Universitat Autònoma de Barcelona

Three essays on urban spatial structure in the Metropolitan Area of Mexican Valley

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Introduction

1.1 Motivation

The positive and negative effects associated with the agglomeration of people and jobs are stronger in cities than elsewhere. The analysis of negative environmental externalities and their effects on the quality of life of the population, -i.e. urban unsustainability- is gaining importance in Urban Economics discussions. A number of studies argue that externalities depend on the functional features and spatial organization of urban areas (Lee and Gordon, 2011; Lemoy et al., 2012; Rossi-Hansberg and Wright, 2007; Sasaki and Mun, 1996), which in turn "depend on initial conditions including the distribution of starting activities" (Capello and Nijkamp, 2004) (p. 11). Empirical evidence on the effects of the spatial distribution of population and employment on urban metabolism is abundant, but the results are inconclusive.

In general, large cities which originally had a monocentric spatial structure where the CBD was the only significant concentration of employment are adopting urban spatial structures that can be polycentric, radial, dispersed or some combination of the three. Polycentrism can be defined as the emergence of alternative employment centers peripheral to the CBD. Both from the theoretical models of New Urban Economics, and from documents on urban planning, polycentrism is presented as a spatial structure that reproduces the benefits of employment agglomeration on a smaller scale, without having to bear the costs of congestion which are characteristic of monocentrism. The new employment centers could redirect workers living in the periphery to closer destinations. However, this improvement in the efficiency of the mobility model would only be achieved if, first, each employment center is able to affect both the intensity with which the soil is used and how it is used, not only in the subcenter itself, but also in the surrounding areas; and second, if it also manages to influence the pattern of commuting of workers who live on its periphery.

There has been neither a definitive nor generalizable response to the matter of to what extent the decentralization of employment allows it to be brought nearer to the population, thereby contributing to reducing distances of travel. Most of the empirical evidence refers to cities in the United States or Europe. Empirical literature that reflect the situation of developing countries, including Latin American countries are, however, scarce. As Aguilera and Mignot (2004) and Næss (2007) argue, the effects of form and urban spatial structure on land use and mobility may differ depending on the economic, social and demographic conditions of the city in question. A peculiarity affecting the cities of developing countries is that, while in the cities of developed countries peripheries are less dense and richer than the central areas; in developing countries, peripheries are mostly poorer and denser than most central areas. From this it follows that the results of the empirical evidence on the subject cannot be generalized “cities in developing countries are both important and problematic realities, having been the recipient of rural unemployment for a long time, and are thus loci where the rural crisis generates its negative effects: poverty, social tensions and social disease, high income inequalities, natural resource scarcity, environmental decay: they all mirror unprecedented and dramatic appearances, concentrated in particular territorial settings, and call for particular attention in spatial economic analysis” (Capello and Nijkamp, 2004)(p. 3).

In this scenario, the Metropolitan Area of the Valley of Mexico (MAMV) is a relevant case of study. The MAMV is ranked in the top three of the most populated, sprawling, congested and polluted cities of the world. Its spatial structure has evolved from a strong monocentrism, to an emerging polycentrism. These changes are the result of a long process of decentralization of the population that began in the fifties and an intense process of decentralization of employment which has taken place during the last decades.

The main aim of this thesis is to investigate to what extent polycentrism presents a more efficient model of residence-to-work mobility than monocentrism or dispersion, thus helping to reduce CO_2 emissions associated with such mobility. The specific objectives, according to how these issues were addressed in each chapter, are: analyzing a) the relationship between the urban spatial structure of the MAMV -distances to major concentrations of employment (CBD and subcenters) and main roads- with the pattern of land uses (employment and population densities), b) the relationship between both the urban spatial structure and the urban spatial form -job and population densities, also the job-population ratio- with commuting distance, and c) the relationship between the urban spatial structure and the urban spatial form with emissions of greenhouse gases (GHGs). Thus, we try to answer the question of whether a model of urban planning that is committed to polycentrism or compact city model can be a good mechanism for a more efficient and sustainable mobility model.

The thesis presents three new aspects. The first one is that it tries to deal with the problems of endogeneity that are usually present in these empirical exercises and have only recently been addressed. The second aspect is that it carries out a more thorough than usual analysis on the impact of different measures of urban spatial form and structure. The third aspect is that it is the first time that a similar analysis has been applied to Mexico City, despite its importance as one of the largest mega-cities on the planet an a typical city of the developing countries.

1.2 The Metropolitan Area of the Mexican Valley (MAMV)

The Valley of Mexico is located in the south of the closed basin of Mexico in the central plateau of the country. The altitude of the valley is 2,200 km above sea level and it is surrounded by mountains and volcanoes that reach up to 5,000 meters. According to the National Population Council (Conapo, the Spanish acronym), the MAMV encompasses Mexico City (which has 16 municipalities) and 59 more municipalities that are part of the State of Mexico (58) and of the State of *Hidalgo* (1). The surface of the MAMV is 7.8 thousand km^2, 2,200 km^2 of which are urbanized. The economic activity of the MAMV represents more than a quarter of the domestic production. In 2010, 19 million people lived in the MAMV (18% of the population of the country). The MAMV is, therefore the hub of economic activity in the country. Along with New York, the MAMV is considered the third most populous city in the world (Habitat, 2011).

Urban dynamics in the MAMV between 1995 and 2010 can be summarized in four trends: (1) the population has increased only gradually over the entire area but with greater intensity in the periphery, (2) the population is more decentralized than employment (3) the economic activity has suffered a more rapid decentralization of population and (4) the urban integration in functional terms has increased (Aguilar, 2002; Garza Villarreal, 2003; Sedesol, 2005; Sobrino, 2012). These trends are illustrated in Table 1.1.

The process of urbanization of the MAMV during the decades prior to the 1995-2010 period was dizzying. Between the fifties and eighties, the periphery of the MAMV was heavily urbanized to accommodate strong rural-urban migration. In the nineties, suburbanization was spurred by the high price of land and housing in the city center (Aguilar and Alvarado, 2005). Between 1995 and 2010, the population increased by about 4 million. However, growth was not spatially homogeneous. To contain the depopulation which had been going on in the CBD, the Government of Mexico City banned in 2002 the building of new housing or commercial areas in the nine municipalities on the border of Mexico City (part of the second and third crowns of the MAMV) while encouraging real estate development in

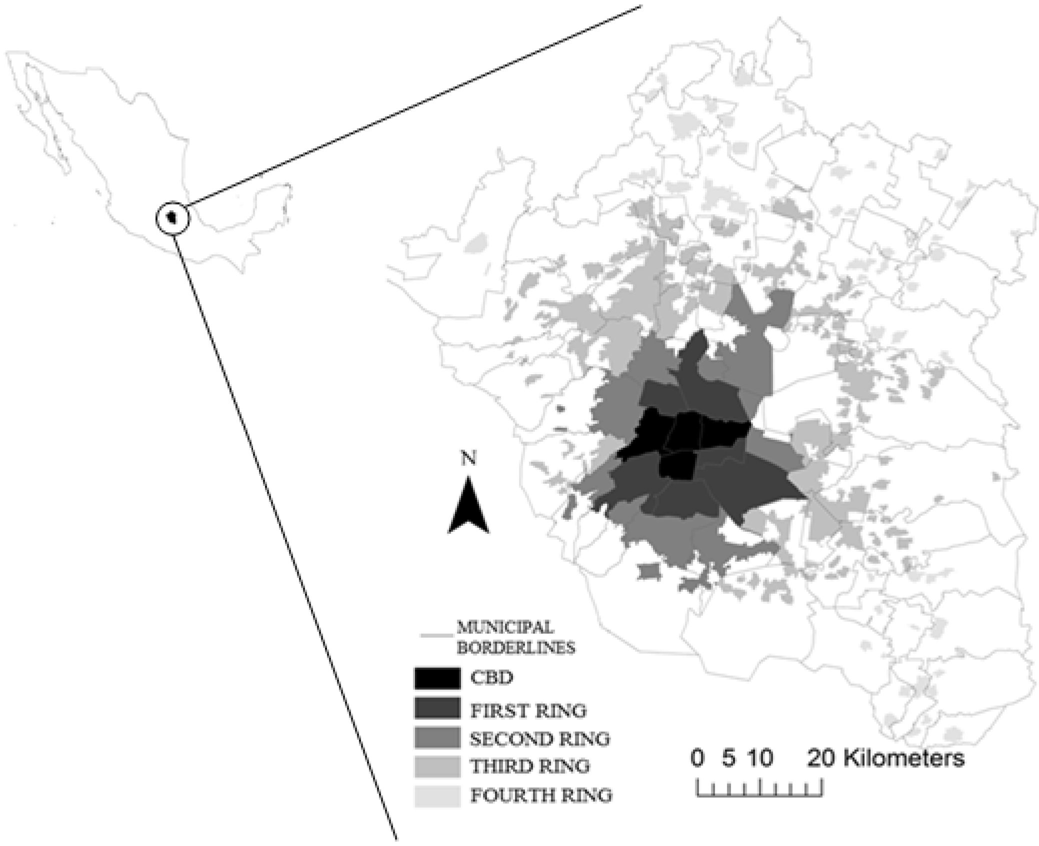


Fig. 1.1 The Metropolitan Area of Mexican Valley (MAMV) location and urbanized area

the CBD (the law was called the *Bando 2* and was adjourned in 2007). The prohibition contained the decentralization of the population, resulting in an increase in land prices in central areas, which drove part of the population to seek places of residence in the outer periphery, where the law was not in force (See the Table 1.1) (Paquette Vassalli and Delaunay, 2009). Suárez-Lastra and Delgado-Campos (2009) presents crowns forming the MAMV according to the historical process of urbanization, this classification is employed in Figure 1.1.

Regarding employment, several studies show how it has only recently been decentralized, while other researchers have shown that decentralization of employment has not occurred until recent decades, and this decentralization has given way to a polycentric urban spatial structure (Aguilar and Hernández, 2011; Graizbord et al., 2005; Pradilla, 2005; Suárez-Lastra and Delgado-Campos, 2009). However, the proportion of employment located in the historical center (in the first crown) exceeds 40%.

Finally, the mobility pattern in the MAMV is based on a preferential use of the car. Between 1990 and 2010 the travelled vehicle-kilometers (VKT) have increased significantly.

Table 1.1 Population and Employment dynamics in the MAMV between 1995 and 2010

	1995	**2010**	**Rate of Variation**
Population (million)1/	16.4	20.1	1.50%
Decentralization Index (km)	14.21	15.77	0.73%
Concentration Index	0.54	0.46	-0.99%
Employment (million)2/	2.92	4.71	4.09%
Located in the Historical Center (%)	0.49	0.41	-1.09%
Decentralization Index (km)	9.92	10.86	0.63%
Concentration Index	0.69	0.63	-0.58%

Sources: 1/INEGI. Population Count made in 1995 and Population Census made in 2010. 2/INEGI. Economic Censuses made in 1994 and 2009.

While the average annual population growth in those 20 years was 1.29%, the growth of the vehicle fleet was of 5.3%. As far as public transport is concerned, the minibuses have been the mode of transport with the greatest presence in the MAMV; 60% of all trips are carried out using this means of transport.

1.3 Thesis Structure

The dissertation consists of three chapters and final conclusions. The three chapters discuss the impact of the urban spatial form and structure on three characteristics of urban metabolism in the MAMV. The first chapter focuses on the impact of varying urban spatial structure on the intensity of land use (population and employment density) between 1995 and 2010. The second chapter discusses the role of various urban spatial form and structure indicators on the pattern of residence-to-work mobility. Finally, in the third chapter, the spatial pattern of GHG emissions associated with that mobility is analyzed in its relationship with urban spatial form and structure.

In Chapter II we analyze the relationship between the elements of the urban structure -the CBD, the employment subcenters and main roads- and the population and employment density in the MAMV in 2000 and 2010. According to theoretical models of Urban Economics, the density gradient captures the relationship between the distance to the elements of urban spatial structure and population and employment densities. The prediction of these models is that the density gradient is negative, it means if the distance increases the density decreases. The aim of the chapter is to assess the ability of subcenters to influence the intensity of land use. The main empirical challenge for the identification of the above mentioned effect is the endogeneity caused by the simultaneity in determining the spatial distribution of population and the identified urban spatial structure. To address this problem we used the Two Stage Least Squared (TSLS) estimator, which is based on measurements of urban spatial form and structure sufficiently delayed in time. The results indicate that the employment centers -the CBD as well as subcenters- and main roads are the elements that structure the pattern of land use dedicated to economic activity, implying that the classic and strong monocentrism of the MAMV has given way to an urban structure in which, in addition to the CBD, the main roads concentrate economic activity. This tendency is being reinforced with the passing of time. Regarding the population density, the CBD and subcenters are statistically relevant. While the density gradient associated with the CBD decreases between 2000 and 2010, the gradient associated with the nearest subcenter increases. In short, the employment subcenters in the MAMV structure the intensity of land use, particularly if it is residential.

In Chapter III the extent to which residing near a subcenter affects on one hand, the likelihood that a worker holds an external displacement (outside the municipality) is explicitly contrasted, and on the other hand, the distance traveled. The empirical exercise is based on the Polycentric Models of Urban Economics (White, 1999), as well as the Theory of Search (van Ommeren, 2004). As in Chapter II, the structure of the data available to us implies the presence of a potential bias due to the absence of variables that capture the preferences of individuals on transport modes. Said preferences affect location decisions of individuals, and therefore the measures related to the location of individuals in relation to the spatial structure; and they also affect the individual mobility decisions. The empirical strategy consisted of, firstly, working with a subsample of the working population who do not choose their place of residence: young people who work but who are not heads of households; and secondly, to control the self bias capturing the possible correlation between being external commuters and the distance of commuting. The results imply that the urban spatial form and structure are relevant; it means that having residence far from the CBD and subcenters increases the traveled distance. And, on the other hand, greater job-ratio (ratio between jobs and workers located in the same area) activity means less commuting. These results imply that, although the urban spatial form and structure are relevant, demographic socio mobility restrictions play a decisive role in individual mobility observed as literature search theory indicates.

In Chapter IV, we analyze the effect of the urban spatial forma and structure variables on the volume of GHG emissions associated with individual commuting in MAMV. Firstly, GHG emissions are estimated by using data from the Origin-Destination Survey, 2007 (ODS-2007) conducted by the National Institute of Statistics, Geography and Informatics (INEGI, the Spanish acronym) of Mexico; and secondly, we carried out an econometric exercise where the volume of emissions from individual GHG is explained by the urban spatial form (population density and job ratio) and urban spatial structure (employment potential, the CBD, the nearest subcenter and the main roads network) in addition to socio-demographic variables to control the individual heterogeneity. Again, the empirical challenge of this exercise is the potential presence of an endogeneity bias associated with lack of variables that capture the preferences of individuals on transport modes, and self-selection. The empirical strategy was to identify the estimated parameters with the subsample comprised of young people who are not heads of households and the use of Heckman Estimator to control the potential bias of self-selection of people who do not travel in motorized means and thus, they are assigned a volume of zero GHG emissions. The main result is an annual average of 150 kg of CO_2 emissions. As in previous chapters, the effect of the variables identified in urban spatial form and structure are in line with theoretical models. The proximity between the place of residence and any of the elements of the urban structure reduces the volume of emissions associated with mobility for work. Also, greater job-ratio implies a lower volume of individual GHG emissions. Finally, a plan based on strengthening the role of the subcenters and allowing a spatially homogeneous distribution of employment -policies that fall within the so-called Compact City Approach would reduce the individual volume of mobility associated with commuting emissions.

1.4 Elements of Urban Planning in the MAMV

Between 1950 and 1980, Mexico's economic growth was driven by a domestic policy of import substitution led to the displacement of large masses of rural population to the cities, particularly towards the Federal District of Mexico. During this period the urban area exceeded the administrative boundaries of the Federal District (Myers, 2002). Until 1993, the Federal District of Mexico, Mexico City today, was ruled by the president of the country, who appointed a staff member to carry out the tasks of government. Between 1952 and 1966, it was considered a priority to contain the proliferation of peripheral settlements. To meet this objective, housing construction was prohibited on the outskirts of the city. Compliance with this law led to conflicts with residents of new neighborhoods, so that often force had to be used, with police intervention. During these years there was a well-defined urban development plan. Over the next decade, urban planning changed course dramatically, allowing the deregulation of land use, which allowed the emergence of new urban developments on the outskirts of Mexico City.

Despite the absence of a clear urban planning policy between 1952 and 1966, there was significant progress in organizing the City; particularly, it was possible to organize a large capacity public transport based on the subway. Also, between 1966 and 1976, local government actions focused on the development of road infrastructure and the extension of the subway network. It was not until 1976 that there was a first attempt on urban planning in the area under the General Law on Human Settlements and Urban Development of the Federal District which recognized at last the "public utility and social interest of the actions of planning and ordering the uses and reserves of its territory." In spite of the existence of urban development plans, effective territorial policies reflected conflicting views (Sedesol, 2005). While in Mexico City real estate development of new areas in the border areas was prohibited and combated, the urbanization of virgin territory corresponding to the State of Mexico was promoted, leading to new settlements, such as *Netzahualcoyotl*, *Cuautitlan Izcalli* and *Valle de Chalco*. These areas stand out today due to high levels of population density. "In developing countries the policies of employment localization have taken various forms: strict zoning regulations, the prohibition of certain economic activities in particular areas, and various fiscal and financial incentives to induce industries and population to move to particular areas" (Lee, 1989)(p. 2).

In terms of the decentralization of economic activity in Mexico, a balance on the degree of industrialization between regions has been attempted. However, until well into the eighties, investments continued to head towards the northern region, particularly towards the MAMV (Myers, 2002). Locally, in the seventies, an industry relocation plan was launched in the Federal District in order to reduce air pollutants (Myers, 2002). On the other hand, actions were carried out that were aimed at decongesting the city center through the relocation of educational and sports facilities, as well as polluting industries on the outskirts of the city (Lemus, 2008). In addition, the federal government has created the Trust for Industrial Parks, Cities and Shopping Centers (Fidein, the Spanish acronym), which since 1970 has focused on promoting industrial decentralization with credits for the development of industrial parks outside Mexico City (Lemus, 2008). Despite infrastructure policies aimed at reducing congestion in the city center were launched, the combination of the lack of systematic planning of land use and insertion in the world market led to outsourcing and polarization [1] of sectorial structures of the MAMV which reinforce the decentralization of employment.

1.5 Emergence of new centers in the MAMV

The emergence of new centers of employment in the MAMV has been promoted by the Mexican state through the supply of urban equipment useful for certain activities or improvements in communications and urban services in certain areas. One way was the deliberate

[1]Clusters and highly competitive financial and industrial clusters can be identified. Outsourcing and structural polarization are the result of deindustrialization spurred by the disappearance of the micro and small uncompetitive industrial companies and the relocation of large and medium-sized enterprises.

effort to build substitutive subcenter in the MAMV, there is the case of *Cuautitlan Izcalli* as example of it. *Cuautitlan Izcalli* was created in 1971 as part of an explicit effort to "create new cities in the metropolitan area" in order "to control population growth, reduce congestion, and provide diversified jobs in the same new city" (Quiroga Leos and Oranday Dávila, 1984) (p. 123). The chosen area was located 36.5 km north of the city center, where communication infrastructure and electrical equipment already existed, as well as there being 46 large companies and also a number of small and medium enterprises. Another way to promote decentralization and the emergence of new employment centers has been the decentralization of certain urban facilities. To mention a few of these, the construction of the *Central de Abastos* (Supply Center) in 1982 south-east of the city, which concentrates trade in perishable products throughout the area; or the placement in the south of Mexico City, the National Autonomous University of Mexico (UNAM, the Spanish acronym) in 1952 and sports facilities for the Olympics in Mexico in 1968; not to mention the policies restricting the development of residential areas within the limits of the Mexico City and its counterparts, intense urbanization policies in the municipalities of the conurbation.

Most of the identified centers directly coincide with the areas taken over by the state policy: such is the case of the *Central de Abastos*, and the more peripheral subcenters, *Cuautitlan*, *Ecatepec* and *Tlalnepantla-Naucalpan*; or indirectly, as in the case of *Villa Coapa*, near the central campus of UNAM and infrastructure created especially for the 1968 Olympics Games. Finally, the subcenter of *Santa Fe*, which did not appear until 2009 west of the MAMV, was intended as a node of industrial development since the seventies. The reasons for this were that a trust had been created where the government of the Federal District would participate in providing investors with facilities in the area, such as electricity, lighting, roads, water and drainage to install industries. However, since the first half of the last decade of the twentieth century, the development project in the area changed to develop a similar area to La Defense in Paris, France. Therefore, in the past 25 years relevant investments have been made to urban equipment (Valenzuela, 2007).

1.6 The impact of distance to subcenters on population density, on commuting activity and on GHG emissions

In terms of economic policy, the aim of this document is to participate in the debate on the ability of polycentrism to influence land use of an urban area, to affect the intensity of use and to organize mobility.

The results of the empirical exercise of Chapter II show that employment subcenters structure the pattern of residential land use. That is to say, the most immediate employment centers identified have, on average, higher population densities and, as the distance increases from employment centers, the density drops. On the other hand, unlike what happens with the effect of CBD that of the subcenters was accentuated between 2000 and 2010. Based on these results, we could anticipate that polycentrism in the Valley of Mexico appears to have the ability to organize increasingly commuting mobility.

However, since the relationship between polycentrism and mobility of commuting requires a more specific study, we analyzed then the effect of proximity to employment centers on the distances of individual commuting in the MAMV using data from the XII and the XIII Population Census made by INEGI on the volume of GHG emissions. Chapter III results indicate that the population located in the vicinity of employment centers has on average lower commuting distances. This implies that residing within walking distance of an employment center results in generally lower commuting activity. Finally, the results of the empirical exercise of Chapter IV show that the commuting activity of the population located in the vicinity of employment centers is actually associated with lower levels of GHG emissions. According to the results, the determining factor in relation to the advantages linked to polycentrism in the MAMV occurs through commuting distance, which, in the case of workers who are residents in the vicinity of employment centers, is in average shorter than those of other workers.

References

Aguilar, A. G. (2002). Las mega-ciudades y las periferias expandidas. *Eure (Santiago)*, 28(85):121–149.

Aguilar, A. G. and Alvarado, C. (2005). La reestructuración del espacio urbano de la ciudad de méxico.¿ hacia la metrópoli multinodal? *Procesos metropolitanos grandes ciudades. Dinámicas recientes en México y otros países*, pages 265–308.

Aguilar, A. G. and Hernández, J. (2011). Metropolitan transformation and polycentric structure in mexico city. identification of urban subcenters 1989-2009. presentado en igu urban commission meeting 2011, canterbury christ church university, canterbury, uk, agosto 14-20, 2011. *Procesos metropolitanos grandes ciudades. Dinámicas recientes en México y otros países*, pages 265–308.

Aguilera, A. and Mignot, D. (2004). Urban sprawl, polycentrism and commuting. a comparison of seven french urban areas. *Urban Public Economics Review*, 1(1):93–114.

Capello, R. and Nijkamp, P. (2004). The theoretical and methodological toolbox of urban economics: from and towards where? *Contributions to Economic Analysis*, 266:1–27.

Garza Villarreal, G. (2003). La urbanización de méxico en el siglo xx.

Graizbord, B., Acuña, B., and Aguilar, A. G. (2005). La estructura polinuclear del área metropolitana. *Procesos metropolitanos y grandes ciudades. Dinámicas recientes en México y otros países*, pages 309–328.

Habitat, U. (2011). Cities and climate change: Global report on human settlements 2011. *London, Royaume-Uni, Etats-Unis: UN-Habitat*.

Lee, B. and Gordon, P. (2011). Urban structure: its role in urban growth, net new business formation and industrial churn. *Région et Dévelopment*, 33:137–159.

Lee, K. S. (1989). *The location of jobs in a developing metropolis*. Oxford University Press, New YOrk.

Lemoy, R., Raux, C., and Jensen, P. (2012). Exploring the polycentric city with an agent-based model. Technical report, Working paper. http://hal. archives-ouvertes. fr/hal-00602087/en.

Lemus, C. B. (2008). *Actores urbanos y políticas públicas: estrategias de los manufactureros de la Ciudad de México ante el neoliberalismo*. UNAM.

Myers, D. J. (2002). *Capital city politics in Latin America: democratization and empowerment*. Lynne Rienner Publishers.

Næss, P. (2007). The impacts of job and household decentralization on commuting distances and travel modes: Experiences from the copenhagen region and other nordic urban areas. *Informationen zur Raumentwicklung*, 2(3):149–168.

Paquette Vassalli, C. and Delaunay, D. (2009). Movilidad residencial y política de redensificación: el área central de la ciudad de méxico. *EURE (Santiago)*, 35(105):95–112.

Pradilla, E. (2005). Zona metropolitana del valle de méxico: megaciudad sin proyecto. *Ciudades: Revista del Instituto Universitario de Urbanística de la Universidad de Valladolid*, (9):83–104.

Quiroga Leos, G. and Oranday Dávila, M. d. R. (1984). La nueva ciudad de cuatitlán-izcalli: una tentativa de ordenamiento territorial y urbanismo del estado de méxico. *Gaceta Mexicana de Administración Pública Estatal y Municipal*, (10):117–146.

Rossi-Hansberg, E. and Wright, M. L. (2007). Urban structure and growth. *The Review of Economic Studies*, 74(2):597–624.

Sasaki, K. and Mun, S.-I. (1996). A dynamic analysis of multiple-center formation in a city. *Journal of Urban Economics*, 40(3):257–278.

Sedesol, C. (2005). Inegi (2007). *Delimitación de las zonas metropolitanas de México 2005*.

Sobrino, J. (2012). La urbanización en el méxico contemporáneo. *Notas de población*.

Suárez-Lastra, M. and Delgado-Campos, J. (2009). Is mexico city polycentric? a trip attraction capacity approach. *Urban Studies*, 46(10):2187–2211.

Valenzuela, A. (2007). Santa fe (méxico): Megaproyectos para una ciudad dividida. *Cuadernos Geográficos*, 40:53–66.

van Ommeren, J. (2004). Commuting: the contribution of search theory. *Contributions to Economic Analysis*, 266:347–380.

White, M. J. (1999). Urban areas with decentralized employment: Theory and empirical work. *Handbook of regional and urban economics*, 3:1375–1412.

Chapter 2

Urban Spatial Structure and Population Density in Mexican Valley from 2000 to 2010. The evolution of a polycentric urban system

2.1 Introduction

The transformation of urban spatial structure of employment taken place in the Metropolitan Area of Mexican Valley (MAMV) during recently decades have been the object of study in many works. Mexico City has being characterized by a monocentric structure; however, it has given way to a polycentric one where other employment centers have been emerging, even if this polycentrism has been qualified as incipient (Suárez-Lastra and Delgado-Campos, 2009) Papers about the polycentrism in the MAMV are focused on to identify and to describe the employment subcenters (Aguilar and Alvarado, 2005; Graizbord et al., 2005; María, 2012; Pradilla, 2005; Suárez-Lastra and Delgado-Campos, 2009) setting aside to weigh up the effect of subcenters on land prices, employment or population densities, i.e., the capacity of polycentrism to dispose land uses in the urban area.

The main objective of this article is the impact of subcenters on job and population densities in the MAMV from 2000 to 2010. The study of effects of urban spatial structure on these densities, as literature has been showed, allows:a) to test the predictions of theoretical models of reference; b) to explain differences in land prices into the metropolitan area; c) to foresee the commuting patter; and d) to understand the essence of polycentrism (Dowall and Treffeisen, 1991; McMillen and Lester, 2003; Muñiz et al., 2008).

The empirical approach used in this paper is based on static and dynamic polycentric functions of population and job density. Main empirical challenge is the endogeneity caused by mutual influence between population and job spatial distribution, and therefore between those profiles and urban spatial structure. That is why the TSLS estimator was employed in order to identify the interested effect. The MAMV apparently is evolving from a strong monocentrism to an incipient polycentrism. Though the CBD continuous being a determinant on land uses, especially on its intensity -job and population densities-; but there are new structural elements working in the MAMV. While metropolitan corridors work as a spatial organizer of job spatial distribution, the identified subcenters in its turn, appears as a spatial organizer of population distribution.

Talking about job density, the structural elements determining its performance in the MAMV was the CBD and Vial Axis. Although the magnitudes of their effects have no suffered changes over time, results imply the traditional strong monocentric structure in the MAMV has given way to a radial urban structure where vial axis work as poles of economical activity. This trend is reinforced by results about which structural elements define the variations on job densities. According to parameters of dynamic analysis, job density growth rate is larger in the vicinity of vial axis while the employment centers -the CBD and the identified subcenters- were no relevant to the observed job density variations. Results obtained by OLS suggested that employment subcenters were statistically significant in the spatial distribution of jobs at least for 2010, but the estimated parameters by the TSLS estimator shows the nearest subcenter is not statistically relevant to define the economical activity distribution.

On population spatial distribution, the CBD and the subcenters are the relevant structural elements. Once the endogeneity issues are considered, these elements appears as the statically significant to explain the population density performance. And, on the other hand, their effect change over time: while the CBD effect are diminishing between 2000 and 2010, the nearest subcenter effect is increasing. Finally when the population density rate of growth is explained, only the nearest subcenter is statistically significant.

The chapter is organized in a standard way. Section 2 reports the literature review on density functions firstly in terms of theoretical foundations and in terms on empirical approaches. Section 3 makes a review on literature analyzing the urban spatial structural changes taken place in the MAMV. Section 4 shows data sources as well as the identification empirical strategy. Section 5 presents the analysis regression. And finally, in Section 6, conclusion is exposed.

2.2 The polycentric density function

The monocentric city model (Alonso, 1960; Mills, 1967; Muth, 1961) describes an ideal city where most of the employment is located in the CBD, and land use intensity is shaped by a compensation mechanism: the bigger commuting mobility costs the lesser land price. Given that the monocentric city model imposes that the CBD concentrates most of the jobs, its main predictions are: a) land prices decrease with distance to the CBD; b) most of commuting flow starts in peripheral area and finishes in the CBD; and c) population and employment density decreases softly with distance to the CBD (Figure 2.1). These implications have been empirically tested in many cities of diverse countries and continents. Most of the research has focused on the population density performance, since mobility, localized employment and land prices data are harder to obtain. The popularity of researches on population intra-metropolitan density can also be explained because density can be controlled, at least partially, through urban planning policies.

The most common density function used to characterize a monocentric urban spatial structure is the exponential negative function. Data on population density and distance to de CBD of each area of the city allows the estimation of the two parameters of the exponential negative density function: the central theoretical density (D_0) and the density gradient (γ_2)[1] (Equation 2.1).

Equation 2.1. *Monocentric exponential negative density function*

$$lnD_i = \gamma_1 + \gamma_2 DIST_{CBD_i} + \varepsilon_i \tag{2.1}$$

In recent decades, the economic activity has decentralized. Employment subcenters have emerged as part of that process, thus giving way to spatial polycentric structures. According to the empirical literature, polycentrism is spreading around the world, affecting cities from US (Giuliano and Small, 1991; McMillen and McDonald, 1998; Shearmur and Coffey, 2002; Shukla and Waddell, 1991), Europe (Garcia-Lopez and Muñiz, 2010; Gilli, 2009; Muñiz et al., 2008; Roca et al., 2009; Veneri, 2010), Asia (Zheng, 1991), Middle East (Alperovich and Deutsch, 1996), and Latin-America (Aguilar and Alvarado, 2005; Dowall and Treffeisen, 1991; Rojas Quezada et al., 2009; Suárez-Lastra and Delgado-Campos, 2009).

Equation 2.2. *Polycentric multiplicative exponential negative density function*

$$lnD_i = \gamma_1 + \gamma_2 DIST_{CBD_i} + \sum_{n=1}^{N} \beta_n DIST_{n_i} + \varepsilon_i \tag{2.2}$$

[1] The density gradient is the slope of the negative exponential function. It measures the proportional changes in density with marginal changes in the distance from the CBD, a value constant at any distance to the CBD.

Equation 2.3. *Polycentric-substitutive exponential negative density function*

$$lnD_i = \gamma_1 + \gamma_2 DIST_{CBD_i} + \sum_{n=1}^{N} \beta_3 DIST_{nearestSBC_i} + \varepsilon_i \quad (2.3)$$

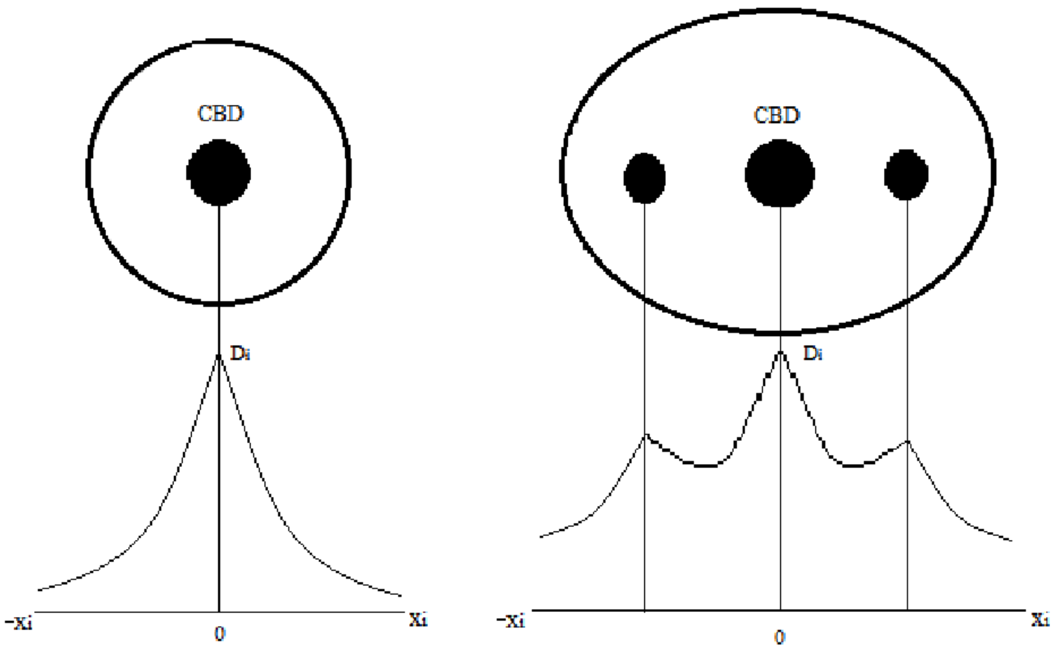


Fig. 2.1 Polycentric-substitutive exponential negative density function

The complementary polycentric density function includes as independent variables as many distances as employment centers (Equation 2.2). Thus, the regression analysis estimates a density gradient for each identified employment center (Dowall and Treffeisen, 1991; García-López et al., 2008; Muñiz et al., 2008; Song, 1992). Instead, the substitutive polycentric density function estimates only one parameter for all subcenters (distance to the closest employment center) which implies that employment subcenters are completely substitutable (Avendaño, 2013; Song, 1992; White, 1999) . In both cases the estimated gradients associated to the subcenters should be negative reproducing -at smaller scale- the effects of distance to the CBD (Figure 2.1).

Empirical literature shows similarities but also relevant differences with regard to the variety of estimated gradients in terms of value, sign and statistical significance. The main features that explain these differences can be summarize in the following points: a) the gradient of employment subcenters localized close to the main CBD can be statistically non-significant or even present a positive sign; since moving away from a subcenter implies coming near to the CBD, so instead of diminishing density with distance to the subcenter, it increases); and b) in comparison to decentralized subcenters (subcenters developed as a

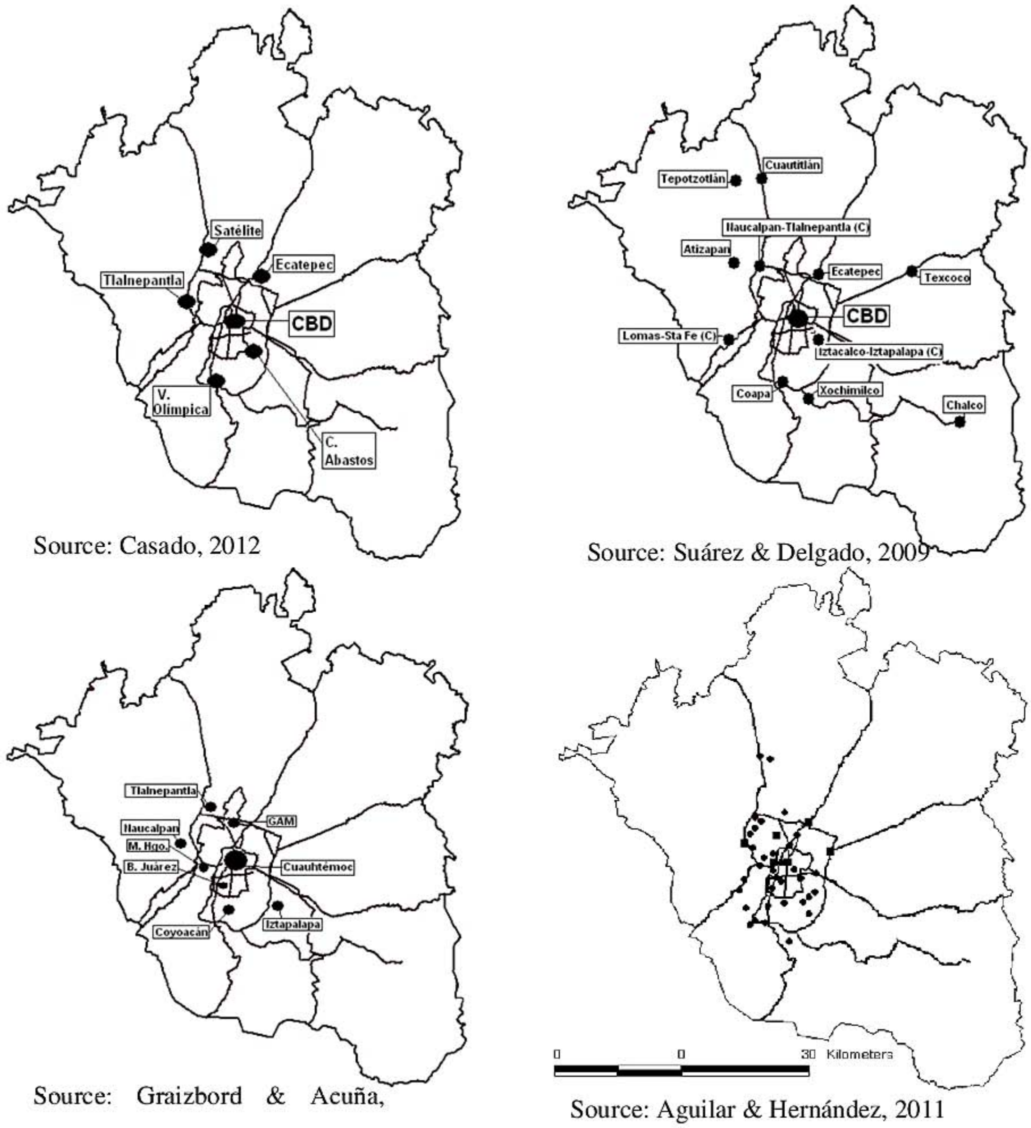


Fig. 2.2 Identified subcenters in the MAMV according to the cited studies

result of the recent decentralization of a relevant share of total employment), christallerian subcenters (former monocentric second order systems that have been functionally integrated into de main central large city) present better results in terms of sign (negative) and statistical significance.[2]

[2]Christallerian subcenters have played a structuring role in their surrounding area, affecting mobility and land prices for decades -sometimes centuries- before becoming subcenters of an integrated metropolitan region (Muñiz et al., 2008)

2.3 Literature review on the trends in the spatial population and job distribution in the MAMV

Recent literature describes the MAMV as a polycentric metropolitan region (Aguilar and Alvarado, 2005; Aguilar and Hernández, 2011; María, 2012; Suárez-Lastra and Delgado-Campos, 2009). However, these studies also highlight the relevance of the traditional CBD captured by the high share of jobs located in the CBD (Aguilar and Alvarado, 2005; Suárez-Lastra and Delgado-Campos, 2009) and the fact that the CBD is still the most common origin and destination of commuting mobility (Graizbord and Santillán, 2005; Nava, 2010).

Different methods have been used to identify employment subcenters in urban areas. In the case of the MAMV (Figure 2.2) summarizes the main results of four different researches: (1) a procedure combining three criteria: fixed thresholds for total employment, job density and/or job ratio (María, 2012); (2) a job-ratio threshold methodology combined with significant errors relative to a the estimated monocentric function (Equation 2.1) (Suárez-Lastra and Delgado-Campos, 2009); (3) a commuting flow methodology (Graizbord and Santillán, 2005), and (4) a statistical threshold method for jobs and the share of jobs in the service sector (Aguilar and Hernández, 2011)(Figure 2.2). Methodologies (1) and (3), although measuring two different forms of polycentrism (morphological the first and functional the later) give to similar results. In comparison, methodology (2) captures some employment centers in peripheral areas, and methodology (4) captures a larger number of subcenters, all of the localized close to the main CBD. Polycentrism in the MAMV has two distinctive elements. The first feature is the role of historical municipalities as embryo of emerged subcenters (Nava, 2010) (Figure 2.1). The second one is the role of vial axes as poles of attraction of economic activity configuring employment corridors with a high and relatively homogeneous job density (Pradilla, 2005).

The question related to what extent the elements that configure urban spatial structure-CBD, employment subcenters, and vial axes- vertebrate or structure the periphery affecting land prices, agglomeration economies, population and employment density and mobility patterns has been poorly addressed. Indirect evidence indicates that in those areas where subcenters have emerged the job-ratio has increased, out-commuters have diminished and the average commuting distance has decreased as well. In the rest of the area both, the share of out-commuters and the average commuting distance have increased. According to Nava (2010) and Graizbord and Santillán (2005) the net result is that average commuting distance in the entire area has increased as well.

2.4 Data and empirical strategy

2.4.1 Data

The MAMV is located in the Southeast of the Mexican Valley, in the central plateau of Mexico. It expands on a 2,249 km^2 surface area. Population in 2010 exceeds 19 million -the MAMV, along with New York Metropolitan Area, is ranked in the third place of the most populous cities in the world (Habitat, 2011). The definition of MAMV used in this research is the one provided by the Mexican National Bureau of Population (Conapo, the Spanish acronym) in 2010 and presented in Figure 1.1. The MAMV is not an administrative unit, but it works as a joint labor market (Tarriba and Alarcón, 2012).

Data sources and geographical references were provided by the Mexican National Institute of Statistics, Geography and Informatics (INEGI). Employment and population data come from Population Censuses made in 1990 and 2010 and from 1994 and 2009 Economic Censuses. The observational level is the census track (AGEB) [3]. The measure unit for Job and Population Densities variables are jobs and population per hectare, respectively. Distances are measured in kilometers.

Subcenters identification. A statistical threshold methodology was used to identify employment centers. An employment center (CBD and subcenters) is defined as a continuous group of AGEBs, all of them having higher employment densities than the average, and they -all together- must contain at least 1% of total employment in the area. This methodology based on statistical thresholds is simple, and it may be adapted to different cities and observational levels. It also avoids the effect of economic cycle on the total employment threshold methodology (Garcia-Lopez and Muñiz, 2010).

Polycentric Employment Density and Polycentric Population Density Functions. In order to identify the effect of urban spatial structural elements on population and economic activity distribution, the empirical exercise consists of the estimation of the density gradients of monocentric and polycentric density functions using the OLS estimator, but also the TSLS estimator [4]. This estimator solves most of the endogeneity problems relative to urban spatial structure variables. A pool with observations for 1990 and for 2010 was built. In addition

[3] Observed unit is the census area called AGEB. The INEGI defines AGEB as the municipal subdivision which shape the basic unit for the sample. The AGEBs' attributes are threefold: a) it is clearly noticed by physical geography b) generally they are homogeneous taking into account the geographic, economic and social features c) AGEBs can be crossed by walk.

[4] The TSLS estimator implies to introduce a variable z -call the instrumental variable- which must be (1) uncorrelated with the error u; and (2) correlated with the endogenous regressor x. The first assumption excludes the instrument from being a regressor for the dependant variable in the main specification. The second assumption requires that there is some association between the instrument and the variable being instrumented. The bivariate TSLS estimator is defined as $\beta_{tsls} = (z^{'}x)^{-1}z^{'}y)$

to the urban structure variables -Euclidian distance to the CBD, Euclidian distance to the closest identified subcenter and the minimal Euclidian distance to the vial axis-, interactions of these variables with a dummy of 2010 observations to control for changes registered in the impact of urban structure variables on densities were also included. On the other hand, the slope of the terrain, the deprivation index and a dummy equals to one if census tract is placed in the area of former lake were included to control heterogeneity. All variables are reported in Table 2.1.

Table 2.1 Variables used in the empirical exercise

Variable	Observations	Mean	Standard Deviation
ln(job density)	9,391	1.57	2.98
ln(population density)	9,391	4.55	1.15
Change of job density rate	4,000	0.79	2.06
Change of population density rate	4,000	0.20	0.69
Distance to the CBD	9,391	18.91	11.70
Distance to the closest SBC	9,391	12.22	11.25
Distance to the vial axis	9,391	3.12	3.94
Deprivation index	9,391	-0.73	1.48
Slope of the terrain	9,391	15.48	67.29
Lacustrine soil (=1)	9,391	0.30	0.46
Observed in 2010 (=1)	9,391	0.50	0.50

Sources: INEGI, the XII and XIII Population and Housing Census

2.4.2 Identifying the urban spatial structure in the MAMV

Between 1990 and 2010 both, population and jobs, have followed a decentralized and deconcentrated pattern. The De-centralization Index of Population and Jobs[5] is the average distance to the CBD weighted by population or jobs. The larger share of population (jobs) in the periphery is, the larger the De-centralization Index of Population (Jobs) is. The De-centralization Index for jobs is 14 km in 1990 and 15 km in 2010. As for jobs, the

[5]The De-concentration Index of Population and Jobs is calculated with the formula $DCCBD = \frac{1}{N}\sum(n = 1)^{N} d_{CBDn} * \frac{J_n}{J_M AMV}$ donde N is the number of census tract in the exercise, J_n is the number of jobs located in the AGEB n, J_{MAMV} is the total number of jobs in the MAMV and d_{CBDn} is the distance from the AGEB n to the CBD.

De-centralization Index increase from 9.92 km in 1994 to 10.86 km in 2009 [6]. The De-concentration Index of Population and Jobs [7] (a version of the Gini index) measures spatial concentration patterns. Its value diminished 14% for population (0.540 in 1990 and 0.461 in 2010) while 8% for employment (0.692 in 1994 and 0.633 in 2009) which indicate that population and jobs tend to be more equally distributed.

In addition to the main CBD, five employment subcenters were identified in 1994 (*Villa Coapa*, *Central de Abastos*, *Tlalnepantla*, *Ecatepec*, and *Cuautitlan*) and six in 2009 (the same subcenters identified in 1994 plus Santa Fe). Most of the subcenters are located in the first ring. Only Cuautitlán is placed in the second ring (Figure 2.3). According to the share of jobs, *Tlalnepantla* and *Central de Abastos* are the most relevant subcenters. Subcenters *Tlalnepantla*, *Ecatepec*, and *Cuautitlan* can be characterized as christallerian subcenters given their historical relevance. The other subcenters have been recently developed. Note that, although we use only two thresholds, our results are quite similar to the list of employment subcenters quoted earlier using three numerical thresholds obtained by María (2012).

Table 2.2 Index of localization by economic sector in the identified employment subcenters

Employment Center	**Industry**	**Trade**	**Serv. for firms and FIRE**	**Services for people**
CBD	0.598	0.925	2.415	1.100
Inner Subcenters				
Tlalpan (*Villa Coapa*)	0.611	0.720	1.363	1.480
Iztapalapa (*C. de Abastos*)	1.211	1.295	0.559	0.892
Alvaro Obregon (Sta. Fe)	0.627	0.815	1.598	1.057
Peripheral Subcenters				
Ecatepec	1.314	1.092	0.456	0.927
Tlalnepantla	1.552	1.270	0.753	0.812
Cuautitlan	1.576	1.409	0.722	0.805

In order to identify the economic profile of employment subcenters, sectorial localization indexes were estimated (Table 2.2). Data for localization indexes estimated at a municipal level were obtained from 2010 Population Census (INEGI). The localization indexes are estimated at a municipality level. Inner subcenters -*Villa Coapa*, *Central de Abastos* and *Santa Fe*- have an economic activity profile similar to the CBD; they are specialized in knowledge-intensive activities such as PS (producer services) and the FIRE sector (finance,

[6] Population suburbanization started decades before employment decentralization, and as a result, the increase of the decentralization index for population is lower than for jobs.

[7] In Lee (2007) the formula used is $IG = \sum_{(n=1)}^{N} J_n A_{(n-1)} - \sum_{(n=1)}^{N} A_n J_{(n-1)}$ where J_n and $J_{(n-1)}$ are the accumulated share of jobs until *AGEBs* n and $n-1$, respectively; and A_n and $A_{(n-1)}$ are the accumulated share of hectares until *AGEBs* n and $n-1$, respectively

insurance and real estate). Peripheral subcenters -*Tlalnepantla*, *Ecatepec*, and *Cuautitlan*- present a clear different profile: they are mostly specialized in manufacturing and wholesale activities.

2.5 Effect of urban spatial structure on employment and population densities

The main objective of the paper is to answer two main questions: whether spatial structural elements have an impact on the job and population spatial distribution in the MAMV demonstrating their capability to vertebrate the surrounding space; and whether these impacts have significantly changed between 1990 and 2010. This section summarizes the main results of the regression analysis. The first three columns of Table 2.3 report the estimated employment density gradients associated to each of the elements that compose the urban spatial structure (CBD, subcenters and transport infrastructure) separately taken. Column 4 in Table 2.3 presents parameters of spatial structural elements put all together in one model. The estimated parameters of column 3 present high correlations among vial axes, the distance to the CBD, and the distance to the identified subcenters, giving place a collinearity problem. In order to avoid collinearity, direct distances to subcenters and to vial axes were substituted by two transformed values: the inverse of those distances (Column 5 in Table 2.3) and the logarithm of these distances (Column 6 in Table 2.3). In each case, control variables such as the deprivation index, slope of the terrain, and kind of soil were also added.

Endogeneity is the main empirical challenge of the empirical exercise. If subcenters and vial axes were developed at the same time that economic activity choose where to locate; the reverse causality between job density and distance to the spatial urban structural elements is possible. Differently than the case of subcenters, the CBD is assumed as exogenous considering its existence since the Aztec Empire period. MAMV's CBD area is one of the most ancient continuously inhabited area in America. Therefore, the problem only can affect subcenters and vial axes variables. Columns 7, 8 and 9 in Table2.3 present the estimated parameters using the TSLS estimator, our strategy for dealing with the endogeneity problem. Two historical variables were used as sources of exogenous shocks: the population density in 1900 and the distance to the closest road existing in 1885 (Figure 2.3). The use of historical variables is common in this literature since urban spatial structure is highly resilient (Baum-Snow, 2010; Garcia-López et al., 2015). More specifically, these historical variables are correlated with subcenters location. They emerged through enlarging the market accessibility: increasing the demand -having high population density in 1900- or reducing transport costs

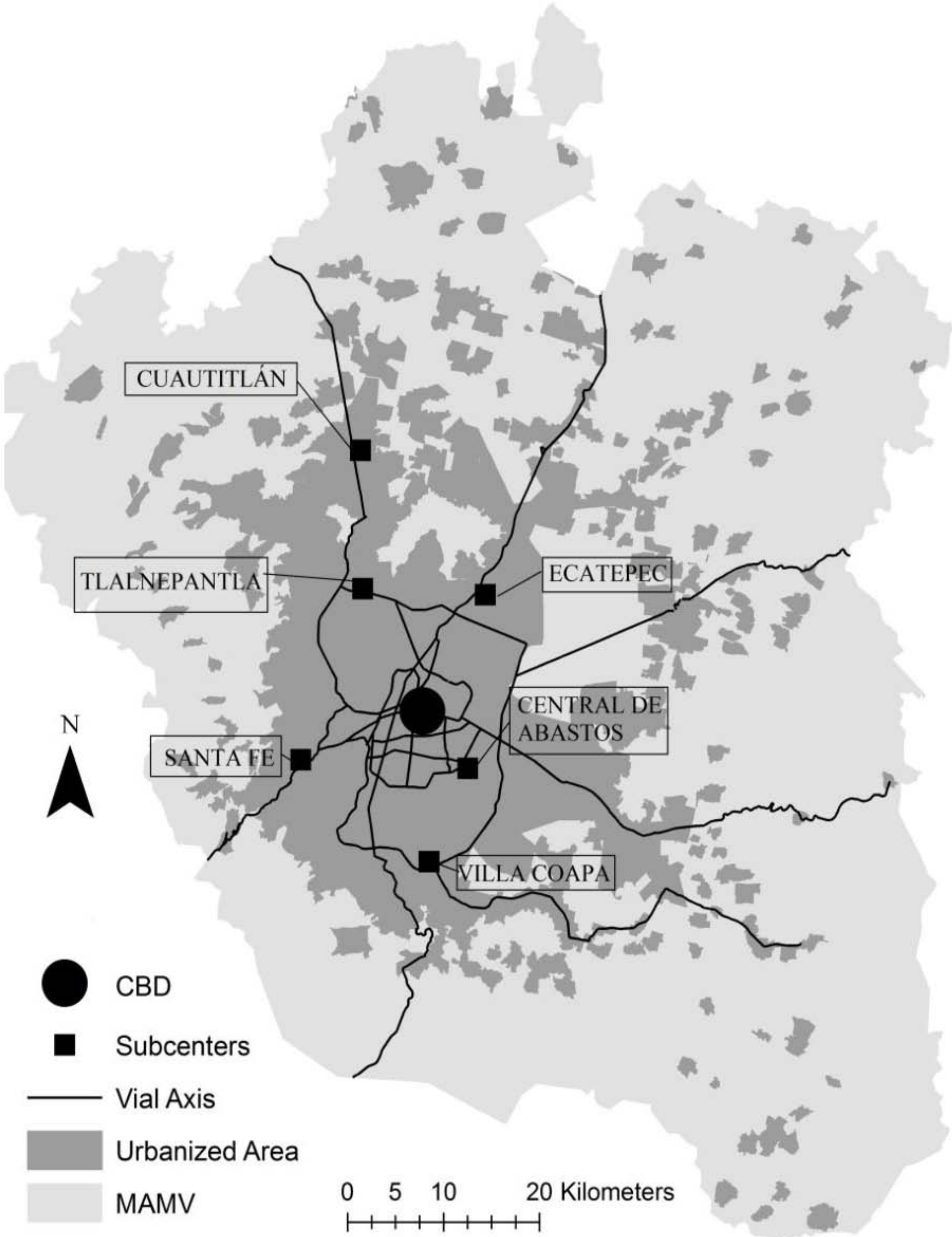


Fig. 2.3 Urban Structure in the MAMV. CBD and Identified Subcenters

-being close to roads existing in 1885-. On the other hand, historical variables are correlated with the laying of vial axes because former roads are in the bottom of the modern vial axes and modern vial axes have been built to connect urban areas in the MAMV. Whereas, the most recently economic activity and population distributions are not completely determined by former roads or populous areas considering changes in the area able to be settled thanks to lakes drained and changes in transport modes.

The job density function

The TSLS estimator. The estimation reported in Column 9 was obtained using the TSLS estimator and it considers subcenters and vial axes as endogenous variables. This is our preferred estimation of the effect of urban structural elements on job density because it allows controlling endogeneity and to identify the net effect of each urban spatial structure elements -distances to the CBD, to the nearest subcenter and to vial axis- as well as the evolution over time of this effect. Statistical tests of instrumental variables weakness -the minimal distance to the roads existing in 1885 and municipal population density in 1900- in the TSLS are reported in the bottom of the table. The reduced form and the first stage of TSLS are reported in the Annex. The instrumental variables are statistically significant and the sign of correlation of these variables with the probability of emerging a subcenter is in accordance with expectations.

Distance to the CBD. In regard to the preferred estimation (Column 9 in Table 2.3), employment density decreases with distance to the main CBD. This result is consistent with the historical and strong MAMV monocentrism. The gradient associated to the CBD has not changed between 1994 and 2009 in spite of the job decentralization process. The TSLS outcome (Column 9) is very similar to the one obtained from the OLS estimator. The magnitude of the effect implies that job density decreased 0.093% for each kilometer further to the CBD. Besides, vial axes also work as poles of attraction of economic activity. Distance to main transport infrastructure. The TSLS outcome suggests that the effect of Vial Axis on job density is statistically significant and its magnitude is larger than the one obtained from OLS. Because minimal distances to vial axes is in logarithms, job density decreases 1.22% with 1% further away from the vial axes.

Distance to employment subcenters. Table 2.3 shows the estimated parameters using the substitutive urban polycentric density function. This function assumes all employment subcenters have the same economic profile. Therefore, the relevant information to characterize the land use pattern regarding subcenters is distance to the closest subcenter instead of distances to every subcenter in the area. In regard to the effect of distance to the closer subcenter on employment density the OLS parameter implies that employment density decreases with distance to the closer subcenter in 2009, whereas in 1994 the effect was not significant. The TSLS estimator indicates that the parameter associated to distance to the closer subcenter is not statistically significant neither in 1994, nor in 2009. The complementary polycentric density function relaxes the assumption concerning to the economical profile of subcenters.

The estimated parameters by OLS associated to the complementary urban polycentric job density function are reported in the first two columns in Table II.4. According to the results in the second column, no subcenter was statistically significant in 1994; whereas three of the six identified subcenters -*Central de Abastos*, *Santa Fe*, and *Ecatepec*- had a statistically significant impact on job density values in 2010. Larger distances to subcenters imply lower employment density values. The other parameters, although most of them are negative, are not statistically relevant to explain deviations from the average employment density.

Control variables. The parameters of control variables indicate that: (1) census tracts located in the former lake area present more jobs per hectare than the other ones; (2) the grater the slope of the terrain is, the less jobs per hectare; and (3) in the OLS outcome the deprivation index is not significant, has a negative effect on the job density, it is not statistically significant. However, in the TSLS outcomes, the effect is significant, revealing the significant correlation between deprivation index and urban structure elements.

The impact of urban spatial structure on employment density changes. The last four columns in Table 2.3 show the outcomes of the model taking as dependent variable the employment density growth rate between 1994 and 2010. Independent variables include urban spatial structure and control variables as well as employment density at the start of the period, i.e. in 1994. The OLS and TSLS outcomes are quite different. The TSLS outcome implies that the distance to vial axes is the only element affecting the employment density changes. Economic activity is increasingly located closer to vial axes, becoming employment corridors. It is interesting to note that the parameter which is statistically significant and negative associated to the employment density in 1994. This result implies: 1) spatial convergence in employment density levels and 2) it also could be understood as favorable evidence to resilience of the city; I mean the past is explaining the future.

The population density function

TSLS estimator. The Table 2.5 follows the sequence of specifications in Table 2.3. In general, the polycentric specification using the logarithmic distances to subcenters and vial axes fits better to the observed population spatial distribution than using direct distances. Just as population follows employment, following the theoretical urban economic exogenous polycentric models, the economic activity is not placed randomly, but it is after increasing its access to the demand through choosing locations close to population. Therefore, the reverse causality is working also in this situation (jobs follow people). This is why instrumental variables estimator is used in addition to the OLS in order to try endogeneity bias.

Distance to the CBD. Population density decreases with distance to the CBD. The effect has diminished between 1990 and 2010. According to the TSLS outcome (Column 9), population density decreases a 0.033% in 1990 and a 0.006% in 2010 for each kilometer further to the CBD. This result is consistent with the suburbanization process which has taken place.

Distance to vial axis. The TSLS outcome indicates that vial axes do not exert an effect on population density. Distance to employment subcenters. While the distance to the CBD effect has diminished between 1990 and 2010, the effect of distance to the closer subcenter (substitutive polycentric density function) has become stronger. Population density decreases 0.457% in 1990 and 0.607% in 2010 for each 1% increase in the distance to the closer subcenter. The estimated parameters by OLS using the complementary polycentric density function are reported in the last two columns of Table 2.4. According to results -with distances in logarithms- only the three most peripheral subcenters, *Tlalnepantla*, *Cuautitlan*, and *Ecatepec*, are statistically significant for population distribution in 2010. Nevertheless *Tlalnepantla* seems to exert an effect opposite to expectations -positive.

Control variables. Control variables indicate that population density is increasing in the most deprived areas and in the most inclined terrain.

The impact of urban spatial structure on population density changes. Last columns in Table 2.5 show the outcomes of the model that takes as dependent variable population density growth. Among structural elements, only distance to the nearest subcenter affects population density growth. Distances to the CBD and to vial axis are not relevant. As was said before, in this case the statistically significant and negative parameter associated to the population density in 1994 would imply that there are on one hand a spatial convergence in population density levels and that Mex́ico is to some degree a resilient city

2.6 Summary and conclusion

The main findings are summarized in following points:

a) Population is more suburbanized and de-concentrated than jobs in the MAMV. However, between 1995 and 2010, decentralization and de-concentration have been more intense for jobs than for population. Notwithstanding, in general, the goodness of fit is greater in the population density specifications than in the job density ones.

b) Six employment subcenters were identified. All of them have been characterized as employment centers in previous literature related to the MAMV. The three subcenters closest to the CBD -*Central de Abastos, Villa Coapa*, and *Santa Fe*- have a similar economic profile than the CBD specialized in knowledge-intensive activities such as services to producers and the FIRE sector. Whereas the other three -*Tlalnepantla, Ecatepec,* and *Cuautitlan*- are specialized in industrial and wholesale activities.

c) The urban spatial structure in the MAMV is composed by three elements: the CBD, historically defined; the employment subcenters, -a more recently phenomena boosted by historical municipalities, institutional decisions, or private location decisions-; and vial axes. Therefore, to identify the effect of these elements on job and population distribution, the main empirical challenge is the endogeneity associated to simultaneous determination between job and population density with urban spatial structure. Subsequently, the TSLS estimator is useful in this context. The roads existing in 1885 and population density in 1900 were valid instruments of urban spatial structure. On the other hand, results suggest that geography and social variables are relevant to explain the spatial distribution of jobs and population.

d) The preferred results -TSLS estimator in which subcenters and vial axes are taken as endogenous variables- suggest that both, employment and population density decrease with distance to the CBD. The employment density gradient of the CBD has not changed between 1994 and 2009. However, regarding to population, the density gradient of the CBD became flatter over time, registering the population suburbanization and dispersion processes.

e) The coefficient associated to the vial axes is statistically significant in the case of employment density. It means that urban spatial structure in the MAMV is evolving to a radial structure in which employment is preferably located in the vial corridors. On the other hand, vial axes do not exert an impact on population density.

f) Subcenters have an impact on population density: the closer to an employment subcenter, the higher population density. And the effect of distance to the closer subcenter is increasing over time.

g) Finally, employment and population density levels seem to converge since density growth is negatively affected by the density level at the beginning of the period. Besides, vial axes and subcenters, not the CBD, are the structural elements behind employment and population density growth patterns.

Table 2.3 Job density as function of urban structure in the MAMV in 1994 and 2009

	Ln(JOB DENSITY)									Δ(JOB DENSITY)			
	Ordinary Least Squares Estimator (OLS)						Two Stage Least Squares Estimation			OLS	Two Stage Least Squares Estimation		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CBD	-0.114a			-0.111a	-0.113a	-0.110a	-0.124a	-0.089a	-0.093a	-0.016b	-0.023a	-0.010	-0.015
	(0.014)			(0.015)	(0.014)	(0.014)	(0.018)	(0.023)	(0.029)	(2.61)	(0.008)	(0.009)	(0.012)
CBD*2010	0.028b			0.071a	0.033a	0.061a	0.020	0.055a	0.014				
	(0.011)			(0.012)	(0.011)	(0.011)	(0.016)	(0.019)	(0.023)				
SBC		-0.070a		0.012	0.283	0.071	0.553	0.116	0.432	0.001	0.259b	0.003	0.198
		(0.017)		(0.019)	(0.244)	(0.152)	(0.439)	(0.166)	(0.481)	(0.010)	(0.132)	(0.066)	(0.143)
SBC*2010		-0.008		-0.069a	0.725b	-0.666a	0.108	-0.718a	-0.141				
		(0.016)		(0.021)	(0.340)	(0.192)	(0.332)	(0.192)	(0.316)				
Vial Axis			-0.187a	-0.059	0.015	-0.286c	-0.375b	-1.149b	-1.222b	-0.114b	-0.111b	-0.275 b	-0.263 c
			(0.052)	(0.043)	(0.010)	(0.144)	(0.191)	(0.513)	(0.487)	(2.200)	(0.052)	(0.120)	(0.139)
Vial Axis*2010			0.038	0.050	0.039a	-0.054	-0.025	0.186	0.213				
			(0.038)	(0.045)	(0.013)	(0.141)	(0.139)	(0.434)	(0.447)				
Ln (job. density) in 1994										-0.516a	-0.511a	-0.513 a	-0.514 a
										(12.090)	(0.041)	(0.041)	(0.041)
Control Variables	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R-squared	0.1887	0.1720	0.1364	0.2072	0.1926	0.2012				0.4415			
Instrumented Var.							Ln(SBC)	Ln(VA)	Ln(SBC) & Ln(VA)		Ln(SBC)	Ln(VA)	Ln(SBC) & Ln(VA)
Instrumental Var.													
Roads existing in 1810 (km)							N	Y	Y		N	Y	Y
Roads existing in 1810 (km)*2010							N	Y	Y		N	N	N
Mun. Pop. Density in 1940							Y	N	Y		Y	N	Y
Mun. Pop. Density in 1940*2010							Y	N	Y		N	N	N
Under id test KP rk test							6.94	13.54	11.77		8.96	12.616	10.31
Weak id CD Wald F test							525.29	540.49	262.51		1,024.48	326.55	143.62
Weak id KP Wald F test							14.16	8.90	9.41		28.81	17.134	16.30
Observations	9,391	9,391	9,391	9,391	9,391	9,391	9,391	9,391	9,391	4,000	4,000	4,000	4,000

[1] Standard Errors in parenthesis. a p<0.1; b p<0.05; c p<0.01. Errors are clusterized by municipality (74). Control variables are geographical variables -slope of the terrain, a dummy of lacustrine soil and socio-demographical variables -a deprivation index-. 1/ Distances to the nearest subcenter and to vial axis are introduced as a direct distance. 2/ Last two are introduced as inverse of the distances. In the rest of the specifications these distances are in logarithms.

Table 2.4 Job and Population Density as function of distances to every structural elements (CBD, subcenters and Vial Axis) (Complementary polycentric density specification)

	Ln(JOB DENSITY)		Ln(POPULATION DENSITY)	
	1.Direct distances	2. Ln(Distances)	3.Direct distances	4. Ln(Distances)
CBD	-0.200***	-0.135***	0.027	-0.037**
	(0.062)	(0.034)	(0.020)	(0.018)
CBD*2010	0.050	0.102***	0.054***	0.003
	(0.041)	(0.028)	(0.016)	(0.012)
Vial Axis	-0.059	-0.265*	0.025*	0.081***
	(0.040)	(0.143)	(0.014)	(0.028)
Vial Axis*2010	0.047	-0.101	-0.018	0.009
	(0.039)	(0.129)	(0.013)	(0.023)
Central de Abastos	0.059	0.323	-0.069***	-0.244
	(0.047)	(0.387)	(0.024)	(0.180)
Central de Abastos*2010	-0.053	-0.707***	-0.024	0.048
	(0.038)	(0.252)	(0.018)	(0.157)
Villa Coapa	0.004	0.051	0.034	0.026
	(0.037)	(0.150)	(0.022)	(0.086)
Villa Coapa*2010	-0.003	-0.181	-0.010	-0.028
	(0.032)	(0.154)	(0.013)	(0.055)
Sta Fe	0.032	0.271	-0.028	-0.094
	(0.037)	(0.298)	(0.018)	(0.180)
Sta. Fe*2010	0.012	-0.404*	-0.004	0.097
	(0.031)	(0.225)	(0.008)	(0.098)
Tlalnepantla	0.005	-0.075	-0.026	-0.091
	(0.038)	(0.202)	(0.018)	(0.115)
Tlalnepantla*2010	-0.024	-0.222	0.016	0.195***
	(0.035)	(0.169)	(0.014)	(0.072)
Cuautitl n	0.016	0.108	0.022*	0.116
	(0.025)	(0.208)	(0.012)	(0.107)
Cuautitl n*2010	-0.004	-0.017	-0.029***	-0.233***
	(0.031)	(0.242)	(0.010)	(0.080)
Ecatepec	0.010	0.113	-0.021**	-0.208**
	(0.026)	(0.215)	(0.008)	(0.093)
Ecatepec*2010	-0.025	-0.336**	0.001	0.069
	(0.028)	(0.151)	(0.006)	(0.066)
Deprivation Index	-0.147	-0.113	-0.066*	-0.052
	(0.096)	(0.100)	(0.039)	(0.039)
Slope of the terraine	-0.002**	-0.002***	-0.001***	-0.001***
	(0.001)	(0.001)	(0.000)	(0.000)
Lacustrine Soil (=1)	0.379	0.505**	0.237**	0.172
	(0.244)	(0.241)	(0.105)	(0.112)
Observations in 2010 (=1)	0.534	4.327***	0.633***	-0.176
	(0.670)	(1.308)	(0.196)	(0.905)
Constant	2.001***	1.399	5.334***	6.351***
	(0.658)	(1.395)	(0.265)	(1.254)
Adjusted R-squared	0.1920	0.1940	0.3311	0.3200
Observations	9,391	9,391	9,391	9,391

[1] Standard error in parenthesis. a p<0.1; b p<0.05; c p<0.01. Errors are clusterized by municipality (74)

Table 2.5 Population density as function of urban structure in the MAMV in 1994 and 2009

	Ln(Population density)									Δ(Population Density)			
	Ordinary Least Squares Estimator (OLS)						Two Stage Least Squares Est. (TSLS)			OLS	TSLS		
	Ln(POPULATION DENSITY)									Δ(POPULATION DENSITY)			
	Ordinary Least Squares Estimator (OLS)						Two Stage Least Squares Estimation			OLS	Two Stage Least Squares Estimation		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Ln(CBD)	-0.056a			-0.056a	-0.056a	-0.057a	-0.051a	-0.041a	-0.033a	-0.0127a	-0.008a	-0.007	-0.004
	(0.004)			(0.006)	(0.004)	(0.005)	(0.005)	(0.011)	(0.013)	(3.70)	(0.003)	(0.005)	(0.005)
Ln(CBD)*2010	0.017a			0.028a	0.016a	0.017a	0.025a	0.019a	0.027a				
	(0.003)			(0.003)	(0.003)	(0.003)	(0.004)	(0.006)	(0.008)				
Ln(SBC)		-0.053a		-0.008	-0.000	-0.064	-0.280a	-0.067	-0.457a	-0.0220	-0.162a	-0.024	-0.196a
		(0.008)		(0.009)	(0.000)	(0.057)	(0.081)	(0.081)	(0.148)	(0.64)	(0.061)	(0.038)	(0.061)
Ln(SBC)*2010		0.010b		-0.009	-0.001a	-0.014	-0.152b	-0.004	-0.150c				
		(0.005)		(0.006)	(0.000)	(0.047)	(0.064)	(0.044)	(0.084)				
Ln(Vial Axis)			-0.076a	0.020	-0.007c	0.078b	0.075b	-0.310	-0.221	0.0745	0.074a	-0.037	0.018
			(0.015)	(0.015)	(0.004)	(0.030)	(0.033)	(0.208)	(0.173)	(3.98)	(0.021)	(0.075)	(0.058)
Ln(Vial Axis)*2010			0.011	-0.024c	-0.024a	0.007	0.013	0.007	0.031				
			(0.009)	(0.013)	(0.007)	(0.026)	(0.028)	(0.093)	(0.095)				
Ln (population density) in 1990										-0.4181a	-0.422a	-0.410a	-0.419a
										(11.35)	(0.037)	(0.038)	(0.038)
Control Variables	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R-squared	0.3065	0.2566	0.2098	0.3108	0.3096	0.3132				0.5166			
Instrumented Var.							Ln(SBC)	Ln(VA)	Ln(SBC) & Ln(VA)		Ln(SBC)	Ln(VA)	Ln(SBC) & Ln(VA)
Instrumental Var.													
Roads existing in 1885 (km)							N	Y	Y		N	Y	Y
Roads existing in 1885 (km)*2010							N	Y	Y		N	N	N
Mun. Pop. Density in 1940							Y	N	Y		Y	N	Y
Mun. Pop. Density in 1940*2010							Y	N	Y		N	N	N
Under id test KP rk test							6.33	11.35	11.66		6.86	12.58	14.30
Weak id KP Wald F test							17.64	5.97	8.39		24.41	13.42	8.26
Observations	9,391	9,391	9,391	9,391	9,391	9,391	9,391	9,391	9,391	4,000	4,000	4,000	4,000

[1] Standard Errors in parenthesis. a $p<0.1$; b $p<0.05$; c $p<0.01$. Errors are clusterized by municipality (74). Control variables are geographical variables -slope of the terrain, a dummy of lacustrine soil and socio-demographical variables -a deprivation index-. 1/ Distances to the nearest subcenter and to vial axis are introduced as a direct distance. 2/ Last two are introduced as inverse of the distances. In the rest of the specifications these distances are in logarithms.

References

Aguilar, A. G. and Alvarado, C. (2005). La reestructuración del espacio urbano de la ciudad de méxico.¿ hacia la metrópoli multinodal? *Procesos metropolitanos grandes ciudades. Dinámicas recientes en México y otros países*, pages 265–308.

Aguilar, A. G. and Hernández, J. (2011). Metropolitan transformation and polycentric structure in mexico city. identification of urban subcenters 1989-2009. presentado en igu urban commission meeting 2011, canterbury christ church university, canterbury, uk, agosto 14-20, 2011. *Procesos metropolitanos grandes ciudades. Dinámicas recientes en México y otros países*, pages 265–308.

Alonso, W. (1960). A theory of the urban land market. *Papers in Regional Science*, 6(1):149–157.

Alperovich, G. and Deutsch, J. (1996). Urban structure with two coexisting and almost completely segregated populations: the case of east and west jerusalem. *Regional Science and Urban Economics*, 26(2):171–187.

Avendaño, A. (2013). *Polycentrism in Bogotá: Substitution or complementary relationships of subcenters with CBD*. PhD thesis, Tesis Doctoral, Departament Economia Aplicada, Universitat Autònoma de Barcelona.

Baum-Snow, N. (2010). Changes in transportation infrastructure and commuting patterns in us metropolitan areas, 1960–2000. *The American economic review*, 100(2):378.

Dowall, D. E. and Treffeisen, P. A. (1991). Spatial transformation in cities of the developing world: Multinucleation and land-capital substitution in bogota, colombia. *Regional Science and Urban Economics*, 21(2):201–224.

García-López, M.-Á. et al. (2008). Quince años de suburbanización en la barcelona metropolitana,¿ se está dispersando la población. *investigaciones económicas*, 32(1):53–86.

Garcia-López, M.-Á., Holl, A., and Viladecans-Marsal, E. (2015). Suburbanization and highways in spain when the romans and the bourbons still shape its cities. *Journal of Urban Economics*, 85:52–67.

Garcia-Lopez, M.-A. and Muñiz, I. (2010). Employment decentralisation: Polycentricity or scatteration? the case of barcelona. *Urban Studies*.

Gilli, F. (2009). Sprawl or reagglomeration? the dynamics of employment deconcentration and industrial transformation in greater paris. *Urban Studies*, 46(7):1385–1420.

Giuliano, G. and Small, K. A. (1991). Subcenters in the los angeles region. *Regional science and urban economics*, 21(2):163–182.

Graizbord, B., Acuña, B., and Aguilar, A. G. (2005). La estructura polinuclear del área metropolitana. *Procesos metropolitanos y grandes ciudades. Dinámicas recientes en México y otros países*, pages 309–328.

Graizbord, B. and Santillán, M. (2005). Dinámica demográfica y generación de viajes al trabajo en el amcm: 1994-2000. *Estudios demográficos y urbanos*, pages 71–101.

Habitat, U. (2011). Cities and climate change: Global report on human settlements 2011. *London, Royaume-Uni, Etats-Unis: UN-Habitat*.

Lee, B. (2007). Edge or edgeless cities? urban spatial structure in us metropolitan areas, 1980 to 2000. *Journal of Regional Science*, 47(3):479–515.

María, C.-I. J. (2012). La estructura policéntrica de los mercados laborales locales de la zona metropolitana del valle de méxico. *Investigaciones geográficas*, (79):97–118.

McMillen, D. P. and Lester, T. W. (2003). Evolving subcenters: employment and population densities in chicago, 1970–2020. *Journal of Housing Economics*, 12(1):60–81.

McMillen, D. P. and McDonald, J. F. (1998). Population density in suburban chicago: a bid-rent approach. *Urban Studies*, 35(7):1119–1130.

Mills, E. S. (1967). An aggregative model of resource allocation in a metropolitan area. *The American Economic Review*, 57(2):197–210.

Muñiz, I., Garcia-López, M. À., and Galindo, A. (2008). The effect of employment subcentres on population density in barcelona. *Urban Studies*, 45(3):627–649.

Muth, R. F. (1961). Economic change and rural-urban land conversions. *Econometrica: Journal of The Econometric Society*, pages 1–23.

Nava, E. (2010). Policentralidad y movilidad en el área metropolitana de la ciudad de méxico: variables relacionadas con la capacidad de atracción de viajes.

Pradilla, E. (2005). Zona metropolitana del valle de méxico: megaciudad sin proyecto. *Ciudades: Revista del Instituto Universitario de Urbanística de la Universidad de Valladolid*, (9):83–104.

Roca, J., Duarte, C. R. M., and Moix, M. (2009). Urban structure and polycentrism: Towards a redefinition of the sub-centre concept. *Urban Studies*, 46(13):2841–2868.

Rojas Quezada, C. A., Muñiz Olivera, I., and García-López, M. Á. (2009). Estructura urbana y policentrismo en el área metropolitana de concepción. *EURE (Santiago)*, 35(105):47–70.

Shearmur, R. and Coffey, W. J. (2002). A tale of four cities: intrametropolitan employment distribution in toronto, montreal, vancouver, and ottawa–hull, 1981–1996. *Environment and Planning A*, 34(4):575–598.

Shukla, V. and Waddell, P. (1991). Firm location and land use in discrete urban space: a study of the spatial structure of dallas-fort worth. *Regional Science and Urban Economics*, 21(2):225–253.

Song, S. (1992). Monocentric and polycentric density functions and their required commutes. *University of California Transportation Center*.

Suárez-Lastra, M. and Delgado-Campos, J. (2009). Is mexico city polycentric? a trip attraction capacity approach. *Urban Studies*, 46(10):2187–2211.

Tarriba, G. and Alarcón, G. (2012). Movilidad competitiva en la zona metropolitana de la ciudad de méxico: diagnóstico y soluciones factibles. *Instituto Mexicano para la Competitividad*.

Veneri, P. (2010). Urban polycentricity and the costs of commuting: Evidence from italian metropolitan areas. *Growth and Change*, 41(3):403–429.

White, M. J. (1999). Urban areas with decentralized employment: Theory and empirical work. *Handbook of regional and urban economics*, 3:1375–1412.

Zheng, X.-P. (1991). Metropolitan spatial structure and its determinants: a case-study of tokyo. *Urban Studies*, 28(1):87–104.

2.7 Appendix A

Table 2.6 First Stage and Reduced Form using TSLS estimator for Job density as function of urban spatial structure

	Ln(Job Density)							Δ(Job Density)				
Dependant Variable	Reduced Form			First Stage in IV				Reduced Form			First Stage in IV	
	Ln(Job Density)			Ln(SBC)	Ln(SBC)*2010	Ln(Vial Axis)	Ln(Vial Axis)*2010	Δ(Job Density)			Ln(SBC)	Ln(Vial Axis)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ln(CBD)	-0.114***	-0.112***	-0.108***	0.037***	-0.025***	0.025***	-0.015***	-0.017***	-0.020***	-0.016***	0.036***	0.029**
	(0.013)	(0.012)	(0.013)	(0.006)	(0.004)	(0.005)	(0.003)	(0.006)	(0.006)	(0.006)	(0.011)	(0.012)
Ln(CBD)*2010	0.029**	0.023*	0.025**	-0.039***	0.042***	-0.026***	0.028***					
	(0.011)	(0.012)	(0.012)	(0.005)	(0.005)	(0.005)	(0.005)					
Ln(SBC)					0.640***	0.127	-0.077					0.111
					(0.037)	(0.088)	(0.051)					(0.103)
Ln(SBC)*2010				0.992***		-0.141	0.103					
				(0.012)		(0.090)	(0.078)					
Ln(Vial Axis)				0.097	-0.070		0.545***				0.038	
				(0.071)	(0.048)		(0.006)				(0.038)	
Ln(Vial Axis)*2010				-0.107	0.092	0.988***						
				(0.075)	(0.074)	(0.009)						
Ln(Population Density in 1900)	0.021*		0.020*	0.243***	-0.156***	-0.032	0.018	0.101**		0.092*	0.336***	-0.132*
	(0.012)		(0.012)	(0.068)	(0.049)	(0.043)	(0.024)	(0.048)		(0.047)	(0.062)	(0.071)
Ln(Population Density in 1900)*2010	-0.003		-0.003	-0.240***	0.237***	0.032	-0.021					
	(0.006)		(0.005)	(0.070)	(0.056)	(0.043)	(0.043)					
Ln(Dist. to Roads in 1885)		-0.170***	-0.153**	0.024	-0.014	0.169***	-0.093***		-0.067**	-0.059*	0.004	0.236***
		(0.058)	(0.060)	(0.034)	(0.022)	(0.039)	(0.022)		(0.032)	(0.034)	(0.046)	(0.060)
Ln(Dist. to Roads in 1885)*2010		-0.016	-0.022	-0.030	0.026	-0.167***	0.179***					
		(0.067)	(0.067)	(0.034)	(0.030)	(0.039)	(0.040)					
Ln(Job Density in 1990)								-0.508***	-0.509***	-0.511***	-0.001	-0.014
								(0.042)	(0.042)	(0.042)	(0.007)	(0.011)
Control Variables	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adjusted R-squared	0.1901	0.1915	0.1922	0.8381	0.9672	0.7732	0.8957					

[1] Standard Errors in parenthesis. *p<0.1; **p<0.05; ***p<0.01. Errors are clusterized by municipality (74). Control variables are geographical variables -slope of the terrain, a dummy of lacustrine soil and socio-demographical variables -a deprivation index-. 1/ Distances to the nearest subcenter and to vial axis are introduced as a direct distance. 2/ Last two are introduced as inverse of the distances. In the rest of the specifications these distances are in logarithms.

Table 2.7 Population density as function of urban structure in the MAMV in 1994 and 2009

Dependant Variable: ln(Population Density)	Population Density							Δ(Population Density)				
	Reduced Form			First Stage in IV				Reduced Form			First Stage in IV	
	Ln(Population Density)			Ln(SBC)	Ln(SBC)*2010	Ln(Vial Axis)	Ln(Vial Axis)*2010	Δ(Population Density)			Ln(SBC)	Ln(Vial Axis)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ln(CBD)	-0.058***	-0.052***	-0.054***	0.039***	-0.022***	0.028***	-0.015***	-0.011***	-0.009***	-0.011***	0.035***	0.032***
	(0.004)	(0.005)	(0.004)	(0.007)	(0.004)	(0.007)	(0.004)	-0.003	-0.003	-0.003	(0.008)	(0.008)
Ln(CBD)*2010	0.016***	0.016***	0.016***	-0.039***	0.043***	-0.030***	0.032***					
	(0.003)	(0.003)	(0.003)	(0.007)	(0.007)	(0.008)	(0.007)					
Ln(SBC)					0.537***	0.080	-0.053					0.003
					(0.010)	(0.115)	(0.059)					(0.102)
Ln(SBC)*2010				0.976***		-0.107	0.116					
				(0.015)		(0.116)	(0.118)					
Ln(Vial Axis)				0.023	-0.017		0.506***				0.001	
				(0.035)	(0.020)		(0.012)				(0.032)	
Ln(Vial Axis)*2010				-0.030	0.036	0.988***						
				(0.036)	(0.039)	(0.006)						
Population Density in 1900	-0.013***		-0.014***	0.042***	-0.023***	-0.028***	0.015***	-0.008***		-0.008***	0.038***	-0.021***
	(0.004)		(0.004)	(0.007)	(0.004)	(0.007)	(0.004)	(0.002)		(0.002)	(0.008)	(0.007)
Population Density in 1900*2010	-0.006**		-0.006**	-0.041***	0.042***	0.029***	-0.030***					
	(0.003)		(0.003)	(0.007)	(0.007)	(0.007)	(0.007)					
Dist. to Roads in 1885		-0.028**	-0.030**	0.018	-0.010	0.079***	-0.040***		-0.010*	-0.005	0.033**	0.090***
		(0.013)	(0.013)	(0.014)	(0.008)	(0.024)	(0.012)		(0.007)	(0.007)	(0.013)	(0.026)
Dist. to Roads in 1885*2010		0.001	0.002	-0.017	0.017	-0.079***	0.082***					
		(0.008)	(0.008)	(0.014)	(0.014)	(0.024)	(0.025)					
Ln(Job Density in 1990)								-0.416***	-0.413***	-0.418***	0.001	0.086**
Control Variables	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y
Adjusted R-squared	0.3150	0.3132	0.3225	0.7707	0.9480	0.6993	0.7225	0.5102	0.5061	0.5113	0.5036	0.4038
Observations	9,391	9,391	9,391	9,391	9,391	9,391	9,391	4,000	4,000	4,000	4,000	4,000

[1] Standard Errors in parenthesis. *p<0.1; **p<0.05; ***p<0.01. Errors are clusterized by municipality (74). Control variables are geographical variables -slope of the terrain, a dummy of lacustrine soil and socio-demographical variables -a deprivation index-. 1/ Distances to the nearest subcenter and to vial axis are introduced as a direct distance. 2/ Last two are introduced as inverse of the distances. In the rest of the specifications these distances are in logarithms.

Fig. 2.4 Original Map of Roads in the Mexican Valley

Chapter 3

Urban Spatial Characteristics and Commuting in the Metropolitan Area of Mexican Valley

3.1 Introduction

The relationship between urban spatial characteristics and mobility is one of the most relevant topics in the fields of Economic Geography and Urban Economics (Banister, 1996; Cervero, 1989; ECOTEC, 1993; Gordon and Richardson, 1989; Ingram, 1998; Owens, 1986). During the last decades, the urban spatial structure of many large cities has changed significantly transforming the classical monocentric urban spatial structure into the current polycentric or scattered urban systems (Anas et al., 1998; McMillen and Lester, 2003; Muñiz et al., 2008). A number of researches analyze how these changes have impacted on mobility patterns (for example: car use (Cervero, 2002; Frank and Pivo, 1994; Schwanen et al., 2001) kilometers travelled by car (Cervero and Wu, 1997); commuting distance (Aguilera and Mignot, 2004; Næss, 2007; Parolin, 2004), energy consumption (Newman and Kenworthy, 1989), CO_2 emissions and carbon footprint (Høyer and Holden, 2003; Muñiz and Galindo, 2005). The key questions in the research are: to what extent living close to an employment center and to vial axis reduces commuting activity (urban spatial structure impact), and to what extent a high population density and job-ratio also reduce commuting activity (urban form impact).

The Metropolitan Area of Mexican Valley (MAMV) is the third most populous urban area in the world. The MAMV has been evolving towards a polycentric urban spatial structure (Aguilar and Alvarado, 2005; Pradilla, 2005; Suárez-Lastra and Delgado-Campos, 2009). Into the MAMV, 23 million journeys every day take place. In the last decades, congestion has become an outstanding issue: in 2010, the automobile average speed on peak hours was 13 km/h; while in 1990, reached 38 km/h. The average time augmented from 57 minutes in 2007 to 77 minutes in 2010 (Tarriba and Alarcón, 2012). How are these two dynamics linked? Are congestion problems related to changes in urban spatial structure pushing for a less efficient mobility or are congestion problems caused by an increasingly overwhelmed transport infrastructure? Focused on mobility flows and journey to work length, the research addresses three main questions for the case of the MAMV: 1) has recent employment decentralization lead to a more spatially homogenous job-worker ratio or job-housing balance? Also, has employment decentralization given place to a larger local self-sufficiency? 2) Are employment subcenters an alternative destination to the CBD for workers living in the periphery by conducting to a reduction in commuting distances? 3) Which is the impact of urban spatial form -population density and job ratio at census tract level- and urban spatial structure -distance to employment centers and transportation infrastructure- on commuting distance?

The adopted methodology consists on the one hand, in the statistical analysis of aggregated mobility flows (volume of commuting, local self-sufficiency and average commuting distances) which took place in 2000 and 2010 in the MAMV. Using wasteful commuting indexes, it was compared theoretical commuting activity and the actual one in order to evaluate the evolution of spatial job-housing balance. On the other hand, it was used an analysis regression to identify the impacts of urban spatial structure and form on: a) the individual decision of being out-commuter; and b) commuting distances taking into account self-selection and endogeneity issues. Results are: a) aggregated data shows a negative correlation between spatially balanced job ratio and commuting distances of out-commuters and a positive correlation between spatially balanced job ratio and local self-sufficiency; and b) according to regression analysis based on individual data and coherently with aggregated data results, over time the probability of being an out-commuter and the average distance of commuting have diminished. Regarding to the effect of urban spatial structure and form on commuting our results indicate that : a) only the Job Ratio has a negative impact on the probability of being an out-commuter, and b) Living close to an employment center (CBD and subcenters) the CBD and the closest subcenter reduces commuting activity. Altogether, results imply that the new structural elements, which would configure the polycentrism in the MAMV, are working to give way to a more efficient mobility pattern.

The reminder of this paper is organized as follows: Section 2 introduces theoretical and empirical review on the relation between journey to work and urban spatial form and structure. Section 3 presents the MAMV and data sources used in the empirical exercise. In Section 4 are exposed the empirical challenges that the proposed exercise and is synthesized the empirical strategy to identify the effects of urban spatial variables on commuting activity. Statistical and econometric results are analyzed in Section 5. Finally, Section 6 presents conclusions and non solved issues as well as possible extensions.

3.2 Literature Review

3.2.1 Theoretical Approaches

The relationship between urban spatial structure and commuting has been studied using distinct theoretical traditions. This section briefly reviews this relationship according to follow approaches: (1) Polycentric Models of Urban Economic and (2) Search Theory.

Polycentric Urban Economic Models. Polycentric models departing from Urban Economics tradition consider that the main factors shaping urban spatial structure are agglomeration economies, transportation costs and congestion. According to such models, polycentric structures -more than one employment center- emerge as a possible equilibrium where congestion costs are lower than in a monocentric city and agglomeration economies are higher than in a sprawled city (Richardson, 1988).

According to Urban Economics literature, the individual utility maximization process implies that workers choose where to live by minimizing journey to work cost (i.e. minimizing distance). In this order, land demand and land prices decrease with increasing distance to employment centers. Hence, workers choice their residence location taking into account the tradeoff between housing prices and costs of commuting at each distance to their employment place (Ross and Yinger, 1995; Sasaki, 1990; Sullivan, 1986; White, 1976, 1988, 1999). Assuming that employment centers are enough far one each other in order to take advantages of land prices and subcenters should be substitutive among them, mobility pattern should follow an "urban village" pattern described in Panel B in Figure III.1. This is the mobility performance under the co-location hypothesis. According to this, periodically workers also firms reconsider their location adjusting it to benefit and cost changes and expectations (Gordon et al., 1991).

Empirical mobility literature wonders if the more spatially balanced job-housing distribution the more workers working at the nearest job location from home, i.e. the more commuting efficiency (Chowdhury et al., 2013). Local self-sufficiency of a spatial unit is defined as the share of people working and living in the same area, municipality for example. So earlier question could be re-expressing whether the more spatially balanced job-housing distribution the more local self-sufficiency.

Wasteful commuting literature configures another useful line to characterize polycentric and sprawled structures since a mobility point of view (Ma and Banister, 2006). Wasteful commuting is defined as the proportional difference between observed commuting and the theoretical one (Chowdhury et al., 2013; Horner, 2002; Ma and Banister, 2006). Therefore, changes in both theoretical minimum and maximum commuting associated to current distribution of employment and population capture indirectly changes in city's urban form and configure a benchmark to answer whether mobility follows an efficient pattern.

Wasteful commuting literature has highlighted the role of others potentially important explanatory factors in commuting activity than urban structure. In this line, Search Theory has demonstrated to be a useful approach to explain commuting behavior given the presence of market imperfections, specifically imperfect information and moving costs (Van Ommeren and van der Straaten, 2008).

Search Theory. Under this theoretical approach, job searching activity is modeled as a random process. Workers receive employment offers at an arrival rate and immediately they have to answer whether they accept it or not. The arrival rate depends on employment distribution regarding worker's location. Jobs are fully characterized by wage (w) and costs of commuting (z). Given individual skills and time preferences, each worker has a reservation wage (w*). Workers' optimal strategy is to refuse offers if w<w* and to accept it in otherwise (Rouwendal and Rietveld, 1994; van Ommeren, 2004).

Simpson (1987) and Rouwendal and Rietveld (1994) explicitly introduced the spatial dimension in the Search Theory framework. They proved that commuting distances distribution is shaped by job-offer and job-acceptable distributions. The first one depends on employment distribution around workers' home location -i.e. urban form- and second one, on the maximizing behavior of the individual. In this way, jobs become less attractive as distance to worker's home increases. Regarding commuting, search theory predicts (1) workers living close to employment centers make shorter trips (2) people who have more house or job mobility restrictions will have a negative performance on their commuting activity (Rouwendal and Rietveld, 1994; Simpson, 1987; van Ommeren, 2004).

Search Theory helps to reconsider commuting efficiency beyond wasteful commuting approach. It highlights the effect of individual characteristics and restrictions on workers' performance in labor markets. According to Simpson (1987) "skill acquisitions broadens spatial extent of the job search" and it constitutes a principle of search theory. Other factors stressed by Search Theory has been the character of residential and job location decisions: workers "do not choose a residence-job combination which offers a unique optimal commuting distance, but accept a wide range of combinations of jobs and residences as they search for better jobs and residences", hence it is possible workers accept longer distances because they “realize that commuting costs are temporary as they may change job or residence in the future” (van Ommeren, 2004)(p. 357). Then, more randomly patterns (like in the Panels c and d in Figure 3.1) in which workers commute where its labor profile finds the best possible match instead of to the nearest subcenter seems possible.

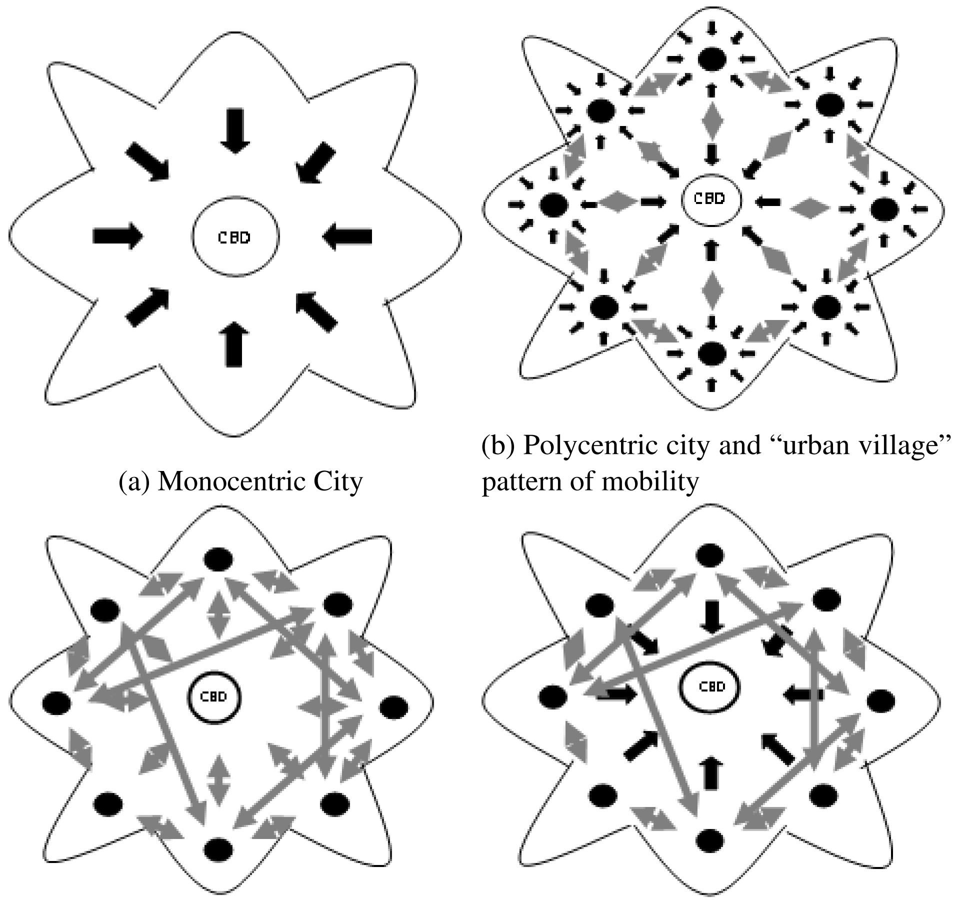
3.2.2 Empirical Review

This section summarizes most relevant empirical findings on the relationship between commuting activity, specifically commuting distances, and urban form and urban spatial structure. Urban form concept encompasses land use pattern as well as urban design (Handy, 1996). Density (jobs and/or population) is the most common indicator related to urban form. Urban spatial structure refers to the basic backbone of the city in terms of employment centers and transport infrastructures. Theoretically and empirically it has been demonstrated that proximity to these elements than conform urban spatial structure can affect densities, land prices and commuting patterns.

High density reduces commuting distance because it is indirectly (population densities) or directly (employment densities) associated to a wide range of job opportunities.

Most of the empirical evidence supports the hypothesis that high density levels conduces to a reduction in commuting distances. Different studies have found an inverse relationship between density and commuting length (Banister, 2006; ECOTEC, 1993; Ewing and Cervero, 2001; Holden and Norland, 2005; Levtnson and Kumar, 1997; Stead, 2001). However, some authors argue that there is no statically significant relationship or a weak one when socio-demographics variables are introduced in the model (Bento et al., 2005; Ewing and Cervero, 2001; Levtnson and Kumar, 1997; van de Coevering and Schwanen, 2006) pointed out that these last findings only apply for cities with a low density profile like the American ones. Some papers have highlighted that commuting length of people living in low density areas is longer than average because poor density areas do not have either speedy public transportation system nor employment opportunities (Banister, 1996; Holden and Norland, 2005). Only a few papers introduce density of destination places as regressor. (Frank and Pivo, 1994) did it and found that work trips ending in higher density areas took more time because of slower travel speeds or longer distances travelled.

People living in the CBD travel shorter commuting distances while people working in the CBD travel larger commuting distances. Evidence supports the idea that the expected commuting distance of workers living in the inner city is shorter than those living far away from it (Buchanan et al., 2006; Muñiz et al., 2013; Næss, 2007; Schwanen et al., 2001; Stead, 2001; Sultana and Weber, 2007; Tkocz and Kristensen, 1994; Wang, 2000). Regarding the evidence on the impact of distance to CBD relative to workplace location, most of the



(a) Monocentric City

(b) Polycentric city and "urban village" pattern of mobility

(c) Polycentric city and random pattern of mobility

(d) Mono-polycentric city and random-radial mobility

Fig. 3.1 Urban structure and mobility pattern

literature find a positive influence from it on trip length (Asikhia and Nkeki, 2013; Sultana and Weber, 2007) although a few studies do not detect a clear relationship (Naess and Sandberg, 1996). In Naess and Sandberg (1996) people working in the CBD have shorter commuting distances than those whose jobs are located in the second and third rings; however, the length of commuting for the fourth ring workers was shorter than the length of commuting for the workers living in the CBD .

Polycentrism and commuting activity: does living close to an employment subcenter imply benefits in terms of commuting? Literature about the effect of polycentrism on commuting activity is not large in comparison to the abundant list of studies that have addressed the effect of density or monocentrism on commuting patterns. In order to expose this literature's main findings it was organized in two groups: on one hand, those studies that analyze the impact of polycentrism on daily journey to work comparing the commuting pattern of polycentric areas with the commuting pattern of monocentric areas; and on the other hand, studies that try to identify whether and how employment subcenters affect commuting patterns either through regression analysis or not.

Regarding the first group of literature followed two objectives: 1) testing the co-location hypothesis, and 2) evaluating the advantages of monocentrism versus polycentrism regarding commuting (wasteful commuting literature). Researches testing the co-location hypothesis commonly use data about changes on commuting once firms are relocated from inner city to the periphery areas, so they study changes on the workers' residence place as answer to firms' relocation. These researches shown that, for workers who do not re-locate themselves, distance travelled in average do no decrease, while for those that effectively co-locate, commuting distances decrease (Aguilera and Mignot, 2004). Literature evaluating the commuting advantages of polycentrism related to monocentrism presents contradictory results. Guth et al. (2009) analyzed differences on wasteful commuting changes within and between a group of monocentric cities and a group of polycentric ones in Germany. It was found that polycentric regions were more travel-efficient than monocentric ones: in the polycentric regions wasteful commuting was lower than in monocentric cities. Similar findings were obtained in American cities (Gordon et al., 1991). Also it was shown that in monocentric cities, actual commuting volumes increased more than worsted jobs-housing balance. However, a number of studies have found the inverse relationship: commuting distances and times are longer in polycentric urban regions than in monocentric urban regions (Aguilera and Mignot, 2004; Schwanen et al., 2001). Finally, Chowdhury et al. (2013) and Cirilli and Veneri (2009) found no consistent relationship between commuting behavior and urban form, the first one studying the Canadian cities and the second the Italian metropolitan areas.

The second group of studies also found controversial results. On one hand, some studies have found that polycentrism reduces commuting distance and commuting times thanks for the presence of employment subcenters in the peripheries (Asikhia and Nkeki, 2013; Giuliano and Small, 1993; Muñiz et al., 2013; Næss, 2007; Wang, 2000; Zhao et al., 2011). Contrary, some studies present evidence that workers residing near an employment subcenters increase in average their commuting activity (Alpkokin et al., 2008; Cervero and Wu, 1998; Parolin, 2004; Schwanen et al., 2001). And finally, other studies found no statistically significant relationship between the emergence of employment subcenters and commuting length (Titheridge and Hall, 2006). According to Aguilera and Mignot (2004), a possible explanation for such disperse and apparently incoherent evidence, is related to the nature of subcenters. Aguilera and Mignot (2004) discusses the expected effect of polycentrism taking into account that subcenters could be complementary instead of substitutive; if so, people should travel farther than to the closer subcenter in order to find a job matching its profile. This distinction among subcenters' nature is also made by Asikhia and Nkeki (2013) with similar findings. Schwanen et al. (2001) pointed out that differences between American and European polycentrism could also explain partially the contradictory findings.

There is more agreement on the effect of polycentrism in the modal transport shift. Following Bertaud et al. (2009), dominantly polycentric cities are more favorable to individual transport instead of the dominantly monocentric cities which are favorable to transit (Næss, 2007; Naess and Sandberg, 1996). Many studies found that polycentrism is accompanied by a decline in the importance of mass transit and cycling and walking (Asikhia and Nkeki, 2013; Parolin, 2004). However, Schwanen et al. (2001) show that polycentrism is not automatically associated to a larger probabilities for driving a car to work, especially if subcenters are well served by public transportation services.

Spatial jobs-housing balance seems to be a necessary but not sufficient condition in order to achieve a lower commuting activity. According to the co-location hypothesis, employment decentralization leads to a better jobs-housing balance (co-location) giving way to shorter commuting distance and time duration. This is the base on which some studies support the potential benefit of polycentrism on commuting activity. Giuliano and Small (1993) found that jobs-housing balance is linked to a positive but small impact on commuting distances. Job-ratio is the most common measure of local balance between jobs and workers. If jobs and workers are spatially mixed at a local level instead of segregated, it could be translated into a lesser commuting activity because it reduces the average worker probability to make an external work journey (Crane and Chatman, 2003; Levtnson and Kumar, 1997; Sultana and Weber, 2007; Wang, 2000). Papers using job-ratio to explain individual commuting distances do not provide a unique answer: a first group of papers concluded that higher job ratios are associated to lower travel distances (Banister, 1996; Frank and Pivo, 1994; Stead, 2001) while a second group did not find any relevant influence (Giuliano and Small, 1993).

The impact of distance to transport infrastructure on the volume of commuting activity can be either positive or negative Proximity to transport networks may lead to longer travel distances because increases travel speed and extends the distance which can be covered in a fixed time (Stead, 2001). Næss (2007) spotlights that main nodes of subways and highways networks are traditionally associated to high local services facilities and therefore to employment opportunities. In this way longer distances between place of residence and infrastructure network may lead to higher commuting distances. However, because highways reinforce the radiality of the whole infrastructure, its impact on travel distances could be negative. In this way, the impact of distance to infrastructure "must be tested without assuming a predetermined sign on its coefficient" (Muñiz and Galindo, 2005) (p. 503).

Individual heterogeneity explains most of the individual commuting choices. There is a consensus about the strong effect of socio demographics variables on commuting behavior. According to Dieleman et al. (2002) personal characteristics seem to be at least as important as urban form variables. Disaggregated data studies analysis commuting individual decisions in order to disentangle the mechanisms driving the effect of urban form (Dieleman et al., 2002; Handy, 1996; van de Coevering and Schwanen, 2006). Most common variables capturing heterogeneity of household are regarding to social and economic restrictions: gender, race, number of children in the household, education level, economic sector and income.

Attitude variables are fundamental to explain commuting behavior Individual preferences on travelling and local environment are conceptualized as attitudes. Attitude variables are correlated to urban form and urban spatial structure but also to mobility choices (Mokhtarian and Cao, 2008). It means that those who prefer walking or biking would prefer to live in dense and/or centric places. If this information is not included into the model, the parameter associated to urban form variables can be overestimated, i.e. mobility choices could be attributed to dense character of the residence place instead of traveling attitudes. Therefore, considering attitudes is relevant to carefully analyze the causality of the relationship between urban form variables and commuting behavior. In this line, Næss (2007) sustains that the more residence and job mobility the more relevant are attitudes to explain commuting patterns.

Previous research on individual mobility in Mexico City Average distance and average time duration of commuting in MAMV have regularly increased during the last decades. Most of the literature sustain that recent employment decentralization has given place to a more spatially balanced job ratio and to a higher local self-sufficiency (Casado, 2007; Graizbord and Santillán, 2005; Guerra, 2015; Suárez-Lastra and Delgado-Campos, 2010). That implies a positive direct impact of urban spatial structure changes on mobility patterns. However, literature also shows that journey to work pattern is changing from a central-periphery one to a more diverse arrangement in which lateral travels are more often. According to Romero-Lankao et al. (2005), Pradilla (2005) and, Bertaud et al. (2009), changes in employment location indirectly affect mobility in a negative way since high capacity public transport system has dramatically decreased in parallel with the increase of lateral trips. While according to María (2012), in those areas where a subcenter has emerged, the distance of commuting has decreased. However, in more peripheral areas the job housing balance worsened [1], external commuters increased and distances too. Other researchers have pointed that changes in urban spatial structure are not the main elements behind congestion, proposing

[1] In María (2012), it is pointed out that bigger municipalities like *Chalco, Ecatepec, Tlalnepantla, Zumpango* and *Texcoco*, all of them in the closest peripheral eastern of city, the highest population densities and the lowest employment densities in the area are reported

as alternative explanation the poor inversion in infrastructure the increasing number journeys, and an inefficient design of roads and highways networks (Guerra, 2015; Romero-Lankao et al., 2005).

3.3 Data and empirical strategy

3.3.1 Data

Two data sources were used for the empirical exercise: (1) individual and household socio-economic variables come from the Census of Population and Housing made in 2000 and in 2010 by the Mexican National Institution of Statistics, Geography and Informatics (INEGI, by Spanish acronym). INEGI provides a sample of the census which is statistically representative at census tract unit (called AGEB by Spanish acronym). Data base identifies the workers' residence census tract and workers report the municipality where they work. Individual journey to work distance is calculated on the ba se of the main road network in the study area using *ArcView*[2]. In the two first parts of Table 3.1 are reported the commuting activity variables and the set of socio-economical variables considered in the empirical work. (2) The urban spatial form and structure variables were built using Economical Census of 1999 and 2009 made by INEGI. Variables capturing urban form are population density and job ratio. The impact of urban spatial structure is captured by three variables: distance from residence place to the CBD, to the nearest subcenter and to the vial axis. An employment subcenter is characterized by an atypical concentration of employment. Employment subcenters were identified using a double statistical threshold (Garcia-Lopez and Muñiz, 2010): it was considered as employment subcenter the set of contiguous census tracts with higher employment densities than the average and at the time containing more than 1% of total employment. The identified urban structure -i.e. the structural elements: the CBD and subcenters- is the same used in previous chapter and it is shown in the Figure 2.3. The mean and variance of urban structural variables are reported in the Part C of Table 3.1.

3.3.2 Empirical Strategy

The main objective of the research is answering the following question: does spatial distribution of jobs and population and employment location impact on the mobility pattern,

[2]Generated distances from census tract centroid to municipal centroid, were assigned to each worker according to its home and job location. Municipal radius, calculated according to a theoretical circle which area was equalized to actual municipal area, were assigned as commuting distances for those local commuter workers (workers living and working into the same municipality), otherwise, this practice is common in mobility commuting literature.

Table 3.1 Job density as function of urban structure in the MAMV in 1994 and 2009

Variable	Definition	All observations		Young and no-head-of-household workers	
		Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
Observations		**770,28**		**280,021**	
A. Commuting Variables					
Ext.com	Share of external commuting in sample (%)	0.407	0.491	0.388	0.487
Comm.Dist	Commuting Distance (km)	7.198	11.175	6.732	10.789
Dist.ext	Commuting Distance (external commuter) (km)	18.146	10.777	17.774	10.539
B. Urban Form and Structure Variables					
cbd.km	Distance to CBD by ageb (km)	2.687	0.721	2.699	0.703
sbc.km	Distance to the closer subcenter by ageb (km)	2.077	0.721	2.073	0.722
hw.km	Distance to the road network by ageb (km)	0.446	1.236	0.470	1.223
pop.den	Population density by ageb (people per ha)	-2.206	0.946	-2.213	0.954
Job.ratio	Job Ratio	-2.394	1.527	-2.398	1.486
C. Socioeconomic Variables					
Age	Age	36.676	13.149	25.046	5.510
Education	Level of education	2.756	1.530	2.927	1.407
Male	1 if male, 0 otherwise	0.614	0.487	0.495	0.500
Head	Head of household	0.476	0.499	-	-
FormalWorker	1 if worker is employed in formal market	0.400	0.490	0.386	0.487
Crowding	Number of persons per bedrooms	2.354	1.410	2.518	1.526
l.wage	Wage (ln)	8.100	0.857	7.913	0.767
Hr.w	Numbers of hours worked	46.198	18.859	44.285	18.253
Owner	1 if people is the owner of the house 0 otherwise	0.664	0.472	0.691	0.462
IMU	Deprivation index	-0.388	0.638	-0.368	0.635
Child.5	Children being from 6 to 12 years old in the household	0.462	0.730	0.520	0.785
Child.6.12	Children being younger than 5 years old in the household	0.541	0.799	0.522	0.810
Manufacture		0.240	0.427	0.235	0.424
Trade	**Dummies for individual employed sector**	0.274	0.446	0.273	0.445
FIRE		0.083	0.276	0.091	0.288
Services		0.308	0.462	0.314	0.464
Ind. housing		0.739	0.439	0.759	0.428
flat		0.167	0.373	0.147	0.354
collective.h	**Dummies of kind of house building**	0.073	0.261	0.072	0.258
no.house		0.001	0.036	0.001	0.034
Observed 2010		0.417	0.493	0.385	0.487
D. Geographical Variables					
slope	Terrain inclination	19.862	76.038	20.647	77.293
zonei	**Dummies of soil endurance**	0.510	0.500	0.519	0.500
zoneii	**according to its mechanical characteristic**	0.113	0.317	0.112	0.315
zoneiii		0.091	0.287	0.091	0.288

[1] Source: own elaboration based on XII and XIII population and housing census and economic census made in 1999 and 2009 in Mexico. Both made by INEGI.

specifically on proportion of external commuters related to all workers and on commuting distance? In order to answer the main question, two empirical strategies have been followed: first, a set of indexes were calculated capturing theoretical and actual commuting external flows considering job-housing balance in 2000 and 2010; and second, a regression analysis had been carried out in order to estimate the impact of urban spatial structural and form variables on journey to work distances and on the probability of being an external commuter in 2000 and 2010. Self-selection and endogeneity issues were addressed using the Heckman estimator and exogenous subsamples: young and no-head-of household workers that are not able to choose their residential places.

External commuting indexes Theoretical commuting pattern is measured using indexes developed by wasteful commuting literature. These indexes measure minimum and maximum commuting according to actual population and employment location and assuming perfect co-location between workers and jobs. Therefore, difference between theoretical commuting and actual commuting is interpreted as a test of whether a better job-housing balance leads to less traffic flows and/or shorter commuting distances. Following Guth et al. (2009) four indexes were calculated:

1. *Structural Minimum Number of Commuting Activities (SmNCA).* Assuming that the only relevant factor to commute is the distribution of jobs and workers, municipalities with more jobs than workers receive commuters from the rest of the area; and those which have a surplus of workers have to expulse this excess. In this way, the minimum number of commuting is the half of sum of the absolute difference between workers resident and jobs in all municipalities $SmNC = 1/(2\sum_{i=1}^{N}|Jobs_i - WR_i|)$.

2. *Structural Maximum Number of Local commuting (SMNLC).* In the same way of previous index, workers could avoid the journey to work only if there is a job in its municipality of residence. Hence, the maximum number of local commuting is calculated adding the minimum value between workers and jobs in each area $SMNC = \sum_{i=1}^{N} min(Jobs_i, WR_i)$.

3. *Intensity of the Structural Minimum Number of Commuting Activities (ISmNCA).* Former indexes give an idea about the amount of commuting associated with the actual distribution of jobs and workers; however, it is impossible to use them to compare the commuting associated to a concrete urban structure with any other one. *ISmNCA* standardizes *SmNCA* weighted by the number of jobs and workers, allowing this comparison. $SmNLC = \sum_{i=1}^{N}|Jobs_i - WR_i| / \sum_{i=1}^{N}(Jobs_i + WR_i)$. This index can be interpreted as the minimum share of jobs in which commuting is unavoidable.

Regression Analysis A regression analysis was instrumented in order to clarify the causal direction between urban spatial structural and form variables and commuting flows. Following Mokhtarian and Cao (2008), commuting activity (CA) is determined by urban spatial structure (US) and socio-economic characteristics (SE), i.e.

$$CA = f(US, SE) + \varepsilon_i \tag{3.1}$$

The empirical challenges in the exercise are multicollinearity and, as commuting literature highlights, endogeneity (self-selection) is relevant when analyzing the individual commuting behavior. Multicollinearity [3] is particularly challenging in this case because urban spatial form and structural variables are inter-dependant one each other. Self-selection is related with interdependence between individual commuting activity for those living and working in the same municipality -in our data commuting equals to zero- and their residence location in terms of proximity to urban spatial structure variables. The harder empirical challenge is the endogeneity. Although endogeneity could be associated with simultaneity between urban spatial structure and form, and commuting pattern, in this exercise endogeneity is associated with omission of relevant variables. The individual commuting choices are strongly influenced by preferences on transport modes and these choices affect residence location.

In general, the proposed exercise implies a no-observed heterogeneity problem and a self-selection based on no-observable gains -i.e. the individual utility which depends on individual preferences on transport modes-. It means that not only people with the same observed characteristics -the set of regressors- responds in different way to being located in the same place relatively to urban spatial structure and form: their observed commuting can be larger or not; but the choice or being or not a commuter is influenced by idiosyncratic gains and individual preferences on transport modes.

Related to self-selection and omitted variables, favorable preferences on mobility are correlated with commuting distances. Therefore the sample made of commuters -workers residing and working in different municipality- is not random and it is more homogeneous relatively on mobility preferences than the set of data made of all population. On the other hand, endogeneity bias associated with omissions of variables capturing individual transport modes preferences appears because of correlation between urban spatial structure and form, and error term is no zero. In this way, the empirical challenge of the effect of urban spatial structure and form on commuting identification is, therefore, to lead with a bias associated to self-selection and endogeneity. Under this scenario, the OLS estimator is not able to identify the effect of urban spatial structure and form variables on commuting. The TSLS estimator [4] is an alternative to try the endogeneity bias; however, we did not find a set of robust instrumental variables in order to use the TSLS estimator. In this order, the identification strategy of the effect of urban spatial structure and form on commuting is using the Heckman estimator combined with subsamples compound by workers with larger restrictions to choose

[3] Specifically in this case, the correlation coefficient between distances to the CBD and to the closer Subcenter or with to vial axis are $\rho(CBD, SBC) = 0.78$ and $\rho(CBD, VA) = 0.71$.

[4] The TSLS estimator implies to introduce a variable z -call the instrumental variable- which must be (1) uncorrelated with the error u; and (2) correlated with the endogenous regressor x. The first assumption excludes the instrument from being a regressor for the dependant variable in the main specification. The second assumption requires that there is some association between the instrument and the variable being instrumented. The bivariate TSLS estimator is defined as $\beta_{tsls} = (z^{'}x)^{-1}z^{'}y$.

their residential place, i.e. to perform their preferences on transport mode, and in this way, the urban spatial characteristics be considered as exogenous variables. Intuition behind is in this way, people that are not able to choose their place of residence have to decide being a commuter or doing their journey by walk, as well as the distance of their commuting but they take as given the urban spatial structure and form (Dujardin et al., 2008; O'Regan and Quigley, 1998).

3.4 Results

3.4.1 General trends of job-housing balance and commuting

Population and jobs are distributed in a more decentralized and de-concentrated pattern in 2010 than in 2000. These trends have been more intense in the case of jobs, as it is shown in Table 3.2. These spatial dynamics have given place to a more balanced job-ratio (increased from 0.77 to 0.84 and its standard deviation decreased from 0.34 to 0.3). It means that, in average, jobs are more close to workers. Similar results were also found in Suárez-Lastra and Delgado-Campos (2009), Aguilar and Alvarado (2005), and Pradilla (2005).

Mobility pattern is described by origin and destination of journeys: 1) while in 2000 the most of external commuters were living into Federal District (61.5%), in 2010 external commuters were mostly living in the Mexico City surrounding municipalities (51%); 2) on the side of destination, the share has diminished in the period although the Mexico City's municipalities attracted most of outer journeys (77% in 2000 and 66% in 2010), 3) journeys from one of the Mexico City surrounding municipalities to another increased more dramatically than any other journey (70% more at the end of the period). These trends are according to the population decentralization (in 2000 Mexico City concentrated 58% and in 2010 the share of population living in this city was 43%) and jobs decentralization (there were 65% of jobs located into Mexico City in 2000 and 50% in 2010) that have taken place during the period analyzed; Romero-Lankao et al. (2005), and Graizbord and Santillán (2005) found similar results.

Commuting activity, on the other hand, shows two main trends: 1) the share of workers making outer journey diminished; and 2) commuting distance increased from 18.03 km in 2000 to 18.36 km in 2010. Table 3.2 reports several statistics to evaluate potential and actual commuting efficiency. SmNLC and ISmNLC capture minimum volume and share of workers that are compelled to be commuters given the spatial distribution of employment, respectively. Both of them diminished: SmNLC went down -4.60% while the drop in the ISmNLC was -19%; i.e. the number of commuting assuming perfect co-location is significantly lower in

2010 than in 2000, though the workers and jobs increased in that lapse. SMNLC augmented 20%. This increase was expected considering that the number of workers has notably enlarged (29%).

Table 3.2 Urban form and commuting indexes

	2000	2010	Growth Rate
Jobs decentralization index	11.04	12.15	0.9%
Workers decentralization index	15.08	15.14	0.3%
Jobs concentration index in the area	0.42	0.37	-12.6%
Workers concentration index in the area	0.33	0.3	-9.5%
Job-ratio	0.776	0.847	11.4%
Self-sufficiency share	0.539	0.608	12%
SmNC (thousand)	1,199	1,145	-4.60%
SMNLC (thousand)	5,674	6,947	20.24%
ISmNC	17%	14%	-19%
Number of commuting activities (thousand)	2,708	2,849	5.07%
Out commuters-workers ratio (Commuting Intensity)	0.476	0.388	-20.4%

Now, what have happened with actual commuting once it is compared with the theoretical one (SmNLC and SMLC)? Real commuting in 2010 was further from the theoretical volume calculated by SmNLC than in 2000: commuting activity was 2.25 times SmNLC in 2000 while in 2010 the ratio increased to 2.48 times SmNLC. However, taking into account the SMLC, the comparison between it and actual commuting volumes indicates that commuting efficiency improved because the maximum commuting associated to urban form increased less than the number of workers. Even more, in 2000, actual local commuters were 64% of potential local commuters, while in 2010 the proportion reached 67%.

Summarizing facts: 1) changes in workers and jobs location has given place to a more spatially balanced local job ratio; and 2) mobility has become more efficient. As Figure 3.2 shows, the increase on the municipal job-ratio has been very homogeneous across the whole urban area and no center/periphery pattern has been found (upper two panels in Figure 3.2). Besides, although there is not a clear correlation between job ratio and self sufficiency (first lower panel in Figure 3.2), the correlation between job ratio growth and self sufficiency growth seems quite strong. Therefore, it seems that a more spatially balanced job ratio has contributed to reduce external commuting. These results are similar to those obtained in

Graizbord and Santillán (2005), Suárez-Lastra and Delgado-Campos (2009), but different to María (2012). [5]

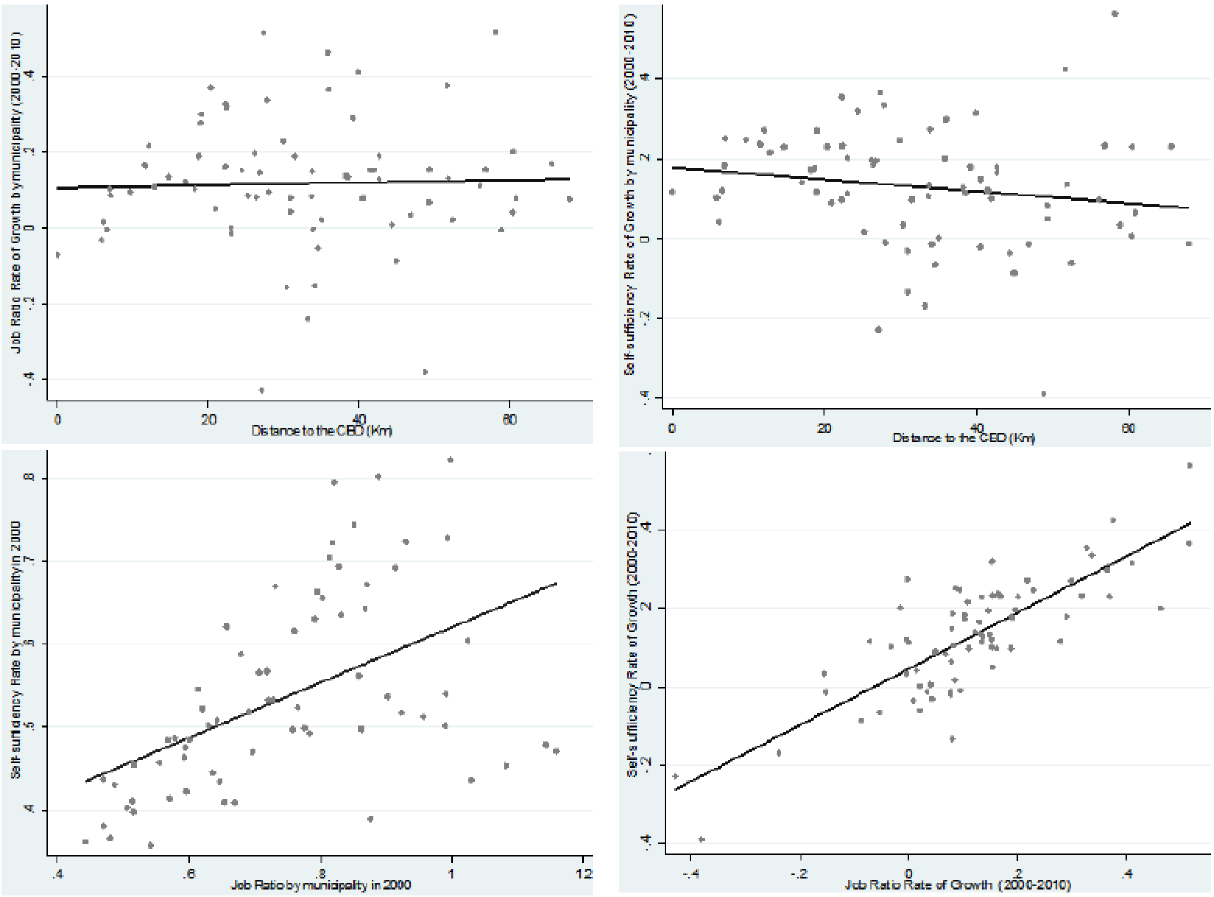


Fig. 3.2 Self-sufficiency, job ratio and distance to the CBD

3.4.2 Regression Analysis Results

The purpose of this section is to identify the effect of urban spatial structure and form on commuting activity using a regression analysis based on individual commuting data in the MAMV in 2000 and 2010. It was made a pool with all observations. Three different specifications were estimated: (1) the first specification contains urban spatial structural variables -distances to employment centers and to vial axis-, (2) the second specification includes urban spatial form variables -population density and job-ratio-, and finally, (3) the third specification includes as explanatory variables both set of variables. In a second step, the individual and geographical characteristics were added in order to control heterogeneity.

[5] Using the Origin-Destination Survey (ODS-2007), María (2012) asserts that suburbanization has leaded to a worse spatial balance causing longer and slower journeys to work.

Table 3.3 Commuting distances as function of urban spatial structure and form. OLS estimation (all observations)

DV: Ln(commuting distance)	**All Observations**					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
ln(CBD)	-0.019		0.016	0.500*		2.899*
	(0.175)		(0.185)	(0.174)		(0.343)
ln(CBD)*2010	-0.149		-0.112	-0.109		-0.487**
	(0.105)		(0.118)	(0.078)		(0.237)
ln(SBC)	-0.270**		-0.185	-0.080		0.781*
	(0.133)		(0.129)	(0.116)		(0.253)
ln(SBC)*2010	-0.014		-0.045	-0.063		-0.310
	(0.096)		(0.098)	(0.079)		(0.217)
ln(Vial Axis)	-0.115		-0.153**	0.061		0.194
	(0.072)		(0.071)	(0.051)		(0.138)
ln(Vial Axis)*2010	0.017		0.056	0.021		0.180
	(0.061)		(0.062)	(0.056)		(0.157)
ln(Population Density)		0.330*	0.247*		0.132***	0.703*
		(0.065)	(0.068)		(0.067)	(0.173)
ln(Population Density)*2010		-0.007	-0.083		-0.060	-0.054
		(0.043)	(0.057)		(0.042)	(0.141)
ln(Job Ratio)		-0.045	-0.099**		-0.203*	-0.301*
		(0.046)	(0.044)		(0.027)	(0.092)
ln(Job Ratio)*2010		0.079***	0.093***		0.143*	0.256**
		(0.043)	(0.050)		(0.041)	(0.118)
Obsreved in 2010 (=1)	-0.084	-0.386*	-0.095	-0.480***	-0.641*	0.172
	(0.292)	(0.140)	(0.293)	(0.240)	(0.153)	(0.637)
Control Variables	N	N	N	Y	Y	Y
Adjusted R-squared	0.0085	0.0086	0.0110	0.1497	0.1497	0.1255
Observations	770,28	770,28	770,28	770,28	770,28	770,28

[1] Note: Standard errors in parenthesis. Errors are clusterized by municipality $*\rho < 0.1$;$**\rho < 0.05$; $***\rho < 0.01$.

The parameters estimated associated to the urban spatial characteristics (structure and form) - by OLS are shown in Table 3.3. Collinearity is treated using logarithms. Because it was made a pool with individual commuting observed either in 2000 and 2010, it was introduced in the specifications some interactions between the urban spatial characteristic variables and a dummy equals to one for 2010 observations. Columns 1, 2, and 3 in Table 3.3 show the results when no control variables are added as regressors. Last columns -4, 5, and 6- report estimated parameters controlling for individual and spatial heterogeneity; i.e. socio-demographic, professional and geographical variables.

Table 3.4 Commuting distances as function of urban structure and form. OLS estimation for subsamples

DV: Ln(commuting distance)	Only Out-commuters			Young and no-head-of-household workers		
	(1)	(2)	(3)	(4)	(5)	(6)
ln(CBD)	5.654*		5.745*	2.533*		2.628*
	(0.792)		(0.858)	(0.301)		(0.316)
ln(CBD)*2010	-0.804**		-0.683***	-0.505*		-0.332
	(0.341)		(0.401)	(0.187)		(0.220)
ln(SBC)	2.134*		2.297*	0.516**		0.746*
	(0.494)		(0.483)	(0.223**		(0.211)
ln(SBC)*2010	0.063		0.187	-0.362***		-0.360
	(0.399)		(0.372)	(0.214)		(0.221)
ln(Vial Axis)	0.461***		0.418***	0.310**		0.213
	(0.236)		(0.234)	(0.145)		(0.134)
ln(Vial Axis)*2010	0.279		0.273	0.105		0.181
	(0.208)		(0.203)	(0.155)		(0.158)
ln(Population Density)		-0.774**	0.679**		0.081	0.716*
		(0.318)	(0.273)		(0.161)	(0.150)
ln(Population Density)*2010		-0.058	0.138		-0.084	-0.082
		(0.357)	(0.248)		(0.143)	(0.137)
ln(Job Ratio)		-1.001*	-0.116		-0.650*	-0.253*
		(0.153)	(0.115)		(0.093)	(0.077)
ln(Job Ratio)*2010		0.225	0.016		0.396*	0.244**
		(0.145)	(0.140)		(0.110)	(0.103)
Obsreved in 2010 (=1)	0.574	-0.270	0.298	-0.218	-1.118**	-0.324
	-1.219	(0.943)	-1.205	(0.597)	(0.464)	(0.607)
Control Variables	Y	Y	Y	Y	Y	Y
Adjusted R-squared	0.1958	0.1142	0.1988	0.1225	0.1103	0.1264
Observations	310,297	310,297	310,297	280,021	280,021	280,021

[1] Note: Standard errors in parenthesis. Errors are clusterized by municipality $*\rho < 0.1$;$**\rho < 0.05$; $***\rho < 0.01$.

Comparing parameters in the three first columns of Table 3.3, the collinearity that a priori was supposed among urban spatial structure and form variables is working but in a trivial way: when the five variables are introduced in the same regression, except the parameter associated to the CBD, either the sign and value of parameters associated to urban spatial structure variables do not differ from those estimated once the regression is made with each set of variables. According to parameters in Column 3, among urban spatial characteristics only the population density, the job ratio and the distance to vial axis are relevant to explain individual commuting activity. This is not the case for the variable distance to the closest subcenter.

Note that, according to results reported in Table 3.3, once the set of control variables are added in the specifications (columns 4, 5 and 6), the goodness of fit dramatically increases which would mean that the explanatory power of individual characteristics on individual commuting variability is larger than urban spatial characteristics. The direction of the parameters associated to the closest SBC, and to vial axis change when control variables are added. It evidences relevant correlations among individual characteristics and urban spatial characteristic variables; which indicates that sorting is working in the MAMV as suggested by Mateos and Aguilar (2013), i.e. people is arranging in the urban area according to some socio-demographical characteristics. Estimations with heterogeneity control variables indicate the larger distance to the CBD or to the closest subcenter are, the larger the individual commuting activity is. And, on the other hand, population density and job ratio continue being statistically significant.

Table 3.3 reports the parameters estimated using all observations in data while Table 3.4 reports parameters estimated with the subsample made of workers that reside and work in different municipalities (out-commuters). In general, the goodness of fit is larger in Table 3.4 than any other reported in Table 3.3. In any case this is expected considering the subsample formed by commuters is more homogeneous than the complete sample. The main change registered by parameters is in terms of absolute magnitude. Another interesting pattern is that while parameters related to distances to the CBD, to the closest subcenter and to vial axis are enlarged, the parameters associated to population density and job ratio are shortened. According to them, commuting distance is shorter for residential location close to the CBD, to the closest subcenter and to vial axis. For the case of urban form variables, population density increases commuting distance, and the Job ratio variable is not statistically significant in the sample of out-commuters.

The estimated effects of the urban spatial structure variables by OLS using all observations -commuters and no-commuters- are systematically statistically significative (Table 3.3 and Table 3.4). Specifically, the estimated effects are as follow: if the distance to the CBD is enlarged by 1%, the commuting distances also increases by 2.7%, if the distance to the nearest subcenter is enlarged by 1%, the commuting distances increases by 0.6%, and if the distance to vial axis is enlarged by 1%, the commuting distances increases by 0.2%. The estimated effects when considering only out-commuters by OLS using only data of commuters the magnitude of the effects is more than the twofold: if the distance to the CBD is enlarged by 1%, the commuting distances increases by 5.5%, if the distance to the nearest subcenter is enlarged by 1%, the commuting distances increases by 2.3%, and if the distance to vial axis is enlarged by 1%, the commuting distances increases by 0.5%. In the case of urban spatial form variables, the estimated effect of population density by OLS using all observations and also using only the subsample of out-commuters, if population density is increased by 1%, commuting distances increases by 0.7%. The job-ratio estimated effect is distinct to zero only for estimations using all observation. In that case, if the job-ratio is increased by 1%, the commuting distances increases by 0.1%.

Summarizing, according to the OLS estimator, workers living further from CBD, subcenters and vial axis, and in high density areas make in average larger commuting. However, it was expected that the outcomes from the OLS estimator are inconsistent under a scenario where self-selection and endogeneity are working. The cited expectations reinforce because differences on the OLS estimated parameters using all observations and those estimated with the commuter subsample.

In order to test the presence of self-selection, a Heckman estimator was used. The dichotomous variable equals to one if worker reside in the municipality where he works and equals zero in any other case. The statistically significance of parameters associated to the Inverse Mills' Ratio (IMR) [6] suggests co-localization choices and commuting distances are correlated and, therefore, parameters estimated by OLS are not consistent. This, on the other hand, allows us to discuss the effect of urban spatial characteristics on the probability of being an external commuter.

In Table 3.5 are reported the parameters estimated by the Heckman estimator [7] for both dependent variables, the dichotomous one -being an external commuter-, and for the commuting distance. Regarding being an external commuter, the urban spatial form variables are statistically relevant: denser and low job ratio environments favor the probability of being an external commuter. In the case of commuting distance, living close to the CBD and far from a peripheral subcenter increase the probability of being an out-commuter.

The estimated effects of the urban spatial structure variables by Heckman are reported in Table 3.5 are as follows. Regarding the probability of being an external commuter, urban form variables are more significant than urban spatial structure variables. One of the results is totally unexpected: high population density increases the probability of being an external commuter. In the case of the job ratio, a high value decreases probability of being an external commuter Note that, in general, the probability of being an external commuter diminished in 2010 in comparison to 2000. The estimated impact of urban spatial variables on individual

[6] The IMR is the ratio of the probability density function to the cumulative distribution function (Heckman, 1979)

[7] In order to held the exclusion restriction it were introduced a dummy variable car ownership and educational level of the head of household and interaction between the number of children and gender (woman=1) in the selection function.

Table 3.5 Commuting distances as function of urban structure using the Heckman estimator

Dependant Variable	All Observations		Young and no-head of household	
	Being a commuter (=1)	Ln(commuting)	Being a commuter (=1)	Ln (commuting)
	(1)	(2)	(3)	(4)
ln(CBD)	0.106	5.348***	0.085	5.481***
	(0.070)	(0.714)	(0.067)	(0.997)
ln(CBD)*2010	-0.002	-0.661	0.003	-0.716*
	(0.030)	(0.499)	(0.040)	(0.426)
ln(SBC)	-0.005	2.308***	0.008	2.116***
	(0.031)	(0.694)	(0.036)	(0.445)
ln(SBC)*2010	-0.024	0.299	-0.030	0.073
	(0.028)	(0.398)	(0.027)	(0.368)
ln(Vial Axis)	0.002	0.409	0.006	0.380
	(0.020)	(0.326)	(0.019)	(0.246)
ln(Vial Axis)*2010	0.017	0.214	0.018	0.207
	(0.017)	(0.232)	(0.016)	(0.273)
ln(Pop. Den.)	0.060***	0.441	0.065***	0.667***
	(0.017)	(0.371)	(0.021)	(0.292)
ln(Pop.Den.)*2010	-0.015	0.188	-0.026**	0.167
	(0.017)	(0.236)	(0.014)	(0.393)
ln(Job Ratio)	-0.039***	0.024	-0.04***	0.030
	(0.009)	(0.136)	(0.008)	(0.118)
ln(JobRatio)*2010	0.039**	-0.121	0.036**	-0.111
	(0.015)	(0.141)	(0.016)	(0.177)
Observed in 2010 (=1)	-0.162**	0.825	-0.177*	0.770
	(0.074)	-1.142	(0.100)	-1.597
Control Var.		Y		Y
IMR		-5.998**		-3.391*
		-2.979		-2.012
Observations		770,28		280,021

[1] Note: Standard errors in parenthesis. Errors are clusterized by municipality $*\rho < 0.1$;$**\rho < 0.05$; $***\rho < 0.01$.

commuting distances obtained by the Heckman estimator suggests that distances to the CBD and to the closest subcenter are statistically relevant. If distance to the CBD is enlarged by 1%, commuting distances also increases by 5.5% while if the distance to the nearest subcenter is enlarged by 1%, the commuting distances increases by 2.11%.

In relation to the estimation by OLS using the sample made of only commuters -column 3 in Table 3.4- the self-selection correction does not imply relevant variations but captures higher impacts This result can be explained considering that the statistically significance of

IMR suggests that the decisions made by workers on residential location and on commuting activity are mutually influenced.

The exercise exposes that urban spatial form variables are specifically affecting the probability of being an out-commuter. Once endogeneity is controlled, there are relevant changes. Referring to being or not a commuter and commuting distance, urban spatial structural variables, before and after controlling for endogeneity, are not statistically relevant. Contrary, in the case of commuting distance, before and after controlling for endogeneity, distance to the closest subcenter has a positive sign and is statistically significant; indicating that living close to an employment subcenter reduces commuting distance.

Finally the estimated effect of the control variables confirm Search Theory predictions: those characteristics implying mobility restrictions -having young children, residing in a marginal area, being woman, or being an old man- are negatively affecting commuting distance; while other characteristics –being a head of household, high wages, high education level, and being a formal or a white collar worker- affect directly the individual commuting distance with a positive sign (larger commuting distances).

3.5 Conclusion

Studying the relationship between urban spatial form and structure and mobility in the MAMV allow us to discuss two main issues: (1) whether polycentric decentralization implies a more efficient and sustainability mobility pattern and (2) whether the relationship identified between urban form and structure and mobility for cities in developed countries is also working for cities in developing countries like the Latin-Americans ones. The other side of these questions is related to policy recommendations oriented to ameliorate the environmental and economic costs of commuting in the developing Latin-American countries cities. The empirical analysis reveals that one of the most difficult challenges is to disentangle the effect of urban spatial variables on commuting activity from the influence of individual modal transportation preferences on the individual residential location and, indirectly, on the commuting activity. In order to isolate the effect of urban spatial variables on commuting activity, it was instrumented an alternative estimator to the OLS one: the Heckman estimator.

Results are as follows. Firstly there is a direct relationship between living close to the CBD and to a peripheral employment subcenter and commuting distance. The coefficient associated to the historical CBD is systematically statistically significative in every estimated model. Albeit the polycentrism appeared in the MAMV, the CBD still has an important impact on the commuting pattern. The coefficient associated to distance to the closest subcenter, once endogeneity and heterogeneity are considered using socio-demographical and geographical variables, continuous having a significant effect on commuting. Therefore subcenters play a relevant role, reducing commuting distances. Regarding to urban form variables, a high population density increases commuting distances while a high job ratio has an opposite effect.

The effect of job-ratio on commuting is as strong as the effect of CBD; this correlation is identified by OLS and Heckman estimators. The higher job-ratio in the residential location is, the shorter distances of commuting are as well as the lesser probability of being a commuter is. It means that dense residential areas with a low job-ratio do not conduce to a lower commuting activity.

The results obtained in the empirical exercise are in line to the implications of urban economic classical models. On the one hand, physical distances continue being relevant: workers living close to CBD perform in average shorter commuting than those living further, i.e. in the periphery. On the other hand, as it is highlighted in the spatial mismatch literature, the larger individual mobility restrictions the shorter commuting distances. Results are in the line of literature for other developed world cities like Barcelona, Spain (Muñiz et al., 2013); Copenhagen, Denmark (Næss, 2007); Chicago, US (Wang, 2000) and for a group of developing world cities experimenting a quickly expansion Benin, Nigeria (Asikhia and Nkeki, 2013); Beijing, China (Alpkokin et al., 2008; Zhao et al., 2011). The most unexpected result when compared with previous research is the positive sign of density. Workers living in dense places have a larger commuting activity. In order to achieve an efficient commuting model, compacity should be interpreted not just as a density matter, but also as mixed use environments.

The results obtained in the empirical exercise imply that urban planning policies can be suitable to reshape commuting pattern in the MAMV. In general, it is possible to particularize that firstly, the land use and the commuting are connected in a way that it is appropriate to manage both aspects by applying integral territorial policies. Secondly, land use policies can be a powerful mechanism to re-shape the commuting pattern in the studied area, especially policies related to increase the job-housing balance. The presence of areas with very high population density combined with low job-ratio pushes to higher commuting activity. Thirdly, talking in terms of employment subcenters, as long as peripheral subcenters are surrounded by dense areas while, enhancing the activities related to population services could be a mechanism to reinforce their character as structural elements and increase their job-housing balance. Fourthly, the gentrification process occurred in the CBD and provoked by the *Bando 2* in 2000 that prohibited the building of new houses in the Second Ring but allowing it in the CBD and in the First Ring, had the effect of reducing commuting activity (although it implied costs from other perspectives as Veneri (2010) have highlighted). Fifthly, in terms of transportation infrastructure, some authors have claimed that it is necessary to increase the connectivity among peripheral points in the city. In this line, the most of the investment have been dedicated in the building of new high speed vial infrastructure like the "*Arco Norte*", "*distribuidores viales*" or "*Segundo Piso del Perifeŕico*". However the commuting pattern in the periphery continuous being larger than in the central areas.

References

Aguilar, A. G. and Alvarado, C. (2005). La reestructuración del espacio urbano de la ciudad de méxico.¿ hacia la metrópoli multinodal? *Procesos metropolitanos grandes ciudades. Dinámicas recientes en México y otros países*, pages 265–308.

Aguilera, A. and Mignot, D. (2004). Urban sprawl, polycentrism and commuting. a comparison of seven french urban areas. *Urban Public Economics Review*, 1(1):93–114.

Alpkokin, P., Cheung, C., Black, J., and Hayashi, Y. (2008). Dynamics of clustered employment growth and its impacts on commuting patterns in rapidly developing cities. *Transportation Research Part A: Policy and Practice*, 42(3):427–444.

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

Asikhia, M. O. and Nkeki, N. F. (2013). Polycentric employment growth and the commuting behaviour in benin metropolitan region, nigeria. *Journal of Geography and Geology*, 5(2):1.

Banister, D. (1996). Energy, quality of life and the environment: the role of transport. *Transport reviews*, 16(1):23–35.

Banister, D. (2006). Transport, urban form and economic growth. *ECMT Regional Round Table*, 137.

Bento, A. M., Cropper, M. L., Mobarak, A. M., and Vinha, K. (2005). The effects of urban spatial structure on travel demand in the united states. *Review of Economics and Statistics*, 87(3):466–478.

Bertaud, A., Lefèvre, B., and Yuen, B. (2009). Ghg emissions. urban mobility and efficiency of urban morphology: a hypothesis. In *Marseille Symposium Report 5th Urban research symposium on cities and climate change: responding to an urgent agenda. Marseille, France*, pages 28–30.

Buchanan, N., Barnett, R., Kingham, S., and Johnston, D. (2006). The effect of urban growth on commuting patterns in christchurch, new zealand. *Journal of Transport Geography*, 14(5):342–354.

Casado, J. M. (2007). *Estructura regional de los mercados laborales locales en México*. PhD thesis, tesis de Doctorado en Geografía, UNAM, México.

Cervero, R. (1989). Jobs-housing balancing and regional mobility. *Journal of the American Planning Association*, 55(2):136–150.

Cervero, R. (2002). Built environments and mode choice: toward a normative framework. *Transportation Research Part D: Transport and Environment*, 7(4):265–284.

Cervero, R. and Wu, K.-L. (1997). Polycentrism, commuting, and residential location in the san francisco bay area. *Environment and Planning A*, 29(5):865–886.

Cervero, R. and Wu, K.-L. (1998). Sub-centring and commuting: evidence from the san francisco bay area, 1980-90. *Urban studies*, 35(7):1059–1076.

Chowdhury, T. A., Scott, D. M., and Kanaroglou, P. S. (2013). Urban form and commuting efficiency: A comparative analysis across time and space. *Urban Studies*, 50(1):191–207.

Cirilli, A. and Veneri, P. (2009). Spatial structure and mobility patterns: towards a taxonomy of the italian urban systems. *Rivista di economia e statistica del territorio*.

Crane, R. and Chatman, D. G. (2003). *Traffic and Sprawl: Evidence from US Commuting from 1985-1997*, volume 6. University of Southern California.

Dieleman, F. M., Dijst, M., and Burghouwt, G. (2002). Urban form and travel behaviour: micro-level household attributes and residential context. *Urban Studies*, 39(3):507–527.

Dujardin, C., Selod, H., and Thomas, I. (2008). Residential segregation and unemployment: the case of brussels. *Urban Studies*, 45(1):89–113.

ECOTEC (1993). *Reducing Transport Emissions through Land Use Planning. Report to the Department of Environment and the Department of Transport*. London: HMSO.

Ewing, R. and Cervero, R. (2001). Travel and the built environment: a synthesis. *Transportation Research Record: Journal of the Transportation Research Board*, (1780):87–114.

Frank, L. D. and Pivo, G. (1994). Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. *Transportation research record*, pages 44–44.

Garcia-Lopez, M.-A. and Muñiz, I. (2010). Employment decentralisation: Polycentricity or scatteration? the case of barcelona. *Urban Studies*.

Giuliano, G. and Small, K. A. (1993). Is the journey to work explained by urban structure? *Urban studies*, 30(9):1485–1500.

Gordon, P. and Richardson, H. W. (1989). Gasoline consumption and cities: A reply. *Journal of the American planning association*, 55(3):342–346.

Gordon, P., Richardson, H. W., and Jun, M.-J. (1991). The commuting paradox evidence from the top twenty. *Journal of the American Planning Association*, 57(4):416–420.

Graizbord, B. and Santillán, M. (2005). Dinámica demográfica y generación de viajes al trabajo en el amcm: 1994-2000. *Estudios demográficos y urbanos*, pages 71–101.

Guerra, E. (2015). The geography of car ownership in mexico city: a joint model of households' residential location and car ownership decisions. *Journal of Transport Geography*, 43:171–180.

Guth, D., Holz-Rau, C., and Maciolek, M. (2009). Employment suburbanisation and commuter traffic in german city regions. In *Proceedings of the 9th Swiss Transport Research Conference, Monte Verita, Ascona*.

Handy, S. (1996). Methodologies for exploring the link between urban form and travel behavior. *Transportation Research Part D: Transport and Environment*, 1(2):151–165.

Heckman, J. (1979). ksample selection bias as a specification error, leconometrica, 47 (1). *161*, page 153.

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

Horner, M. W. (2002). Extensions to the concept of excess commuting. *Environment and Planning A*, 34(3):543–566.

Høyer, K. G. and Holden, E. (2003). Household consumption and ecological footprints in norway–does urban form matter? *Journal of Consumer Policy*, 26(3):327–349.

Ingram, G. K. (1998). Patterns of metropolitan development: what have we learned? *Urban studies*, 35(7):1019–1035.

Levtnson, D. M. and Kumar, A. (1997). Density and the journey to work. *Growth and change*, 28(2):147–172.

Ma, K.-R. and Banister, D. (2006). Excess commuting: a critical review. *Transport Reviews*, 26(6):749–767.

María, C.-I. J. (2012). La estructura policéntrica de los mercados laborales locales de la zona metropolitana del valle de méxico. *Investigaciones geográficas*, (79):97–118.

Mateos, P. and Aguilar, A. G. (2013). Socioeconomic segregation in latin american cities. a geodemographic application in mexico city. *Journal of Settlements and Spatial Planning*, 4(1):11.

McMillen, D. P. and Lester, T. W. (2003). Evolving subcenters: employment and population densities in chicago, 1970–2020. *Journal of Housing Economics*, 12(1):60–81.

Mokhtarian, P. L. and Cao, X. (2008). Examining the impacts of residential self-selection on travel behavior: A focus on methodologies. *Transportation Research Part B: Methodological*, 42(3):204–228.

Muñiz, I., Calatayud, D., and Dobaño, R. (2013). The compensation hypothesis in barcelona measured through the ecological footprint of mobility and housing. *Landscape and Urban Planning*, 113:113–119.

Muñiz, I. and Galindo, A. (2005). Urban form and the ecological footprint of commuting. the case of barcelona. *Ecological Economics*, 55(4):499–514.

Muñiz, I., Garcia-López, M. À., and Galindo, A. (2008). The effect of employment subcentres on population density in barcelona. *Urban Studies*, 45(3):627–649.

Næss, P. (2007). The impacts of job and household decentralization on commuting distances and travel modes: Experiences from the copenhagen region and other nordic urban areas. *Informationen zur Raumentwicklung*, 2(3):149–168.

Naess, P. and Sandberg, S. L. (1996). Workplace location, modal split and energy use for commuting trips. *Urban Studies*, 33(3):557–580.

Newman, P. W. and Kenworthy, J. R. (1989). Gasoline consumption and cities: a comparison of us cities with a global survey. *Journal of the american planning association*, 55(1):24–37.

O'Regan, K. M. and Quigley, J. M. (1998). Where youth live: economic effects of urban space on employment prospects. *Urban Studies*, 35(7):1187–1205.

Owens, S. E. (1986). *Energy, planning and urban form*. Taylor & Francis.

Parolin, B. (2004). Employment centers and the journey to work in sidney: 1981-2001. *City Economy*, pages 1533–1575.

Pradilla, E. (2005). Zona metropolitana del valle de méxico: megaciudad sin proyecto. *Ciudades: Revista del Instituto Universitario de Urbanística de la Universidad de Valladolid*, (9):83–104.

Richardson, H. W. (1988). Monocentric vs. policentric models: The future of urban economics in regional science. *The Annals of Regional Science*, 22(2):1–12.

Romero-Lankao, P., López-Villafranco, H., Rosas-Huerta, A., Gunther, G., and Correa-Armenta, Z. (2005). Can cities reduce global warming? urban development and the carbon cycle in latin america. *Urban Development and Carbon Cycle in Latin America*.

Ross, S. and Yinger, J. (1995). Comparative static analysis of open urban models with a full labor market and suburban employment. *Regional Science and Urban Economics*, 25(5):575–605.

Rouwendal, J. and Rietveld, P. (1994). Changes in commuting distances of dutch households. *Urban Studies*, 31(9):1545–1557.

Sasaki, K. (1990). The establishment of a subcenter and urban spatial structure. *Environment and Planning A*, 22(3):369–383.

Schwanen, T., Dieleman, F. M., and Dijst, M. (2001). Travel behaviour in dutch monocentric and policentric urban systems. *Journal of Transport Geography*, 9(3):173–186.

Simpson, W. (1987). Workplace location, residential location, and urban commuting. *Urban Studies*, 24(2):119–128.

Stead, D. (2001). Relationships between land use, socioeconomic factors, and travel patterns in britain. *Environment and Planning B: Planning and Design*, 28(4):499–528.

Suárez-Lastra, M. and Delgado-Campos, J. (2009). Is mexico city polycentric? a trip attraction capacity approach. *Urban Studies*, 46(10):2187–2211.

Suárez-Lastra, M. and Delgado-Campos, J. (2010). Patrones de movilidad residencial en la ciudad de méxico como evidencia de co-localización de población y empleos. *EURE (Santiago)*, 36(107):67–91.

Sullivan, A. M. (1986). A general equilibrium model with agglomerative economies and decentralized employment. *Journal of Urban Economics*, 20(1):55–74.

Sultana, S. and Weber, J. (2007). Journey-to-work patterns in the age of sprawl: Evidence from two midsize southern metropolitan areas*. *The Professional Geographer*, 59(2):193–208.

Tarriba, G. and Alarcón, G. (2012). Movilidad competitiva en la zona metropolitana de la ciudad de méxico: diagnóstico y soluciones factibles. *Instituto Mexicano para la Competitividad*.

Titheridge, H. and Hall, P. (2006). Changing travel to work patterns in south east england. *Journal of Transport Geography*, 14(1):60–75.

Tkocz, Z. and Kristensen, G. (1994). Commuting distances and gender: a spatial urban model. *Geographical Analysis*, 26(1):1–14.

van de Coevering, P. and Schwanen, T. (2006). Re-evaluating the impact of urban form on travel patternsin europe and north-america. *Transport policy*, 13(3):229–239.

van Ommeren, J. (2004). Commuting: the contribution of search theory. *Contributions to Economic Analysis*, 266:347–380.

Van Ommeren, J. N. and van der Straaten, J. W. (2008). The effect of search imperfections on commuting behaviour: Evidence from employed and self-employed workers. *Regional Science and Urban Economics*, 38(2):127–147.

Veneri, P. (2010). Urban polycentricity and the costs of commuting: Evidence from italian metropolitan areas. *Growth and Change*, 41(3):403–429.

Wang, F. (2000). Modeling commuting patterns in chicago in a gis environment: A job accessibility perspective. *The Professional Geographer*, 52(1):120–133.

White, M. J. (1976). Firm suburbanization and urban subcenters. *Journal of Urban Economics*, 3(4):323–343.

White, M. J. (1988). Urban commuting journeys are not wasteful. *Journal of Political Economy*, 96(5):1097–1110.

White, M. J. (1999). Urban areas with decentralized employment: Theory and empirical work. *Handbook of regional and urban economics*, 3:1375–1412.

Zhao, P., Lu, B., and de Roo, G. (2011). The impact of urban growth on commuting patterns in a restructuring city: Evidence from beijing. *Papers in Regional Science*, 90(4):735–754.

Table 3.6 Commuting Distances as function of urban spatial structure and form by OLS estimator

DV: Ln(commuting distance)	All Observations					
	(1)	(2)	(3)	(4)	(5)	(6)
CBD	-0.019		0.016	0.500***		2.899***
CBD*2010	-0.149		-0.112	-0.109		-0.487**
Ln(SBC)	-0.270**		-0.185	-0.080		0.781***
Ln(SBC)*2010	-0.014		-0.045	-0.063		-0.310
Ln(Vial Axis)	-0.115		-0.153**	0.061		0.194
Ln(Vial Axis)*2010	0.017		0.056	0.021		0.180
Ln(Pop. Density)		0.330***	0.247***		0.132*	0.703***
Ln(Pop. Density)*2010		-0.007	-0.083		-0.060	-0.054
Ln(Job Ratio)		-0.045	-0.099**		-0.203***	-0.301***
Ln(Job Ratio)*2010		0.079*	0.093*		0.143***	0.256**
Age				0.052***	0.051***	0.119***
Squared Age				-0.001***	-0.001***	-0.001***
Education				0.284***	0.289***	0.529***
Work Hours				0.004***	0.004***	0.012***
Formal Employee				2.573***	2.528***	5.343***
Overcrowding house				0.001	-0.006	-0.033
ln(wage)				0.557***	0.557***	1.217***
Deprivation Index				0.013	0.132	0.145
Manufacture				-0.143	-0.180	-0.057
Trade				-0.061	-0.125	0.034
FIRE				1.017***	0.936***	2.365***
Personal Services				0.226	0.165	0.873**
Own House (=1)				-0.095***	-0.071**	-0.248**
Flat House				0.375***	0.147	0.433*
Shanty House				-0.077	-0.224**	-0.285*
Slope of the terraine				-0.000	-0.000	0.002
Kind of soil 1				-0.519***	-0.296	-0.908***
Kind of Soil 2				-0.227*	-0.102	-0.263
Man (=1)				0.296***	0.305***	0.915***
Head of household				0.082**	0.096***	0.256***
Children under 5*woman				-0.086***	-0.074***	-0.125***
Children 6-12 years old*woman				-0.137***	-0.128***	-0.306***
Observed in 2010(=1)	-0.084	-0.39***	-0.095	-0.480**	-0.641***	0.172
Constant	-2.18***	-2.18***	-2.12***	-11.33***	-10.30***	-16.96***
Adjusted R-squared	0.0085	0.0086	0.0110	0.1497	0.1497	0.1255
Observations	770280	770280	770280	770280	770280	770280

[1] Standard Errors in parenthesis. *p<0.1; **p<0.05; ***p<0.01. Errors are clusterized by municipality (74).

Table 3.7 Commuting Distances as function of urban spatial structure and form by OLS estimator using subsamples

DV: Ln(commuting distance)	Only Out-commuters			Young and no-head-of-household workers		
	(1)	(2)	(3)	(4)	(5)	(6)
CBD	5.654***		5.745***	2.533***		2.628***
CBD*2010	-0.804**		-0.683*	-0.505***		-0.332
Ln(SBC)	2.134***		2.297***	0.516**		0.746***
Ln(SBC)*2010	0.063		0.187	-0.362*		-0.360
Ln(Vial Axis)	0.461*		0.418*	0.310**		0.213
Ln(Vial Axis)*2010	0.279		0.273	0.105		0.181
Ln(Pop. Density)		-0.774**	0.679**		0.081	0.716***
Ln(Pop. Density)*2010		-0.058	0.138		-0.084	-0.082
Ln(Job Ratio)		-1.001***	-0.116		-0.650***	-0.253***
Ln(Job Ratio)*2010		0.225	0.016		0.396***	0.244**
Age	0.574	-0.270	0.298	0.492***	0.461***	0.476***
Squared Age	0.104***	0.115***	0.098***	-0.009***	-0.008***	-0.008***
Education	-0.001***	-0.001***	-0.001***	0.794***	0.823***	0.795***
Work Hours	0.089***	0.039	0.123***	0.016***	0.016***	0.016***
Formal Employee	0.010***	0.013***	0.009***	4.586***	4.356***	4.486***
Overcrowding house	1.061***	0.985***	0.981***	0.002	-0.028	-0.005
ln(wage)	-0.053*	-0.129***	-0.048	1.402***	1.328***	1.441***
Deprivation Index	0.466***	0.341***	0.547***	0.624	1.693***	0.541
Manufacture	0.689	3.485***	0.749	-0.726*	-0.837**	-0.765*
Trade	-0.683*	-0.545	-0.605	-0.228	-0.483	-0.332
FIRE	-0.935***	-0.920***	-0.903***	2.513***	2.121***	2.473***
Personal Services	0.149	-0.138	0.178	0.569	0.250	0.546
Own House (=1)	-0.446**	-0.516**	-0.440**	-0.325***	-0.205*	-0.305***
Flat House	-0.225*	-0.055	-0.187*	0.484**	-0.444	0.394*
Shanty House	0.184	-1.408***	0.109	-0.119	-0.975***	-0.170
Slope of the terraine	-0.409**	-2.356***	-0.460**	0.000	-0.002	0.001
Kind of soil 1	0.003	-0.005*	0.003	-1.499***	-0.335	-1.259***
Kind of Soil 2	-0.798	1.648*	-0.541	-0.689***	-0.114	-0.443**
Man (=1)	-0.372	0.596	-0.159	0.764***	0.800***	0.741***
Head of household	1.062***	1.173***	1.053***	0.000	0.000	0.000
Children under 5*woman	0.021	0.409***	0.017	-0.313***	-0.244***	-0.300***
Children 6-12 years old*woman	-0.041	0.073	-0.043	-0.246***	-0.201***	-0.252***
Observed in 2010(=1)	-0.259***	-0.168***	-0.256***	-0.218	-1.118**	-0.324
Constant	-6.987***	9.342***	-7.129***	-21.997***	-14.394***	-21.852***
Adjusted R-squared	0.1958	0.1142	0.1988	0.1225	0.1103	0.1264
Observations	310,297	310,297	310,297	280,021	280,021	280,021

[1] Standard Errors in parenthesis. *p<0.1; **p<0.05; ***p<0.01. Errors are clusterized by municipality (74).

Table 3.8 Commuting distances as function of urban spatial form and structure by the Heckman estimator

DV: Ln(commuting distance)?	All Observations		Young and no-head-of-household workers	
	Being a commuter (=1)	Ln(commuting)	Being a commuter (=1)	Ln(commuting)
	(1)	(2)	(3)	(4)
CBD	0.106	5.348***	0.085	5.481***
CBD*2010	-0.002	-0.661	0.003	-0.716*
Ln(SBC)	-0.005	2.308***	0.008	2.116***
Ln(SBC)*2010	-0.024	0.299	-0.030	0.073
Ln(Vial Axis)	0.002	0.409	0.006	0.380
Ln(Vial Axis)*2010	0.017	0.214	0.018	0.207
Ln(Pop. Density)	0.060***	0.441	0.065***	0.667**
Ln(Pop. Density)*2010	-0.015	0.188	-0.026*	0.167
Ln(Job Ratio)	-0.039***	0.024	-0.041***	0.030
Ln(Job Ratio)*2010	0.039**	-0.121	0.046***	-0.111
Age	0.015***	0.033	0.055***	0.186**
Squared Age	-0.000***	-0.000	-0.001***	-0.003**
Education	0.086***	-0.198	0.120***	-0.063
Man (=1)	0.085***	0.741***	0.084***	0.776***
Head of household	0.017*	-0.039		
ln(wage)	0.179***	-0.099	0.195***	0.493*
Work Hours	0.001***	0.003	0.002***	0.005
Manufacture	-0.046	-0.431	-0.096	-1.013***
Trade	-0.029	-0.770*	-0.043	-1.161***
FIRE	0.281***	-0.777	0.305***	-0.531
Personal Services	0.061	-0.654***	0.021	-0.684***
Own House (=1)	-0.021***	-0.114	-0.031***	-0.163
Flat House	0.102***	-0.247	0.094**	-0.082
Shanty House	-0.021	-0.383**	-0.010	-0.426**
Formal Employee	0.700***	-1.764	0.635***	-0.676
Overcrowding house	0.001	-0.044*	0.006	-0.036
Deprivation Index	-0.007	0.775**	0.036	0.938*
Slope of the terraine	0.000	0.003	-0.000	0.004*
Kind of soil 1	-0.133**	-0.045	-0.180**	-0.367
Kind of Soil 2	-0.038	-0.019	-0.072	0.058
Children under 5 years old	-0.006*	-0.010	-0.014**	-0.048
Children from 6 to 12 years old	0.001		-0.003	
Children under 5*woman	-0.024***		-0.038***	
Children 6-12 years old*woman	-0.046***		-0.044***	
Having automobile (=1)	-0.021*		-0.040**	
Observed in 2010(=1)	-0.162**	0.825	-0.177*	0.770
Constant	-2.708***	7.982	-3.318***	-1.165
IMR		-5.998**		-3.391*
Observations		770,280		280,021

[1] Standard Errors in parenthesis. *p<0.1; **p<0.05; ***p<0.01. Errors are clusterized by municipality (74).

Chapter 4

Urban spatial form and structure and emissions of greenhouse gases (GHG) derived from commuting in the Metropolitan Area of Mexico Valley (MAMV)

4.1 Introduction

The battle against climate change will be won or lost in cities, since they currently house more than half of the world's population. As production sites, they are responsible for between 30% and 40% of global CO_2 emissions. As places of consumption, this percentage may reach 70% (Dodman, 2009; Habitat, 2011; Satterthwaite, 2008; Walraven, 2009) [1]. With 25% of total emissions, transportation is one of the main activities that contribute to climate change [2]. One possible way of reducing the volume of emissions in metropolitan areas is urban planning. According to supporters of the "Compact City Model" (Bürer et al., 2004; Ewing and Cervero, 2001; Holtzclaw, 1994; Holtzclaw et al., 2002; Leck, 2006; Litman,

[1] Cities are considered production sites since goods and services are produced there, and therefore energy is utilized which in turn emits CO_2. As places of consumption, mobility and energy used at home constitute a good part of the direct emissions of, CO_2, to which the CO_2 built on premises, roads and consumer goods (carbon footprint) should be added. Note that the final percentage depends on the minimum size of population for it to be considered a city, as well as the territorial scale used (municipality, metropolitan area, metropolitan region)

[2] "transportation represented 27% of total US GHG emissions in 2011" (EPA, 2015); "transport's greenhouse gas (GHG) emissions account for close to 27% of total emissions" (Staff, 2008)

2011; Newman and Kenworthy, 1989), the population living in dense urban centers with good access to employment opportunities carry out journeys, especially commuting -which are characterized by a high percentage of journeys on foot or by public transport, as well as short distance travel- which translates into lower per capita emissions. Therefore, along with the environmental awareness of the population and technological improvements for means of transport, planning the metropolitan area can be a powerful tool for reducing the total volume of emissions.

The main objective of this research is to determine the effect of the urban spatial form and structure on GHG emissions associated with commuting in the MAMV. To achieve this objective, firstly, GHG emissions were estimated using data from the Origin-Destination Survey, 2007 (ODS-2007) conducted by the National Institute of Statistics, Geography and Informatics (INEGI, the Spanish acronym) of Mexico. Secondly, different econometric models were estimated where the individual volume of GHG emissions is explained by various urban spatial form and structure indicators -population density, job ratio, employment potential, distance to the CBD, distance to the sub-employment centers and distance to the main roads-, and other socio-economic and geographic variables. The empirical challenge is the endogeneity problems provoked by the omission of preferences on modes of transport and self-selection bias. In this way, sample selection and two-stage Heckman selection model were used to correct those biases.

This research is in particular relevant for the empirical literature because it uses a Latin American megalopolis -with 20 million inhabitants, such as the MAMV- as a case study. As was highlighted in Newman and Kenworthy (1989), in recent decades, the rate of motorization in cities from developing countries has been vertiginous; while the necessary investment to promote, improve and extend public transport has not been made. According to Romero-Lankao (2007) this is especially valid for the whole of Latin American cities and particularly for the MAMV, where most of the modes of transport used are private vehicles and low capacity buses. Another of the singularities of the Mexican metropolis is that, contrary to what happens in the cities from developed countries, car usage percentage is higher in the center than at the periphery. These issues can lead to unexpected correlations which would undermine validity to the Compact City approach.

The findings can be summed up in two ideas. Firstly, considering overall volume of GHG emissions associated with commuting (between 3.1 and 5.5 million tons of CO_2 per year), the average emission per employee (150 kg of CO_2 per year) is below the amount obtained in cities of Europe, America and Australia. Secondly, the estimated effect of urban spatial form and structure are in the way that the Compact City Approach predicts.

The document structure is the standard. In Section 2 the literature and empirical evidence on the relationship between urban spatial form and structure and GHG emissions are reviewed. Section 3 presents the MAMV. Section 4 presents the data -the variables used and the estimation of GHG emissions-. Section 5 is devoted to the empirical strategy adopted in order to identify the effect of urban spatial form and structure on individual GHG emissions. In Section 6 the main findings are presented. Finally, Section 7 analyzes the findings and policies implications are discussed in it.

4.2 The effect of urban spatial form and structure on GHG emissions associated with commuting. What does empirical evidence say?

The literature that has approached the contribution of cities to climate change is extensive. However, few studies have used GHG emissions as an indicator of environmental impact [3] (Ewing and Rong, 2008; Holtzclaw et al., 2002; Kenworthy and Laube, 2005; Leck, 2006; Newman and Kenworthy, 1989). A review of the empirical evidence that has directly addressed the relationship between GHG emissions and the urban spatial form and structure shows a clear effort to depurate analysis techniques. A first group of literature would consist of those studies where GHG emissions are compared in central and dense places with corresponding emissions in sparse, peripheral places within a single urban region (Norman et al., 2006; VandeWeghe and Kennedy, 2007). A second group, presents simple correlations between some measures of urban spatial form and structure and either GHG emissions or carbon footprint (Andrews, 2008; Brown et al., 2008; Ma et al., 2014). In both cases, the results support the existence of global environmental benefits linked to high density and centrality.

One of the problems presented by the above-mentioned papers is that they do not consider other factors than urban spatial form and structure as determining forces in the volume of emissions. This omission could cause an upward bias in the value of the parameter that captures the effect of such urban spatial form and structure, i.e. an overestimation of their actual impact. To solve this problem, a third group of studies present econometric models with spatially aggregated data (at neighborhood, district or municipality level) where other aspects such as energy prices or income per capita are included as explanatory variables (Croci et al., 2013; Kennedy et al., 2009; Muñiz and Galindo, 2005). These studies have

[3] The most commonly used indicators of environmental impact are fuel consumption, energy used, percentage of trips by car or km traveled by car

also found a statistically significant impact associated with such variables of urban spatial form and structure, although lower than that obtained in the first group of papers. Although the methodology used in this third group of studies improves the first two, they show the characteristic limitations of the models estimated with spatially aggregated data. It should be remembered that it is people, not territories, who emit direct or indirect CO_2 to the atmosphere, so that if we are trying to capture relevant causation relationships, it is preferable to work with individual data, which allow the control of the socio-economic characteristics of individuals. The fourth group of studies uses individual data (Ryu, 2005). Once again, empirical evidence seems to corroborate the existence of environmental benefits associated with density and centrality.

Both aggregated models and individual data models could obtain biased parameters due to endogeneity problems (Cao et al., 2009). For models with individual data, the main problem of endogeneity is the "self-selection". If individuals choose their place of residence taking into account their preferences for mobility, failure to consider this information can skew the value of urban spatial form and structure parameters. The most common solutions are: a) select samples of population with little ability to choose their place of residence (such as young people who work and live in their parents' house) (Dujardin et al., 2008; O'Regan and Quigley, 1998); b) include a variable that captures the preferences of individuals with regard to mobility and translate this information in the regression model [4]. A fifth group of studies have estimated the effect of the urban spatial form and structure of GHG emissions by controlling the endogeneity (Høyer and Holden, 2003; Muñiz et al., 2013). The results of both studies are mixed. While in Høyer and Holden (2003) the variable of urban spatial form used (density) exerts a minor effect the greater the size of the city considered is, in Muñiz et al. (2013) both variables, density and distance from the center, exert the desired effect, even when the emissions associated with the holiday period are added.

The reading made from the available empirical evidence is generally favorable to the Compact City Approach. The fact that the population density exerts a negative impact while the distance to the center exerts a positive impact on the volume of emissions per capita somehow legitimizes policies that seek to contain urban sprawl.

[4] For models with spatially aggregated variables, the main problem of endogeneity is the possible presence of a double causality. Mobility would be affected by urban spatial form and structure, but it could also happen the other way around; i.e. the urban spatial form and structure could be partly a result of the mobility patterns. The most common solution to this problem is the estimation with instrumental variables, which normally are urban spatial form -population density- variables sufficiently delayed in time to override the possibility that the spatial structure depends on mobility patterns that exist today (Baum-Snow, 2010; Duranton and Turner, 2012; Garcia-López et al., 2015)

4.3 Mobility and GHG in the MAMV

Few studies have measured the evolution of total GHG emissions in the MAMV derived from individual mobility (Guerra, 2014; Romero-Lankao, 2007; Romero-Lankao et al., 2005). In all cases a significant increase associated with different causes has been detected: a) increase in the number of cars (Guerra, 2014, 2015); b) increase in time and distance traveled due to the suburbanization of the population (Graizbord and Santillán, 2005; María, 2012; Romero-Lankao et al., 2005); c) the passage from a monocentric system to a polycentric system (Romero-Lankao et al., 2005), and d) liberalization-deregulation-privatization of the transport sector (Romero-Lankao et al., 2005). The strategy of the public sector to reduce total emissions does not contemplate significant changes in the spatial form-structure, but instead renewing the vehicle fleet and improving its energy efficiency (Romero-Lankao, 2007).

4.3.1 Components that determine the volume of greenhouse gases. The ODS-2007

According to data provided by the ODS-2007, more than 21 million trips are made on a weekday in the MAMV, 55% of which are carried out in motorized means of transportation. Although it is a huge amount, it is clearly below the values observed in other cities of Europe and the USA in per capita terms (Bertaud et al., 2009). The volume of greenhouse gases released into atmosphere and associated to individual mobility depends on: a) the frequency of journeys, b) mode of travel used -the car is the most polluting means of transportation- and c) the distance traveled. These are the three elements that are taken into account in calculating individual GHG emissions. The exploitation of the ODS-2007 allows contemplating the spatial behavior of each of the three factors. According to survey data, the frequency of travel by means of a motorized vehicle falls as the distance to the CBD increases; the percentage of car use decreases with distance to the CBD (a reverse behavior observed in cities in the US and Europe); and the average distance of travel increases with distance from the CBD.

4.4 Data, vehicles and calculating of GHG emissions

4.4.1 Data and variables

Mobility data. Data on mobility from which the individual volume of GHG is calculated come from the Origin-Destination Survey 2007 (ODS, 2007) conducted by the INEGI in that year. The survey reports the travelling conducted on a weekday -it does not include weekend trips or holidays- of the target population; as well as their demographic and economic characteristics. For each trip, means of transportation as well as the points of origin and destination are identified (from which the minimum distances based on the road network were calculated). The sample is representative at urban district (155 districts) and contains information about 146,437 individuals.

Data on characteristics of individuals and households. To control individual heterogeneity we have the socio-demographic information of individuals sampled from the ODS-2007. The variables included in the models are: 1) gender, 2) dummy householder, 3) age 4) educational level 5) economic sector in which they are engaged in case they work, 6) salary (range), 7) number of children under 6 at home, 8) number of individuals between 6 and 15 years at home; 9) dummy of household type (single parent = 1).

Geographical data. The geographical control variables included in the regression models with spatially aggregated data are the slope and a soil-type dummy equal to one in case of lacustrine ground. For the calculation of the slope we used information from INEGI 1:1 million scale [5].

Variables of urban spatial form and structure. Firstly, urban spatial form and structure variables are separated. Urban spatial form variables capture the intensity of land use -population density- and the job ratio -the local relationship between the number of jobs and the number of workers. Urban spatial structure variables capture the distance of the population regarding employment centers. Secondly, both variables -i.e. the urban spatial form and structure- are included in an analysis regression.

For the calculation of urban spatial form variables -i.e. population density and the job ratio-, information from the ODS-2007 was used. In this way, the observational unit is district (t). With respect to the urban spatial structure variables -the employment potential, the distances from the CBD and sub-employment centers-, they were estimated with the information obtained from the National Geo-statistical Framework by INEGI 2010 using a census tract [6] as an observation unit. The variables used are detailed below:

- *Population Density.* It measures the intensity of land use for residential purposes. The area used to estimate population density refers to the urbanized area (H_URB_t: urbanized hectares). The calculation was based on information from the National Geo-

[5] The calculation of the slope was made at census tract level (i). The formula used is $slope_i = (r_i^2 + h_i^2)^{\frac{1}{2}}$ where r_i is the estimated radius of a circle equal to the area of census tract i, and h_i is the difference of the curves of minimum level and maximum of census tract i. The contour map is available on http://www.inegi.org.mx/geo/contenidos/topografia/topografia_1m.aspx//

[6] AGEB (Basic Geo-statistical Area) is a spatial unit defined by the INEGI conceptually similar to a standard census tract. The geo-statistical framework used is available in http://www.inegi.org.mx/geo/contenidos/geoestadistica/m_geoestadistico.aspx

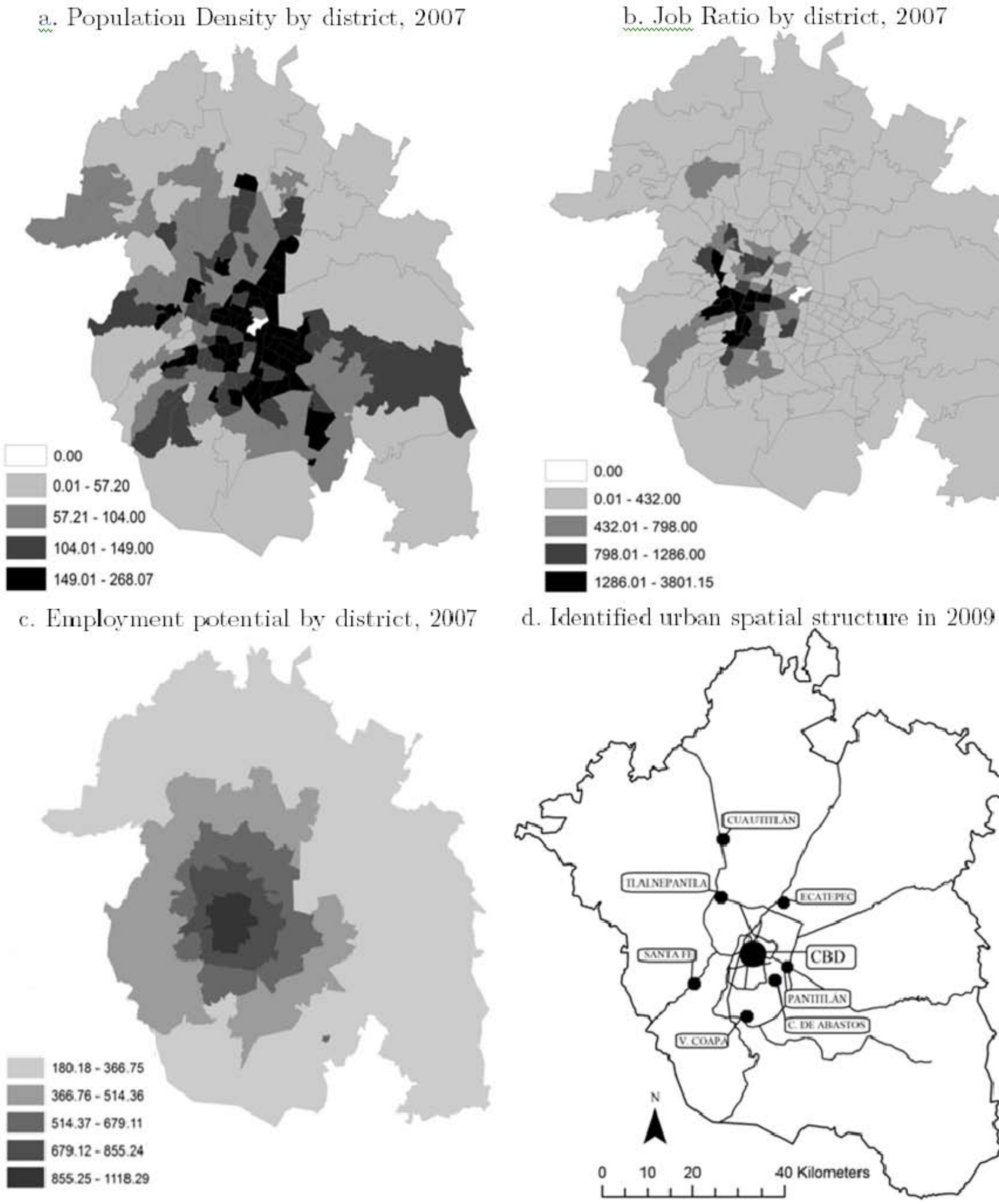


Fig. 4.1 Urban spatial form -population density and job ratio- and urban spatial structure -employment potential, distances to employment centers and minimal distance to vial axis- in the MAMV, 2007

statistical Framework 2010 (INEGI), and the district division from ODS-2007. The size of the resident population was estimated in each district (t) Thus the population density refers to the number of inhabitants per hectare in each urban district (t): $DPO_t = \frac{POP_t}{H\_URB_t}$.

- *Job Ratio*. This variable captures the local relationship between the number of jobs and the number of workers located in the same area. Based on the ODS-2007 the number of jobs located in each urban district (t) was identified; hence it could have a single source for calculating both the employment located in t and the working resident population in such t. The ratio is simply the ratio between the two quantities.

- *Employment Potential*. The calculation of the potential for employment was based on the standard definition: $EP_t = \sum_{j=1}^{J} job_j * dist_{jt}^{-1}$, where job_j refers to the volume of employment located in the district j, and $dist_{jt}$ refers to the Euclidean [7] distance between the centroid of the districts j and t. Both the information from coordinates X and Y from the district centroids and the information from employment located in each of the districts was obtained from mapping and design data resulting from the ODS-2007, respectively.

- *Distance to job centers* -CBD and sub-centers. It refers to the Euclidean distance between the centroids of employment centers (CBD and sub-centers) to the census tract where the individual i resides. The coordinates of the centroids of the census tracts were taken from the definition of the Geo-statistical Framework of the Population and Housing Census 2010 at census tract level. In this exercise, seven employment sub-centers were identified, in addition to the CBD with the method of two consecutive thresholds: (1) areas with an employment density greater than average and (2) contiguous areas that meet the first threshold and account for more than 1% of total employment (Muñiz et al., 2008), stemming from employment data obtained from Economical Census 2004 (representative at census tract level).

- *Minimum distance to road network*. The distances to the main road network were calculated using ArcMap10 software. It estimates the minimum distance from each census tract centroid of residence of the individual i to the network configured by these roads. This variable captures, on the one hand, job accessibility via better level of communications between the different points of the city, and on the other, the jobs located on the edges of the network itself that, as noted in the literature, concentrates a significant proportion of economic activity (Guerra, 2014).

4.4.2 Calculating of GHG emissions

GHG emissions are measured in terms of the volume of equivalent CO_2, which is a measurement unit that adds different Greenhouse Gas (GHG) emissions. Direct emissions of

[7] Euclidean distance is defined as $dist_{jt} = ((x_j - x_t)^2 + (y_j - y_t)^2)^{\frac{1}{2}}$

Table 4.1 CO_2 emission equivalency factors gCO_2 per passenger-km according to sources Stokenberga (2012), Muñiz and García-López (2003) and Bertaud et al. (2009)

	Stokenberga, 2011 1\	Muniz and Galindo, 2003 2\	Bertaud et al, 2009 3\
Automobile	162	135	230
Bus	27	32	33
Subway	20	32	103
Low capacity bus	58	57	36
Taxi	180	135	230
Motorcycle	68	67	108
Metro and Bus	24	32	68
Bus and Low capacity bus	43	45	35
Subway and Bus	39	45	70
Taxi and other mean	108	88	144

[1] Notes: 1\ The CO_2 emissions equivalency factors estimated by Stokenberga (2012) are based on ODS-2007 made in the MAMV and an energy efficiency of gas equal to 6.7 km per liter for automobiles. 2\ The CO_2 emissions equivalency factors estimated by Muñiz and Galindo (2005) were taken from those calculated by Estevan and Sanz for Spain. 3\ The CO_2 emissions equivalency factors reported in Bertaud et al. (2009) were taken by McKinsey and Company (2008) which uses the energy efficiency data for the London transportation system.

commuting are estimated in this exercise, i.e. leaving aside the emissions associated with the manufacture of vehicles and the construction of transport infrastructure. The equation used to calculate the annual equivalent CO_2 emissions made by an individual i is:

$$ECO_{2i} = \sum_{(j=1)}^{J} (\sum_{(z=1)}^{Z})EqF_z \cdot dist_{zji}) \cdot 260 \tag{4.1}$$

Where ECO_{2i} are the equivalent CO_2 emissions of the trips made by the individual i for work journeys; EqF_z is the CO_2 emission equivalency factor per the means of transportation z per passenger and per kilometer (grams of $CO_2/km - passenger$); $dist_{zji}$ is the distance route of the trip j; 260 are the working days in a year. CO_2 emission equivalency factors (EqF_z) depend on the energy efficiency of vehicles, the weight of the various primary sources of energy and the intensity of vehicle use. For the calculation of CO_2 emission equivalency factors from three different sources are considered. [8]

The calculated volume of mobility CO_2 emissions is between 3.1 and 5.5 million tons, depending on the conversion factors used (4.2). According to the GHG Emissions Inventory

[8] In all cases, the means of transportation with a greater impact on CO2 is the automobile. In both Stokenberga (2012) and Muñiz and Galindo (2005) factors, the use of buses is especially rewarded over the subway use. The Bertaud et al. (2009) conversion factors, unlike Stokenberga (2012) and Muñiz and Galindo (2005) factors, punishes the use of low-capacity buses.

Table 4.2 CO_2 emissions per crown (thousand ton)

	All mobility1/			Commuting			Other mobility than commuting		
	Stokenberga	M&G	Bertaud	Stokenberga	M&G	Bertaud	Stokenberga	M&G	Bertaud
CBD	287	256	421	220	196	322	87	76	128
	8.70%	8.20%	7.60%	8.80%	8.30%	7.60%	9.70%	9.30%	8.80%
1st Ring	838	783	1,390	645	606	1,078	229	207	366
	25.40%	25.10%	25.00%	25.90%	25.50%	25.50%	25.50%	25.40%	25.20%
2nd Ring	975	918	1,649	740	703	1,267	262	237	423
	29.50%	29.40%	29.70%	29.70%	29.60%	30.00%	29.10%	29.00%	29.20%
3rd Ring	1,010	976	1,742	756	738	1,314	263	243	435
	30.60%	31.30%	31.40%	30.30%	31.10%	31.10%	29.20%	29.80%	30.00%
4th Ring	194	190	351	132	131	244	57	54	98
	5.90%	6.10%	6.30%	5.30%	5.50%	5.80%	6.40%	6.60%	6.80%
Total	3,303	3,122	5,553	2,493	2,375	4,226	898	818	1,450
	100%	100%	100%	100%	100%	100%	100%	100%	100%

[1] own estimates based on the 2007 ODS and conversion factors used by Bertaud et al. (2009); Muñiz and Galindo (2005); Stokenberga (2012), respectively. Figures may not add up due to the fact that each work or study (daily mobility) trip was associated with one back home, while every movement for other reasons is also associated with another return trip and this might not be so for all cases.

2006 by the Ministry of Environment in the MAMV, the volume of GHG emissions from transport is about 20 million tons, of which 5 are produced by freight. The methodology used is the one developed by the Intergovernmental Panel on Climate Change, United Nations Environment Programme and the World Meteorological Organization and is based on fuel demand. Thus, the difference between the weight of CO_2 registered in the inventory -15 million of ton- and the maximum estimated in the exercise -5 million ton- is due to in the second computation does not count the emissions associated with the mobility of non-residents, nor taxi emissions when they are free, and the emissions associated with congestion, nor mobility during weekends or holidays, so that our approach underestimates the total emissions.

Table (4.3) shows the distribution of emissions, taking into account the mean of transportation. In our estimates, regardless of the conversion factor used, the automobile is the mean with the largest share of CO_2 emissions, which range between 49% and 59%, depending on the factor used. According to our calculation, the average annual per capita emissions would be between 162 and 189 kg of CO_2 per person per year -between 346 and 616 kg if only the people who actually perform at least one motorized trip are considered. [9]

Figure (4.2) shows the spatial pattern of emissions per capita. In the more peripheral crowns, per capita emissions are higher than in the central areas. The number of trips per

[9] The range of estimated CO_2 emissions per capita in other cities in the developed world is from 1,250 kg -in Stockholm- to 2,150 kg -in Rome.

Table 4.3 CO_2 emissions according to means of transportation

gCO2/passenger-km	Stokenberga (2007)		Muñiz y Galindo (2003)		Bertaud (2011)	
	CO2	%	CO2	%	CO2	%
Automobile	1,950.00	59.05%	1,630.00	52.13%	2,770.00	49.86%
Bus	57.6	1.74%	68.2	2.18%	70.4	1.27%
Subway	217	6.57%	347	11.10%	1,120.00	20.16%
Low capacity bus	81.8	2.48%	80.4	2.57%	50.8	0.91%
Taxi	227	6.87%	170	5.44%	290	5.22%
Motorcycle	32	0.97%	31.5	1.01%	50.7	0.91%
Metro & Bus	74.1	2.24%	101	3.23%	214	3.85%
Bus & Low capacity bus	150	4.54%	156	4.99%	120	2.16%
Subway & Bus	401	12.14%	452	14.46%	720	12.96%
Taxi & other mode of transport	112	3.39%	90.4	2.89%	150	2.70%
TOTAL	3,302.50	100%	3,126.50	100%		

capita in the center is lower, and car use is higher than at the periphery, which determines that the highest per capita emissions occurring in the periphery are due to the fact that the journeys made are longer. This pattern is similar to that obtained in Romero-Lankao et al. (2005).

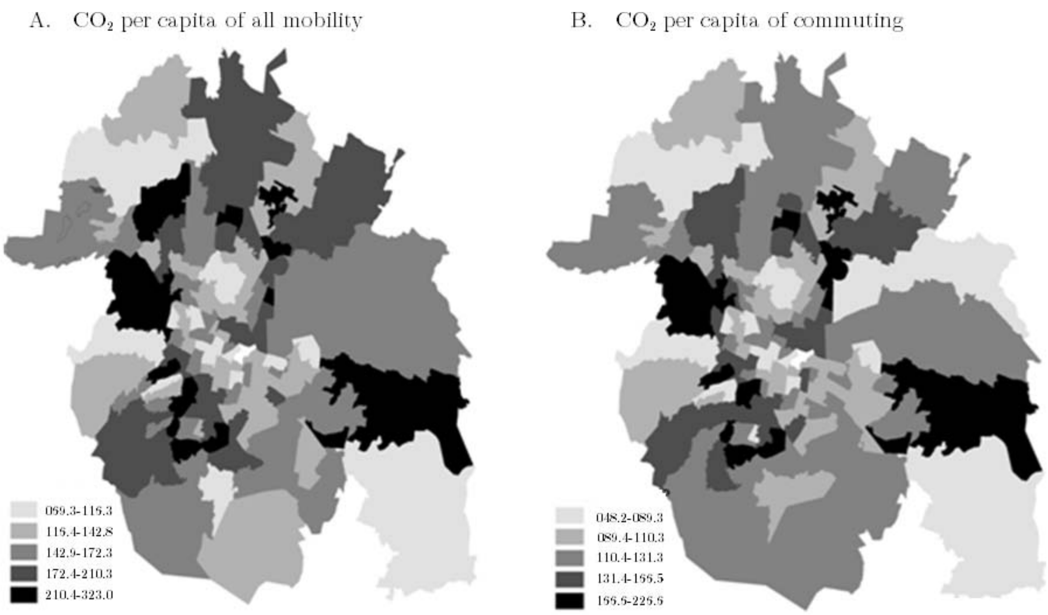


Fig. 4.2 Average per capita emissions by type of mobility (CO_2 kg)

4.5 Empirical strategy

To identify the effect of the urban spatial form and structure of the MAMV on the volume of individual GHG emissions associated with commuting, it was made a multiple regression analysis using the specification (1).

$$GHG_i = \beta_1 \cdot FU_{(t,i)} + \beta_2 \cdot X_{(i,t)} + e_i(1) \tag{4.2}$$

Where GEI_i is the volume of GHG emissions of the individual i; $FU_{t,i}$ is the vector of urban spatial form and structure variables of district t where i resides; X_i is a vector of control variables referring to demographic and socioeconomic characteristics of the individual i, as well as the geography of the district t; β_1 and β_2 are the parameter vectors of $FU_{t,i}$ and X_i regressors, respectively.

Table 4.4 Variables used in regression analysis

Dependant Variable:		Source	Median
GEI_o	Individual CO2 emissions of commuting (Kg)	ODS, 2007	150.14
GEI_t	Individual CO2 emissions of all mobility (Kg)	Conversion Factors (Muñiz and Galindo, 2005))	213.78
Urban Spatial Form and Structure Variables:			
DPO	Population Density (residing workers per ha)	ODS-2007	128.03
JR	Job Ratio (jobs per thousand of residing workers)	Economical Census, 2004	486.55
PE	Employment Potential (thousand de employments)	Geostatistical framework for the MAMV in 2010, INEGI	590.21
CBD	Distance to the CBD (km)		15.18
SBC_1	Inverse of the distances to the closest SBC (km)		109.63
RV	Minimal distance to vial axis (km)		0.4
Control Variables:			
GENDER	Gender (man=1)	ODS-2007	0.62
HEAD_H	Head of household (=1)		0.46
AGE	Age		38.22
EDUCATION	Education level		2.83
SECT2	Industrial sector employee (=1)		0.13
SECT3	Construction sector employee (=1)		0.05
SECT4	Trade sector employee (=1)		0.22
SECT5	Service sector employee (=1)		0.41
SECT6	Communication and transport sector employee (=1)		0.07
SECT7	Public administration employee (=1)		0.07
MANUAL-worker	Blue collar worker (=1)		0.61
IR	Household income (minimum wage range)		3.44
OWNER	Homeownership (=1)		0.67
CHILD6	Children younger than 6 years old in the household		0.46
YOUNG615	People from 6 to 15 years old in the household		0.63
MONO-PARENTAL	Single-parent household (=1)		0.27
Geographical Control Variable:			
SLOPE_T	Slope of the terrain (meters)	Contour map, 2010. INEGI	0.38
LAKE	Lacustrine soil (=1)	SIRE A.C.	

It is common, in this type of exercise, to consider the fact that mobility depends on the urban spatial form and structure as well as the demographic and socio-economic characteristics of individuals (environmental approach). However, the empirical literature that addresses the relationship between individual mobility and urban spatial form and structure has highlighted the possible bias caused by the omission of variables that capture the preferences and attitudes of individuals around mobility (Cao et al., 2009; Cervero, 2007). These preferences or attitudes influence individual decisions regarding commuting in two alternative ways: firstly, directly through the choice of means of transportation, distance and frequency of trips; secondly, through the choice of place of residence -which it meanwhile depends on the urban spatial characteristics. That is, if the people who prefer to travel by car choose their place of residence prioritizing those places that allow this type of mobility, and if individuals who prefer to avoid using the car are more likely to reside in those areas where they can easily access public transport (self-selection approach), then the correlation between individual preferences for a specific mean of transportation and urban spatial form and structure is nonzero.

Therefore, if individual preferences for means of transportation are not considered, even when demographic and economic characteristics are controlled, the exogeneity assumption will not be satisfied and, therefore, the OLS estimator for β_1 would be biased by two mechanisms. Firstly, the endogeneity bias associated with the omission of variables (the β_1 parameters would capture not only the effect of the urban spatial characteristics, but also the effect that preferences on mode of transport have on the choice of the urban environment of residence through the correlation between the variables of urban spatial form and structure and preferences for modes of transport). Secondly, the self-selection bias: in the volume of GHG emissions two different behaviors were observed (1) the population with zero emissions on the one hand and (2) the volume of population with non-zero emissions. We assume that this behavior is associated with successive decisions: (1) to travel or not by motorized means and (2) the frequency, mode of transport and commuting distance. Both decisions are directly affected by the unobservable variables (preferences on modes of transport). And, under this assumption, the two successive decisions would not be independent. While the endogeneity bias caused by omitted variables would tend to overestimate β_1 parameters, the self-selection bias would tend to assess these parameters downwards, since it does not weigh zero mobility observations as a result of a process of generating different data to the total of the mobility.

To identify the parameters of the variables of urban spatial form and structure -β_1-, different methods have been proposed. The first is the inclusion of variables that capture the influence of preferences on modes of transport in the choice of place of residence (Muñiz et al., 2013). A second method used is to constrain the samples to quasi-experimental situations that can ensure that the location of an individual is exogenous regarding to his mobility preferences, such as unexpected changes in location due to government relocation programs (Oreopoulos, 2003). The third method is to use the Instrumental Variables estimator. The fourth method is to use the Heckman estimator to deal with endogeneity associated with the omission of variables associated with selection bias [10] (Cameron and Trivedi, 2010). The fifth method is to restrict the sample to individuals who do not choose their place of residence [11] (Dujardin et al., 2008; O'Regan and Quigley, 1998).

The first method could not be used as the ODS, 2007 did not explicitly ask individuals about preferences regarding mobility and its influence on their location. The second method (relocation programs) was not applied for obvious reasons. The third method (TSLS estimator) could not be used because despite carrying out numerous tests, it was not possible to identify robust indicators. Having discarded the first three methods, the strategy consisted of applying methods four and five. Although both the Heckman estimator and the use of a restricted sample of individuals to ensure the exogeneity of errors seek to correct the endogeneity caused by the lack of information about the influence of individual preferences for modes of transport on an individual's location, they correct different biases. The first corrects the bias caused by the correlation between the errors (which capture the influence of preferences on modes of transport in location decisions) and urban spatial form and structure variables. The second method corrects the selection bias. Selection bias implies that the correlation between the regressors and the dependent variable considering a sample of individuals with a certain pattern of behavior is different from the correlation between such variables once the entire population is taken into account, because the sample with the specific pattern of behavior has unobserved characteristics correlated with regressors which are different from the rest of the population (Cameron and Trivedi, 2010). Firstly, the parameter vector β_1 is estimated through a sampling restriction approach. Based on the specification (1), β_1 it is estimated through OLS, by restricting the sample to young adults living with their parents (assuming the place of residence was chosen by parents). This situation would ensure the exogeneity of errors in the specification (1).

Secondly, the Heckman estimator, corresponding to the restricted sample applies. In our case, there are two groups of individuals with clearly different behaviors: on the one hand are individuals with GHG emissions other than zero, and on the other, those with zero greenhouse gas emissions. The Heckman estimator was used since the relationship between the variables of urban spatial form and structure and volume of GHG emissions in the sample of individuals with GHG> 0 is assumed to be different from the existing population relationship between the two kinds of variables. This is because the observed behavior is the result of two decisions: (1) choosing a location depending on the decision to travel or not in

[10] Although most of these applications have been made in the literature of labor economics, it is structurally similar to the exercise undertaken.

[11] The most common practice is to work with the young population living in the parental household. An inherent limitation of this method is the young people can share their parents' preferences (Dujardin et al., 2008); and to the extent that this happens, the exogeneity of these observations would not be guaranteed.

motorized means and (2) mode, distance and frequency of said trips. Both decisions could be modeled independently if there were variables able to capture the influence of preferences on modes of transport; if so, the OLS estimator would yield unbiased and consistent parameters. However, in our case, these preferences are unobserved factors that affect both decisions together. The Heckman estimator can cope with the omission of these variables by estimating the Inverse Mill's Ratio (or "non-selection hazard"). In short, the estimation strategy of the impact of the urban spatial form and structure on the volume of individual GHG emissions associated with commuting consists in the use of the Heckman estimator.

4.6 The impact of the spatial form and structure on GHG emissions associated with commuting

Four different models were defined in the regression analysis. Multicollinearity problems are removed using logarithms. The first three specifications try to identify the effect of urban spatial characteristics according its type, i.e. either the form or the structure; while in the fourth specification it were grouped in a single model all variables of urban spatial form and structure in order to get the net effect of each of those variables though it procedure could imply multicollinearity problems.In Table 4.4 the parameters obtained are reported, using the defined specifications.

In the first column, the parameters for urban spatial form and structure variables in the OLS estimation appear; the entire sample -both individuals who emit GHG and those who do not- was used. Since the urban spatial form and structure can affect the probability of emitting GHGs, the model was re-estimated with the Heckman estimator (columns 2 and 3). The parameters of the Inverse Mills Ratio (IMR) are significant in all cases, so it is confirmed that the correlation of the errors of the two decisions -the first, to travel or not in a motorized means and the second, the mode, distance and frequency of trips that sets the volume of GHG emissions from commuting- is nonzero; that is to say, both decisions are not independent of each other, and therefore there is a selection bias in the OLS estimate. Parameters associated to subcenters in Panel C and the associated to population density in Panel D show differences regarding to the sign. The higher the population density or job ratio, the less the probability of performing movements that generate emissions is; while the larger employment potential and distance to the CBD, the greater the probability of performing movements that generate emissions is. Moreover, as can be seen in column 6, in general the statistically significance of the parameters increases significantly compared to the first column, so OLS estimation underestimates the actual impact of the urban spatial form and structure on GHG emissions.

In columns 4, 5 and 6 the estimated parameters using a restricted sample of young individuals who work and are not heads of households. The idea is that this population cannot impose their preferences for location, so this would correct endogeneity in estimating where the whole sample is used. Comparing these values with those obtained in the first column, where the whole sample is used, and a significant drop was observed, so this type of endogeneity, if not corrected, implies overestimation of the impact of such variables of urban spatial form and structure.

There is a large group of young and no-head-of-household people reporting no emissions, so the models with the restricted sample were estimated by Heckman and estimated parameters are shown in columns 5 and 6. Again, the absolute value of the urban spatial form and structure parameters (column 6) is significantly higher than that obtained in the OLS estimate (column 4). Column 6 is our best approximation of the value of the parameters that capture the impact of the urban spatial form and structure on GHG emissions associated with commuting. Moreover, as can be seen in tables Annex 1 and Annex 2, socioeconomic variables show the expected sign. Being a man, a household head, with a high educational level, not carrying out manual labor and having a high level of income, the probability of generating high GHG emissions increases.

Taking each variables group of urban spatial form and structure independently (panels A, B and C) the parameters listed in column 6 are statistically significant and have the expected sign. In panel D, i.e. taking all together the urban spatial variables as independent variables, the parameters listed in column 6 are statistically significant and have the expected sign except for the distance to the vial axis. Because of specifications are a log-log type, estimated parameters imply elasticities. According to Panel D and column 6: (1) if the population density is increased by 1%, the volume of CO_2 would also increase by 0.105%; (2) if the job ratio is increased by 1%, the volume of CO_2 would also decrease by 0.304%, (3) if the distance to the CBD is increased by 1% the volume of CO_2 would also increase by 0.282%, and (4) if the distance to the nearest subcenter is increased by 1% the volume of CO_2 would also increase by 0.039%.

The parameters associated with the employment potential and with the minimal distance to vial loss of statistical significance along the several specifications. In our preferred estimate (Column 6 of Table 4.5, the estimated parameter implies that residing near a vial axis is irrelevant in terms of emissions. Likewise is taken place in the case of employment potential. This result supports what would be expected according to the proposals of urban planning that pursue a concentrated decentralization model based on a polycentric urban village type (Bertaud, 2004). Therefore, it can be concluded that polycentrism has no failed in its role of organizing and guiding peripheral trips offering nearer destinations to the CBD to reduce the

Table 4.5 GHG emissions of commuting as a function of urban spatial form and structure variables

DV: Ln(GHG_i) (Kg de CO_2)	All Population			Young and no-head-of-household people		
	OLS	Heckman Estimator		OLS	Heckman Estimator	
Specification A	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Population Density)	0.419***	0.094***	-0.078***	0.484**	0.101***	0.006
	(0.134)	(0.011)	(0.023)	(0.201)	(0.019)	(0.041)
Ln(Job Ratio)	-0.798***	-0.116***	-0.374***	-0.919***	-0.131***	-0.437***
	(0.103)	(0.008)	(0.026)	(0.146)	(0.017)	(0.058)
Adj. R-squared	0.0743			0.0581		
IMR			0.890***			1.537***
Observations	82,368		82,368	19,636		19,636
Specification B	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Employment Potential)	-0.206	0.038***	-0.618***	-0.168	0.055*	-0.554***
	(0.366)	(0.015)	(0.021)	(0.455)	(0.031)	(0.040)
Adj. R-squared	0.0682			0.0498		
IMR			1.036***			1.200***
Observations	82,368		82,368	19,636		19,636
Specification C	(1)	(2)	(3)	(4)	(5)	(6)
Ln(dist. to the CBD)	0.368**	0.035***	0.345***	0.358	0.033**	0.329***
	(0.183)	(0.009)	(0.013)	(0.266)	(0.016)	(0.023)
Ln(dist. to the nearest SBC)	-0.132	-0.035***	0.054***	-0.146	-0.041***	0.034*
	(0.094)	(0.007)	(0.011)	(0.125)	(0.014)	(0.021)
Ln(dist. to vial axis)	0.030**	0.005***	0.006***	0.043**	0.007***	0.007*
	(0.013)	(0.001)	(0.002)	(0.018)	(0.002)	(0.004)
Adj. R-squared	0.0693			0.0512		
IMR			1.074***			1.266***
Observations	82,368		82,368	19,636		19,636
Specification D	(1)	(2)	(3)	(4)	(5)	(6)
Ln(Population Density)	-0.088	-0.032**	0.104***	-0.170	-0.054**	0.105***
	(0.197)	(0.012)	(0.016)	(0.257)	(0.024)	(0.034)
Ln(Job Ratio)	-1.312***	-0.247***	-0.155***	-1.579***	-0.289***	-0.304***
	(0.185)	(0.013)	(0.040)	(0.181)	(0.021)	(0.095)
Ln(Emp. Potential)	2.092***	0.444***	0.014	2.165***	0.473***	0.220
	(0.378)	(0.034)	(0.095)	(0.635)	(0.078)	(0.181)
Ln(dist. to the CBD)	0.476***	0.073***	0.285***	0.321	0.053*	0.282***
	(0.133)	(0.013)	(0.030)	(0.205)	(0.030)	(0.062)
Ln(dist. to the nearest SBC)	-0.007	-0.005	0.051***	-0.022	-0.008	0.039*
	(0.080)	(0.008)	(0.010)	(0.095)	(0.016)	(0.023)
Ln(dist. to vial axis)	-0.004	-0.001	-0.001	0.002	-0.000	-0.003
	(0.012)	(0.001)	(0.001)	(0.017)	(0.002)	(0.003)
Adj. R-squared	0.0760			0.0600		
IMR			0.856***			1.488***
Observations	82,368		82,368	19,636		19,636

[1] Standard Errors in parenthesis. Errors are clusterized by municipality. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

distance and therefore the volume of emissions. The distance of the place of residence of individuals to the network of main roads does not seem to be relevant.

Table 4.6 Marginal effects of the variables of interest obtained from estimating with probit estimator car use as a transport mean as a function of urban spatial form, structure and control variables

Marginal Effect (DV: using automobile (=1))	All Observations	Young and no-head-of-household people
Population Density	-0.063***	-0.069***
Job Ratio	0.022+	0.040**
Employment Population	0.266***	0.165***
Distance to the CBD	0.060***	0.057***
Distance to the nearest subcenter	-0.007	-0.01
Distance to vial axis	-0.003	-0.0001
Observations	82,368	19,636

[1] Errors are clusterized by municipality. +p<0.15; *p<0.1; **p<0.05; ***p<0.01

In Table 4.6, Table 4.7, and Table 4.8, models corresponding to column 6 of Table 4.5 are estimated, using as a dependent variable, instead of GHG emissions, the probability of moving by car, the distance traveled and the number of estimated trips per day, respectively. The idea is that the individual volume of GHG emissions is calculated from these variables so we can track which of the three mechanisms is more sensitive to urban spatial form and structure variables in the MAMV.

Table 4.7 Marginal Effects obtained from the estimation with an orderly probit for the number of trips as a function of the urban spatial form and structure

Marginal Effect (DV: number of trips)	All Observations	Young and no-head-of-household people
Population Density	-0.002	0.004
Job Ratio	0.032***	0.060***
Employment Population	-0.119***	-0.143***
Distance to the CBD	-0.031***	-0.029+
Distance to the nearest subcenter	-0.006	-0.011***
Distance to vial axis	0.001	0.0004
Observations	82,368	19,636

[1] Errors are clusterized by municipality. +$p < 0.15$; *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

The negative density (higher density, lower GHG emissions) can be explained because the density reduces the likelihood of automobile use, reduces the distance and does not affect the number of daily trips. The negative sign of job ratio is due solely to the fact that more job ratio reduces the distance. The negative sign of the parameter of job potential can be mainly explained since a greater potential for employment reduces the distance. Finally, living away from the CBD increases emissions because it involves longer trips, but curiously reduces the likelihood of using the car.

In order to test how far the impact of the urban spatial form and structure of GHG emissions associated with commuting (detected in previous models) can be extended to all quotidian mobility (commuting, shopping and entertainment), all the models have been recalculated using GHG emissions from all daily mobility as a dependent variable (Appendix C.3 and Appendix C.4). If the urban spatial form and structure parameters lose value and significance, the compactness policies that aim to reduce the total emissions would be brought into question. However, the results show no significant differences.

Table 4.8 Marginal Effects obtained with a Heckman estimation of the traveled distance as a function of the urban spatial form and structure

Marginal Effect (DV: total traveled distance)	All Workers	Young and no-head-of-household people
Population Density	0.120***	0.191***
Job Ratio	-0.078***	-0.087***
Employment Population	-0.367***	-0.168***
Distance to the CBD	0.115***	0.254***
Distance to the nearest subcenter	0.061***	0.062***
Distance to vial axis	-0.001	-0.003*
Observations	82,368	19,636

[1] Errors are clusterized by municipality. $+p < 0.15$; $*p < 0.1$; $**p < 0.05$; $***p < 0.01$

4.7 Discussion

Endogeneity and compactness policies. Controlling endogeneity has been a recurrent practice in recent studies that have addressed the relationship between mobility and spatial form and structure of urban areas. The different techniques used to reverse the effect of individual preferences and attitudes on transport, and to capture the net effect of the built environment on mobility, often yield parameters with lower values and significance than in estimates where it is unchecked. Numerous studies show that urban form is less important than in studies where individual preferences of transport are controlled. However, authors such as Ewing and Rong (2008) argue that the effect of individual preferences on modes of transport through urban form (via the choice of place of residence) cannot be ignored in the design of urban policies; and, in fact, self-selection would reflect up to what point urban form is important in shaping the pattern of mobility that can affect location decisions. Therefore, urban planning policies should be legitimized in terms of the results obtained without control of the endogeneity of self-selection. In our case, the value and significance of the parameters from the estimation where residential self-selection is controlled through the use of a restricted sample and the Heckman estimator, is generally greater than the corresponding to the results obtained by the OLS estimator. This would imply that the impact of the urban spatial form and structure is not less, but greater than the OLS estimation indicates. Only in the case of an inversion of the distance to the nearest sub-center, the opposite occurs, which indicates that the impact of the proximity on the individual sub-center emission volume acts through a mechanism of self-selection.

Individual versus aggregates. Comparing the value and significance of the urban spatial form and structure parameters of the estimate from individual data corresponding to the estimate where spatially aggregated information is used and the possible double causality is controlled with instrumental variables, it is clear that, except for population density, there is a problem of "ecological fallacy" (Ewing and Rong, 2008). In the case of population density, the added data estimation does not overestimate the effect but it directly involves dense environments associated with GHG emissions per capita greater than those of the scattered environments; individual data estimates show that this relationship is reversed [12].

Commuting and Total Mobility. The impact of the spatial urban spatial form and structure of GHG emissions associated with all the daily mobility is similar to that detected in the estimation that uses commuting data explicitly. The exception is the density variable, which ceases to be statistically significant. This would imply that residing in dense environments does not reduce GHGs associated with shopping and leisure mobility.

4.8 Conclusion

The result of this study is that urban form and structure influence the volume of individual emissions associated with commuting, even after controlling the endogeneity of these variables. Another result is the estimation of the volume of emissions per capita and its spatial pattern. On average, each inhabitant of the MCMA emits about 189 kg of CO_2 annually for mobility. On the spatial pattern, while the inhabitants of the most central areas have a greater number of visits and chances of using the car as a means of transport than the average population, the volume of GHG emissions increases as we move away from the city center, reproducing the spatial pattern of the average distance of travel.

The exercise demonstrates the opportunity of urban planning as a tool to shape a way of commuting in the MCMA whose volume of GHG emissions is lower. More specifically, the

[12]The error in estimation is related to the difference between the median and the average of individual GHG emissions. This difference is particularly pronounced in lesser dense environments

effect of variables such as population density and employment population ratio on the volume of GHG emissions from commuting caused by the employed population has a negative sign; while the sign corresponding to the distance to the CBD parameter is positive. The empirical evidence is thus consistent with the Compact City approach which proposes to densify, mix, and centralize as a strategy to curb the volume of emissions. The results have implications for urban planning, but are not obvious. For example, the impact of negative density indicates that policies to curb the expansion of low-density suburbs reduce the volume of greenhouse gases associated with commuting. However, the density has no effect once the rest of daily mobility is added to commuting. Furthermore, high density tends to generate pollution problems locally. Considering these aspects makes us cautious about the effectiveness of compactness policies based on increasing density levels. The parameters of job-ratio and employment potential variables indicate a beneficial effect associated with the proximity between workers and jobs. From this, it follows that the decentralization policies of economic activity concentrated to shorten the distance between workers and jobs reduce total emissions. The positive sign of the parameter of the distance to CBD would endorse policies in line with a slow decentralization of the population. Finally, according to the value of the parameter associated to sub-center distance in the OLS estimation of distance, enhancing polycentrism would help reduce GHG emissions.

This study has the inconvenience of not considering weekend or holiday period mobility, which would allow us to evaluate the overall effect of the urban spatial form and structure on the total volume of GHG emissions associated with people transportation in the MAMV. Also, static analysis limits an overall assessment of the role of the urban spatial form and structure as a tool to obtain a commuting with fewer negative externalities. Both problems have to do with the availability of data.

References

Andrews, C. J. (2008). Greenhouse gas emissions along the rural-urban gradient. *Journal of Environmental Planning and Management*, 51(6):847–870.

Baum-Snow, N. (2010). Changes in transportation infrastructure and commuting patterns in us metropolitan areas, 1960–2000. *The American economic review*, 100(2):378.

Bertaud, A. (2004). The spatial organization of cities: Deliberate outcome or unforeseen consequence?

Bertaud, A., Lefèvre, B., and Yuen, B. (2009). Ghg emissions. urban mobility and efficiency of urban morphology: a hypothesis. In *Marseille Symposium Report 5th Urban research* *symposium on cities and climate change: responding to an urgent agenda. Marseille, France*, pages 28–30.

Brown, M. A., Southworth, F., and Sarzynski, A. (2008). *Shrinking the carbon footprint of metropolitan America*. Brookings Institution Washington, DC.

Bürer, M., Goldstein, D., and Holtzclaw, J. (2004). Location efficiency as the missing piece of the energy puzzle: how smart growth can unlock trillion dollar consumer cost savings. In *Proceedings, 2004 ACEEE Summer Study on Energy Efficiency in Buildings*. Citeseer.

Cameron, A. C. and Trivedi, P. K. (2010). *Microeconometrics using stata*, volume 2. Stata Press College Station, TX.

Cao, X., Mokhtarian, P. L., and Handy, S. L. (2009). Examining the impacts of residential self-selection on travel behaviour: a focus on empirical findings. *Transport Reviews*, 29(3):359–395.

Cervero, R. (2007). Transit-oriented development's ridership bonus: a product of self-selection and public policies. *Environment and planning A*, 39(9):2068–2085.

Croci, E., Melandri, T., Molteni, T., and Zadorozhna, O. (2013). *Determinants of GHG emissions from urban ground transportation: review of simple of European Cities*, volume 1. IEFE Center for Research on Energy and Environmental Economics and Policy.

Dodman, D. (2009). Blaming cities for climate change? an analysis of urban greenhouse gas emissions inventories. *Environment and Urbanization*, 21(1):185–201.

Dujardin, C., Selod, H., and Thomas, I. (2008). Residential segregation and unemployment: the case of brussels. *Urban Studies*, 45(1):89–113.

Duranton, G. and Turner, M. A. (2012). Urban growth and transportation. *The Review of Economic Studies*, 79(4):1407–1440.

EPA, U. (2015). U.s. greenhouse gas inventory report archive.

Ewing, R. and Cervero, R. (2001). Travel and the built environment: a synthesis. *Transportation Research Record: Journal of the Transportation Research Board*, (1780):87–114.

Ewing, R. and Rong, F. (2008). The impact of urban form on us residential energy use. *Housing Policy Debate*, 19(1):1–30.

Garcia-López, M.-Á., Holl, A., and Viladecans-Marsal, E. (2015). Suburbanization and highways in spain when the romans and the bourbons still shape its cities. *Journal of Urban Economics*, 85:52–67.

Graizbord, B. and Santillán, M. (2005). Dinámica demográfica y generación de viajes al trabajo en el amcm: 1994-2000. *Estudios demográficos y urbanos*, pages 71–101.

Guerra, E. (2014). The built environment and car use in mexico city is the relationship changing over time? *Journal of Planning Education and Research*, 34(4):394–408.

Guerra, E. (2015). The geography of car ownership in mexico city: a joint model of households' residential location and car ownership decisions. *Journal of Transport Geography*, 43:171–180.

Habitat, U. (2011). Cities and climate change: Global report on human settlements 2011. *London, Royaume-Uni, Etats-Unis: UN-Habitat*.

Holtzclaw, J. (1994). *Using residential patterns and transit to decrease auto dependence and costs*, volume 11. Natural Resources Defense Council San Francisco, CA.

Holtzclaw, J., Clear, R., Dittmar, H., Goldstein, D., and Haas, P. (2002). Location efficiency: Neighborhood and socio-economic characteristics determine auto ownership and use-studies in chicago, los angeles and san francisco. *Transportation planning and technology*, 25(1):1–27.

Høyer, K. G. and Holden, E. (2003). Household consumption and ecological footprints in norway–does urban form matter? *Journal of Consumer Policy*, 26(3):327–349.

Kennedy, C., Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havranek, M., Pataki, D., Phdungsilp, A., Ramaswami, A., and Mendez, G. V. (2009). Greenhouse gas emissions from global cities. *Environmental science & technology*, 43(19):7297–7302.

Kenworthy, J. R. and Laube, F. B. (2005). An international comparative perspective on sustainable transport in european cities. *European Spatial Research and Policy*, 12(1):11.

Leck, E. (2006). The impact of urban form on travel behavior: a meta-analysis. *Berkeley Planning Journal*, 19(1).

Litman, T. (2011). Evaluating public transit benefits and costs. *Victoria Transport Policy Institute*, 65.

Ma, J., Heppenstall, A., Harland, K., and Mitchell, G. (2014). Synthesising carbon emission for mega-cities: a static spatial microsimulation of transport co 2 from urban travel in beijing. *Computers, Environment and Urban Systems*, 45:78–88.

María, C.-I. J. (2012). La estructura policéntrica de los mercados laborales locales de la zona metropolitana del valle de méxico. *Investigaciones geográficas*, (79):97–118.

McKinsey and Company (2008). *Sustainable Urban Infraestructure. London a view to 2025*. Number 1. McKinsey & Company.

Muñiz, I., Calatayud, D., and Dobaño, R. (2013). The compensation hypothesis in barcelona measured through the ecological footprint of mobility and housing. *Landscape and Urban Planning*, 113:113–119.

Muñiz, I. and Galindo, A. (2005). Urban form and the ecological footprint of commuting. the case of barcelona. *Ecological Economics*, 55(4):499–514.

Muñiz, I. and García-López, M.-A. (2003). Cubic spline population density functions and satellite city delimitation: The case of barcelona. *Urban Studies*, 40(7):1303–1321.

Muñiz, I., Garcia-López, M. À., and Galindo, A. (2008). The effect of employment sub-centres on population density in barcelona. *Urban Studies*, 45(3):627–649.

Newman, P. W. and Kenworthy, J. R. (1989). Gasoline consumption and cities: a comparison of us cities with a global survey. *Journal of the american planning association*, 55(1):24–37.

Norman, J., MacLean, H. L., and Kennedy, C. A. (2006). Comparing high and low residential density: life-cycle analysis of energy use and greenhouse gas emissions. *Journal of urban planning and development*, 132(1):10–21.

O'Regan, K. M. and Quigley, J. M. (1998). Where youth live: economic effects of urban space on employment prospects. *Urban Studies*, 35(7):1187–1205.

Oreopoulos, P. (2003). The long-run consequences of living in a poor neighborhood. *The quarterly journal of economics*, pages 1533–1575.

Romero-Lankao, P. (2007). Are we missing the point? particularities of urbanization, sustainability and carbon emissions in latin american cities. *Environment and Urbanization*, 19(1):159–175.

Romero-Lankao, P., López-Villafranco, H., Rosas-Huerta, A., Gunther, G., and Correa-Armenta, Z. (2005). Can cities reduce global warming? urban development and the carbon cycle in latin america. *Urban Development and Carbon Cycle in Latin America*.

Ryu, H. C. (2005). *Modeling the per capita ecological footprint for Dallas County, Texas: Examining demographic, environmental value, land-use, and spatial influences*. PhD thesis, Texas A&M University.

Satterthwaite, D. (2008). Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions. *Environment and urbanization*, 20(2):539–549.

Staff, I. E. A. (2008). *CO_2 Emissions from Fuel Combustion: 1972*. Organization For Economic.

Stokenberga, A. (2012). Explaining and projecting the carbon footprint of mexico's urban transport. In *Transport Research Board 91st Annual Meeting*.

VandeWeghe, J. R. and Kennedy, C. (2007). A spatial analysis of residential greenhouse gas emissions in the toronto census metropolitan area. *Journal of Industrial Ecology*, 11(2):133–144.

Walraven, A. (2009). The impact of cities in terms of climate change. *United Nations Environment Programme*.

4.9 Appendix C

Table 4.9 GHG emissions of commuting as a function of urban spatial form and structure variables by OLS

	All Workers				Young and no-head-of-household people			
Ln(Population Density)	0.419***			-0.088	0.484**			-0.170
	(0.134)			(0.197)	(0.201)			(0.257)
Ln(Job Ratio)	-0.798***			-1.312***	-0.919***			-1.579***
	(0.103)			(0.185)	(0.146)			(0.181)
Ln(Employment Potential)		-0.206		2.092***		-0.168		2.165***
		(0.366)		(0.378)		(0.455)		(0.635)
Ln(dist. to the CBD)			0.368**	0.476***			0.358	0.321
			(0.183)	(0.133)			(0.266)	(0.205)
Ln(dist. to the nearest SBC)			-0.132	-0.007			-0.146	-0.022
			(0.094)	(0.080)			(0.125)	(0.095)
Ln(min. dist. to vial axis)			0.030**	-0.004			0.043**	0.002
			(0.013)	(0.012)			(0.018)	(0.017)
Man (=1)	0.305***	0.324***	0.323***	0.308***	0.197	0.247*	0.247*	0.214*
	(0.088)	(0.091)	(0.090)	(0.087)	(0.121)	(0.147)	(0.145)	(0.122)
Age	0.110***	0.112***	0.112***	0.110***	0.568***	0.558***	0.547***	0.568***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.142)	(0.147)	(0.152)	(0.146)
Squared age	-0.002***	-0.002***	-0.002***	-0.002***	-0.011***	-0.011***	-0.010***	-0.011***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.003)	(0.003)	(0.003)
Head of household (=1)	1.172***	1.167***	1.164***	1.188***	0.000	0.000	0.000	0.000
	(0.063)	(0.066)	(0.065)	(0.061)	(0.000)	(0.000)	(0.000)	(0.000)
Education level	0.507***	0.454***	0.464***	0.497***	0.640***	0.627***	0.634***	0.640***
	(0.053)	(0.051)	(0.051)	(0.053)	(0.094)	(0.100)	(0.099)	(0.096)
Industrial Sector (=1)	2.120***	2.283***	2.241***	2.140***	1.864***	2.022***	1.983***	1.909***
	(0.239)	(0.254)	(0.255)	(0.231)	(0.378)	(0.382)	(0.386)	(0.370)
Trade Sector (=1)	0.685***	0.823***	0.811***	0.708***	1.256***	1.375***	1.380***	1.293***
	(0.229)	(0.255)	(0.251)	(0.222)	(0.330)	(0.345)	(0.343)	(0.323)
Service Sector (=1)	1.436***	1.529***	1.507***	1.423***	1.253***	1.282***	1.273***	1.255***
	(0.215)	(0.221)	(0.220)	(0.207)	(0.302)	(0.300)	(0.301)	(0.293)
Construction Sector (=1)	1.164***	1.313***	1.276***	1.172***	1.211***	1.353***	1.317***	1.258***
	(0.247)	(0.266)	(0.268)	(0.238)	(0.389)	(0.397)	(0.399)	(0.379)
Com. and Transp. Sector	1.313***	1.457***	1.429***	1.312***	1.062***	1.157***	1.145***	1.083***
	(0.212)	(0.231)	(0.229)	(0.205)	(0.375)	(0.386)	(0.385)	(0.363)
Public Admon Sector (=1)	2.389***	2.548***	2.536***	2.395***	2.392***	2.521***	2.525***	2.428***
	(0.237)	(0.243)	(0.242)	(0.227)	(0.361)	(0.365)	(0.366)	(0.351)
Blue Collar Worker (=1)	-1.779***	-1.769***	-1.767***	-1.777***	-1.444***	-1.440***	-1.438***	-1.434***
	(0.086)	(0.088)	(0.090)	(0.086)	(0.139)	(0.141)	(0.143)	(0.140)
Own House (=1)	-0.192***	-0.138*	-0.175**	-0.209***	-0.232	-0.161	-0.203	-0.240*
	(0.064)	(0.079)	(0.068)	(0.062)	(0.144)	(0.157)	(0.148)	(0.139)
Internet Service (=1)	0.041	0.011	0.020	0.032	-0.332	-0.370	-0.361	-0.352
	(0.105)	(0.114)	(0.113)	(0.106)	(0.217)	(0.238)	(0.235)	(0.217)
People in ages 0-6	-0.019	0.009	0.005	-0.013	-0.055	-0.012	-0.017	-0.044
	(0.044)	(0.047)	(0.047)	(0.045)	(0.083)	(0.090)	(0.090)	(0.084)
People in ages 6-12	-0.155***	-0.124***	-0.129***	-0.141***	-0.139	-0.099	-0.101	-0.118
	(0.034)	(0.037)	(0.038)	(0.035)	(0.087)	(0.089)	(0.090)	(0.088)
Single-parent household	-0.153*	-0.229**	-0.192**	-0.160*	0.169	0.092	0.130	0.159
	(0.086)	(0.089)	(0.081)	(0.085)	(0.129)	(0.128)	(0.118)	(0.126)
Wages	0.314***	0.251***	0.255***	0.298***	0.126*	0.051	0.054	0.104
	(0.043)	(0.055)	(0.055)	(0.046)	(0.075)	(0.092)	(0.092)	(0.076)
Lacustrine Soil	-0.010	0.202	0.317***	0.004	0.206	0.440**	0.553***	0.206
	(0.107)	(0.137)	(0.117)	(0.090)	(0.173)	(0.193)	(0.164)	(0.140)
Slope of the terrain	-0.000	-0.001**	-0.001**	-0.000	-0.001**	-0.001**	-0.001**	-0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-3.010***	-4.287*	-6.215***	-11.912***	-8.059***	-9.870***	-11.349***	-15.462***
	(1.107)	(2.305)	(0.678)	(2.074)	(2.187)	(3.565)	(1.719)	(3.551)
Adjusted R-squared	0.0743	0.0682	0.0693	0.0760	0.0581	0.0498	0.0512	0.0600
Observations	82,368	82,368	82,368	82,368	19,636	19,636	19,636	19,636

Table 4.10 GHG emissions of commuting as a function of urban spatial form and structure variables by Heckman estimator taking into account all workers

	(1)		(2)		(3)		(4)	
Ln(Population Density)	0.094***	-0.078***					-0.032**	0.104***
	(0.011)	(0.023)					(0.012)	(0.016)
Ln(Job Ratio)	-0.116***	-0.374***					-0.247***	-0.155***
	(0.008)	(0.026)					(0.013)	(0.040)
Ln(Employment Potential)			0.038***	-0.618***			0.444***	0.014
			(0.015)	(0.021)			(0.034)	(0.095)
Ln(dist. to the CBD)					0.035***	0.345***	0.073***	0.285***
					(0.009)	(0.013)	(0.013)	(0.030)
Ln(dist. to the nearest SBC)					-0.035***	0.054***	-0.005	0.051***
					(0.007)	(0.011)	(0.008)	(0.010)
Ln(min. dist. to vial axis)					0.005***	0.006***	-0.001	-0.001
					(0.001)	(0.002)	(0.001)	(0.001)
Man (=1)	-0.001	0.274***	-0.000	0.278***	-0.000	0.278***	-0.001	0.273***
	(0.012)	(0.016)	(0.010)	(0.011)	(0.012)	(0.012)	(0.012)	(0.015)
Age	0.017***	0.044***	0.018***	0.046***	0.018***	0.046***	0.017***	0.044***
	(0.002)	(0.005)	(0.002)	(0.004)	(0.002)	(0.005)	(0.002)	(0.004)
Squared age	-0.000***	-0.000***	-0.000***	-0.001***	-0.000***	-0.001***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Head of household (=1)	0.218***	0.268***	0.228***	0.270***	0.226***	0.274***	0.224***	0.254***
	(0.010)	(0.041)	(0.011)	(0.038)	(0.011)	(0.038)	(0.011)	(0.037)
Education level	0.090***	0.193***	0.087***	0.190***	0.088***	0.193***	0.090***	0.194***
	(0.004)	(0.016)	(0.003)	(0.012)	(0.004)	(0.013)	(0.004)	(0.014)
Industrial Sector (=1)	0.405***	0.148*	0.433***	0.191**	0.426***	0.199***	0.413***	0.123
	(0.032)	(0.084)	(0.026)	(0.083)	(0.025)	(0.073)	(0.026)	(0.081)
Trade Sector (=1)	0.128***	0.076	0.152***	0.100**	0.149***	0.104***	0.134***	0.062
	(0.029)	(0.048)	(0.029)	(0.045)	(0.025)	(0.039)	(0.024)	(0.049)
Service Sector (=1)	0.266***	0.160***	0.282***	0.192***	0.279***	0.192***	0.266***	0.138**
	(0.028)	(0.058)	(0.026)	(0.056)	(0.023)	(0.048)	(0.022)	(0.059)
Construction Sector (=1)	0.210***	0.142**	0.233***	0.168***	0.227***	0.165***	0.214***	0.117*
	(0.039)	(0.068)	(0.029)	(0.058)	(0.029)	(0.053)	(0.030)	(0.060)
Com. and Transp. Sector	0.247***	0.122**	0.272***	0.154**	0.267***	0.158***	0.249***	0.101
	(0.035)	(0.062)	(0.030)	(0.060)	(0.029)	(0.056)	(0.027)	(0.068)
Public Admon Sector (=1)	0.466***	0.239***	0.492***	0.298***	0.490***	0.313***	0.469***	0.224***
	(0.031)	(0.086)	(0.034)	(0.084)	(0.031)	(0.077)	(0.025)	(0.085)
Blue Collar Worker (=1)	-0.322***	-0.288***	-0.319***	-0.307***	-0.318***	-0.314***	-0.323***	-0.280***
	(0.010)	(0.055)	(0.011)	(0.055)	(0.010)	(0.052)	(0.011)	(0.055)
Own House (=1)	-0.040***	-0.025*	-0.032***	-0.020	-0.039***	-0.028**	-0.043***	-0.026**
	(0.011)	(0.013)	(0.010)	(0.013)	(0.009)	(0.013)	(0.011)	(0.013)
Internet Service (=1)	-0.002	0.108***	-0.004	0.106***	-0.004	0.110***	-0.004	0.112***
	(0.012)	(0.015)	(0.013)	(0.020)	(0.015)	(0.017)	(0.017)	(0.019)
People in ages 0-6	0.018**	-0.012	0.022***	-0.009	0.022**	-0.009	0.019**	-0.013**
	(0.007)	(0.008)	(0.008)	(0.009)	(0.009)	(0.008)	(0.008)	(0.006)
People in ages 6-12	-0.026***	-0.038***	-0.020***	-0.039***	-0.021***	-0.040***	-0.023***	-0.041***
	(0.005)	(0.009)	(0.005)	(0.009)	(0.005)	(0.007)	(0.005)	(0.008)
Single-parent household	-0.022	-0.075***	-0.055***	-0.080***	-0.047***	-0.071***	-0.027*	-0.060***
	(0.015)	(0.016)	(0.016)	(0.017)	(0.014)	(0.014)	(0.015)	(0.014)
Wages	0.049***	0.141***	0.039***	0.136***	0.040***	0.135***	0.046***	0.140***
	(0.004)	(0.008)	(0.004)	(0.007)	(0.004)	(0.008)	(0.004)	(0.010)
Lacustrine Soil	-0.010	0.060***	0.021**	0.150***	0.040***	0.197***	-0.013	0.121***
	(0.010)	(0.015)	(0.010)	(0.013)	(0.010)	(0.015)	(0.011)	(0.013)
Slope of the terrain	-0.000***	0.000	-0.000***	-0.000***	-0.000***	-0.000***	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Educa*Head of Household	-0.032***		-0.046***		-0.044***		-0.034***	

Table 4.11 GHG emissions of commuting as a function of urban spatial form and structure variables by Heckman estimator taking into account only young and no-head-of-household workers

	(1)		(2)		(3)		(4)	
Ln(Population Density)	0.101***	0.006					-0.054**	0.105***
	(0.019)	(0.041)					(0.024)	(0.034)
Ln(Job Ratio)	-0.131***	-0.437***					-0.289***	-0.304***
	(0.017)	(0.058)					(0.021)	(0.095)
Ln(Employment Potential)			0.055*	-0.554***			0.473***	0.220
			(0.031)	(0.040)			(0.078)	(0.181)
Ln(dist. to the CBD)					0.033**	0.329***	0.053*	0.282***
					(0.016)	(0.023)	(0.030)	(0.062)
Ln(dist. to the closestSBC)					-0.041***	0.034*	-0.008	0.039*
					(0.014)	(0.021)	(0.016)	(0.023)
Ln(min. dist. to vial axis)					0.007***	0.007*	-0.000	-0.003
					(0.002)	(0.004)	(0.002)	(0.003)
Man (=1)	-0.020	0.242***	-0.011	0.242***	-0.012	0.245***	-0.017	0.246***
	(0.026)	(0.030)	(0.022)	(0.028)	(0.024)	(0.027)	(0.023)	(0.029)
Age	0.111***	0.097	0.110***	0.067	0.108***	0.065	0.112***	0.085
	(0.024)	(0.062)	(0.031)	(0.049)	(0.028)	(0.061)	(0.029)	(0.064)
Squared age	-0.002***	-0.001	-0.002***	-0.001	-0.002***	-0.001	-0.002***	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Head of household (=1)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Education level	0.116***	0.252***	0.117***	0.225***	0.118***	0.230***	0.117***	0.250***
	(0.010)	(0.038)	(0.008)	(0.021)	(0.006)	(0.024)	(0.008)	(0.033)
Industrial Sector (=1)	0.345***	0.323**	0.368***	0.261**	0.361***	0.269***	0.357***	0.300**
	(0.064)	(0.140)	(0.060)	(0.117)	(0.059)	(0.102)	(0.050)	(0.138)
Trade Sector (=1)	0.232***	0.250**	0.250***	0.213**	0.251***	0.225***	0.241***	0.238*
	(0.062)	(0.114)	(0.062)	(0.102)	(0.049)	(0.083)	(0.056)	(0.122)
Service Sector (=1)	0.220***	0.354***	0.225***	0.306***	0.224***	0.313***	0.223***	0.336***
	(0.052)	(0.109)	(0.057)	(0.094)	(0.054)	(0.083)	(0.051)	(0.105)
Construction Sector (=1)	0.199***	0.348***	0.218***	0.308***	0.212***	0.309***	0.210***	0.327**
	(0.065)	(0.119)	(0.063)	(0.110)	(0.069)	(0.110)	(0.071)	(0.141)
Com. and Transp. Sector	0.189***	0.296**	0.205***	0.255**	0.203***	0.260***	0.195***	0.277**
	(0.068)	(0.124)	(0.068)	(0.103)	(0.053)	(0.089)	(0.051)	(0.125)
Public Admon Sector (=1)	0.436***	0.617***	0.455***	0.546***	0.456***	0.568***	0.446***	0.598***
	(0.064)	(0.150)	(0.068)	(0.125)	(0.059)	(0.123)	(0.075)	(0.169)
Blue Collar Worker (=1)	-0.268***	-0.311***	-0.267***	-0.253***	-0.266***	-0.262***	-0.266***	-0.302***
	(0.021)	(0.091)	(0.026)	(0.059)	(0.023)	(0.053)	(0.020)	(0.082)
Own House (=1)	-0.055**	-0.047	-0.044**	-0.029	-0.051**	-0.044	-0.056***	-0.057*
	(0.024)	(0.037)	(0.022)	(0.027)	(0.023)	(0.039)	(0.020)	(0.031)
Internet Service (=1)	-0.062**	0.049	-0.061**	0.065	-0.061**	0.064	-0.065*	0.053
	(0.025)	(0.054)	(0.025)	(0.043)	(0.028)	(0.046)	(0.035)	(0.044)
People in ages 0-6	0.015	-0.018	0.020	-0.011	0.019	-0.011	0.017	-0.017
	(0.017)	(0.016)	(0.015)	(0.016)	(0.016)	(0.019)	(0.013)	(0.016)
People in ages 6-12	-0.026**	-0.056***	-0.021**	-0.048**	-0.021**	-0.048***	-0.022*	-0.057***
	(0.012)	(0.018)	(0.010)	(0.018)	(0.010)	(0.016)	(0.012)	(0.021)
Single-parent household	0.009	-0.018	-0.031	-0.034	-0.022	-0.020	-0.000	-0.008
	(0.025)	(0.027)	(0.035)	(0.030)	(0.034)	(0.027)	(0.032)	(0.037)
Wages	0.018***	0.117***	0.009	0.106***	0.009	0.105***	0.014	0.117***
	(0.007)	(0.014)	(0.009)	(0.013)	(0.008)	(0.010)	(0.009)	(0.014)
Lacustrine Soil	0.024	0.159***	0.055**	0.252***	0.075***	0.300***	0.021	0.205***
	(0.019)	(0.028)	(0.022)	(0.033)	(0.023)	(0.037)	(0.020)	(0.031)
Slope of the terrain	-0.000***	-0.000	-0.000***	-0.000***	-0.000***	-0.000	-0.000**	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 4.12 GHG emissions of commuting as a function of urban spatial form and structure variables by Heckman estimator taking into account only young and no-head-of-household workers

	Using Automobile (=1)		Number of trips		Distance of commuting	
	All sample	Subsample	All sample	Subsample	All sample	Subsample
Ln(Population Density)	-0.205***	-0.225***	0.009	-0.014	0.197***	0.190***
	(0.069)	(0.072)	(0.047)	(0.061)	(0.015)	(0.026)
Ln(Job Ratio)	0.073	0.131**	-0.102***	-0.176***	-0.048***	-0.087***
	(0.049)	(0.054)	(0.036)	(0.037)	(0.012)	(0.022)
Ln(Employment Potential)	0.539***	0.540***	0.376***	0.424***	-0.357***	-0.168**
	(0.148)	(0.175)	(0.102)	(0.150)	(0.038)	(0.081)
Ln(dist. to the CBD)	0.195***	0.189***	0.101***	0.086	0.220***	0.254***
	(0.046)	(0.051)	(0.036)	(0.057)	(0.014)	(0.033)
Ln(dist. to the nearest SBC)	-0.024	-0.033	0.020	0.033**	0.074***	0.062***
	(0.023)	(0.032)	(0.015)	(0.015)	(0.008)	(0.014)
Ln(min. dist. to vial axis)	-0.001	-0.0006	-0.003	-0.001	-0.001	-0.003*
	(0.004)	(0.006)	(0.003)	(0.003)	(0.000)	(0.002)
Man (=1)	0.015	-0.013	-0.080***	-0.003	0.167***	0.146***
	(0.015)	(0.024)	(0.011)	(0.022)	(0.010)	(0.017)
Age	0.018***	-0.057	0.019***	0.035	0.009***	0.105***
	(0.002)	(0.040)	(0.002)	(0.027)	(0.002)	(0.034)
Squared age	-0.001***	0.001*	-0.0002***	-0.001	-0.000***	-0.002***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Head of household (=1)	0.042***		0.259***		0.035	
	(0.013)		(0.012)		(0.022)	
Education level	0.181***	0.124***	0.151***	0.192***	0.069***	0.143***
	(0.008)	(0.012)	(0.007)	(0.014)	(0.009)	(0.026)
Industrial Sector (=1)	-0.083**	-0.174***	0.211***	0.122*	-0.033	-0.028
	(0.032)	(0.057)	(0.043)	(0.067)	(0.048)	(0.079)
Trade Sector (=1)	0.081**	-0.050	0.155***	0.123*	-0.047	-0.006
	(0.036)	(0.059)	(0.046)	(0.064)	(0.028)	(0.067)
Service Sector (=1)	0.039	0.001	0.196***	0.098	0.015	0.098
	(0.034)	(0.059)	(0.042)	(0.060)	(0.035)	(0.063)
Construction Sector (=1)	-0.232***	-0.299***	0.062	-0.016	0.044	0.065
	(0.041)	(0.081)	(0.048)	(0.066)	(0.037)	(0.061)
Com. and Transp. Sector	0.198***	0.019	0.214***	0.083	-0.144***	-0.010
	(0.033)	(0.067)	(0.036)	(0.062)	(0.040)	(0.070)
Public Admon Sector (=1)	0.010	-0.020	0.257***	0.177**	0.032	0.163*
	(0.034)	(0.066)	(0.044)	(0.082)	(0.057)	(0.089)
Blue Collar Worker (=1)	-0.033***	-0.002	-0.133***	-0.118***	-0.131***	-0.144***
	(0.012)	(0.029)	(0.014)	(0.024)	(0.030)	(0.040)
Own House (=1)	0.111***	0.148***	-0.063***	-0.063***	-0.028***	-0.033*
	(0.022)	(0.030)	(0.010)	(0.021)	(0.010)	(0.017)
Internet Service (=1)	0.283***	0.341***	0.061***	0.026	0.047***	0.087***
	(0.024)	(0.035)	(0.015)	(0.026)	(0.013)	(0.024)
People in ages 0-6	0.0154	-0.001	0.0097	0.010	-0.022***	-0.006
	(0.009)	(0.019)	(0.006)	(0.013)	(0.005)	(0.010)
People in ages 6-12	0.004	-0.034**	0.018**	-0.015	-0.032***	-0.017
	(0.009)	(0.016)	(0.007)	(0.010)	(0.006)	(0.011)
Single-parent household	-0.245***	-0.215***	-0.004	0.075***	0.015*	0.011

Chapter 5

Conclusions

5.1 Main Results

The central aim of the thesis is to analyze the effects of polycentrism on patterns of land use and individual mobility. This analysis would assess how much policies aimed at developing a polycentric urban structure would be beneficial to combat congestion and pollution. The thesis' three empirical exercises were presented with the specific objective of identifying the effect that employment subcenters have on the pattern of land use and individual mobility in the metropolitan area of the Mexican Valley (MAMV). The specific case of the MAMV is important, firstly, because it is one of the world's most populous urban areas; secondly, because the empirical cases of urban areas in developing or Latin American countries such as the MAMV are scarce, and thirdly, because the MAMV is one of the most congested urban regions of the world.

The synthesis of the results of the three chapters implies that the benefits associated with polycentrism could be concretized in the consolidated the MAMV emerging polycentrism.

Regarding the role of subcenters, the results indicate that: (1) subcenters play an important role in determining the residential land use. Also they affect the pattern of the observed variation in population density: the density variation decreases as the distance increases from identified employment subcenters. Hence the effect of distance to the nearest subcenter in the population density appears to be strengthened over time. This result would indicate that the trade-off course between consumption of residential land and distance from job centers is operating in the MAMV. The subcenters would be able to structure the pattern of land use, and advantages associated with the polycentric theoretically could materialize; i.e. the population actually residing closer to an employment center makes on average smaller distances than the population living at a greater distance from employment centers. (2) Subcenters effectively manage to reduce commuting distance. This confirms the assumption that workers who reside near to any subcenters have, on average, shorter distances to travel than the other commuting workers whom residences are relatively further to subcenters. (3) Finally, the subcenters also contribute to the reduction of the equivalent CO2 emissions. This effect seems to be related to the effects of subcenters on commuting distance, on the choice of transport modes or the number of work-related journeys. Regarding the effect of the other elements of urban spatial structure, the effect of CBD always appears as the most powerful element in the definition of the pattern of land use and mobility, although its effect is attenuated with the passing of time.

The other important result for policy implications is one that has to do with urban form variables: population density and the employment-population ratio. High population densities are associated with longer commuting distances, which is a result contrary to what theoretical models imply, but consistent with the hypothesis that residential segregation seems to operate in the MAMV. The employment-population ratio has a positive effect on commuting distance and magnitude similar to the CBD; so the mixture of land use seems to be a good tool to reduce commuting distances.

5.2 Policy Implications

Regarding urban policy in the MAMV, it is a priority to reduce congestion and GHG emission levels; on the latter, the results imply that successful measures would achieve shorter commuting distances. In this sense, the policy implications of the results are associated with models of polycentric urban structure on one side, and compact city on the other. A polycentric urban spatial structure is characterized by the decentralization of employment under a pattern focused on employment subcenters located beyond the CBD; while a compact city is characterized by dense development patterns, urban areas connected by a public transport system, and the existence of spaces with different land uses.

Subject to an assessment of the overall impact of policies associated with these models, we first suggest the construction of an administrative level at a metropolitan level with the ability to design a plan for urban development at the metropolitan level. In this regard, there have been some attempts which have been insufficient, though. Firstly, the formation of a number of committees around specific issues since 1994: the commission of drainage, water for the metropolitan area, the Metropolitan Transportation and Road Commission (COMETRAVI, the Spanish acronym) and the Metropolitan Public Safety Commission and Law Enforcement; and in 1995 the Metropolitan Commission on Human Settlements (Cometah, the Spanish acronym) and the Metropolitan Environmental Commission. All these commissions were intended to address and resolve in a coordinated fashion common problems of the two entities and the federal government. Secondly, the formation of the Environmental Commission of the Megalopolis, which is a coordinating body of the Federal Government and Mexico City, the State of Mexico and the states of *Hidalgo*, *Puebla* and *Tlaxcala*. The objective of this committee is the design of common environmental measures. And I say insufficient because the problems in these areas continue to affect the inhabitants of the MAMV twenty years after those commissions were formed.

As to urban variables, the result which could be controversial in terms of policy implications is the positive sign of population density. Reading the development model Compact City implies that the density itself does not reduce mobility patterns but must be accompanied by a mix of uses. Therefore, land use policies that reward the density and diversity can be a powerful tool to reorder commuting patterns in the MAMV, especially in areas that already show high population densities.

Finally, policies associated with the model of polycentric urban structure consist of strengthening subcenters that have emerged, as well as promoting employment centers in the outskirts of the eastern part of the MAMV area with very high population densities and no identified employment center. That is, policies that encourage job growth in the identified subcenters. More specifically, to the extent which peripheral subcenters such as *Cuautitlan*, *Tlalnepantla* and *Ecatepec* are surrounded by areas of high population density, a good measure would increase economic activity related to personal services to increase the job-resident balance. Regarding transport infrastructure, it is necessary to increase the connectivity of subcenters, particularly peripherals. Although the municipalities which form the third crown have made important investments to develop high-velocity roads, such as the *Arco Norte*, or investments have been made to construct vial distributors and second floors to connect points inside the second crown investment, there are still signs of congestion. As far as the public transport goes, launched projects have focused on ordering transport on the main roads of Mexico City (*Avenida Insurgentes*, 1 West Avenue, 4 South Avenue and two more lines on the first ring of the city) through a fast bus network. However, this measure continues to be insufficient given the enormous volume of daily journeys that take place in the MAMV. In sum, our results point to the need to improve transport infrastructure and public transport to strengthen polycentric development that shyly emerges in the MAMV.