuting) in municipalities that are not the central city and subcentres, at the time that the private efficiency increases (less time spent by commuters) as we move away from the center and from the sub-centres because of congestion effects that are within and towards them. However in the case of subcentres as its urbanization economies are lower than the central city, is possible that there are less congestion, so in this case is unclear and it is also expected that as we move away from the identified sub-centres, the average time of private transport when commuters use them increases with the distance (more time, less efficiency).

The second one is urban compactness which is also relevant in shaping commuting patterns and their effects. Compact cities, whose degree of compactness is usually measured with residential density, are expected to be associated with shorter travel distances (lower social costs) at the time that it is associated with a more sustainable mobility patterns in terms of CO_2 emissions thanks to a higher spatial concentration of houses and job places (Camagni et al., 2002; Schwanen, 2001; Giuliano and Narayan, 2003; Schwanen et al., 2004; Muñiz and Galindo, 2005; Bento et al., 2005; Travisi and Camagni, 2005; Travisi et al., 2006, 2010; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008; Veneri, 2010; Cirilli and Veneri, 2010a, 2010b, 2010c and; Melo et al., 2012). Moreover, urban compactness enhances the competitiveness of a mass transit system what entails a higher share of public transport and a lower concentration of private transport. On the other hand, the higher the cities' compactness, the higher their level of traffic congestion which in turn could be associated with an increase in commuting duration that could affect differently in the efficiency of public and private transport: it is more likely that in compact cities due to congestion the efficiency of public transport are higher than the private ones (commuters spent more time when they use private means of transport to reach its workplace than if they use public ones). Therefore, to examine the effects of the residential density in this work we calculated the (3) POPULATION DENSITY[118] which is measured as the ratio between inhabitants that each municipality has and the built-up area[119] in square kilometers that it covers compared to other studies in the literature that use the gross population density (inhabitants/administrative area in km^2) as a proxy of the residential density.

Finally, the last two variables of the spatial urban structure that we have taken into account[120] and they can influence commuting patterns are (4) LAND USE BALANCE (diversity of land-use) and (5) EMPLOYMENT RESIDENTS RATIO (economic and residential balance), so the functional diversification of the territory suggested by a wide variety of studies in the literature: in terms of diverse or mixed land-use by (Frank and Pivo, 1994, Cervero, 1996, 2002; Cervero and Kockelman, 1997 and; Cervero and Murakami, 2010) and in terms of job-housing balance by (Giuliano and Small, 1993; Levinson and Kumar, 1994; Peng, 1997; Sultana, 2002; Modarres, 2003, 2011; Schwanen et al., 2004; Muñiz and Galindo, 2005; Bento et al., 2005; Camagni et al., 2002; Travisi and Camagni, 2005; Travisi et al., 2006, 2010; Veneri, 2010; Cirilli and Veneri, 2010a, 2010b, 2010c and; Melo et al., 2012). More specifically, functional diversification taking into account both mentioned dimensions favours the proximity between places of living and working. Therefore, we hypothesize that thanks to a reduction in the distance between jobs and homes, 1) the higher is the functional diversification based on a diversity of land-use in a given municipality, the lower the average commuting distance travelled by commuters (less social costs, private component of the mobility) and as a consequence the emissions of the CO_2 per commuter (external costs due to mobility) and of other pollutants are also reduced and, 2) the higher is the functional diversification based on job-housing balanced measured as the ratio between employment to residents, the lower are the social costs of commuting, measured as the average distance from residence to work travelled by workers and then, the higher and the lower the concentration of public and private transport are respectively. The two dimensions of the functional diversification of the territory have been approximated as follows. The former related to the diversity of land-use has calculated borrowing from what (Frank and Pivo, 1994:48) has proposed, so by using the entropy index to describe the evenness of the distribution of built square footage among land-use categories. In our case, we take into account seven different

[118] As we see in following Section 4.4, the Population density for each municipality has been calculated in the inverse measure due to econometric reasons.

[119] To calculated the total built up area (in km^2) for each municipality in the metropolitan area we use the data from Corine Land Cover considering the following artificial land uses: (1) full consideration of the land uses: continuous urban fabric (11100), discontinuous urban fabric (11210), discontinuous green urban areas (11220), industrial areas (12110), commercial and service areas (12110), port areas (12300), green urban areas (14100), courses field areas (14210) and rest of sport and leisure facilities (14220), (2) not taking into account the road and highway networks and associated land (12210), railroad networks (12220), mineral extraction sites (13100) and dump sites (13200) and finally, (3) not completely counting he artificial surface for: airports (12400) and construction sites (13300). In the case of airport areas, in order to calculate the total area for this use; this study has carried out an average proportion between the occupation of the airport runways in relation to the total airport area. In addition, related to the construction sites, it has deducted the areas which are roads, highway networks and railroad networks from the total area of the construction sites.

[120] Although there are studies (Gordon et al., 1989; Camagni et al., 2002; Schwanen et al., 2004; Travisi and Camagni, 2005; Travisi et al., 2006, 2010; Veneri, 2010; Cirilli and Veneri, 2010a, 2010b, 2010c and; Melo et al., 2012) that reveals that city size has a strong influence on the commuting patterns: the higher the city size, the higher the commuting distance in our work we do not take it into account as a independent variable because of the first econometric model draft that we estimated, the results showed that city size measured as the aforementioned studies has suggested (built-up area in square kilometers) was not statically significant.

categories of land-use on the basis of Corine Land Cover categories[121]: urban centre and continuous residential urban fabric, discontinuous residential urban fabric, industrial and commercial and service areas, infrastructural areas, logistic areas, green urban areas and other areas. So, the entropy index of mix land-use is expressed as the following (equation 7) shows:

$$Land\ use\ balance_{i(entropy\ value)} = -\sum_{j=1}^{n}\left(LU_{ij} \cdot \left[Ln\left(LU_{ij}\right)\right]\right) \qquad (7)$$

Where (Land use balance$_i$)[122] is the land diversity of territory (i=municipality), (j) is each of the considered land use categories and (LU_{ij}) is the probability to find (j) in the given municipality (i). The higher is the (Land use balance$_i$) for a given municipality (i), the higher the land diversity of this given territory (i). The latter, related to the economic and residential balance (job-housing balance) in our case we used the employment resident ratio which is measured as the ratio between jobs (localised workplaces) and residents (population, inhabitants) that are in a given municipality (i).

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 factors in the estimation, however permits a better interpretation of the empirical results avoid, or at least reduce, problems of under-specification of the model. The first control is the variable independent (6) AVERAGE AGE (in logarithm form) borrowed from (Camagni et al., 2002) and which is computed as the average age of building (years). The underlying idea is that in the last decades the speed of house-construction has increased but new settlements have not been planned with enough attention to the proximity to mass transit. In this sense, another housing control variable borrowed from the literature (see previous Section, 2.3; Camagni et al, 2002; Veneri, 2010 and; Cirilli and Veneri, 2010a, 2010b, 2010c) is (7) GROWTH RATE OF POPULATION 1991-2001 which is calculated as the percent growth rate of population from 1991 to 2001 in a given municipality (i). As a matter of fact, cities (municipalities) with a higher average age (newer housing) and with a higher growth rate of its population (newer residential areas) are expected to be less efficient in terms of social and external costs of mobility and present a lower (higher) concentration of public (private) transport. Secondly, by studying the contributions of the influence of transport factors on commuting patterns that the literature has suggested by (Gordon et al., 1989; Dubin, 1991; Camagni et al., 2002; Bento et al., 2005; Travisi and Camagni, 2005; Travisi et al., 2006, 2010; Susilo and Maat, 2007; Veneri, 2010 and; Cirilli and Veneri, 2010b, 2010c), in our work we use the following three transport independent variables, (8) SHARE OF NO MOTORIZED TRANSPORT (in logarithm form) which is calculated as the market share of soft means of transport, so the percentage of all trips made by walking and bicycling in a given municipality (i), (9) PRIVATE TRANSPORT

[121] The original database of artificial land uses provide by Corine Land Cover present 15 different categories: continuous urban fabric (11100), discontinuous urban fabric (11210), discontinuous green urban areas (11220), industrial areas (12110), commercial and service areas (12110), port areas (12300), green urban areas (14100), courses field areas (14210), rest of sport and leisure facilities (14220), highway networks and associated land (12210), railroad networks (12220), mineral extraction sites (13100) dump sites (13200) airports (12400) and finally, construction sites (13300). From these categories we turn them into seven ones.

[122] This (equation 7) can be rewritten as follows (disaggregated form): $Land\ use\ balance\ (entropy\ value) = -[urban\ centre\ and\ cont.residt.urban\ fabric * log_{10}(urban\ centre\ and\ cont.residt.urban\ fabric)] + [dicont.residt.urban\ fabric * log_{10}(dicont.residt.urban\ fabric)] + [industrial\ and\ commercial\ and\ serv.areas * log_{10}(industrial\ and\ commercial\ and\ serv.areas)] + [infrastructural\ areas * log_{10}(infrastructural\ areas)] + [logistic\ areas * log_{10}(logistic\ areas)] + [green\ urban\ areas * log_{10}(green\ urban\ areas)] + [othr.areas * log_{10}(othr.areas)]$

INTENSITY (in logarithm form) which is computed as the share of commuters-to-work that use motorized private means of transports over the total employment (localized workplaces) for a given municipality (i) and finally, (10) RELATIVE COMPETITVENESS OF PRIVATE TRANSPORT [redacted] We hypothesize that (1) the higher is the share of no motorized transport (walking and bicycling), the higher the share of commuters that use "more sustainable" means of transport, so the lower the social and externals costs of mobility and the higher the concentration of public means of transport, (2) the higher the private transport intensity, the larger the share of commuters that use "less sustainable" means of transport, which are likely to worsen the costs of commuting (both social and environmental) and the higher is obviously the concentration of private means of transport, and finally (3) the higher is the relative competitiveness of private transport for a given municipality (i), the lower are the travelled time for commuters to use private means of transport, so the lower is the probability to use public means of transport to reach on its workplaces and as a result, the higher the environmental and social costs of mobility are. Then, another control variable that has been included in the analysis as regards the geographical localization of municipalities within the Barcelona Metropolitan Region, in order to take into account of the differences between municipalities that are in the center or in the coast of the metropolitan region is (11) COAST MUNICIPALITIES which is computed as 1, if the municipality is adjacent to the coast and as 0, otherwise. The use of territorial dummies allow for these differences, although is unclear about what is expected in terms of its influence on the commuting patterns. Finally, two socioeconomic variables[123] have been included in the model in order to control for different characteristics of the resident population as it has shown in the literature by (Gordon et al., 1989; Dubin 1991; Kockelman, 1995; Giuliano and Narayan, 2003; Schwanen et al., 2003, 2004; Bento et al., 2005; Muñiz and Galindo, 2005; Shearmur, 2006; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008 and; Watts, 2009) in terms of income, and by (Schwanen et al., 2001, 2002, 2003, 2004; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008, Veneri, 2010 and; Cirilli and Veneri, 2010a) in terms of education. The first variable is the (12) SOCIOECONOMIC FACTOR [redacted] and; the second variable is the share of population with a bachelor degree or more[125], (13) HUMAN CAPITAL. A higher socioeconomic factor and human capital for a given municipality (i) could be expected to be associated with a higher INCOME and, as a consequence, a higher number of car owners that can influence commuting mode choice, so the higher the social and environmental costs due to commuting and the larger (fewer) the concentration of private (public) means of transport.

[123] Although there are studies that reveals that demographic structure of the population matters for the commuting patterns, such as (Tkocz and Kristensen, 1994; Schwanen et al., 2001, 2002, 2003, 2004; Bento et al., 2005; Shearmur, 2006; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008; Veneri, 2010; Cirilli and Veneri, 2010a and; Commins and Nolan, 2011) which present that: the older the population is, the lower are the social and environmental costs due to commuting are, due to elderly people tend to use more public means of transport or commuting less distance and times, in our work we not take into account as a independent variable the demographic structure because of the first econometric models draft that we estimated, the results present that the demography of population measured as some aforementioned studies has suggested: ratio between the people aged between 40 and 64 over people aged between 15 and 39 was not statically significant.

[124] [redacted]

[125] The ratio has taken into account the population above 25 years to 65 years with a bachelor degree or more. The data comes from INE (Instituto Nacional de Estadística) and IDESCAT (Institut d'Estadística de Catalunya).

4.3. Data

The following (Table 12) defines the variables names along with descriptions, data sources and the computation that our study has used to determine the variables explained previously

Table 12. Variable descriptions and sources for the Barcelona Metropolitan Region

Variable name	Variable description	Data Source and computation	Year
URBAN STRUCTURE - BUILT ENVIRONMENT VARIABLES			
Distance to CBD (Barcelona)	Distance by road in (km) from each municipality in the Barcelona Metropolitan Region to the Barcelona (CBD)	Network road graphs and matrix of distances between municipalities (in kilometres) were provided by the Department of Regional Policy and Public Works (DPTOP). Based on these maps by using a GIS software is computed the distances to the CBD	1991, 1996, 2001
Distance to the nearest Sub-centre* (inverse measure)	Distance by road in (km) from each municipality in the Barcelona Metropolitan Region to the nearest Sub-centre	Network road graphs and matrix of distances between municipalities (in kilometres) were provided by the Department of Regional Policy and Public Works (DPTOP). Based on these maps by using a GIS software is computed the distances to the nearest Sub-centre	1991, 1996, 2001
Population density (inverse measure)	Ratio between inhabitants in each municipality divided by the built-up area (in square km) of this municipality	Population data comes from INE (Instituto Nacional de Estadística) and the built-up area is computed for each municipality from data provided by Corine Land Cover.	1991, 1996, 2001 and 1990, 2000
Land use balance (entropy value)	Land use diversity of a given municipality calculated as the Shannon form of Entropy.	Land use categories comes from the built-up area in square kilometres provided by Corine Land Cover. This built-up area for each municipality has been classified into 7 different land use categories	1990, 2000
Employment residents ratio	Ratio between jobs (localised workplaces) in each municipality divided by the inhabitants of this municipality	Residence-to-work mobility provided by IDESCAT (Institut d'Estadística de Catalunya) and population data comes from INE (Instituto Nacional de Estadística)	1991, 1996, 2001
TRANSPORTATION CONTROL VARIABLES			
Share of no motorized transport (logarithm)	Percentage of all trips made by walking and bicycling	Data related to mode choice and means of transport was provided by INE (Instituto Nacional de Estadística)	2001
Private transport intensity (logarithm)	Share of commuters that use motorized private transports over the total employment	Data related to mode choice and means of transport was provided by INE (Instituto Nacional de Estadística)	2001
Relative competitveness of private transport	[redacted]	[redacted]	[redacted]
SOCIODEMOGRAPHIC CONTROL VARIABLES			
Growth rate of population, 1991-2001	Percent growth rate of population from 1991 to 2001 for a given municipality	Population data comes from INE (Instituto Nacional de Estadística)	1991, 2001
Socioeconomic factor	[redacted]	[redacted]	[redacted]
Human Capital (percentage)	Share of population (>25 to 65 years) with a bachelor degree or more	Population data comes from INE (Instituto Nacional de Estadística)	1991, 1996, 2001
HOUSING CONTROL VARIABLES			
Average age (logarithm)	Average age of building in years	Data of housing comes from INE (Instituto Nacional de Estadística)	1991, 2001
GEOGRAPHICAL CONTROL VARIABLES			
Coast Municipalities	1 if municipality is adjacent to coast, otherwise 0	GIS database provided by Department of Regional Policy and Public Works (DPTOP)	1991, 1996, 2001

Source: Own Elaboration. Note: *Distance to the nearest all, large and emerging sub-centres

4.4. Empirical analysis

In order to test these hypotheses, spatial econometric models have been carried out using the above-mentioned 164 municipalities that are within the Barcelona Metropolitan Region as unit of analysis. All the dependent variables have been computed as explained in Section 4.1 (equation 1 to 6) and as regards independent variables is used the measurements and descriptions presented in the previous Sections 4.2 and 4.3. However, our data may have a location component, so according to the literature of spatial econometric techniques there are two problems -namely, (1) spatial dependence between the observations and (2) spatial heterogeneity. Spatial dependence between adjacent municipalities will have similar patterns of intermunicipality commuting. As a consequence, ordinary least squares (OLS) estimation is likely to be blighted by spatial correlation, which can take two forms- spatial lag and spatial error. The former is associated with the dependent variable being correlated with its nearby observations and ignoring this form of spatial correlation leads to inconsistent, biased estimators, so the inference of significance from OLS can be incorrect. The latter form of spatial correlation entails the correlation of errors with those of nearby observations, but ignoring this form of autocorrelation does not affect the consistency of estimators, only their efficiency. In our work, to deal with spatial dependence and spatial heterogeneity three types of regression models have been estimated: ordinary least squares (OLS), spatial lag model (SLM) and finally spatial error model (SEM). Hence, the basic forms of these three types of regressions models can be written as follows (equations 8, 9 and 10 respectively):

$$\gamma = X\beta + \varepsilon \qquad (8)$$

$$\gamma = \rho W y + X\beta + \varepsilon \qquad (9)$$

$$\gamma = X\beta + \varepsilon_w \qquad (10.1)$$

$$\text{and, } \varepsilon_w = \lambda W \varepsilon + \xi \qquad (10.2)$$

Where (X) is a matrix of observations on the explanatory variables, (ε) is the vector of error terms, (Wy) is the spatially lagged predictor, (ρ) is the spatial coefficient of the SLM, (ε_w) is the vector of error terms, spatially weighted using the weights matrix (W), (λ) is the spatial error coefficient of the SEM and finally, (ξ) is a vector of uncorrelated error terms. As regards to the spatial lag model (SLM), (n) is the number of municipalities and (W) a spatial weighting matrix of dimension (n x n, in our case 164 x 164) whose elements assign the neighbours to each municipality. The weights matrix used in this study is characterized as $W = \{w_{ij}\}$, such that $0 < w_{ij} \leq 1 \; \forall \; i \neq j$, if (i) and (j) are neighbours, otherwise $w_{ij} = 0$, and in which $w_{ii} = 0$. In the weighted matrix, neighbours are defined as those municipalities that share a common border (administrative border) by using queen-standardized weights as a spatial matrix of contiguity[126] and the hypothesis of spatial correlation is related to the parameter (ρ), where $H_0: \rho = 0$ (if there is no spatial dependence, and γ does not depend on neighboring γ values, p=0) is tested against the alternative, $H_1: \rho \neq 0$. If H_0 is rejected, two possibilities arise. A positive and significant parameter estimate of (ρ) indicates a positive correlation between i.e. employment growth rate in neighbouring municipalities (in this example the employment growth rate is the dependent variable). That is, high employment growth rate tend to 'spillover' and have a positive effect on employment growth rates in

[126] Compared to queen-standardized weights to define the spatial matrix of contiguity, there are other forms: by using rook-standardized weight or by using distance-standardized weights. However, we use queen contiguity matrix in this case after tested what has the best performance.

neighbouring municipalities. However, this effect could also be negative, which indicates that conditional to the other explanatory variables of the spatial lag model, the employment growth within one municipality tend to be at its neighbour's expense (is taken the same example as previously). Then, as regards to the spatial error model, the dependence between municipalities works through the error process as the error from different regions may display spatial covariance. In technical terms, the difference between the spatial lag model and the spatial error model relate to the parameter (ρ) and the error term (Ɛ) as we could observe by comparing the previous (equations 9 to 10.1 and 10.2). In the spatial error model (SEM), $\rho \equiv 0$ and $\mathcal{E} = \lambda W \mathcal{E} + \xi$, or rearranging: $\mathcal{E} = (I - \lambda W)^{-1}\xi$, where (λ) is a scalar spatial error coefficient, $\xi \sim N(0, \sigma^2 I)$ and the original error terms has the non-spherical covariance matrix $E[\mathcal{E}\mathcal{E}'] = (I - \lambda W)^{-1}\sigma^2 I (I - \lambda W)^{-1}$. If the spatial error model is the right specification, the interpretation of the model is that a random shock will not only affect the region where it is introduced. Instead, it will spread to neighbouring municipalities and also throughout the system, so if λ=0, then there is no spatial correlation between the errors.

Social costs of commuting

To examine the determinants of the social costs due to residence-to-work mobility the regressions models that we estimate according to the previous three different econometric models (equations 8, 9 and 10) are:

$$LnDAC_i = DAC_0 + \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d_{SUB}^{-1}} + \beta_3 \mathrm{DnPop^{-1}} - \beta_4 \mathrm{Land} - \beta_5 \mathrm{E/P} + \beta_6 \mathrm{Socioeco} + \beta_7 \mathrm{HCapital} + \beta_8 \mathrm{LnAge} + \beta_9 \mathrm{Coast} + \mathcal{E}$$

(equation 11)

$$LnDAC_i = DAC_0 + \rho W DAC_i + \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d_{SUB}^{-1}} + \beta_3 \mathrm{DnPop^{-1}} - \beta_4 \mathrm{Land} - \beta_5 \mathrm{E/P} + \beta_6 \mathrm{Socioeco} + \beta_7 \mathrm{HCapital} + \beta_8 \mathrm{LnAge} + \beta_9 \mathrm{Coast} + \mathcal{E}$$

(equation 12)

$$LnDAC_i = DAC_0 + \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d_{SUB}^{-1}} + \beta_3 \mathrm{DnPop^{-1}} - \beta_4 \mathrm{Land} - \beta_5 \mathrm{E/P} + \beta_6 \mathrm{Socioeco} + \beta_7 \mathrm{HCapital} + \beta_8 \mathrm{LnAge} + \beta_9 \mathrm{Coast} + \lambda W \mathcal{E} + \xi$$

(equation 13)

Where (DAC_i) is the average commuting distance for commuters that living in municipality (i), (DAC_0) is the intercept of the regression model, (d_{CBD}) is the distance from municipality (i) to the CBD, (d_{SUB}^{-1}) is the distance from municipality (i) to the nearest sub-centre, ($DnPop^{-1}$) is the net population density, (Land) is the diversity of land use that a municipality (i), (E/P) is the ratio between employment and population, (Socioeco) is a socioeconomic factor for a each municipality (i) and it is a proxy of income, (HCapital) is the share of population above 25 years to 65 with a bachelor degree, (Age) is the average age of building for each municipality and, (Coast) is a geographical dummy variable that shows which municipalities are adjacent to the coast. Then, β coefficients represent the gradients associated with each independent variable and the sign of these coefficients are expected to be according to the hypotheses explained in the previous Section 4.2 and (Ɛ) is the vector of error terms, ($WDAC_i$) is the spatially lagged predictor of the dependent variable: average commuting distance and (ρ) is its spatial coefficient, and finally (WƐ) is the vector of error terms, spatially weighted using the weights matrix (W), (λ) its spatial error coefficient and (ξ) is a vector of uncorrelated error terms. In addition, in order to examine in-depth the influence of the urban structure on commuting patterns, it is also studied the influence of sub-centre according to its characterization: large and emerging proposed by (Masip, 2012a) on the social costs of mobility by means of the average distance travelled by commuters. Starting from the (equations 11 to 13), the following (equation 14 to 16) and (equation 17 to 19) show the estimated regression models taking into account large and emerging sub-centre influence:

$$LnDAC_i = DAC_0 + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ LARGE} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 E/P + \beta_6 Socioeco + \beta_7 HCapital + \beta_8 LnAge + \beta_9 Coast + \varepsilon$$

(equation 14)

$$LnDAC_i = DAC_0 + \rho WDAC_i + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ LARGE} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 E/P + \beta_6 Socioeco + \beta_7 HCapital + \beta_8 LnAge + \beta_9 Coast + \varepsilon$$

(equation 15)

$$LnDAC_i = DAC_0 + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ LARGE} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 E/P + \beta_6 Socioeco + \beta_7 HCapital + \beta_8 LnAge + \beta_9 Coast + \lambda W\varepsilon + \xi$$

(equation 16)

$$LnDAC_i = DAC_0 + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ EMERGING} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 E/P + \beta_6 Socioeco + \beta_7 HCapital + \beta_8 LnAge + \beta_9 Coast + \varepsilon$$

(equation 17)

$$LnDAC_i = DAC_0 + \rho WDAC_i + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ EMERGING} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 E/P + \beta_6 Socioeco + \beta_7 HCapital + \beta_8 LnAge + \beta_9 Coast + \varepsilon$$

(equation 18)

$$LnDAC_i = DAC_0 + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ EMERGING} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 E/P + \beta_6 Socioeco + \beta_7 HCapital + \beta_8 LnAge + \beta_9 Coast + \lambda W\varepsilon + \xi$$

(equation 19)

After these nine regression models have been estimated using ordinary least squares (OLS), spatial lag model (SLM) and spatial error model (SEM) methods for each analyzed year 1991, 1996 and 2001 at the time that it has been taken into account sub-centres influence according its characterization: all subcentres, large subcentres and emerging subcentres, the results reported here will only consider the models estimated by spatial error model (SEM) because its results present better performance than the others. In this sense, the results of (OLS) and (SLM) estimated regression models are summarized in the Appendix (Table A1 to A6). Hence, the following (Table 13) shows the results of what are the determinants of social costs due to residence-to-work commuting by taking into account the influence of all sub-centres. At first glance, the results highlight that urban structure exerts a significant influence on average commuting distance, the influence is virtuous to reduce the social costs due to commuting and that it has become more and more prominent since 1991: a) the independent variables related to urban structure (columns 1 to 3) are all statistically significant and they have a considerably explanatory power of the average commuting distance travelled by workers i.e. in 2001 the R^2 is 51,7%; b) in addition all these variables have the expected sign and the hypothesis explained in Section 4.2 are corroborated, centres defined by means of CBD and sub-centres are virtuous to reduce the social costs of commuting and urban compactness measured as net population density as well. Hence, the statistically positive sign of (β_1) reveals that as we move away from the central city of Barcelona (CBD), the higher is the average commuting distance travelled by workers due to the urbanization and localization economies of the CBD becomes lower; then, the same is true for sub-centres but in a less extent due to is taken the assumption that their urbanization and localization economies exert a less considerably influence compared to CBD (inverse distance), so the statistically negative sign of (β_2) shows that as we move away from the nearest sub-centre, the higher is also the average commuting distance and; the statistically positive sign of the net population density (measured as inverse magnitude) coefficient (β_3) entails that the municipalities that are more compact, the lower their residents employed population commutes; finally c) these influences as we mentioned have become since 1991 more relevant, this is observed through analyzing the significance level (t-value) for each urban structure variable: i.e. the significance level of CBD has increased from (2,15436) to (3,05867) since 1991, the same as for sub-centres and urban compactness which since 1991 have increased their t-values from (-2,57892) to (-3,05411) and from (4,95213) to (6,24958) respectively.

Secondly, when other two more urban structure variables are included and it has taken into account for sociodemographic, housing and geographical control variables (column 4 to 6) the regression models reveals that the previous mainly urban structure variables are still statistically significant and they present the expected sign, so centres (CBD and sub-centres) and urban compactness are behind the reduction of social costs due to commuting, although what is true now is that there is quite more evident that CBD influence is slightly more relevant that sub-centre influence: previously i.e. in 2001, CBD's t-value in absolute terms is approximately the same as sub-centre's t-value, (3,05867) versus (-3,05411) and with the inclusion with other variables this is changed for (3,46300) versus (-2,60519) respectively. As regards two more included urban structure variables, land use balance (diversity of land) and employment to residents ratio (job balance and imbalance) the results show that both variables have the expected sign in all analyzed years but they are not statistically significant for all of them, only in 2001 both variables are statistically significant above 99% of confidence. In this case, is statistically corroborated the previous hypothesis presented in Section 4.2 related to land use and job balance: the statistically negative sign of (β_4) coefficient reveals that diversity of land matters on social costs due to commuting, the higher is the diversity of land in a municipality (the higher is its land mix use), the lower is the average commuting distance for its resident employed population to commute to work; and the statistically negative sign of (β_5) coefficient shows that job balance measured as employment to residents ratio as most studies in the literature has suggested, it also influences on social costs due to mobility, the higher a municipality present a workplace orientation, the lower are the commuting costs.

Then, as regards to sociodemographic control variables, the results shows that the socioeconomic factor as proxy of income, although it has a statistically effect, it does not have the expected sign. The statistically negative sign of (β_6) coefficient, (i.e. -2,59824*** in 2001) entails that the higher is the income for resident employed population, [redacted] the lower is the average commuting distance, so the mobility social costs.

Table 13. Spatial determinants of social costs due to commuting. Regression models estimated by Spatial Error Model (SEM): all sub-centres

Dependent Variable	Y = Ln Average commuting distance (2001, 1996, 1991)					
Independent Variables (Spatial Error Model)	(1) 1991	(1) 1996	(1) 2001	(2) 1991	(2) 1996	(2) 2001
Constant	1,91655***	2,08759***	2,02235***	-28,24249	-64,47502*	-47,846*
(t-value)	(15,68396)	(21,7282)	(22,26462)	(-0,57928)	(-1,69433)	(-1,85135)
(probability)	0,00000	0,00000	0,00000	0,56239	0,09020	0,06411
Distance to Barcelona - CBD	0,00560**	0,00523**	0,00715***	0,00474**	0,00484**	0,00540***
(t-value)	(2,15436)	(2,2847)	(3,05867)	(2,10216)	(2,44097)	(3,46300)
(probability)	0,03121	0,02233	0,00222	0,035539	0,01466	0,00053
Distance to nearest Subcentre (inverse)	-0,46507***	-0,31631**	-0,36636***	-0,40831***	-0,19430*	-0,25165***
(t-value)	(-2,57892)	(-2,47732)	(-3,05411)	(-2,60985)	(-1,69417)	(-2,60519)
(probability)	0,00991	0,01323	0,00225	0,00905	0,09023	0,00918
Population Density (inverse)	126,8195***	226,5838***	217,7521***	89,5230***	177,0981***	187,0916***
(t-value)	(4,95213)	(6,82576)	(6,24958)	(3,60254)	(5,39529)	(6,14457)
(probability)	0,00000	0,00000	0,00000	0,00031	0,00000	0,00000
Land use balance				-0,10098	-0,27447**	-0,24473***
(t-value)				(-0,66444)	(-2,19589)	(-2,82542)
(probability)				0,50640	0,02809	0,00472
Employment residents ratio (LTL / Pob)				-0,08673	-0,18112	-0,30234***
(t-value)				(-0,56709)	(-1,48530)	(-3,24116)
(probability)				0,57065	0,13746	0,00119
Socioeconomic factor				-2,05580***	-1,86327***	-2,59824***
(t-value)				(-2,97962)	(-2,87697)	(-5,52719)
(probability)				0,00288	0,00401	0,00000
Human Capital (%)				3,72521***	1,40155***	1,08815***
(t-value)				(6,76908)	(3,85107)	(5,03738)
(probability)				0,00000	0,00011	0,00000
Average Age (Ln)				3,94925	8,77224*	6,58044*
(t-value)				(0,61447)	(1,74869)	(1,93147)
(probability)				0,53890	0,08034	0,0534
Coast Municipalities				0,00370	0,10845	0,179021***
(t-value)				(0,04016)	(1,54488)	(3,56344)
(probability)				0,96796	0,12237	0,00036
Lambda	0,35995***	0,32281***	0,45131***	0,27651***	0,19497*	0,22181**
(t-value)	(3,58367)	(3,13514)	(4,87794)	(2,59599)	(1,75188)	(2,02184)
(probability)	0,00000	0,00000	0,00000	0,00943	0,07979	0,04319
Number of observations	164	164	164	164	164	164
R-squared	0,27728	0,40682	0,51709	0,46221	0,52550	0,68840
Adjusted R-squared	-	-	-	-	-	-
F-statistic	-	-	-	-	-	-
F (sig)	-	-	-	-	-	-
Log likelihood	-89,49951	-49,19280	-7,54796	-64,59752	-29,71985	31,25715

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

The literature suggest that the expect sign should be positive, due to people with higher incomes could choice with less difficulties the locations of their households and consequently they tend to commute more long distances than employed population with lower incomes.

Hence compared to the studies carried out by (Gordon et al., 1989b; Dubin 1991; Kockelman, 1995; Giuliano and Narayan, 2003; Schwanen et al., 2003, 2004; Bento et al., 2005; Muñiz and Galindo, 2005; Shearmur, 2006; Susilo and Maat, 2007; Vega and Reynolds-Feighan, 2008 and; Watts, 2009), our results contradict the hypotheses as regard income effect. For example, (Gordon et al., 1989b:143) states: *the rich would consequently consume more housing space at any location, and since the marginal change in commuting cost is invariant with income, rents have to decline with distance for the locational equilibrium condition to hold. The rich therefore consume more housing space at lower land rents and live further out than the poor. Thus commuting times increases with income"* and more indeed in nonmonocentric spatial structures: *"in a nonmonocentric (dispersed or polycentric) city, the income effects may even be stronger because higher income households do not necessarily have to trade off commuting costs against housing space as is inevitable for locational equilibrium in the monocentric model: higher income households have the buying power to choose the sites they prefer and the housing space they desire in the nonmonocentric city"*. Two reasons could be behind this regression model outcome: a) the selected indicator used as proxy of municipality income is not correct, although by examining [redacted] and b) what could be quite more reasonable is that in the case of the Barcelona Metropolitan Region, the workers with the highest incomes choose centres (CBD and sub-centres) or their neighbouring areas (municipalities) to set their residences. This latter reason is reasonable in the sense that if it is true then is accorded to the fact that average commuting distance is longer for commuters that locate their residences far away from CBD and from sub-centres. As regards education role by means of human capital, measured as share of population with a bachelor degree or more, the model reveals that human capital is positive statistically associated with the social costs of commuting: the coefficient (β_7) is positive statistically for all years at its level of significance is all above 99% of confidence. As a result, this confirms what we expected and what other studies in the literature have found previously in terms of education and commuting distance.

Finally, although they are no statistically significant for all analyzed years, the housing control variable by means of average age building and the geographical dummy variable by means of if a given municipality is adjacent to coast matter on the social costs due to commuting. The former, is positively associated with the average commuting distance travelled by workers, corroborating what we expected in Section 4.2 and what aforementioned studies in the literature have found: the higher (the newer) is the average age of building for a given municipality, the higher are the average commuting distances that the workers which have their residences located there do. The latter, according to the sign of (β_9) is also positive statistically associated with long commuting distances but only in 2001. Coast municipalities dummy variable for the other years does not exert a statistically influence on commuting patterns. So, in 2001 what it may be behind of such result is that since 1991 because of suburbanization process of population beyond the central city of Barcelona and towards the rest of the metropolitan area, driven by inhabitants which were looking for other and second residences but still working in centres, have had the consequence that coast municipalities have mainly concentrated this dynamic and, the resident employed population of these municipalities have to commute longer to reach on their workplaces in 2001.

To examine in-depth and give more details about the relationship between sub-centres influence on commuting patterns, the following (Table 14) and (Table 15) by using the previous (equation 14 to 16) and (equation 17 to 19) reveals the influence of sub-centres on social costs due to commuting related to the nature of them: large and emerging respectively as what (Masip, 2012a) has proposed. According what we expected, large sub-centres should exert considerably higher influence to reduce commuting costs due to its urbanization and localization economies are more prominent than the emerging sub-centres.

Table 14. Spatial determinants of social costs due to commuting. Regression models estimated by Spatial Error Model (SEM): large sub-centres

Dependent Variable	Y = Ln Average commuting distance (2001, 1996, 1991)					
Independent Variables (Spatial Error Model)	(1) 1991	(1) 1996	(1) 2001	(2) 1991	(2) 1996	(2) 2001
Constant	1,86126***	2,07916***	2,00643***	-34,7121	-65,0022*	-46,48771*
(t-value)	(14,47402)	(21,94346)	(22,55255)	(-0,70561)	(-1,71451)	(-1,80109)
(probability)	0,00000	0,00000	0,00000	0,48042	0,08643	0,07168
Distance to Barcelona - CBD	0,00625**	0,00506**	0,00732***	0,00504*	0,00466**	0,00538***
(t-value)	(2,27847)	(2,2007)	(3,15331)	(2,14579)	(2,35401)	(3,50317)
(probability)	0,02269	0,02775	0,00161	0,03188	0,01857	0,00045
Distance to nearest Large Subcentre	-0,33426*	-0,30544***	-0,33387***	-0,29239*	-0,19345*	-0,25119***
(t-value)	(-1,93186)	(-2,55017)	(-2,91061)	(-1,92415)	(-1,76965)	(-2,70622)
(probability)	0,05337	0,01076	0,00360	0,05433	0,07678	0,00680
Population Density (inverse)	128,4077***	228,2092***	218,2244***	89,65536***	178,3818***	186,6326***
(t-value)	(4,15506)	(6,90714)	(6,24473)	(3,57539)	(5,44930)	(6,14273)
(probability)	0,00003	0,00000	0,00000	0,00034	0,00000	0,00000
Land use balance				-0,10146	-0,27335**	-0,24947***
(t-value)				(-0,66048)	(-2,18920)	(-2,88900)
(probability)				0,50894	0,02858	0,00386
Employment residents ratio (LTL / Pob)				-0,10010	-0,18639	-0,30463***
(t-value)				(-0,64886)	(-1,53235)	(-3,27721)
(probability)				0,51642	0,12543	0,00104
Socioeconomic factor				-2,09002***	-1,84394***	-2,60309***
(t-value)				(-3,02412)	(-2,84318)	(-5,53697)
(probability)				0,00249	0,00446	0,00000
Human Capital (%)				3,72962***	1,39365***	1,09686***
(t-value)				(6,70064)	(3,83118)	(5,09078)
(probability)				0,00000	0,00012	0,00000
Average Age (Ln)				4,79816	8,84186*	6,40104*
(t-value)				(0,73988)	(1,76907)	(1,88120)
(probability)				0,45937	0,07688	0,05994
Coast Municipalities				-0,00094	0,10799	0,18055***
(t-value)				(-0,01001)	(1,54466)	(3,61492)
(probability)				0,99200	0,12242	0,00030
Lambda	0,40290***	0,32416***	0,44652***	0,31130***	0,18708*	0,21062*
(t-value)	(4,15506)	(3,15131)	(4,80390)	(2,99065)	(1,67422)	(1,90818)
(probability)	0,00003	0,00162	0,00000	0,00278	0,09408	0,05636
Number of observations	164	164	164	164	164	164
R-squared	0,27156	0,408230	0,51420	0,45542	0,52593	0,68912
Adjusted R-squared	-	-	-	-	-	-
F-statistic	-	-	-	-	-	-
F (sig)	-	-	-	-	-	-
Log likelihood	-90,75787	-49,01403	-7,95145	-65,97834	-29,59488	31,53122

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

Table 15. Spatial determinants of social costs due to commuting. Regression models estimated by Spatial Error Model (SEM): emerging sub-centres

Dependent Variable		Y = Ln Average commuting distance (2001, 1996, 1991)					
Independent Variables (Spatial Error Model)		(1) 1991	(1) 1996	(1) 2001	(2) 1991	(2) 1996	(2) 2001
Constant		1,87427***	2,05741***	1,99619***	-25,27672	-65,07686*	-46,85275*
	(t-value)	(15,90669)	(21,63003)	(23,15609)	(-0,51686)	(-1,69968)	(-1,80065)
	(probability)	0,00000	0,00000	0,00000	0,60525	0,08919	0,07175
Distance to Barcelona - CBD		0,00622**	0,00567**	0,00749***	0,00521**	0,00510***	0,00573***
	(t-value)	(2,40908)	(2,44467)	(3,27060)	(2,32869)	(2,56760)	(3,72034)
	(probability)	0,01599	0,01449	0,00107	0,01987	0,01024	0,00019
Distance to nearest Emerging Subcentre		-0,47542***	-0,27837**	-0,35815***	-0,38893***	-0,15497	-0,22357***
	(t-value)	(-2,79091)	(-2,26116)	(-3,27565)	(-2,56686)	(-1,39173)	(-2,48426)
	(probability)	0,00525	0,02374	0,00105	0,01026	0,16400	0,01298
Population Density (inverse)		126,1421***	227,6077***	218,1225***	90,68221***	178,3166***	188,551***
	(t-value)	(4,94125)	(6,83782)	(6,29512)	(3,64783)	(5,42078)	(6,18135)
	(probability)	0,00000	0,00000	0,00000	0,00026	0,00000	0,00000
Land use balance					-0,09784	-0,27483**	-0,24184***
	(t-value)				(-0,64313)	(-2,18964)	(-2,78300)
	(probability)				0,52013	0,02855	0,00538
Employment residents ratio (LTL / Pob)					-0,10786	-0,18805	-0,30463***
	(t-value)				(-0,70502)	(-1,53995)	(-3,26251)
	(probability)				0,48079	0,12357	0,00111
Socioeconomic factor					-1,97137***	1,40736***	-2,55593***
	(t-value)				(-2,84010)	(3,85534)	(-5,42769)
	(probability)				0,00450	0,00011	0,00000
Human Capital (%)					3,68275***	1,40736***	1,07980***
	(t-value)				(6,68428)	(3,85534)	(4,98597)
	(probability)				0,00000	0,00011	0,00000
Average Age (Ln)					3,55430	8,84900*	6,44656*
	(t-value)				(0,55131)	(-2,86050)	(1,87932)
	(probability)				0,58141	0,00422	0,06019
Coast Municipalities					0,01151	0,11023	0,17467***
	(t-value)				(0,12468)	(1,56184)	(3,47127)
	(probability)				0,90077	0,11832	0,00051
Lambda		0,36032***	0,33628***	0,44915***	0,26941***	0,20099*	0,22667**
	(t-value)	(3,58836)	(3,29776)	(4,84438)	(2,51806)	(1,81161)	(2,07176)
	(probability)	0,00033	0,00097	0,00000	0,01180	0,07004	0,03828
Number of observations		164	164	164	164	164	164
R-squared		0,282192	0,40454	0,52074	0,46082	0,52307	0,68737
Adjusted R-squared		-	-	-	-	-	-
F-statistic		-	-	-	-	-	-
F (sig)		-	-	-	-	-	-
Log likelihood		-88,95287	-49,66968	-6,88579	-64,73763	-30,1793	30,95101

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

By analyzing the results of the regression models presented in the previous (Table 14) and (Table 15) and making a comparison with the results that we have just explained by taking into account all sub-centres, as (Table 13) has shown, we can conclude that: a) conceptually there no significant differences, the variables (both spatial structure and control ones) that were statistically significant and had the expected sign in the previous general regression models (Table 13) are now still being statistically significant with the same confidence level and having the expected sign, corroborating as a result, the hypotheses explained previously and, b) there is a clear evidence about what we expected based on large sub-centres are more efficient to reduce social costs due to mobility by means of average commuting distance travelled by workers. Large sub-centres according to what (Table 14) present, have a slightly higher significance level compared to the emerging ones (Table 15), so the difference of significance values between them is (-2,70622) versus (-2,48426) respectively, what remarks not only the efficiency of reducing commuting costs as regards its nature of formation what it may entail a quite higher explanatory power of the former set of regression models, i.e. in 2001, the R^2 for large sub-centres model is 68,91% compared to 68,73% for the emerging ones but also, it could explain the ability of them to be stable when other spatial structure and control variables are included: if we observe the significance levels of large sub-centres, emerging sub-centres and CBDs in the (Table 14) and (Table 15) respectively without taking into account the expand regressions models (column 1 to 3), then we can conclude that in this case, emerging sub-centres are more efficient (i.e. in 2001, its significance level is -3,27565 –even more than the CBD- compared to -2,91061 for the large ones in the same year) as well as this efficiency is reflected in the R^2 of the regression model as previously, 52,07% in comparison with 51,42% of large sub-centres regression models. Such observations is related what we pointed out previously, urbanization and localization economies are more prominent in large sub-centres than the emerging sub-centres ones, the explanation are related to its nature of formation: large sub-centres according to (Masip, 2012a) have a strong local labour market and they are important economic poles within the metropolitan areas, so they are both places to live and work, in other words they are able to retain its resident employed population as well as attracting working from all the metropolitan area that it means that they have relevant both urbanization economies related to its capacity to retain its population and localization economies related to attract workers, while emerging sub-centres as (Masip, 2012a) points out they only have a functionally autonomous local labour market or able to attract workers, so they only have prominent urbanization economies or localization ones but not both contrary to what large sub-centres have.

Indeed, these explanations are corroborated with the descriptive analysis carried out in Section 3.2 which reveals that a) i.e. in 2001, 53,99% of workers living in large sub-centres have a job in the same sub-centre and 19,62% in CBD compared to 44,66% and 25,63% respectively in the case of workers living in emerging sub-centres what entails a less relevant urbanization economies in emerging ones because of they are not able to retain its workers and being functionally autonomous from CBD as large sub-centres do and, b) i.e. in 2001 as well, considering jobs located in large and emerging sub-centres, 62,67% of them are held by people living in the same large sub-centres compared to 40,77% in the case of emerging ones, so again urbanization economies it seems to be stronger in large ones but not in the case of localization economies (related to the fact of attracting a huge number of in-commuting flows –workers-), due to in emerging sub-centres the 26,98% and the 15,66% of jobs are held by people living in other municipalities and in the CBD respectively compared to 19,87% and 9,19% in the case of large ones. This difference is quite higher in the case of jobs held by people living in other sub-centres; 16,36% compared to 8,27%. Hence, it seems to corroborate that large sub-centres tend to have urbanization economies rather than localization ones and emerging sub-centres, in its turn, stand out for the latter type of agglomeration economies, and as a result, because of this distinction in sub-centre nature formation there is a certain type of sub-centres that are more able to reduce social costs due to commuting compared to another.

Environmental costs of commuting

To study the factors of the environmental (external) costs due to residence-to-work commuting the regressions models that we estimate according to the previous three different econometric models (equations 8, 9 and 10) are:

$$EI_i = EI_0 + \beta_1 d_{CBD} - \beta_2 d_{SUB}^{-1} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 LnComPr + \beta_6 Growth9101 + \beta_7 Socioeco + \beta_8 HCapital + \beta_9 Coast + \mathcal{E}$$

(equation 20)

$$EI_i = EI_0 + \rho W EI_i + \beta_1 d_{CBD} - \beta_2 d_{SUB}^{-1} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 LnComPr + \beta_6 Growth9101 + \beta_7 Socioeco + \beta_8 HCapital + \beta_9 Coast + \mathcal{E}$$

(equation 21)

$$EI_i = EI_0 + \beta_1 d_{CBD} - \beta_2 d_{SUB}^{-1} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 LnComPr + \beta_6 Growth9101 + \beta_7 Socioeco + \beta_8 HCapital + \beta_9 Coast + \lambda W\mathcal{E} + \xi$$

(equation 22)

Where (EI_i) is the Environmental Index measured as it is explained in the previous Section 4.1 on the basis of mode choice and distance travelled by commuters in order to quantify CO_2 emissions per commuter in each municipality (i)[127], (EI_0) is the intercept of the regression model, (d_{CBD}) is the distance from municipality (i) to the CBD, (d_{SUB}^{-1}) is the distance from municipality (i) to the nearest Sub-centre, ($DnPop^{-1}$) is the net population density, (Land) is the diversity of land use that a municipality (i), (ComPr) is [redacted] (Growth9101) is the percent growth rate of population from 1991 to 2001 for each municipality (i) in the metropolitan area, (Socioeco) is a socioeconomic factor for a each municipality (i) [redacted] the purpose is that this socioeconomic factor could be a proxy for income, (HCapital) is the share of population above 25 years to 65 with a bachelor degree or more and, (Coast) is a geographical dummy variable that shows which municipalities are adjacent to the coast. Then, β coefficients represent the gradients associated with each independent variable and the sign of these coefficients are expected to be according to the hypotheses explained in the previous Section 4.2 and ($\mathcal{E}$) is the vector of error terms, (WEI_i) is the spatially lagged predictor of the dependent variable: Environmental Index in 2001 and (ρ) is its spatial coefficient, and finally ($W\mathcal{E}$) is the vector of error terms, spatially weighted using the weights matrix (W), (λ) its spatial error coefficient and (ξ) is a vector of uncorrelated error terms. In addition, in order to examine in-depth the influence of the urban structure on commuting patterns, it is also studied as previously, the influence of sub-centre according to its characterization: large and emerging proposed by (Masip, 2012a) but in this case, on the environmental costs of mobility by means of CO_2 emissions per commuter in each municipality. Starting from the previous (equations 20 to 22) the following (equation 23 to 25) and (equation 26 to 28) show the estimated regression models taking into account large and emerging subcentre influence:

[127] In order to estimate the following regression models, this dependent variable calculated as the previous (equation 2) explained in Section 4.1 has been normalized by its mean value.

$$EI_i = EI_0 + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ LARGE} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 LnComPr + \beta_6 Growth9101 + \beta_7 Socioeco + \beta_8 HCapital + \beta_9 Coast + \varepsilon$$

(equation 23)

$$EI_i = EI_0 + \rho W EI_i + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ LARGE} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 LnComPr + \beta_6 Growth9101 + \beta_7 Socioeco + \beta_8 HCapital + \beta_9 Coast + \varepsilon$$

(equation 24)

$$EI_i = EI_0 + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ LARGE} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 LnComPr + \beta_6 Growth9101 + \beta_7 Socioeco + \beta_8 HCapital + \beta_9 Coast + \lambda W \varepsilon + \xi$$

(equation 25)

$$EI_i = EI_0 + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ EMERGING} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 LnComPr + \beta_6 Growth9101 + \beta_7 Socioeco + \beta_8 HCapital + \beta_9 Coast + \varepsilon$$

(equation 26)

$$EI_i = EI_0 + \rho W EI_i + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ EMERGING} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 LnComPr + \beta_6 Growth9101 + \beta_7 Socioeco + \beta_8 HCapital + \beta_9 Coast + \varepsilon$$

(equation 27)

$$EI_i = EI_0 + \beta_1 d_{CBD} - \beta_2 d^{-1}_{SUB\ EMERGING} + \beta_3 DnPop^{-1} - \beta_4 Land - \beta_5 LnComPr + \beta_6 Growth9101 + \beta_7 Socioeco + \beta_8 HCapital + \beta_9 Coast + \lambda W \varepsilon + \xi$$

(equation 28)

After these nine regression models have been estimated using ordinary least squares (OLS), spatial lag model (SLM) and spatial error model (SEM) methods for 2001 at the time that it has been taken into account sub-centres influence according its characterization: all subcentres, large subcentres and emerging subcentres, the results reported here will only consider the models estimated by spatial error model (OLS) because its results present better performance than the others (SLM's and SEM's results show that the spatial coefficients ρ and λ are not statistically significant respectively). In this sense, the results of (SLM) and (SEM) estimated regression models are summarized in the Appendix (Table B1 and Table B2). Hence, the following (Table 16) shows the results of what are the determinants of environmental (external) cost due to residence-to-work mobility by taking into account the influence of all, large and emerging sub-centres as regression models expressed in (equation 20), (equation 23) and (equation 26) respectively. At first moment, the results highlight that urban structure exerts a significant influence on CO_2 emissions per commuter, the influence is virtuous to reduce this external cost due to commuting: a) the independent variables related to urban structure (distance to CBD, distance to the nearest Sub-centre, net population density and diversity of land use) are all statistically significant and they have the expected sign corroborating the previous hypotheses explained in Section 4.2, centres defined by means of

CBD and sub-centres are virtuous to reduce the environmental costs of commuting and urban compactness and diversity of land as well. Hence by examining (column 1) the statistically positive sign of (β_1=0,00924***) reveals that as we move away from the central city of Barcelona (CBD), the higher is CO_2 emissions per commuter due to the urbanization and localization economies of the CBD becomes lower and workers tend to commute longer and by using private means of transport; then, on the one hand, the same is true for sub-centres but in a less extent due to is taken the assumption that their urbanization and localization economies exert a less considerably influence compared to CBD (inverse distance), so the statistically negative sign of (β_2=-0,26308**) shows that as we move away from the nearest sub-centre, the higher is also the environmental costs due to commuting and on the other, the statistically positive sign of the net population density (measured as inverse magnitude) coefficient (β_3=127,1455***) and the statistically negative sign of diversity of land (land mix use) coefficient (β_4=-0,33840***) entail that municipalities that are more compact and diverse of land use, the lower are the environmental costs associated with CO_2 per commuter; b) in addition, the results show that large sub-centres (column 1.2) are more efficient than emerging ones (column 1.3) to be able to reduce the environmental costs what is according to what we explained previously as regards social costs: the significance level of large sub-centres are quite higher (-2,31182) compared to emerging's sub-centre significance level (-2,18999). However, the urban structure factor that exerts the most influence to reduce the CO_2 emissions per commuter is the central city of Barcelona (CBD), its t-value (5,51497) is the highest compared to the other t-values of rest urban structure variables, and finally c) these differences between large and emerging sub-centres efficiency in order to exert influence on the environmental costs is also depicted by the difference in terms of capacity of explanatory power of the three models: when the large sub-centres have taken into account (column 1.2) the regression model presents the highest adjusted R^2, 69,77% compared to when the emerging ones are considered (column 1.3), 69,66% and compared to when all subcentres' (both large and emerging) regression model which explains in this case, the 69,75% of the environmental costs by means of CO_2 emissions per commuter.

Secondly, when other control variables are included as regards transportation, sociodemographic, education and geographical determinants, the regressions models (column 1, to 1.3) reveals that a) the majority of variables are statistically significant and they have the expected sign and, b) there no conceptually changes in terms of significance levels and influence that they exert on environmental costs when is taken into account different type of sub-centres according to its nature formation. Hence, referring with transportation control variable, the results present that the relative competitiveness of private transport exert a statistically effect on environmental costs and its effect is according with what we expected, corroborating the hypotheses. The statistically positive sign of (β_5=0,50341***) coefficient entails that the higher is the competitiveness of private means of transport over public transport, [redacted] the higher are the CO_2 emissions per commuter.

Then as regards sociodemographic and education control variables that have taken into account, the regression models results reveals that although they are all statistically significant, the socioeconomic factor control variable which tries to be a proxy of income presents the unexpected sign: statistically negative sign of (β_7=-1,65441***) coefficient, entails that the higher is the income for resident employed population, [redacted] the lower is the CO_2 emissions per commuter, so the mobility environmental costs.

Table 16. Spatial determinants of environmental costs due to commuting. Regression models estimated by Ordinary Least Squares (OLS): all, large and emerging sub-centres

Dependent Variable		Y = Environmental Index 2001 (CO2 emissions on the basis of transport mode choice and distance travelled by commuters)		
Independent Variables (OLS Model)		(1)	(1.2)	(1.3)
Constant		0,553461***	0,55342***	0,52970***
	(t-value)	(4,63580)	(4,63930)	(4,52646)
	(probability)	0,00000	0,00000	0,00001
Distance to Barcelona - CBD		0,00924***	0,00932***	0,00958***
	(t-value)	(5,51497)	(5,60231)	(5,82450)
	(probability)	0,00000	0,00000	0,00000
Distance to nearest Subcentre (inverse)		-0,26308**		
	(t-value)	(-2,29803)		
	(probability)	0,02290		
Distance to nearest Large Subcentre			-0,25768**	
	(t-value)		(-2,31182)	
	(probability)		0,02211	
Distance to nearest Emerging Subcentre				-0,23486**
	(t-value)			(-2,18999)
	(probability)			0,03002
Population Density (inverse)		127,1455***	126,9413***	128,4553***
	(t-value)	(2,94413)	(2,93981)	(2,97084)
	(probability)	0,00374	0,00379	0,00344
Land use balance		-0,33840***	-0,34639***	-0,33513***
	(t-value)	(-3,32069)	(-3,41227)	(-3,27457)
	(probability)	0,00112	0,00082	0,00130
Competitveness Private/Public Transport (Ln)		0,50341***	0,50558***	0,50351***
	(t-value)	(5,92181)	(5,94470)	(5,91289)
	(probability)	0,00000	0,00000	0,00000
Growth rate of population 1991-2001		0,25841***	0,25428***	0,25848***
	(t-value)	(4,71066)	(4,62763)	(4,70461)
	(probability)	0,00000	0,00000	0,00000
Socioeconomic factor		-1,65441***	-1,64988***	-1,61150***
	(t-value)	(-2,83980)	(-2,83212)	(-2,75499)
	(probability)	0,00512	0,00524	0,00657
Human Capital (%)		0,98586***	0,99757***	0,97861***
	(t-value)	(3,76293)	(3,81292)	(3,72492)
	(probability)	0,00023	0,00019	0,00027
Coast Municipalities		0,07073	0,07189	0,06548
	(t-value)	(1,25449)	(1,27451)	(1,16243)
	(probability)	0,21156	0,20440	0,24685
Number of observations		164	164	164
R-squared		0,71429	0,71441	0,71342
Adjusted R-squared		0,69759	0,69772	0,69667
F-statistic		42,78	42,8039	42,5977
F (sig)		0,00000	0,00000	0,00000
Log likelihood		2,00637	2,03909	1,75636

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

In this sense, the reasonable explanations of this result (socioeconomic factor is negative associated with environmental costs) are the same as it given previously as regards social costs: a) the selected indicator used as proxy of municipality income is not correct, [redacted] and b) what could be quite more reasonable is that in the case of the Barcelona Metropolitan Region, the workers with the highest incomes choose centres (CBD and sub-centres) or their neighbouring areas (municipalities) to set their residences. This latter reason is reasonable in the sense that if it is true then is accorded to the fact that CO_2 emissions per commuter are higher as commuters (workers) locate their residences far away from CBD and from sub-centres. On the other hand, as regards demographic control variable and the role of education, the results are according to hypothesis pointed out in the previous Section 4.2.: a) the demographic dynamic measured as growth rate of population since 1991, is positively statistically (β_6=0,25841***) associated with environmental costs, so the higher is the growth rate of population in a municipality, the higher are the CO_2 emissions per capita, what it is according to the literature due to is assumed that new settlements formed by a higher speed of house-construction have not planned with enough attention to proximity to public transport and their residents tend to rely on private ones, so it is obvious that this is no efficient from the perspective of external costs of mobility and; b) education by means of human capital measured as the share of population above 25 years to 65 with a bachelor degree or more, is positive statistically associated with the CO_2 per commuter, so the coefficient (β_8=0,98586***) is positive statistically (above 99% confidence level) and, as a result, this confirms what we expected and what other studies in the literature have found previously in terms of education and environmental costs. Finally, the results shows that the geographical control variable based on coast localization, measured as a dummy variable, which municipalities adjacent to coast is 1 and otherwise 0, do not exert statistically influence on the CO_2 emissions per commuter (its significance level is: 0,21156 below 90% of confidence).

Location factors and efficiency of private and public means of transport

In this empirical last section, this study tries to examine the determinants of location (competitiveness for concentration) and efficiency of private and public means of transport. Starting from the meaningful contribution to the literature made by (Camagni et al., 2002) this current work estimates the following two of regressions models according to the basis on only the previous (equation 8) due to now is not expected that spatial autocorrelation problems arises. As a result, spatial lag and spatial error estimations are not useful here. Hence, the former set is related to the determinants of location for public and private means of transport, and the regressions models to estimate are formulated in (equation 29) and (equation 30). Then, the latter set of regressions as regards public and private transport efficiency is expressed in the following (equation 31) and (equation 32):

$$LnPu\_Share_i = Pu\_Share_0 - \beta_1 \mathrm{d_{CBD}} + \beta_2 \mathrm{d_{SUB}^{-1}} - \beta_3 \mathrm{DnPop^{-1}} + \beta_4 \mathrm{E/P} + \beta_5 \mathrm{LnShareNMTrans} - \beta_6 \mathrm{Growth9101} + \beta_7 \mathrm{Socioeco} + \varepsilon$$

(equation 29)

$$LnPr\_Share_i = \mathrm{Pr}\_Share_0 + \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d_{SUB}^{-1}} + \beta_3 \mathrm{DnPop^{-1}} - \beta_4 \mathrm{E/P} - \beta_5 \mathrm{LnShareNMTrans} + \beta_6 \mathrm{LnPrTransIn} + \beta_7 \mathrm{Growth9101} + \beta_8 \mathrm{Socioeco} + \varepsilon$$

(equation 30)

Where (Pu_Share_i) and (Pr_Share_i) are the share of commuters-to-work of municipality (i) that use public / private means of transport over the total number of commuters-to-work respectively, (Pu_Share_0) and (Pr_Share_0) are the intercept of the regression models, (d_{CBD}) is the distance from municipality (i) to the CBD, (d_{SUB}^{-1}) is the distance from municipality (i) to the nearest Sub-centre, ($DnPop^{-1}$) is the net population density, (E/P) is the ratio between employment and population, (ShareNTrans) is the market share of soft means of transport made by commuters in the municipality (i), (PrTransIn) is the share of commuters-to-work that use motorized private means of transport over the total employment in a given municipality (i), (Growth9101) is the percent growth rate of population from 1991 to 2001 for each municipality (i) in the metropolitan area, and, (Socioeco) is a socioeconomic factor for a each municipality (i) [redacted] the purpose is that this socioeconomic factor could be a proxy for income,. Then, β coefficients represent the gradients associated with each independent variable and the sign of these coefficients are expected to be according to the hypotheses explained in the previous Section 4.2 and (Ɛ) is the vector of error terms.

$$AvPuTime_i = AvPuTime_0 + \beta_1 d_{CBD} - \beta_2 d_{SUB}^{-1} - \beta_3 LnDnPop + \varepsilon$$

(equation 31)

$$AvPrTime_i = AvPrTime_0 - \beta_1 d_{CBD} - \beta_2 d_{SUB}^{-1} + \beta_3 LnDnPop + \varepsilon$$

(equation 32)

Where ($AvPuTime_i$) and ($AvPrTime_i$) are the average commuting time when public / private means of transport are used respectively for workers in municipality (i), ($AvPuTime_0$) and ($AvPrTime_0$) are the intercept of the regression models, (d_{CBD}) is the distance from municipality (i) to the CBD, (d_{SUB}^{-1}) is the distance from municipality (i) to the nearest Sub-centre, (DnPop) is the net population density and finally β coefficients represent the gradients associated with each independent variable and the sign of these coefficients are expected to be according to the hypotheses explained in the previous Section 4.2 and (Ɛ) is the vector of error terms. In addition, in order to examine in-depth the influence of the urban structure on commuting patterns, it is also studied as previously, the influence of sub-centre according to its characterization: large and emerging proposed by (Masip, 2012a) but in this case, on the factor of location and efficiency of the public and private means of transport. Starting from the previous (equations 29 to 32), the following (equation 33 to 36) and (equation 37 to 40) show the estimated regression models by ordinary least squares (OLS) taking into account large and emerging subcentre influence:

$$LnPu\_Share_i = Pu\_Share_0 - \beta_1 d_{CBD} + \beta_2 d_{SUB\ LARGE}^{-1} - \beta_3 DnPop^{-1} + \beta_4 E/P + \beta_5 LnShareNMTrans - \beta_6 Growth9101 + \beta_7 Socioeco + \varepsilon$$

(equation 33)

$$LnPu\_Share_i = Pu\_Share_0 - \beta_1 d_{CBD} + \beta_2 d_{SUB\ EMERGING}^{-1} - \beta_3 DnPop^{-1} + \beta_4 E/P + \beta_5 LnShareNMTrans - \beta_6 Growth9101 + \beta_7 Socioeco + \varepsilon$$

(equation 34)

$$Ln\_PrShare_i = \mathrm{Pr}Share_0 + \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d^{-1}_{SUB\ LARGE}} + \beta_3 \mathrm{DnPop^{-1}} - \beta_4 \mathrm{E/P} - \beta_5 \mathrm{LnShareNMTr} + \beta_6 \mathrm{LnPrTrIn} + \beta_7 \mathrm{Growth9101} + \beta_8 \mathrm{Socioec} + \mathcal{E}$$

(equation 35)

$$Ln\_PrShare_i = \mathrm{Pr}Share_0 + \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d^{-1}_{SUB\ EMERGING}} + \beta_3 \mathrm{DnPop^{-1}} - \beta_4 \mathrm{E/P} - \beta_5 \mathrm{LnShareNMTr} + \beta_6 \mathrm{LnPrTrIn} + \beta_7 \mathrm{Growth9101} + \beta_8 \mathrm{Socioec} + \mathcal{E}$$

(equation 36)

$$AvPuTime_i = AvPuTime_0 + \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d^{-1}_{SUB\ LARGE}} - \beta_3 \mathrm{LnDnPop} + \mathcal{E}$$

(equation 37)

$$AvPuTime_i = AvPuTime_0 + \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d^{-1}_{SUB\ EMERGING}} - \beta_3 \mathrm{LnDnPop} + \mathcal{E}$$

(equation 38)

$$AvPrTime_i = Av\mathrm{Pr}Time_0 - \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d^{-1}_{SUB\ LARGE}} + \beta_3 \mathrm{LnDnPop} + \mathcal{E}$$

(equation 39)

$$AvPrTime_i = Av\mathrm{Pr}Time_0 - \beta_1 \mathrm{d_{CBD}} - \beta_2 \mathrm{d^{-1}_{SUB\ EMERGING}} + \beta_3 \mathrm{LnDnPop} + \mathcal{E}$$

(equation 40)

Hence, the following (Table 17) shows the results of what are the determinants of public and private transport location factors by taking into account the influence of all, large and emerging sub-centres as regression models expressed in (equations 29-30), (equations 33-34) and (equations 35-36) respectively. At first moment, the results highlight that urban structure exerts a significant influence on localization (concentration) of public and private transport, and it is virtuous to rise public means of transport concentration (competitiveness) and to reduce the private ones: a) the independent variables related to urban structure (distance to CBD, distance to the nearest sub-centre and net population density) are all statistically significant and they have the expected sign corroborating the previous hypotheses explained in Section 4.2, centres defined by means of CBD and sub-centres are virtuous to become highly relevant for public transport localization and to reduce the concentration of private means of transport. Hence by comparing (column 1) with (column 2) the statistically negative sign of (β_1=-0,01973***) and the statistically positive sign of (β_1=0,00253***) respectively, reveal that as we move away from the central city of Barcelona (CBD), the lower (higher) is the presence of public (private) means of transport. Then, on the one hand, the same is true for sub-centres but in a less extent (CBD's t-value tend to be higher than Sub-centres' significance level) due to is taken the assumption that their urbanization and localization economies exert a less considerably influence compared to CBD (inverse distance), so the statistically positive sign of (β_2=0,79187***) and the statistically negative sign of (β_2=-0,12839***) presented in (column 1) and (column 2) show that as we move away from the nearest sub-centre, the lower (higher) is also the presence of public (private) means of transport and on the other, the statistically negative sign of the net population density (measured as inverse magnitude) coefficient (β_3=-473,4643***) for public transport and the statistically positive sign coefficient (β_3=31,07537***) for private one entail that municipalities that are more compact, the higher (lower) are the public (private) means of transport, b) in addition, the results show that large sub-centres (column 1.1) and (column 2.1) are more efficient than emerging ones (column 1.2) and (column 1.3) to be able to decrease the concentration of private means of transport due to its t-value which is (-3,70730) are fairly higher than the emerging's ones (-3,65325). However, surprisingly the latter ones are more virtuous than large sub-centres to strengthen public transport's market due to in this case they present a higher t-value, (2,94305) versus (2,85446), and finally c) these difference between large and emerging sub-centres efficiency in order to exert influence on the public and private transport concentration in municipalities is also shown by the difference in terms of capacity of explanatory power of the set of regressions models. In terms of public transport, when the large sub-centres have taken into account (column 1.1) the regression model presents the lowest adjusted R^2, 57,24% compared to when the emerging ones are considered (column 1.2) which is 57,38% and compared to when all sub-centres (both large and emerging) are taken into account, which its regression model explains the 57,87% of the public transport localization in municipalities. Inversely, as regards private transport, the emerging sub-centres regression model presents the lowest adjusted R^2, 82,90% compared to large ones regression model, 82,94% and in comparison with when all sub-centres have taken into account, which model presents a adjusted R^2 of 83,21%, so the highest explanatory capacity to explain the concentration of private means of transport.

Secondly, when other urban spatial structure and control variables are included as regards transportation and sociodemographic determinants, the two sets of regressions models (column 1 to 1.2) and (column 2 to 2.2) reveals that a) the majority of variables are statistically significant and they have the expected sign and, b) there no conceptually changes in terms of significance levels and influence that they exert on competitiveness of public and private means of transport when is taken into account different type of sub-centres according to its nature formation. Hence, referring with transportation control variables, the results present that a) the share of no motorized transport in municipalities exerts a statistically effect in public and private transport localization and its effect is according with what we expected, corroborating the hypotheses: the statistically positive sign of (β_5=0,40122***) coefficient for public transport (column 1) and the statistically negative sign of (β_5=-12734***) coefficient for private transport (column 2) entail that the higher is the market share of no motorized means of transport (walking and bicycling trips) in municipalities, the higher (lower) are public and private means of transport concentration (market share, so competiveness) in these municipalities, so soft means of transport are clearly related to public transport presence and, b) the private transport intensity measured as the share of commuters-to-work that use motorized private means of transport over the total employment in a given municipality (i) exerts the expected (positive, β_6=0,20840***) statistically influence on private transport: is obvious that the higher is the intensity of private transport in a municipality, the higher is its market share (presence) in this municipality.

Then, as regards sociodemographic control variable, the two sets of regression model results reveal that the socioeconomic factor control variable which is a proxy of income presents a unclear sign but it is accorded to what we find previously when income were negatively statistically associated with social and environmental costs of commuting what suggests that people with higher wages tend to live in centres (CBD and sub-centres) or in their adjacent municipalities, so the statistically positive sign of (β_8=2,44136**) coefficient for public transport (column 1) and the statistically negative sign of (β_8=-0,75152***) coefficient for private means of transport (column 2) entail that the higher is the income for resident employed population in a given municipality (i), the higher (lower) is the presence of public (private) means of transport localization (competitiveness) respectively.

Table 17. Spatial determinants of location factors for means of transport. Regression models estimated by Ordinary Least Squares (OLS): all, large and emerging sub-centres

Dependent Variables	Y = Ln Share Public Transport 2001			Y = Ln Share Private Transport 2001		
Independent Variables (OLS Model)	(1)	(1.1)	(1.2)	(2)	(2.1)	(2.2)
Constant	-1,18560***	-1,13984***	-1,11119***	-0,75900***	-0,76436***	-0,77088***
(t-value)	(-4,67468)	(-4,4831)	(-4,45241)	(-23,43266)	(-23,52598)	(-24,10407)
(probability)	0,00000	0,00000	0,00001	0,00000	0,00000	0,00000
Distance to Barcelona - CBD	-0,01973***	-0,02039***	-0,02081***	0,00253***	0,00262***	0,00271***
(t-value)	(-6,12506)	(-6,33663)	(-6,58629)	(6,12488)	(6,35328)	(6,66691)
(probability)	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
Distance to nearest Subcentre	0,79187***			-0,12830***		
(t-value)	(3,25313)			(-4,05161)		
(probability)	0,00139			0,00008		
Distance to nearest Large Subcentre		0,68149***			-0,11482***	
(t-value)		(2,85446)			(-3,70730)	
(probability)		0,00489			0,00029	
Distance to nearest Emerging Subcentre			0,67588***			-0,10949***
(t-value)			(2,94305)			(-3,65325)
(probability)			0,00374			0,00035
Population Density (inverse)	-473,4643***	-476,1256***	-480,5033***	31,07537***	31,37685***	32,17444***
(t-value)	(-5,61448)	(-5,60582)	(-5,66896)	(2,88237)	(2,88797)	(2,95887)
(probability)	0,00000	0,00000	0,00000	0,00450	0,00443	0,00357
Employment residents ratio (LTL / Pob)	-0,69701***	-0,67191***	-0,69269***	0,51924***	0,52258***	0,52250***
(t-value)	(-3,24290)	(-3,11119)	(-3,20262)	(8,43057)	(8,42275)	(8,40960)
(probability)	0,00144	0,00221	0,00165	0,00000	0,00000	0,00000
Share no motorized transport (Ln)	0,40122***	0,40979***	0,39990***	-0,12734***	-0,12728***	-0,12645***
(t-value)	(4,45352)	(4,52369)	(4,39784)	(-8,67506)	(-8,60328)	(-8,53546)
(probability)	0,00001	0,00000	0,00002	0,00000	0,00000	0,00000
Private transport intensity (Ln)				0,20840***	0,21224***	0,210561***
(t-value)				(6,89018)	(6,98476)	(6,89925)
(probability)				0,00000	0,00000	0,00000
Growth rate of population 1991-2001	0,29109**	0,30138**	0,29286**	-0,02629*	-0,028123*	-0,02664*
(t-value)	(2,42925)	(2,49605)	(2,42997)	(-1,71591)	(-1,82068)	(-1,72301)
(probability)	0,01626	0,01359	0,01623	0,08817	0,07058	0,08688
Socioeconomic factor	2,44136**	2,44159**	2,36746*	-0,75152***	-0,74325***	-0,73580***
(t-value)	(2,04328)	(2,02733)	(1,96581)	(-4,67204)	(-4,58409)	(-4,53165)
(probability)	0,04270	0,044331	0,05109	0,00000	0,00000	0,00001
Number of observations	164	164	164	164	164	164
R-squared	0,59683	0,59085	0,59213	0,84035	0,83782	0,83744
Adjusted R-squared	0,57874	0,57249	0,57382	0,83211	0,82945	0,82905
F-statistic	32,9912	32,1832	32,3537	101,986	100,095	99,8129
F (sig)	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
Log likelihood	-122,26	-123,468	-123,212	215,778	214,49	214,297

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

Finally, the determinants related to urban structure based on job-housing balance, measured as the ratio between employment to population and referring with demographic dynamics of the population based on new urban settlements of expansion, measured as percent growth of population since 1991 for each municipality, although they exert a statistically influence on the concentration of public and private means of transport, they presented the unexpected signs according to the results of the two estimated sets of regression models, so contradicting the hypotheses that this study made in the previous Section 4.2. The former determinant, present a negative statistically sign (β_4=-0,69701***) as (column 1) shows for the public transport and a positive statistically sign (β_4=0,51924***) as (column 2) reveals for the private transport, so what it means is that the higher a municipality is job-oriented, the lower (higher) is the presence of public and private transport. This is not accorded what current in the literature has suggested due to is expected that the higher a job-oriented municipality is and so, the higher are the urbanization and localization economies there, the higher should be the presence of public transport in such cities. Hence, the more plausible explanation is that in this case, by selecting employment to resident ratio as an indicator of job-housing balance and imbalance in municipalities is not reveals correctly if an area is job or residential oriented. Then, as regards the latter determinant, the results show a positive statistically sign (β_7=0,29109**) as (column 1) depicts for the public transport and a negative statistically sign (β_7=-0,02629*) as (column 2) reveals for the private transport, so what it means is that the higher a municipality has grown in terms of inhabitants since 1991, so the higher has been its urban expansion (new settlements), the higher (lower) competitiveness of public (private) means of transport respectively. Again, this is not accorded to the state of art due to it is reasonable that new settlements (faster urbanization process) has not been provided yet for public transport. However, in this case, there is a reason that it could explain these results and are accorded to what we find previously: since 1991 the municipalities that most have grown in terms of population percent growth are the centres (CBD and sub-centres) and their neighbours' municipalities and as results, these satisfies a higher (lower) concentration of public (private) transport market respectively in such urban areas.

In terms of public and private transport efficiency, the following (Table 18) presents the results of urban structure influence by taking into account the effects that exert all, large and emerging sub-centres according to the regression models expressed in (equations 31-32), (equations 37-38) and (equations 39-40) respectively. The results of these two sets of regression models present that: a) urban structure variables could only explain 17,07% of the public transport efficiency (column 1) and a quite less, 11,83% as regards private transport (column 2) in addition, b) all variables are statistically significant and have the expected sign according to the hypotheses with the exception of population density that are related to urban compactness. Hence, the statistically positive sign (β_1=0,20125***) coefficient for public transport as (column 1) is depicting and the statistically negative sign (β_1=-0,09362***) presented in (column 2), reveal that we expected, public transport are more efficient in CBD contrary to private transport: as we move away from the central city of Barcelona (CBD), the lower (higher) is the efficiency (less average time commuters spend by travelling from home-to-work) of public (private) means of transport because of CBD's urbanization and localization economies aims to commuters to use public transport compared to private ones to prevent negative externalities that occurs in CBD, i.e. congestion, that causes an excessive spent time to commute if they use private means of transport. As a result, this is accorded what this study found previously in the sense that CBD helps to arise public transport competitiveness (concentration) compared to the private ones. Then, on the one hand, the same is true for sub-centres but in a less extent (CBD's t-value tend to be higher than sub-centres' significance level) due to is taken the assumption that their urbanization and localization economies exert a less considerably influence compared to CBD (inverse distance), so the statistically negative sign of (β_2=-7,50889**) and the statistically also negative sign of (β_2=-3,51527*) presented in (column 1) and (column 2) show that as we move away from the nearest sub-centre, the lower is the efficiency of both public and private means of transport but more accentuated for the public ones. These results are according to what we expected in terms of public transport efficiency but it seems that in the case of private ones not. However, as we took the assumption that sub-centres' urbanization and localization economies are lower compared to CBD's ones, it is more likely that in sub-centres the negative externalities due to agglomeration are also lower, i.e. congestion and consequently, workers could commute by private transport because of it is not cause a highly considerably increment of its commuting time. On the other hand, as we mentioned before, the results show that urban compactness by means of net population density exert an unexpected influence on public and private transport efficiency which contradict the hypothesis presented in Section 4.2.: the positive statistically sign of (β_3=0,86281**) for public time in 2001 and the negative statistically sign of (β_3=-0,74903***) for private one imply that the higher is the urban compactness the higher (lower) is the average time spent by commuters that use public (private) transport, so the lower (higher) is its efficiency respectively. A reasonable explanation about this conclusion is that in this case of population density, it also takes into account congestion effect which causes distortions in the results.

Table 18. Spatial determinants of public and private transport efficiency. Regression models estimated by Ordinary Least Squares (OLS): all, large and emerging sub-centres

Dependent Variables	Y = Public Time 2001			Y = Private time 2001		
Independent Variables (OLS Model)	(1)	(1.2)	(1.3)	(2)	(2.1)	(2.2)
Constant	32,81971***	32,68297***	32,29589***	33,68904***	33,52211***	33,44918***
(t-value)	(8,71480)	(8,70610)	(8,62779)	(15,68692)	(15,59759)	(15,68078)
(probability)	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
Distance to Barcelona - CBD	0,20215***	0,20350***	0,21059***	-0,09701***	-0,09362***	-0,09323***
(t-value)	(4,46723)	(4,52496)	(4,74726)	(-3,75947)	(-3,63636)	(-3,68816)
(probability)	0,00000	0,00000	0,00000	0,0002	0,00037	0,00030
Distance to nearest Subcentre	-7,50889**			-3,51527*		
(t-value)	(-2,31110)			(-1,89719)		
(probability)	0,02210			0,05960		
Distance to nearest Large Subcentre		-7,42671**			-2,85736*	
(t-value)		(-2,34774)			(-1,80776)	
(probability)		0,02011			0,08659	
Distance to nearest Emerging Subcentre			-6,72074**			-3,18887*
(t-value)			(-2,21813)			(-1,84687)
(probability)			0,02795			0,066612
Population Density (Ln)	0,86281**	0,85748**	0,84857**	-0,74903***	-0,76084***	-0,75504***
(t-value)	(2,36732)	(2,35660)	(2,32901)	(-3,60388)	(-3,65289)	(-3,63652)
(probability)	0,01911	0,01965	0,02110	0,0004	0,00035	0,00037
Number of observations	164	164	164	164	164	164
R-squared	0,18601	0,18685	0,18393	0,11834	0,11232	0,11733
Adjusted R-squared	0,17075	0,17160	0,16863	0,10181	0,09567	0,10078
F-statistic	12,1877	12,2555	12,021	7,15903	6,74861	7,08938
F (sig)	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
Log likelihood	-553,051	-552,966	-553,26	-460,938	-461,497	-461,033

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

Finally, c) the results show that large sub-centres (column 1.1) and (column 2.1) are more efficient than emerging ones (column 1.2) and (column 1.3) to be able to increase (decrease) the efficiency of public (private) means of transport respectively, because of its t-value what is (-2,34774) are fairly higher than the emerging's ones (-2,21813) related to public transport and quite lower (-1,80776) compared to emerging's significance level which is (-1,84687) in the case of private transport. In addition this difference between large and emerging sub-centres ability in order to exert influence on the public and private transport efficiency is also shown by the difference in terms of capacity of explanatory power of the set of regressions models: as regards public transport, when large sub-centres have taken into account the regression model present higher adjusted R^2, 18,68% compared to when emerging ones are considered, 16,86% and inversely, in terms of private transport, the regression model that considers emerging sub-centres presents a higher adjusted R^2, 10,07% in comparison with the large's one, 9,56%.

5. CONCLUSIONS, FINAL REMARKS

Our study has attempt to contribute to the current literature as regards the relationship between urban spatial structure and commuting patterns by a) giving a new perspective of urban scale analysis focused on intra-urban level by examining the influence that sub-centres exert on the social and environmental costs of mobility as well as on location factors and efficiency of public and private transport, b) filling the lack of empirical research in these issues in the Barcelona Metropolitan Region and finally, c) drawing future polices that enhance social and environmental sustainability in the aforementioned study case by using the previous achieved results of sub-centres' and CBD's (polycentric urban structure) influence on commuting patterns.

The descriptive and regression analysis that we carried out in Section 3.2 and Section 4-4.4 respectively, suggest that polycentric spatial structure by means of CBD and sub-centres are virtuous to define a more intra-metropolitan efficient mobility pattern because of they are able to reduce the social and environmental costs of mobility at the time that they increase the competitiveness and efficiency of more sustainable means of transport. As regards the former analysis, we can remark briefly that a) the co-location hypothesis in the Barcelona Metropolitan Region since 1991 is corroborated due to people who live in sub-centres is also employed there and other people working in sub-centres live close to them. For example the descriptive analysis stand out that in 2001, a percentage of 63,17% of the workers living in a large sub-centre have a job in a sub-centre and as regards emerging ones this share is around 55,34%. In addition, for the same year by focusing on jobs that they have, the analysis reveals that in large sub-centres 19,87% of jobs are filled by workers from other municipalities and 62,87% by residents compared to emerging ones which due to its lower urbanization economies but higher in occasions, localization ones could attract more workers but retain less, so the previous percentages for emerging sub-centres are around 26,98% and 40,77% respectively and finally, b) the average commuting distance for residents in subcentres since 1991 have been shorten at the point that it is almost equal of average commuting distance for CBD's employed residents in 2001, so the resident employed population that commute less to reach on its workplace has located its households first in the CBD, then in sub-centres and finally in other municipalities. Referring with the regression analysis, the results of the estimated models mainly present that a) urban spatial structure factors considerably matter on the social and environmental costs and the concentration and efficiency of public and private means of transport and, b) other control variables related to transport, sociodemographic dynamics, housing characteristics and geographical location are necessary to explain more efficiently the previous points as regards costs of commuting.

In detail, the regression models estimated by Ordinary Least Squares (OLS), Spatial Lag Model (SLM) and Spatial Error Model (SEM) in each correspondingly case, reveal that a) centres (CBD and sub-centres) are able to reduce both average commuting distance and CO_2 emissions per commuter at the time that they could able to increase the competitiveness and efficiency of public transport and minimizes the private ones, b) these influences that centres exert are not equally across centres, CBD are more virtuous than sub-centres and, between sub-centres the large ones are more efficient than the emerging ones, c) urban compactness and job balance and diversity of land are also exert a remarkable influence on the aim of minimizing the aforementioned costs of commuting and achieving a more sustainable means of transport in Barcelona's metropolitan municipalities, although as regards compactness and job-balance influence on concentration and efficiency of means of transport they present a unexpected effect, d) socioeconomic characteristics, even though in the literature has suggested that it is positively associated with long commuting distances and consequently higher CO_2 emissions, our study has found that it is statistically negatively associated with them due to it seems that employed population with higher income in Barcelona Metropolitan region tend to live in CBD and in sub-centres or in its neighbouring municipalities so, they commute shorter and finally, e) human capital and demographics dynamics of cities focusing on new urban settlements are positive associated with both higher commuting distance for workers and environmental costs of mobility. Thus, it seems that planning a metropolitan area by taking into account centres by means of CBD and sub-centres entails a more sustainable mobility pattern because they are remarkably able to prevent and reduce the private and external costs due to mobility.

Finally, for future research, the findings of this work may entail a revisiting of the compact city concept. By taking the spatial structure approach of the compact city, although there are many studies in the literature that encourages policy-makers to promote the compact city of dense development focused around downtown (CBD) in order to reduce the need to travel long distances, to consume less energy and resources and to achieve higher economic performance, other studies have such as (Gordon and Richardson, 1997; Echenique et al. 2012 and; Gaigné et al., 2012) prospect that it is not a desirable goal due to the negative externalities that generates or that there no significant positive benefits. In that sense, Gaigné's work, pointed out that policy-makers should pay more attention to the various implications of urban compactness due to the increasing-density policy affects prices, wages and land rents which could reshape the urban system and entailing a higher level of negative externalities such as social inequity, congestion and pollution. However, by analyzing the three different models: a) compaction, b) market-led dispersal and c) planned expansion that Echenique's study proposes and by thinking a little bit more about the main results that the present study reaches on: municipalities identified as sub-centres exert a meaningful influence to enhance sustainability by means of reduction of social and environmental costs due to commuting. This it brings in mind that in-between of the models proposed by Echenique's study, a new urban structure model of planning metro areas could emerge, on the basis of the next research question: why we do not propose and promote a urban structure model at intra-metropolitan scale based on a set of compact cities formed by CBD and its surrounding sub-centres?. In this sense, the work carried out by (Masip, 2012b) complements this current research by showing that sub-centres not only exert virtuous influence on achieving a more efficient social and environmental commuting patterns but also, they are able to be positively associated with economic efficiency by means of labour productivity and firm formation.

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APPENDIX

In this section is reported the results by estimating the regression models that explain the determinants of social and environmental costs due to mobility by using Ordinary Least Squares (OLS) and Spatial Lag Model (SLM) for the former case, and Spatial Lag Model (SLM) and Spatial Error Model (SEM) for the latter one.

Table A1. Spatial determinants of social costs due to commuting. Regression models estimated by Ordinary Least Squares (OLS) : all sub-centres

Dependent Variable	Y = Ln Average commuting distance (2001, 1996, 1991)					
Independent Variables (OLS Model)	(1) 1991	(1) 1996	(1) 2001	(2) 1991	(2) 1996	(2) 2001
Constant	2,09127***	2,15645***	2,04044***	-13,53189	-57,37503	-46,18739*
(t-value)	(22,80688)	(28,70992)	(30,50617)	(-0,27510)	(-1,49516)	(-1,78410)
(probability)	0,00000	0,00000	0,00000	0,78361	0,13691	0,07637
Distance to Barcelona - CBD	0,00177	0,00334*	0,00621***	0,00244	0,00391**	0,00503***
(t-value)	(0,90067)	(1,89349)	(3,81319)	(1,25244)	(2,18827)	(3,64921)
(probability)	0,36913	0,06010	0,00019	0,21233	0,03015	0,00035
Distance to nearest Subcentre (inverse)	-0,58617***	-0,35121***	-0,37329***	-0,47805***	-0,19436*	-0,23121**
(t-value)	(-3,27213)	(-2,76091)	(-3,02264)	(-3,01250)	(-1,66964)	(-2,36594)
(probability)	0,00131	0,00643	0,00291	0,00303	0,09702	0,01922
Population Density (inverse)	126,8574***	232,9989***	229,2104***	92,12715***	185,1595***	198,335***
(t-value)	(4,91411)	(6,99496)	(6,36475)	(3,64167)	(5,55530)	(6,42000)
(probability)	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
Land use balance				-0,06814	-0,24310*	-0,24062***
(t-value)				(-0,43921)	(-1,88977)	(-2,68263)
(probability)				0,66112	0,06066	0,00810
Employment residents ratio (LTL / Pob)				-0,09907	-0,19232	-0,31570***
(t-value)				(-0,63015)	(-1,53725)	(-3,33482)
(probability)				0,52953	0,12628	0,00106
Socioeconomic factor				-1,91972***	-1,91352***	-2,74721***
(t-value)				(-2,58301)	(-2,79645)	(-5,48251)
(probability)				0,01073	0,00582	0,00000
Human Capital (%)				3,76743***	1,48055***	1,08928***
(t-value)				(6,82854)	(4,01096)	(4,95105)
(probability)				0,00000	0,00000	0,00000
Average Age (Ln)				2,02233	7,83748	6,36269*
(t-value)				(0,31186)	(1,54914)	(1,86403)
(probability)				0,75557	0,12339	0,06422
Coast Municipalities				-0,01734	0,11611*	0,19303***
(t-value)				(-0,20491)	(1,74078)	(4,02458)
(probability)				0,83790	0,08371	0,00008
Number of observations	164	164	164	164	164	164
R-squared	0,22670	0,36786	0,431987	0,44095	0,51626	0,67883
Adjusted R-squared	0,21201	0,356011	0,421337	0,40785	0,48799	0,66006
F-statistic	15,4398	31,0366	40,5612	13,3214	18,2616	36,1673
F (sig)	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
Log likelihood	-92,7288	-52,6155	-17,1594	-66,4495	-30,6754	29,5963

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

The previous (Table A1) and the following (Table A2 and A3) summarize the first set of regression models in terms of social (private) costs of commuting taking into account all, large and emerging sub-centres respectively.

Table A2. Spatial determinants of social costs due to commuting. Regression models estimated by Ordinary Least Squares (OLS) : large sub-centres

Dependent Variable	Y = Ln Average commuting distance (2001, 1996, 1991)					
Independent Variables (OLS Model)	(1) 1991	(1) 1996	(1) 2001	(2) 1991	(2) 1996	(2) 2001
Constant	2,07775***	2,15136***	2,02628***	-21,8202	-58,91090	-44,97311*
(t-value)	(21,9795)	(29,09421)	(31,24828)	(-0,44027)	(-1,54233)	(-1,73937)
(probability)	0,00000	0,00000	0,00000	0,66035	0,12504	0,08396
Distance to Barcelona - CBD	0,00133	0,00306*	0,00638***	0,00215	0,00374**	0,00500***
(t-value)	(0,65719)	(1,71969)	(3,94754)	(1,07966)	(2,08372)	(3,65863)
(probability)	0,51201	0,08742	0,00011	0,28199	0,03883	0,00034
Distance to nearest Large Subcentre	-0,46466**	-0,35119***	-0,35361***	-0,37363**	-0,20246*	-0,24020***
(t-value)	(-2,54295)	(-2,81657)	(-2,92830)	(-2,32977)	(-1,78359)	(-2,53652)
(probability)	0,01195	0,00546	0,00390	0,02113	0,07645	0,01219
Population Density (inverse)	128,6995	235,6895***	228,7602***	91,67491***	185,9443***	197,0456***
(t-value)	(4,92220)	(7,11699)	(6,33524)	(3,58123)	(5,59250)	(6,39248)
(probability)	0,00000	0,00000	0,00000	0,00045	0,00000	0,00000
Land use balance				-0,06434	-0,24463*	-0,24601***
(t-value)				(-0,40941)	(-1,90577)	(-2,75643)
(probability)				0,68281	0,05854	0,00654
Employment residents ratio (LTL / Pob)				-0,12541	-0,19727	-0,31651***
(t-value)				(-0,79098)	(-1,58258)	(-3,35553)
(probability)				0,43018	0,11556	0,00099
Socioeconomic factor				-1,93961**	-1,88966***	-2,73827***
(t-value)				(-2,57892)	(-2,76221)	(-5,47813)
(probability)				0,01085	0,00644	0,00000
Human Capital (%)				3,79805***	1,46659***	1,09607***
(t-value)				(6,80757)	(3,97333)	(4,99774)
(probability)				0,00000	0,00010	0,00000
Average Age (Ln)				3,11451	8,04045	6,20256*
(t-value)				(0,47668)	(1,59662)	(1,81939)
(probability)				0,63427	0,11240	0,07079
Coast Municipalities				-0,03016	0,11544*	0,19418***
(t-value)				(-0,35309)	(1,73269)	(4,05790)
(probability)				0,72450	0,08515	0,00000
Number of observations	164	164	164	164	164	164
R-squared	0,20676	0,36903	0,43009	0,42800	0,51747	0,68051
Adjusted R-squared	0,19170	0,35720	0,41941	0,39413	0,48927	0,66183
F-statistic	13,728	31,1928	40,2496	12,6373	18,3503	36,4465
F (sig)	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
Log likelihood	-94,7906	-52,4638	-17,4321	-68,3047	-30,4699	30,0249

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

Table A3. Spatial determinants of social costs due to commuting. Regression models estimated by Ordinary Least Squares (OLS) : emerging sub-centres

Dependent Variable	Y = Ln Average commuting distance (2001, 1996, 1991)					
Independent Variables (OLS Model)	(1) 1991	(1) 1996	(1) 2001	(2) 1991	(2) 1996	(2) 2001
Constant	2,03786***	2,12637***	2,02057***	-11,64679	-57,99878	-44,99238***
(t-value)	(23,58741)	(29,45962)	(33,12861)	(-0,23632)	(-1,50282)	(-1,72634)
(probability)	0,00000	0,00000	0,00000	0,81350	0,13493	0,08629
Distance to Barcelona - CBD	0,00259	0,00370**	0,00644***	0,00312*	0,00414**	0,00532***
(t-value)	(1,32238)	(2,10032)	(4,08118)	(1,60522)	(2,32406)	(3,93975)
(probability)	0,18795	0,03726	0,00007	0,110520	0,02142	0,00012
Distance to nearest Emerging Subcentre	-0,59748***	-0,30189**	-0,38150***	-0,46931***	-0,15173	-0,20260**
(t-value)	(-3,43569)	(-2,43946)	(-3,33721)	(-3,00232)	(-1,33864)	(-2,20443)
(probability)	0,00075	0,01580	0,00105	0,00313	0,18266	0,02897
Population Density (inverse)	126,2492***	234,9019***	229,7714***	93,28046***	186,6657***	200,091***
(t-value)	(4,90526)	(7,01924)	(6,42956)	(3,68728)	(5,58848)	(6,46267)
(probability)	0,00000	0,00000	0,00000	0,00031	0,00000	0,00000
Land use balance				-0,06445	-0,24282*	-0,23667***
(t-value)				(-0,41515)	(-1,87801)	(-2,62495)
(probability)				0,67861	0,06226	0,00953
Employment residents ratio (LTL / Pob)				-0,12509	-0,20092	-0,31901***
(t-value)				(-0,79821)	(-1,60457)	(-3,36489)
(probability)				0,42598	0,11063	0,00096
Socioeconomic factor				-1,8514**	-1,91483***	-2,71570***
(t-value)				(-2,48451)	(-2,78736)	(-5,40026)
(probability)				0,01405	0,00598	0,00000
Human Capital (%)				3,71271***	1,49087***	1,08260***
(t-value)				(6,71877)	(4,02748)	(4,90487)
(probability)				0,00000	0,00000	0,00000
Average Age (Ln)				1,76883	7,91718	6,20243*
(t-value)				(0,27223)	(1,55597)	(1,80492)
(probability)				0,78581	0,12176	0,07304
Coast Municipalities				-0,00346	0,11818*	0,18811***
(t-value)				(-0,04070)	(1,76617)	(3,92585)
(probability)				0,96757	0,07934	0,00013
Number of observations	164	164	164	164	164	164
R-squared	0,23169	0,36149	0,43862	0,44074	0,51317	0,67734
Adjusted R-squared	0,21711	0,34952	0,42810	0,40762	0,48471	0,65848
F-statistic	15,8827	30,1952	41,6719	133.099	18,0369	35,9209
F (sig)	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000
Log likelihood	-92,2037	-53,4374	-16,1952	-66,4803	-31,1979	29,2162

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

Then, the following (Table A4, A5 and A6) summarize the second set of regression models estimated by spatial lag models method for social costs due to mobility by taking into account all, large and emerging sub-centres respectively.

Table A4. Spatial determinants of social costs due to commuting. Regression models estimated by Spatial Lag Model (SLM): all sub-centres

Dependent Variable	Y = Ln Average commuting distance (2001, 1996, 1991)					
Independent Variables (Spatial Lag Model)	(1) 1991	(1) 1996	(1) 2001	(2) 1991	(2) 1996	(2) 2001
W*Ln Average commuting distance	0,19875*	0,19655**	0,33331***	0,10156	0,06435	0,13899*
(t-value)	(1,92320)	(1,97310)	(3,57704)	(1,08622)	(0,69889)	(1,73987)
(probability)	0,05445	0,04848	0,00347	0,27738	0,48461	0,08188
Constant	1,65480***	1,72421***	1,37812***	-15,55939	-57,17682	2,30992***
(t-value)	(7,30205)	(7,69864)	(6,99276)	(-0,32793)	(-1,53892)	(8,39162)
(probability)	0,00000	0,00000	0,00000	0,74296	0,12382	0,00000
Distance to Barcelona - CBD	0,00172	0,00245	0,00314*	0,00243	0,00358*	0,00394***
(t-value)	(0,87582)	(1,3383)	(1,79323)	(1,2686)	(1,93774)	(2,63467)
(probability)	0,38112	0,18079	0,07293	0,20458	0,052654	0,00842
Distance to nearest Subcentre (inverse)	-0,5357***	-0,32167***	-0,34281***	-0,45386***	-0,18787*	-0,20976**
(t-value)	(-3,0647)	(-2,59441)	(-2,95713)	(-2,95151)	(-1,66228)	(-2,23174)
(probability)	0,00217	0,00947	0,00310	0,00316	0,09646	0,02563
Population Density (inverse)	120,7862***	223,6911***	212,911***	89,45403***	182,0115***	184,376***
(t-value)	(4,77782)	(6,84608)	(6,26828)	(3,65598)	(5,62312)	(6,21283)
(probability)	0,00000	0,00000	0,00000	0,00025	0,00000	0,00000
Land use balance				-0,06438	-0,24486**	-0,23873***
(t-value)				(-0,42973)	(-1,96740)	(-2,80249)
(probability)				0,66738	0,04913	0,00507
Employment residents ratio (LTL / Pob)				-0,08181	-0,18109	-0,29994***
(t-value)				(-0,53744)	(-1,48781)	(-3,28080)
(probability)				0,59095	0,13679	0,00103
Socioeconomic factor				-1,91544***	-1,89057***	-2,65283***
(t-value)				(-2,67050)	(-2,85434)	(-5,56822)
(probability)				0,00757	0,00431	0,00000
Human Capital (%)				3,69226***	1,44276***	1,02628***
(t-value)				(6,84742)	(4,00504)	(4,80420)
(probability)				0,00000	0,00000	0,00000
Average Age (Ln)				2,26017	7,79344	-0,14690**
(t-value)				(0,36132)	(1,59064)	(-2,44786)
(probability)				0,71785	0,11168	0,01437
Coast Municipalities				-0,01926	0,10788*	0,17015***
(t-value)				(-0,23508)	(1,65064)	(3,63185)
(probability)				0,81414	0,09881	0,00028
Number of observations	164	164	164	164	164	164
R-squared	0,24910	0,38794	0,48971	0,44568	0,51799	0,68948
Adjusted R-squared	-	-	-	-	-	-
F-statistic	-	-	-	-	-	-
F (sig)	-	-	-	-	-	-
Log likelihood	-90,9959	-50,6058	-10,2913	-65,9265	-30,4468	32,0463

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

Table A5. Spatial determinants of social costs due to commuting. Regression models estimated by Spatial Lag Model (SLM): large sub-centres

Dependent Variable	Y = Ln Average commuting distance (2001, 1996, 1991)					
Independent Variables (Spatial Lag Model)	(1) 1991	(1) 1996	(1) 2001	(2) 1991	(2) 1996	(2) 2001
W*Ln Average commuting distance	0,21819**	0,20540**	0,33522***	0,12058	0,07046	0,13238*
(t-value)	(2,10979)	(2,06513)	(3,59847)	(1,28626)	(0,76590)	(1,64348)
(probability)	0,03487	0,03890	0,00032	0,198350	0,44373	0,10028
Constant	1,60083***	1,70282***	1,36203***	-23,66696	-58,51127	-45,10174*
(t-value)	(7,10947)	(7,69338)	(6,95776)	(-0,49595)	(-1,58262)	(-1,81807)
(probability)	0,00000	0,00000	0,00000	0,61992	0,11350	0,06905
Distance to Barcelona - CBD	0,00130	0,00213	0,00327*	0,00215	0,00338*	0,00384***
(t-value)	(0,64637)	(1,15003)	(1,87457)	(1,09861)	(1,81519)	(2,54719)
(probability)	0,51803	0,25013	0,06085	0,27193	0,06949	0,01085
Distance to nearest Large Subcentre	-0,42519**	-0,33089***	-0,32678***	-0,35345**	-0,19896*	-0,22978**
(t-value)	(-2,39815)	(6,94228)	(-2,88780)	(-2,28708)	(-1,81215)	(-2,51539)
(probability)	0,01647	0,00000	0,00387	0,02219	0,06996	0,01188
Population Density (inverse)	121,7939***	225,3408***	212,3182***	88,5159***	182,4029***	188,2757***
(t-value)	(4,76982)	(6,94228)	(6,23590)	(3,57973)	(5,64777)	(6,33195)
(probability)	0,00000	0,00000	0,00000	0,00034	0,00000	0,00000
Land use balance				-0,05994	-0,24620**	-0,24717***
(t-value)				(-0,39567)	(-1,98312)	(-2,88658)
(probability)				0,69234	0,04735	0,00389
Employment residents ratio (LTL / Pob)				-0,10323	-0,18449	-0,29045***
(t-value)				(-0,67383)	(-1,52082)	(-3,17511)
(probability)				0,50041	0,12830	0,00149
Socioeconomic factor				-1,93258***	-1,86370***	-2,67297***
(t-value)				(-2,66653)	(-2,81507)	(-5,56219)
(probability)				0,00766	0,00487	0,00000
Human Capital (%)				3,70689***	1,42474***	1,04215***
(t-value)				(6,80862)	(3,95431)	(4,85737)
(probability)				0,00000	0,00000	0,00000
Average Age (Ln)				3,32309	7,96823	6,18529*
(t-value)				(0,52820)	(1,63431)	(1,89087)
(probability)				0,59735	0,10219	0,05864
Coast Municipalities				-0,03164	0,10641	0,17318***
(t-value)				(-0,38313)	(1,63065)	(3,68189)
(probability)				0,70161	0,10296	0,00024
Number of observations	164	164	164	164	164	164
R-squared	0,23444	0,39108	0,48861	0,43481	0,51956	0,68682
Adjusted R-squared	-	-	-	-	-	-
F-statistic	-	-	-	-	-	-
F (sig)	-	-	-	-	-	-
Log likelihood	-92,7003	-50,245	-10,4911	-67,5675	-30,1936	31,377

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

Table A6. Spatial determinants of social costs due to commuting. Regression models estimated by Spatial Lag Model (SLM): emerging sub-centres

Dependent Variable	Y = Ln Average commuting distance (2001, 1996, 1991)					
Independent Variables (Spatial Lag Model)	(1) 1991	(1) 1996	(1) 2001	(2) 1991	(2) 1996	(2) 2001
W*Ln Average commuting distance	0,20388**	0,20526**	0,33004***	0,10677	0,06945	0,13482*
(t-value)	(1,98010)	(2,06610)	(3,56058)	(1,14402)	(0,75438)	(1,67394)
(probability)	0,04769	0,03881	0,00037	0,25261	0,45061	0,09414
Constant	1,59584***	1,67845***	1,36604***	-13,75217	-57,7468	-45,14649*
(t-value)	(7,1915)	(7,58136)	(7,06222)	(-0,28943)	(-1,54590)	(-1,80601)
(probability)	0,00000	0,00000	0,00000	0,77225	0,12212	0,07091
Distance to Barcelona - CBD	0,002470	0,00273	0,00338**	0,00307*	0,00377**	0,00413***
(t-value)	(1,26080)	(1,49292)	(1,96994)	(1,60749)	(2,04437)	(2,75591)
(probability)	0,20737	0,13545	0,04884	0,10794	0,04091	0,00585
Distance to nearest Emerging Subcentre	-0,55454***	-0,27923**	-0,34954***	-0,44725***	-0,14657	-0,19312
(t-value)	(-3,27654)	(-2,32048)	(-3,25497)	(-2,96245)	(-1,33354)	(-2,17516)
(probability)	0,00105	0,02031	0,00000	0,00305	0,18235	0,02961
Population Density (inverse)	119,9205***	224,8409***	213,6244***	90,40609***	183,2082***	191,0237***
(t-value)	(4,7761)	(6,85736)	(6,33399)	(3,69604)	(5,6485)	(6,39709)
(probability)	0,00000	0,00000	0,00000	0,00021	0,00000	0,00000
Land use balance				-0,06052	-0,24469**	-0,23833***
(t-value)				(-0,40386)	(-1,95666)	(-2,7560)
(probability)				0,68630	0,05038	0,00585
Employment residents ratio (LTL / Pob)				-0,10546	-0,18846	-0,29241***
(t-value)				(-0,69511)	(-1,5474)	(-3,18316)
(probability)				0,48698	0,12176	0,00145
Socioeconomic factor				-1,84922***	-1,88988***	-2,65035***
(t-value)				(-2,57296)	(-2,84297)	(-5,48575)
(probability)				0,01008	0,00446	0,00000
Human Capital (%)				3,63599***	1,44966***	1,02836***
(t-value)				(6,73615)	(4,01347)	(4,76943)
(probability)				0,00000	0,00005	0,00000
Average Age (Ln)				2,01571	7,86474	6,18800*
(t-value)				(0,32177)	(1,59653)	(1,8772)
(probability)				0,74762	0,11036	0,06048
Coast Municipalities				-0,06022	0,10922*	0,16698***
(t-value)				(-0,07316)	(1,66602)	(3,54526)
(probability)				0,94167	0,09570	0,00039
Number of observations	164	164	164	164	164	164
R-squared	0,25531	0,38361	0,49485	0,44599	0,51520	0,68391
Adjusted R-squared	-	-	-	-	-	-
F-statistic	-	-	-	-	-	-
F (sig)	-	-	-	-	-	-
Log likelihood	-90,3588	-51,2432	-9,42027	-65,8987	-30,9318	30,6093

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

Finally, the following (Table B1 and B2) summarize the set of regression models estimated by spatial lag models and spatial error model method for environmental costs due to mobility.

Table B1. Spatial determinants of environmental costs due to commuting. Regression models estimated by Spatial Lag Model (SLM): all, large and emerging sub-centres

Dependent Variable		Y = Environmental Index 2001 (CO2 emissions on the basis of transport mode choice and distance travelled by commuters)		
Independent Variables (Spatial Lag Model)		(2)	(2.2)	(2.3)
W* Environmental Index		-0,04219	-0,04108	-0,04281
	(t-value)	(-0,51304)	(-0,49898)	(-0,52084)
	(probability)	0,60792	0,61779	0,60247
Constant		0,58242***	0,58152***	0,55889***
	(t-value)	(4,65817)	(4,66577)	(4,56012)
	(probability)	0,00000	0,00000	0,00000
Distance to Barcelona - CBD		0,00975***	0,00982***	0,01010***
	(t-value)	(5,17280)	(5,22499)	(5,41379)
	(probability)	0,00000	0,00000	0,00000
Distance to nearest Subcentre (inverse)		-0,26664**		
	(t-value)	(-2,39430)		
	(probability)	0,01665		
Distance to nearest Large Subcentre			-0,26075**	
	(t-value)		(-2,40826)	
	(probability)		0,01602	
Distance to nearest Emerging Subcentre				-0,23856**
	(t-value)			(-2,28641)
	(probability)			0,02223
Population Density (inverse)		129,8784***	129,6039***	131,243***
	(t-value)	(3,06876)	(3,06230)	(3,09715)
	(probability)	0,00214	0,00219	0,00195
Land use balance		-0,33775***	-0,34589***	-0,33436***
	(t-value)	(-3,41811)	(-3,51419)	(-3,36935)
	(probability)	0,00063	0,00044	0,00075
Competitveness Private/Public Transport (Ln)		0,51306***	0,51499***	0,51332***
	(t-value)	(6,13077)	(6,15272)	(6,12430)
	(probability)	0,00000	0,00000	0,00000
Growth rate of population 1991-2001		0,25597***	0,25187***	0,25600***
	(t-value)	(4,81399)	(4,72871)	(4,80735)
	(probability)	0,00000	0,00000	0,00000
Socioeconomic factor		-1,68581***	-1,68048***	-1,64255***
	(t-value)	(-2,98012)	(-2,97036)	(-2,89289)
	(probability)	0,002881	0,00297	0,00381
Human Capital (%)		1,00332***	1,01477***	0,99613***
	(t-value)	(3,88709)	(3,93401)	(3,85072)
	(probability)	0,00010	0,00008	0,00011
Coast Municipalities		0,07518	0,07623	0,06993
	(t-value)	(1,35979)	(1,37830)	(1,26605)
	(probability)	0,17389	0,16810	0,20549
Number of observations		164	164	164
R-squared		0,71481	0,71490	0,71395
Adjusted R-squared		-	-	-
F-statistic		-	-	-
F (sig)		-	-	-
Log likelihood		2,12789	2,15444	1,88109

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration

Table B2. Spatial determinants of environmental costs due to commuting. Regression models estimated by Spatial Error Model (SEM): all, large and emerging sub-centres

Dependent Variable		Y = Environmental Index 2001 (CO2 emissions on the basis of transport mode choice and distance travelled by commuters)		
Independent Variables (Spatial Error Model)		(3)	(3.1)	(3.2)
Constant		0,52936***	0,53010***	0,50458***
	(t-value)	(4,46262)	(4,48661)	(4,33974)
	(probability)	0,00000	0,00000	0,00001
Distance to Barcelona - CBD		0,00912***	0,00922***	0,00947***
	(t-value)	(5,33351)	(5,45372)	(5,63870)
	(probability)	0,00000	0,00000	0,00000
Distance to nearest Subcentre (inverse)		-0,27276**		
	(t-value)	(-2,42843)		
	(probability)	0,01516		
Distance to nearest Large Subcentre			-0,26337**	
	(t-value)		(-2,41949)	
	(probability)		0,01554	
Distance to nearest Emerging Subcentre				-0,24295**
	(t-value)			(-2,31844)
	(probability)			0,02042
Population Density (inverse)		130,8815***	130,4164***	132,1291***
	(t-value)	(3,1306)	(3,11897)	(3,15655)
	(probability)	0,00174	0,00181	0,00159
Land use balance		-0,33178***	-0,34031***	-0,32894***
	(t-value)	(-3,33096)	(-3,42999)	(-3,29053)
	(probability)	0,00086	0,00060	0,00100
Competitveness Private/Public Transport (Ln)		0,49032***	0,49332***	0,49044***
	(t-value)	(5,93943)	(5,97352)	(5,93081)
	(probability)	0,00000	0,00000	0,00000
Growth rate of population 1991-2001		0,26598***	0,26133***	0,26625***
	(t-value)	(4,9429)	(4,85189)	(4,94034)
	(probability)	0,00000	0,00000	0,00000
Socioeconomic factor		-1,59127***	-1,59392	-1,54607***
	(t-value)	(-2,83744)	(-2,83974)	(-2,74647)
	(probability)	0,00454	0,00451	0,00602
Human Capital (%)		1,01491***	1,02464***	1,00681***
	(t-value)	(3,95614)	(4,00145)	(3,91470)
	(probability)	0,00007	0,00006	0,00009
Coast Municipalities		0,07279	0,07359	0,06783
	(t-value)	(1,28198)	(1,30006)	(1,19558)
	(probability)	0,19984	0,19357	0,23186
Lambda		0,09593	0,08701	0,09570
	(t-value)	(0,82391)	(0,74465)	(0,82182)
	(probability)	0,40998	0,45647	0,41117
Number of observations		164	164	164
R-squared		0,71565	0,71552	0,714774
Adjusted R-squared		-	-	-
F-statistic		-	-	-
F (sig)		-	-	-
Log likelihood		2,24863	2,23787	1,99657

***, **, * variables significant at 99 per cent, 95 per cent and 90 per cent respectively

Source: Own Elaboration