

Urban sprawl, land use and air pollution in urban areas with a case study on the San Juan Metropolitan Area, Puerto Rico

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"Master of Science"

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Affidavit

I, **PILAR SOFÍA GÓMEZ-LOBO SANTIAGO**, hereby declare

1. that I am the sole author of the present Master's Thesis, "URBAN SPRAWL, LAND USE AND AIR POLLUTION IN URBAN AREAS WITH A CASE STUDY ON THE SAN JUAN METROPOLITAN AREA, PUERTO RICO", 74 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

Defining urban sprawl is a difficult task. Beyond low-density, uncontrolled development and urban expansion, there is no one unified concept or definition. As a consequence, several metrics and indicators are used to characterize urban sprawl. A literature review has been done in the first part of this thesis in order to complete the difficult task of finding the ideal set of indicators and thereby an ideal definition, that may also be applied to our case study of the San Juan Metropolitan Area. One of the main concerns of this thesis is the environmental consequences of urban sprawl. Therefore, further on in the literature review, a discussion of the causes and consequences of sprawl will show how the automobile plays a very important role in both being the origin of the ‘problem’ and in its increased use resulting in more carbon dioxide emissions and concentrations. The change and loss of landscape is the other important environmental consequence of sprawl. The second part of this thesis draws its focus to the San Juan Metropolitan Area in Puerto Rico (SJMA). Representing the main urban areas of the island, the San Juan Metropolitan Area has gone through an interesting process of development and urban growth. Following in the United States’ footsteps, Puerto Rico experienced rapid growth in population and in infrastructure development during the 1950s. With a steady population growth rate until the late 1990s to early 2000s and an ever increasing use of the car as a means of transport, suburbanization was practically inevitable. More recent years show for a slow-down in population growth, but the consequences and outcomes—traffic congestion and loss of landscape, for instance—of sprawl remain. To fulfill the ultimate aim of this research—finding appropriate policy approaches to mitigate and control the negative effects of sprawl in the SJMA—census data, income data, transport data, land use regulation data, and remote sensing image information have been used and analyzed to list the policy implications accordingly. In order to make urban life more attractive than suburban life in the SJMA, more investments are required in the public transportation system and in the betterment of the other public amenities the urban centers of the SJMA have to offer. An island-wide land use regulation system is also required.

Keywords: urban sprawl, Puerto Rico, San Juan Metropolitan Area, urban economics

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List of Abbreviations and Acronyms

ACS - American Community Survey

CBP - County Business Patterns

CO₂ - carbon dioxide

DIS - degree of urban dispersion

EPA - United States Environmental Protection Agency

GDP - gross domestic product

GNI - gross national income

km² - square kilometer

MCCM - monocentric city model

NO₂ - nitrogen dioxide

PCCM - polycentric city model

SGA - Smart Growth America

SO₂ - sulphur dioxide

SJMA - San Juan Metropolitan Area,

also San Juan-Caguas-Guaynabo Metropolitan Statistical Area

SPC - sprawl per capita

TS - total sprawl

UP - degree of urban permeation of landscape

US - United States

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1. Introduction

An environmental issue or problem is not only solved by scientists and researchers. Cooperation between different groups of experts and workers has always been cumbersome in the development of national environmental policies and even international environmental law. The interdisciplinary character of this topic was a big part of the motivation behind my choice of the topic. The other part of my motivation to write this thesis were my experiences in living in a city with a unique mix of areas with high population density and areas of dispersed development, with car dependency and ineffective land-use planning present not only in the San Juan Metropolitan Area, but all over the island.

The concept of urban sprawl is generally recognized as the spreading of urban developments, such as houses and shopping centers, throughout undeveloped land near a city. There are different indicators, metrics and characteristics that, when measured and taken into account, add more depth to the general definition of sprawl as a concept and as a phenomenon. You can visually perceive if land is sprawling, also if this land is dominated by urban development and/or solitary buildings. The more developed and dispersed urban area there is (i.e., presence of urban patches), the higher the degree of urban sprawl.

Urban sprawl is concerned with economic and social development, culture and history, urban planning, policy making and the environment. How the phenomenon of urban sprawl is studied and explained depends a lot on the point of departure of the researcher. Is it from the economic or the environmental point of view? Even though the term has gained somewhat of a negative connotation because it is associated with undesired and arguably unnecessary occupation of land (e.g., malls), for some, it is a positive phenomenon because it represents growth and development. The aim of this study is to identify and measure urban sprawl and how policies can be used as tools to reduce or better control the phenomenon and thus, reduce the negative environmental effects that come from it. The challenge lies in finding the policies that are in most harmony with the interests of developers, inhabitants, government and conservationists alike.

The use of the car or auto reliance remains, throughout this and other studies that are considered throughout this thesis, the main driver and cause behind prolonged urban sprawl. Other causes of sprawl to be considered are transportation costs, growing population, rising incomes, desire for more living space, ‘flight from blight’, local revenue reliance, and geophysical borders.

The increased use of the car as a means of transport is the main cause of sprawl considered in this thesis because the consequence deriving from it is one of the main environmental consequences of urban sprawl: air pollution. The many consequences of urban sprawl can be social, economic, environmental, or many at a time. There is also the concern with the change of the natural landscape and the loss of agricultural or farmland.

Just as environmental degradation is without a doubt a serious concern of scientists, governments and people alike, the phenomenon and concept of urban sprawl has also gained popularity in discussion. Which leads us to the discussion of the research question that this thesis aims to answer. Can policies reduce and control the consumption of land, reduce tendencies to sprawl in a given area without alienating the plans of growth and development that the area might have?

To first properly discuss the topic, I have gone through previous publications that work with the definitions, origins and effects of sprawl. This first part of the thesis—Chapters 2, 3 and 4—serves as the literature survey. Chapter 2 deals with defining the concept and phenomenon of urban sprawl in detail. Maintaining a focus on literature that deals with the North American landscape and scenario, the chapter provides a review of the definitions of sprawl. Chapter 3 is dedicated to identifying the causes and/or drivers of urban sprawl. To end the first part of the thesis, Chapter 4 offers insight on the consequences of urban sprawl. Urban sprawl can have both negative and positive outcomes. The information collected for these three chapters was essential to establish a mindset when it came to analyzing the data collected for the case study and thoroughly understand how policies would influence the factors, metrics and indicators with the goal of reducing the environmental impact that sprawl can yield.

The second part of the thesis (Chapters 5 and 6) is dedicated mainly to the case study of the San Juan Metropolitan Area in Puerto Rico. The aim of the case study in

Chapter 5 is to portray an image of urban development in Puerto Rico, specifically the San Juan Metropolitan Area. Chapter 5 presents a profile on the SJMA; it includes information obtained from data collection efforts in census, income, transport, land use regulation, and remote sensing imagery. For this last profile component, Martinuzzi et al.'s study (2006) was of essential help. This chapter is where the most limitations of the work and research may be found, as some desired data was not available and the analysis of remote sensing data requires some training. The research/study would have benefited plenty from more data availability—car registration data specifically—, as well as working with actual numbers rather than well formulated estimates. The analysis is more qualitative than quantitative. Lack of expertise in specific areas, such as analyzing remote sensing satellite imagery proved to be another challenge in presenting a somewhat complete case study. Nevertheless, with the gathering of data of a total of 19 municipalities of the SJMA for the 2000 and 2010 Census (US Census Bureau, 2015), interesting results were found with relation to the movement of people within the region and their land consumption behavior, and preferences in mode of transportation. The end of Chapter 5 is dedicated to the discussion of the policy implications for the SJMA.

Chapter 6 continues with the focus on how policies influence urban sprawl, particularly how can they work in the reduction of urban sprawl, with the goal of reducing the environmental consequences that result from the fast paced and somewhat uncontrolled urban expansion. For this chapter, Tietenberg and Lewis' textbook *Environmental Economics & Policy* was a substantial source of information. Lastly, the Conclusion offers a summary and a critical discussion of the topic, as well as recommendations for future research.

2. What is urban sprawl?

This chapter is dedicated to providing a review of the definitions of sprawl available in the literature. The focus will remain on literature and publications that researched and dealt with the American landscape. The reason for this is that our case study, the San Juan Metropolitan Area in Puerto Rico, has in fact gone through a similar pattern of urban development to that of a typical US city. However, a brief comparison with how sprawl is defined in other parts of the world would prove to be interesting and

useful. The phenomenon of sprawl occurs in many different ways. This is particularly evident when comparing Europe and mainland US.

2.1.Definition

For the most part, urban sprawl has gained a negative connotation. The concept may mean different things to different people and sectors of society. This fragmentation in views may prove to make a successful discussion possible (Brueckner, 2000). This discussion may have three stances: (1) being completely against urban sprawl, (2) being a supporter of urban sprawl because it is a synonym of growth and development and represents the perpetuation of the choice of consumers and developers, and (3) believing that sprawl should not be stopped completely, rather just better controlled. In many scenarios a debate between conservationist and developers exists. Different professions might place themselves on one of the three stances mentioned above.

Urban Sprawl may be considered a term that refers to anything from low-density urban development to dispersed or decentralized forms of urban expansion (Ewing, 1997; El Nasser and Overberg, 2001). Urban sprawl is the term used to denominate extensive, low-density form of urban land transformation correlated with low agricultural productivity¹, environmental degradation, reduced efficiency in public services, increased commuting times and fuel consumption (Johnson, 2001). When a landscape is affected by sprawl, patches of urban development or solitary buildings can be observed (Jaeger, et al., 2010). Basudeb (2012) defines sprawl as unplanned, uneven pattern of urban growth, which is driven by many processes and ultimately leads to inefficient resource utilization. The main resource in question here is land. Special emphasis should be made on the term ‘unplanned’.

Sprawl is a concept that is difficult to define. This, in turn, makes the quantification process a rather complicated one (Johnson, 2001; Basudeb, 2012; Jaeger, et al., 2010; Schneider and Woodcock, 2008). Population density and the way and/or to what purposes land is used are important and recurring factors to take into consideration when defining sprawl. More sprawling regions will show relatively low population density, and the inhabitants of these regions live far from their places of work,

¹ Later on, in Chapter 6, more will be discussed on the role of agricultural productivity and policy making in helping mitigate sprawl.

education, recreation, etc. This distance, most likely, requires the use of personal, passenger cars to move around.

The definition of urban sprawl is not as simple as quantifying land area which has changed into urban use. In this case, remote sensing data should be considered the best tool to identify patterns and processes in urban landscape changes over time. Remote sensing does, however, present certain technical difficulties in interpreting the visual information. It is common practice to document the existence of urban sprawl over time by looking at the change in rural and urban population and then look within urban areas at the evolving relationship between suburbs or ‘edge cities’ and central cities (Nechyba and Walsh 2004).²

Nechyba and Walsh (2004) define sprawl as the tendency toward lower city densities as city foot prints expand.³ They also state that a full analysis of the phenomenon is difficult due to the lack of a useful integrated model of urban economies. More will be discussed on these monocentric and polycentric city models in Chapter 3 of this thesis. Sprawling development (low-density residential development) involves so-called ‘edge cities’ as clusters of population and economic activity at the outskirts of the city center (the urban fringe). Sprawl happens when individual houses appear across what before were rural landscapes (Nechyba and Walsh, 2004).

In Chapter 13 of *The Costs of Sprawl Revisited*, Anthony Downs et al. (1998) define sprawl in terms of assortment of land use patterns (i.e., commercial or residential use), and specific consequences of these patterns. Here, it may be observed that there is no distinction between the causes, consequences, and characteristics of sprawl. While sprawl at the micro level is understood as a phenomenon indicated by the development of land in small patches very much separated from one another, at the macro level,

² Central cities are understood as the traditional ‘downtown’ concept or the traditional central business district. Edge cities, similar to suburbs, are developed areas (that came to be after the central city) that have their own political, economic, and commercial base independent of the central city. The concept of suburb focuses more on the residential aspect; it is defined as a town where people live in houses near a larger city.

³ Similar to the definition of *ecological footprint*, a city foot print is a measure of the demand on the Earth’s ecosystem from urban centers as a whole and the humans that inhabit them. This measure of demand for natural capital is standardized and raises the question of the planet’s ecological capacity to regenerate. Land is viewed as a natural resource (Ewing et al., 2010).

sprawl is indicated by the change in the structure of a city from monocentric to polycentric in form (Schneider and Woodcock, 2008).

A study by Schneider and Woodcock (2008) shows that urban sprawl is characterized using land cover patterns taken from remote sensing data together with census data. From their findings, they list four possible city types: (1) *expansive growth cities* are characterized by their large sizes, dispersed form of expansion and considerably lower population densities; (2) *frantic growth cities* are characterized by the extremely fast rate at which land is converted and by unregulated growth, there is dispersion and fragmentation in the development patterns of these cities; (3) *high growth cities* are characterized by rapid urban development and decreasing population densities, land conversion is limited to areas that are either near the center or near the urban fringe, newer growth takes a more scattered form; and, finally (4) *low growth cities* are characterized by a land development that has occurred parallel to population growth, land conversion is more of the infilling⁴ type than the scattered type. Table 1 might help illustrate this better. According to these explanations, most cities in the US belong to the *expansive growth* category (Schneider and Woodcock, 2008).

Jan K. Brueckner (2000) defines urban sprawl as the excessive spatial growth of cities. The key term here being excessive, it is a fact that cities do need to grow in size to accommodate a growing population. The problem arises when this happens at an uncontrollable and disproportionate rate. Parting from the aspects of excessive urban development, a city is sprawling if it shows for at least one of those aspects: Is it too extensive? Is its employment too dispersed? Is there insufficient population density? Results for the Maryland, US state area show that there is an increase in the land fragmentation in all areas except those closest to a city boundary. In fact, the fragmentation is largest in areas that are farthest from urban centers (Irwin and Bockstael, 2007).

2.1.1. Summary of definitions

In this section a summary of the previously discussed definitions of urban sprawl will be outlined. With this summary, it will be specified which definition or combination

⁴ Let infilling be understood as the rededication of land in an urban environment. It involves recycling or reusing existing urban infrastructure (Brooks et al., 2011).

Table 1: Summary of characteristics for the four city types (Schneider and Woodcock, 2008, 688)

<i>Group</i>	<i>Spatial extent of city</i>	<i>Percentage increase in spatial extent</i>	<i>Dispersed or constrained</i>	<i>Scattered or contiguous</i>	<i>Population density</i>	<i>Examples</i>
Expansive-growth cities	Large	Small	Dispersed	Contiguous	Low	Baltimore Washington Montreal
Frantic-growth cities	Small	Large	Dispersed	Scattered	High	Guangzhou Dongguan Chengdu
High-growth cities	Small	Large	Constrained	Scattered	High	Calgary Brasilia Ankara Bangalore Wuhan
Low-growth cities	Small	Small	Constrained	Contiguous	High	Guadalajara Curitiba Ahmedabad Nairobi

of definitions will be used for the rest of this thesis. In *Measuring Sprawl and its Impact*, Ewing et al. (2002) define urban sprawl as “the process in which the spread of development across the landscape far outpaces population growth”. The Transportation Research Board (2002) defines urban sprawl as “peripheral growth that expands in an unlimited and non-contiguous way outward from the solid built-up core of a metropolitan area”. Urban sprawl is characterized by low-density development (Edwin, 1997). For an area or region to be sprawling there must be significant per capita land consumption and almost complete reliance on the car for transportation (Martinuzzi et al., 2006). According to Tietenberg and Lewis (2009), from an economic point of view, sprawl happens when land use in a particular area is dispersed or segregated and not concentrated. With this we have now a sort of checklist for our definition of sprawl: low-density, dispersed development, and almost sole dependency on the car as a means for transport.

2.2. Metrics and indicators of urban sprawl

Urban sprawl can be translated into many variables which can be measured by different metrics and indicators. In this section a list of metrics and/or indicators will be provided in order to better understand how sprawl as a phenomenon develops and is defined. There are basically no differences between that which is a metric and that which is an indicator of urban sprawl, and both help in establishing standards for the definition of the concept. The metrics (measures) and indicators may serve as a checklist of all the variables and factors that make up a sprawling region.

Some sort of quantification of urban sprawl is necessary in order to establish objectives for environmental quality, to identify trends and changes in time and space within them, and to detect statistical relationships between urban sprawl and ecological consequences (Jaeger, et al. 2010). Jaeger et al. (2010) introduce four measures of urban sprawl: degree of urban dispersion (*DIS*), total sprawl (*TS*), degree of urban permeation of the landscape (*UP*), and sprawl per capita (*SPC*). Through these measures, sprawl is characterized through a geometric point of view. The measures relate to each other as follows: $TS = DIS \times \text{urban area}$, $UP = TS / \text{size of the studied landscape}$, and $SPC = TS / \text{number of inhabitants}$. *UP* describes to what degree a landscape is permeated by settlement areas and solitary buildings. *SPC* relates sprawl to the number of inhabitants. For industrial regions with low numbers of inhabitants, *SPC* may be defined in terms of number of jobs in the region under study, or the sum of inhabitants and jobs. Remote sensing data provided information on the rate of urban growth, on the spatial configuration of growth, on whether there is any discrepancy in the observed and expected growth, on whether there is any temporal or spatial disparity in growth, and on whether this growth is sprawling or not (Jaeger et al. 2010). Other metrics are spatial rather than temporal: population moving from the inner city to the suburbs, a comparison of land use and population growth, time cost on traffic, decrease of open space (Basudeb, 2012).

Table 2: Measures and variables for urban sprawl as applied in two studies (adapted from Ewing et. al, 2002; Schneider and Woodcock, 2008)

<i>Factors</i>	<i>Variables</i>
Residential/population density	Population per km ² of urban land
	Gross population density in persons per km ²
	Gross population density of urban lands
	Weighted average lot size for single family dwellings (households) in m ²
	Estimated density at center of the metro area
	Rate of decline in density from center (density gradient)
Neighborhood mix of homes, shops, and others	Percentages of residents with business or institutions within 1/2 block from their homes
	Percentage of residents with satisfactory neighborhood shopping within 1 km
	Ratio of jobs to residents
	Ratio of population-serving jobs to residents. (Population serving jobs include retail, personal services, entertainment, health, education, and professional services.)
	Percentage of the population living within 3 km of the central business district (CBD)
	Percentage of population living more than 10 km from the CBD
Fragmentation, scatter, accessibility	Percentage change in patch density
	Average block length in urbanized portion of the metro area
	Average block size in km ²
	Percentage of small blocks
	Ratio of population density to the highest density center in the metro area
Built-up land (size and density)	Spatial extent of urban area in km ²
	Amount of new urban land in km ²
	Ratio of amount of urban land to all land
	Change in density of urban land: difference in ratio of urban land: difference in ratio of urban expansion to all land

A study completed by Smart Growth America (Ewing et al., 2002) introduces a four factor sprawl index. The four factors are: (1) residential density, (2) mixture of residence, employment, and service facilities, (3) vitalization of inner city, and (4) accessibility to road network, each made up of several measurable components.⁵ Please refer to Table 2 above for the measures/variables as applied in this and one other study reviewed for this thesis. Similar to the definition of urban sprawl used by the Smart Growth America study/report, in *Who Sprawls Most? How Growth Patterns Differ Across the US* (Fulton et al., 2001) sprawl may be indicated by the rate of land consumption compared to the rate of population growth —if land is consumed at a faster rate, then sprawl for this region is considered as increasing.

In another study, Burchfield et al. (2006), use the percentage of undeveloped land in the nearest square kilometer⁶ (km²), —the percentage of open space in square kilometers surrounding an average residential development (i.e., in the vicinity of a developed residential community). An average of this measure across developed niches or patches in a metropolitan area is supposed to give an index of sprawl for the metropolitan area being examined. By applying this index they find that an increase in the amount of residential development was not necessarily biased towards sprawling for the period between 1976 and 1992. Their results —within the study of US urban development— also show that commercial development was indeed biased towards sprawling areas in the time period under study. Development has not necessarily been controlled to achieve a more sustainable consumption of land, rather demands for more space have been satisfied. There are variations across metropolitan areas and the explanation for this variation provided by urban economists is the evidence behind the causes of sprawl that will be discussed further in this thesis, in Chapter 3.

There are many indicators of sprawl that have been considered and measured throughout studies. Some indicators help more than others in assessing sprawl in a given region. Some may criticize the sole reliance on population density as an indicator of sprawl. The reason for this might be that, as some studies may show, there are many

⁵ In relation to sprawl, *Smart Growth* is an urban planning and transportation theory that concentrates growth in compact, walkable urban centers to avoid sprawl (Boeing et al., 2014).

⁶ Throughout this thesis the metric system will be the working system of measurement.

causes other than population growth—car reliance, demand for land, fluctuations in transportation costs, among others—behind urban sprawl. Further on in Chapter 3, some of these causes —many related to government action— will be discussed.

Galster et al. (2001) created a very complete sprawl index, using eight factors: density, continuity, concentration, clustering, centrality, nuclearity, mixed use, and proximity. In their study, low levels in one or more of these dimensions would be considered a pattern of land use defined as sprawling.

In Schneider and Woodcock's (2008) study, the goal through the indicators is to characterize the nature of the changes in land use and compare and contrast trends across cities and countries. Land use change information was derived for each city⁷ from the analysis of change detection from remote sensing data, application of landscape metrics, as well as demographic data.

The indicators describe the spatial extent of urban areas, the rates of land conversion, the location and pattern of new urban land, the amount of discontinuous growth, and the efficiency of land development, as suggested by population density. The sample used in this study is based on post-industrialized, industrialized and emerging market cities for the simple reason that socioeconomic data are more readily available (Schneider and Woodcock, 2008). This is, of course, an important detail to account for. Urban development occurs in different ways across the different types of economies. Political boundaries or delimitations, even though they encircle urban space, change over time and are thus not reliable in this sense. Urban land use might end up being over or underestimated (Cohen, 2004).

2.2.1. Summary and outlook on metrics and indicators across cities/metropolitan areas

There are plenty of indicators and metrics of urban sprawl to choose from. This simply serves as evidence that sprawl has drivers and causes in the many areas of urban studies, and in turn, makes urban sprawl difficult to define as a concept and phenomenon. Considering the metrics discussed in the previous sections, the basic approach to measuring urban sprawl may lie in relating the rate of urban growth and

⁷ See Table 1.

expansion (land cover) to the rate of population growth. If land is consumed and converted at a faster rate than that of the population growth, then the region being studied has tendencies to sprawl (Stone, 2008). Metrics of urban sprawl describe the spatial extension of urban land and rates at which land is converted; locations and patterns of new urban land are determined and patches of land (signaling discontinuous growth) may be spotted. Efficiency in land development is determined by how proportionate to each other land conversion/change/use and population growth happen (Turner, 2007).

Linked to this efficiency are some of the causes of urban sprawl that will be discussed in the next chapter. Sprawling land is not efficient land development. Many of the causes and characteristics of urban sprawl have their origin in the decision the consumers (of the land) make. These decisions (where to live, where to work, how to move from one place to another, how many children to have etc.) are in turn highly influenced by governments and their decisions to subsidize or tax one thing or the other and their policies on land use and development, transportation, or, more controversially speaking, on population growth (Bart, 2010).

3. What are the causes for urban sprawl?

This section will list the major causes behind the phenomenon known as urban sprawl. Sprawl is a phenomenon driven, in great part, by socio-economics causes. Where urban areas are located also depends on the availability of this land for developmental purposes, be that building of new residential communities or commercial centers/establishments, or roads, etc. Geophysical borders (e.g., mountains, ground-water bodies) do play an important role in the decision-making on land use, much like zoning laws determine the future use of open and free space (Schneider and Woodcock, 2008). Despite all the technological advances accounted for until today, the physical characteristics of the environment continue to shape cities: sprawl increases plenty with the presence of underground water at the urban fringe, hills and small-scale irregularities of the terrain promote scattered development, a temperate climate (considered a factor that increases the value of open space) will increase sprawl (Burchfield, et al., 2006).

Some studies aim to explain sprawl by exploring the causes behind the phenomenon (Glaeser et al., 2001; Pendall, 1999; and Fulton et al. 2001). Glaeser et al. (2008) established a correlation between sprawl and the degree of decentralization of employment (i.e., how much of the region's employment is within how many kilometers from the city center). Pendall (1999) aimed to explain the phenomenon in terms of land values, metropolitan political organization, local government spending, traffic congestion, and various local land use policies. Parting from Pendall's study, Fulton et al. (2001) examined urban land use in relation to population change for every US metropolitan area.

Robert Wassmer (2008) evaluates a few possible causes for sprawl in the US, as he places focus on the increasing number of local suburban governments. A few theories that back up the reason people move to the suburbs are discussed: car reliance, natural evolution, 'flight from blight' and local revenue reliance. In cities where the mode of transportation of choice is the car there is considerably more sprawl compared to cities that have a well-functioning public transportation system. 'Flight from blight' refers to the choice households make to move further away from the city center in search of better public amenities. This is heavily linked to the reliance on local revenue, given that governments use local revenue to provide for these public amenities. The richer a given local government is, supposedly the better will be the living standards in this area.

The causes to be discussed will be divided through the sub-sections, these are: *transportation costs related causes, auto reliance, 'flight from blight' (the push and pull factor), and local revenue reliance*. A special focus will be made on this 'push and pull' factor in sub-section 3.1, dealing with the monocentric and the polycentric city models. Section 3.1 offers a theoretical explanation of the monocentric city model and the polycentric city model, with a separate sub-section (3.1.1) dedicated to transportation costs related causes of urban sprawl. This is dealt with separately simply to establish the importance transportation costs have over the decision making of the consumers and/or households. Section 3.2 touches on the other causes of urban sprawl; they have been grouped together according to how closely-related they are to each other. Sub-section 3.3 will provide for a summary of the causes for urban sprawl discussed here and a conclusion answering important questions, like which causes are the most important and

why and how the push and pull factor may be used to find appropriate policies to reduce the negative effects of urban sprawl.

3.1.Theoretical explanation and some empirical evidence: the monocentric and the polycentric city models

In the monocentric city model (MCCM)⁸, residential development around the city center is shaped by the trade-off between convenient commuting close to the center and affordable housing further away; with equal utility across residential areas, housing prices decline as we move farther away from the city core to offset the commuting costs (Burchfield et al., 2006). The more recent polycentric city model (PCCM) is described in Joel Garreau's *Edge city: life on the new frontier* (1992). The PCCM accounts for factors such as utility gains from lower average land rents and increasing returns due to economics of agglomeration (Strange, 2008). As the term suggests, in the PCCM, there is no one single city center (social, financial, political); there are several. A city is polycentric if there is an even distribution of its population among several centers.

A common way to document the existence of urban sprawl over time is to look at the evolution of rural and urban population levels and then to examine within these urban areas the evolving relationship between suburbs and central cities (e.g., how much commuting there is from the suburbs to the city center). This rather follows the monocentric city model, which provides for a simple framework to understand sprawl by emphasizing on the importance of transportation technology, government subsidies, and basic demand for land and urban area. The MCCM, however, typically ignores a specification in individual and family (household) tastes for open space and does not address job suburbanization or employment decentralization (Glaeser and Kahn, 2003; Burchfield, et al., 2006). Therefore, the model fails to well analyze the welfare losses from sprawl-related loss of open space. The MCCM defines open space as the rural land located at the urban fringe or edge (Nechyba and Walsh, 2004).

⁸ In the mono-centric city model, urban spatial structure rises from the trade-off between commuting costs and land rents. Equilibrium happens when land rents at the urban edge are lower and offset increased commute costs. Declining rent gradients lead to declining density gradients the farther from the metropolitan business centre and the closer to the urban edge you are (Fujita, 1989).

On the other hand, the polycentric city model (PCCM) analyses the fixed infrastructure costs that are present in the building of new subcenters, as well as how productivity suffers as we move further away from the core of the city (Glaeser and Kahn, 2003). Loss of open space and other consequences of urban sprawl will be discussed further in Chapter 4 of this thesis. Also discussed in Nechyba and Walsh (2004), in the PCCM there are multiple employment centers located throughout many metropolitan areas. These centers are so-called ‘edge cities’ and they pose difficulties when modeling urban patterns based on transportation and housing distribution. As opposed to the MCCM, the PCCM contributes to the formation of employment centers outside the central business district. Dense employment sub-sectors happen at the outskirts of cities.

Cities will sprawl less if they specialize in sectors like business services, which tend to be centralized in the average city. Elements that increase the importance of the central business district will decrease sprawl. Also, cities with higher historical population growth rates sprawl less. Characteristics that make open space more valuable and attractive are more prone to encourage larger housing lots and more frequent undeveloped parcels, which serve as public open space (Burchfield, et al., 2006).

Nechyba and Walsh (2004) present yet another model: the *Tiebout Local Public Finance Model*. This model is based on the premise that residential location choices within metropolitan areas are made based on many other factors besides transportation and commuting costs (e.g., local schools, crime rates, and other public amenities). These considerations are important when discussing the costs and benefits of sprawl, even if they are not directly regarded as causing growing city footprints and declining population densities—two of the main characteristics of sprawl.

In Tiebout’s model, zoning is the means by which communities or governments can limit and mold immigration and development to suit the cost structure of local public goods. If local public services are more costly when development is scattered, then disinclination to scattered or sprawling development should be less important; sprawl should be more dominating where local taxpayers pay a lesser share amount in local government expenses (Burchfield, et al., 2006).

3.1.1. Transportation costs related causes

As cities become more popular and attractive, they grow up and out. Therefore means of transport also go through some changes. Examples of these changes are creation or alteration of the public transport system (trains, subways, trams, buses etc.), and an increase in the availability of cars; in turn, the changes are followed with some changes in transport costs.⁹ Federal and state governments have favored the automobile through their high spending on roads and highways and relatively low gas taxes and low subsidies for public transportation (Hart and Spivak, 1993). This is more so true for the US than for Europe, where there are higher gas taxes.

Since the availability of cars causes transportation costs to go down, it becomes more attractive and feasible to live further away from the city center; people are more able to commute further distances. However, one should not jump to this conclusion too quick, because transport costs have many different effects. For instance, raising transport costs make long commutes and further distances less attractive, employment becomes, thus, more decentralized as new employment subcenters emerge; but fewer people actually reach this employment subcenter. As these employment subcenters make way for less densely populated communities, smaller portions of the population are actually meant to reach them (Glaeser and Kahn, 2003)

Transportation costs influence sprawl in a few different ways, following the two models previously discussed:

- In the monocentric city model, lower transportation costs will make the perimeter of the city bigger and population density smaller. Thus, more land is consumed (more urban sprawl).
- In the polycentric city model, increased use of cars (instead of public transportation), reduces the fixed costs of new construction (e.g., for employment centers). This is so because the immense fixed costs that belong to public

⁹ Transport costs are a monetary measure of what the transport provider must pay to produce transportation services. They exist as infrastructure and operating costs, depending on a variety of conditions related to geography, infrastructure, administrative barriers, energy, and on how passengers and freight are carried (Notteboom and Rodrigue, 1998).

transportation infrastructure are not an issue anymore.¹⁰ Firms can and do move from the centre because trucks can easily distribute products far and wide. The truck is the commercial equivalent of the automobile and makes job suburbanization or employment decentralization possible (Glaeser and Kahn, 2003).

The automobile is an attractive good because trips arguably take less time than with public transportation. Glaeser et al., (2008) study these time differences using the 1995 National Personal Transportation Survey. Cars appeared to be twice as fast as buses and nearly as fast as trains. Road transport (trucks and cars) has allowed regions that are far from the raw materials and far from waterways to grow. There is a high correlation between the usage of cars and living in areas at the city fringe where there is low population density. This serves to back up the idea that the automobile and its growing popularity has made sprawl possible (Glaeser and Kahn, 2003).

The question as to what came first, the car or sprawl, is often present in discussions of the phenomenon. Better formulated: did the increase in availability of cars contribute to urban sprawl, or did the occurrence of sprawl cause the increase in availability of cars? (Rosenthal, 2007). It is a fact that the further development of road transport has led the way for firms and households to lose the need to be situated in the city center. Suburbanization of residences and employment then happens to accommodate the firms and households that are relocating. As discussed in Chapter 2 of this thesis, the increase in construction of roads and buildings is characteristic of urban sprawl.

An important issue arising from the increase in availability of cars is that of traffic congestion. An infamous problem in cities like Los Angeles, CA, congestion is influenced by vehicle kilometers (miles) travelled and by time and place (Tietenberg and Lewis, 2009). With regard to urban sprawl, traffic congestion will make those affected by it want to eliminate it because it costs them time and money. The options then are to move closer to the workplace or the creation of new employment centers closer to the residences that are located outside of the city core (i.e., the suburbs). The

¹⁰ The fixed costs of maintaining the roads and infrastructure needed for the trucks and cars to get to the edge cities are less substantial than the fixed costs that belong to public transportation infrastructure (Glaeser and Kahn, 2003).

first option works more towards the reduction of urban sprawl because cities become more densely populated; the second option is more the inverse because jobs are being decentralized, more patches of buildings start popping up across the once-free landscape. An environmental consequence arising from congestion is, of course, air pollution from vehicle emissions. This and other environmental consequences will be discussed later in Chapter 4. Pollution from vehicle emissions is an indirect environmental consequence of urban sprawl and policies try to tackle the issue of congestion directly with various tools in charging for driving on congested roads or at congested times (congestion pricing) (Tietenberg and Lewis, 2009). Chapter 6 of this thesis will go deeper into how policies relate to sprawl.

As a major cause of urban sprawl, transportation technologies determine urban form. Most modern cities in the US are based on the automobile. This form of urban life is almost synonymous to sprawl. What is known as the personal, passenger car or the automobile is the root cause of the phenomenon. The causes are not found in bad government policies or bad urban planning. In the previous chapter, characteristics of sprawl have been discussed. One of them is population decentralization. The automobile has two effects on population decentralization: by reducing transport costs—as most studies recognize and agree—the car generates an increase in the distance between homes and employment centers; cars also eliminate scale economies,¹¹ on-road transport has replaced commercial sea and rail transport in terms of frequency of use, and gives way for employment decentralization or ‘job suburbanization’, which reduces the traffic congestion in downtown streets, and thus the negative outcomes from traffic pollution, like greenhouse gas production and local smog. Still under the view of the monocentric city model, the arrival of the automobile and the lower transportation costs that came along with it became the principal driver behind sprawling communities through the greater part of the 20th Century (Glaeser and Kahn, 2003).

¹¹ In microeconomics, economies of scale are the cost advantages that enterprises obtain due to size, output, or scale of operation, with cost per unit of output generally decreasing with increasing scale as fixed costs are spread out over more units of output (Investopedia, 2003)

3.2. Other causes for urban sprawl

Among other sources of urban sprawl are the demand for land or the desire for more living space, growing population, rising incomes, ‘flight from blight’, and local revenue reliance. In this section we will discuss these further in some detail. In one way or another the causes for urban sprawl are interconnected. The sub-sections are therefore listed accordingly, by those causes that are related to each other through economic, social or other types of links.

3.2.1. Demand for land/desire for more living space, growing population and rising incomes

The desire for more living space may have its origin in the rising incomes of the individuals and/or households that sprawl. People might also seek amenities that the city center lacks. Increases in land consumption subsidies may make way for lower population densities. An example of government action that may be considered as generating sprawl is zoning regulations that prohibit further construction within the city and the reduction of the home mortgage interest, which promotes housing consumption (Voith, 1999).

Brueckner (2000) argues that urban spatial expansion is a result of three important drivers: a growing population, rising incomes, and falling commuting costs. An ever growing population needs land to be accommodated in and with rising incomes this population has more options and decision-making power as to where and of what size this accommodation is. Without looking at the negative consequences sprawl may bring, these are all good things, both socially and economically speaking. On the other hand, we know that by developing communities at the urban fringe, some farmland (or land that had other non-commercial uses) might be sacrificed. This, thus, alters the allocation of land between agricultural and urban uses and yields to more criticism against urban sprawl (Brueckner, 2000). This allocation of land is guided by the competition between urban uses and agricultural uses. Recently the outcomes have been more in favor of urban use, thus leading to considerable urban growth and inspiring criticism against sprawl (Mitchell, 2001).

Three market failures are listed: (1) failure to account for the benefits of open space, (2) excessive commuting because of a failure to account for the social costs of traffic congestion, and (3) failure to make new development pay for the infrastructure costs it generates. Urban growth stemming from a growing population, rising incomes, and decreasing commuting costs is not totally undesirable because these things are all good for the local economy and well-being of the inhabitants. Nevertheless, it is the market failures mentioned here that place a negative stigma on these sprawl drivers, mainly due to the ill-allocated land (between agricultural and urban uses) (Brueckner, 2000).

There is empirical evidence on the role of rising incomes in urban sprawl in Margo (1992) and Brueckner (2000). The rise of real incomes and fast transport has led to an enabling of people to move out from the centers to find the open residential surroundings they desire. The rate of suburbanization has been on the increase due to declining transportation costs and rising incomes, government tax, expenditure, and zoning policies. Considering public finances, the driver of suburbanization is the desire of households (individuals and families) to segregate in accordance with preferences for local taxes and amenities, as well as the desire to take advantage of peer externalities (Nechyba and Walsh, 2004). At a more local level, it is property taxes that incentivize low-density development in the monocentric city model (Brueckner and Kim, 2003). The next section discusses this household desire to segregate in accordance with local taxes and public amenities available.

3.2.2. 'Flight from blight' and local revenue reliance

'Flight from blight' can be defined as the movement of households/change of residence or workplace location due to the desire of living and working in more ideal environments, that include better public safety, better public school systems, etc. When people and firms rely on local revenue there is a lot of pressure on taxes, intergovernmental transfers and others in order for local governments to pay for all the services and amenities it provides for the public. People might be seeking amenities that the city center lacks. Public finance is also important in the sense that larger intergovernmental transfers lead to local residents bearing less of the costs of extending infrastructure to service new scattered development (Burchfield, et al., 2006).

There are drivers that pull people out of the cities and into the suburbs, these are the attractive features of the suburbs (e.g., more living space for less money, more recreational areas, etc.). There are the drivers that push people out of the cities, these are the unattractive features of the city (e.g., higher crime rates, poor public school systems, etc.). This push is exactly how the term ‘flight from blight’ defines itself. Local amenities such as the ones aforementioned greatly influence the decisions of households regarding residential location (Wassmer, 2008). These amenities are also important when it comes to housing prices. Nice parks, good public schools etc. will make for more expensive real-estate. However, it is not precisely known how these housing and distribution decisions have contributed to the ever expanding diameters of cities (Oates, 1969). This is backed up by the theory that cars enable households to consider wider geographic areas in which to reside (Nechyba and Walsh, 2004).

What is known as ‘flight from blight’ justifies sprawl as being driven by higher tax rates, higher crime rates, deteriorating infrastructures, poor public school systems, and a greater presence of the poor and lower class observed in US central cities. Reliance of local revenue is seen as a possible cause to sprawl concerning property or sales taxation; by raising local sales tax revenue, ‘edge cities’ can better use their proximity to large city centers to expand their jurisdictional boundaries, and this may also aid in the creation of greater sprawl (Wassmer, 2008). To reduce sprawl, the expected influence of a property tax on urban land use can be a reduction in the rate of development, then a decrease in population density, and an increase in the spatial size of an urban area (Brueckner and Kim, 2003).

The results of increasing fragmentation as one moves further away from the urban center are consistent with the declining pull of urban centers. This declining pull is due to decreasing transportation costs, job suburbanization, inner city fiscal and social problems (e.g., crime rates going up), and also due to advances in communications and information technologies (Irwin and Bockstael, 2007).

Introducing the concept of job suburbanization, Kain with his *Spatial Mismatch Theory* (1968),¹² suggests that spatial mismatch has led to a disconnect in locations between jobs and low-income residential developments that are inhabited by individuals of families that are less willing to move. In cities that do not offer a reliable public transportation system or lack one altogether, this spatial mismatch may reduce employment opportunities for the lower income households, which may not have access to a car. For those that depend on public transport because they normally do not have access to a car, life in the city edge or the suburbs is not an option because the lifestyle in these areas revolves around the personal passenger car. Differences in poverty rates somehow correlate with the political boundaries within metropolitan areas. These differences are created through zoning regulations, using markets and local public finance considerations. Poverty rates become higher in city centers because it is the middle and higher income households that may afford a car and actually move to the suburbs. Lower income households remain closer to the city center, given the existence of public transport. Since people living in the suburbs continue to travel to the city center to their workplaces, the segregation depicted here is more related to the housing market. Regarding local public finance, suburbs might be financially administered as a separate jurisdiction (Glaeser et al., 2008).

3.3. Summary and conclusion

Decentralized employment, ancient public transport infrastructure, uncertainty regarding metropolitan growth, and unincorporated land in the urban edge all serve to increase sprawl. The determinants of urban growth and decentralization of economic activities within cities will, in turn, determine the causes behind urban sprawl (Burchfield, et al., 2006). Much of the urban economic literature has succeeded in identifying the main causes for urban sprawl thanks to their focus on the trade-off between transportation costs and land prices. Nevertheless, these studies lack further analysis on the micro level of how urban landscapes within the enlarging borders

¹² *Spatial mismatch* is the mismatch between where low-income households and where suitable job opportunities are available. Being the result of residential segregation, economic restructuring, and the suburbanization of employment, it has mostly been studied as a phenomenon affecting African-Americans. The concept/theory was first proposed by John F. Kain in a seminal article “Housing Segregation, Negro Employment, and Metropolitan Decentralization” (Kain, 1968).

change (Nechyba and Walsh, 2004). Table 3 summarizes the causes of urban sprawl. They are listed in order of importance as judged according to the information presented in the previous subchapters.

Table 3: Causes of urban sprawl (summary)

<i>Importance</i>	<i>Cause</i>
Highest	Car reliance
	Transportation costs
	Growing Population
	Rising Incomes
	Demand for land/desire for more living space
	‘Flight from blight’ (the push and pull factor)
	Local revenue reliance (+government tax, -government expenditure)
	Other government action (e.g., zoning policies)
Lowest	Geophysical Borders

The spread-out landscape characteristically belonging to the US has resulted from a combination of car purchases, large public investments in road infrastructure, limited public investment in central cities, the heterogeneity in the population within cities, and how easy it is for households to move. In almost direct opposition to this, we have Western Europe, which is known for investing more in public transportation within cities. Policies in Europe exist more towards spending more on the maintenance of the city center and its amenities, thus developing a culture that is less willing to move location of residence. European governments are of the belief that this improves household welfare. More homogeneity in population can be observed in European cities when compared to US cities (Nechyba and Walsh, 2004).

The reasons behind the location of a business and the location of residence of the commuters that have to get there are endogenous in the long run (Nechyba and Walsh, 2004). Meaning, no other outside factor determines this location other than the desires of those that make the decisions. In the short run, it is the particular circumstances (e.g., local amenities) that may drive these decisions. This will be considered later in Chapter 6 of this thesis, touching on the policies topic.

Treating land like the resource that it is, the consumers and their decisions are some of the main determinants of its outcome. These decisions are determined by many socio-economic factors and how much value the consumers give to it (e.g., availability of public goods and amenities, access to commercial activity), for which governments and policy makers have the upper hand in influencing and changing. Regardless of the preferences of the consumers, some of these local public goods, like access to open space, may not qualify for the claim that it has to be delivered to all. However, schooling, protection from crime and environmental hazards, and access to neighborhoods that are broadly functional do qualify for such a claim. This contrast between local public goods and their availability within the given urban area, sprawling or not, may determine the value the consumers give to the good and thus their decision for household location of residence accordingly (Nechyba and Walsh, 2004).

Sprawl is a phenomenon mainly driven by socio-economic causes. The rate of suburbanization has been on the increase due to declining transportation costs and rising incomes, government tax, expenditure, and zoning policies. The car is considered to be the main driver of sprawling cities and sprawling employment centers. Regarding car reliance, there is always the question as to what came first, sprawl or car availability. Car reliance is closely related to transportation costs because the car has made transportation costs go down dramatically. Development of land in the US seems to be centered on the automobile, so there is more investment on road infrastructure. People generally prefer the car as a means of transport because it arguably reduces the commuting cost of time (when compared to public transportation). The car offers other minor benefits for the consumer.

What is known as ‘flight from blight’ justifies the phenomenon as being driven by higher tax rates, higher crime rates, deteriorating infrastructures, poor public school systems, and a greater presence of the poor and lower income classes observed in US city centers. These push people out of the cities and into the suburbs. The contrasts between local public goods and their availability within the given urban area may determine the value the consumers give to the good and thus greatly influence their choice for residence location. By adding revenue from local property or sales taxation, ‘edge cities’ can expand their jurisdictional boundaries, thus aiding in the creation of

more sprawl (Wassmer, 2008). The expected influence of a property tax on urban land use can be a reduction in the rate of development, followed by a decrease in population density, and an increase in the spatial size of an urban area (urban footprint) (Brueckner and Kim, 2003).

With growing populations comes the demand for more land to accommodate the people. Consumer behavior and preference are also important factors in this regard. Households tend to enjoy and prefer big lots for their houses, that include a garage, large driveway, garden, patio and so on. Rising incomes make the acquisition of these spaces even more possible. Existing, dense urban centers do not please this suburban demand. Geophysical borders are placed with the lowest importance simply because they are not determined by modern socio-economic factors. Since the beginning of civilization people have started settlements wherever there is the source of food and water.

4. What are the environmental and social consequences of urban sprawl?

Just as urban sprawl has become a hot topic in recent years, to a different but related degree, so have (probably, even more so) the concerns with climate change and environmental degradation and pollution. Environmental problems comprise air and water pollution, as well as the availability of natural resources. The three major environmental impacts that have roots in urban sprawl are the use-up of land that once used to be farmland or forest (from the construction of roads and large suburban lots), increased car-related air pollution, and increased supply of greenhouse gases (raised by the increased aggregate gasoline consumption).

It has been briefly mentioned in Chapter 3, how geological and geographical characteristics affect the development of cities. Now, going a bit in the opposite direction, the environmental consequences of urban sprawl will be discussed in the following sub-sections. The main environmental issues with regard to sprawl are: carbon dioxide (CO₂) concentrations and air pollution, loss of natural landscape, and reductions in the quality of life. The last sub-section will present some arguments that explain the social consequences of sprawl. Note that consequences may be both negative and positive.

4.1. Carbon dioxide emissions and air pollution

Considering environmental consequences of urban sprawl, these effects are particularly reflected in the air quality as a result of the increase in personal, passenger car usage. Pollution from CO₂, ozone, fine particles, SO₂, NO₂, and lead continue to pose challenges for the outdoor air quality. However, the US has experienced some progress in the cleaning of the air since the 1970s according to the United States Environmental Protection Agency (EPA) and evidenced by the decrease in frequency of the visible air pollution. Some pollutants are harmful even when not visible and affect public health and welfare. This is an issue to be discussed later in Sub-chapter 4.3, Quality of life. There is also loss of landscape and rural environments are affected (Ewing et al. 2002; Bart, 2010; Stone, 2008).

It is a general notion that the volume of (road) transport CO₂ emissions are related to GDP, meaning that the richer the country is the more transport would take place. More on the micro scale, generally, the richer a person is, the more likely that person is to own a car and use it for daily transport instead of other means like the public transport system, bicycle, etc. The construction of new roads and buildings is considered to be a primary reason for the growth in road transport. The people that live in suburban and car-centric communities, however, continue to use the same city centers but reach them from farther distances (Bart, 2008).

The links between urban sprawl and air pollution (which includes but is not limited to pollutants such as carbon monoxide, particulate matter, sulfur oxides, and nitrogen oxides), though not as straightforward as they might seem, are, related to road traffic congestion, and increases in vehicle kilometers travelled¹³ (Nechyba and Walsh, 2004). Emission regulations have become stricter, both in Europe and the US; higher emissions per kilometer are more a result of people switching to bigger and/or stronger cars (e.g., sport utility vehicles, SUV). The dispersed spatial distribution of households and centers of employment increases traffic congestion because people travel larger distances from home to work and vice versa. Therefore, greenhouse gas emissions, increased CO₂ concentrations (result of the carbon monoxide reacting with other

¹³ The authors use miles. For every reference that uses miles, it will be directly translated into kilometers, as the metric system is the working system of measurement in this thesis.

pollutants in the air), and local air pollution (due in part to the high temperature combustion present in industrial activity and motor vehicles) in general become a major issue.

4.2.Loss of landscape

The breaking up of undeveloped land alters habitats, deteriorates natural resources, and eliminates functional landscapes. However, it is not so simple to establish a correlation between changes in land use and changes in land cover, although it is often that the first lead to the latter. This uncertainty is most present in low-density development (Irwin and Bockstael, 2007).

The costs and impacts of dispersed land development are thoroughly studied (Ewing et al., 2002; Alberti, 2005). While the popping up of ‘edge cities’ lead to less dense metropolitan areas, it also leads to a decline in commuting and thus kilometers travelled per individual, given that employment is more decentralized within the urban area (Glaeser and Kahn, 2003). The suburbanization of employment, discussed differently as in the previous chapter, is an effect instead of a cause of sprawl and it is not considered a fundamental force behind urban expansion. Sprawl leads to more sprawl. As it is explained, uncontrolled suburban socio-economic growth might take away incentives for the re-development of land that is closer to the city center, downtown areas decay, and less and less people have the desire to live there (Brueckner, 2000).

4.3.Quality of life

The Smart Growth America report mentioned before describes in a rather simple way the impact urban sprawl has on the quality of life of the population. This impact on the quality of life can be almost completely translated as an impact on the environment. A lot of the impact comes as a consequence of the increased use of personal cars observed in these sprawling areas. People living in more sprawling areas tend to drive bigger distances, own more cars, breathe more polluted air, face greater risk of traffic fatalities, and walk and use public transport less (Ewing et al., 2002). Scientific evidence, in the form of increased hospital admissions and emergency department visits for heart attacks, asthma attacks and strokes, shows that long- and short-term exposures

to fine particulate matter (PM 2.5), may cause respiratory conditions, premature death and detrimental effects of the cardiovascular system (United States EPA, 2015).

When considering the inhabitants and how they are affected by urban sprawl, it is important to avoid confusing recreational with environmental concerns. Among some groups, certain uses of land are extremely unattractive, for example, strip malls, fast food outlets. In these cases, complaints and concerns are not on the spatial extent of sprawl, rather on the type of development. This is external to most of the definitions of urban sprawl considered throughout this thesis. The focus of this thesis is on low density and dispersed development. However, strip malls and parking lots are part of this dispersed development characteristic of sprawl and might contribute to the loss of landscape and/or agricultural or farm land. Also, recreational concerns are important in the control of urban growth and development because recreational facilities are part of the “push and pull” factor discussion, as people prefer to live in places where there are green areas, parks, etc.

4.4. Other social and economic consequences of urban sprawl

So far several socioeconomic considerations have been discussed as causes and drivers for the phenomenon. However, from sprawl social and economic problems also arise. These problems are not tied to the people that choose to relocate in the suburbs, rather with the people that remain in the inner cities. The movement of jobs and homes from the city centre to the suburbs has generated an abandoned, lower class, which does not earn enough to support a car-centered way of life (Glaeser and Kahn, 2003).

Some apparent benefits to urban sprawl will be discussed in the next paragraph. These do not cease to result in some costs worth evaluating: inefficient congestion on roads, high levels of metropolitan car pollution, the loss of open space amenities, and unequal provision of public goods and services across sprawling metropolitan areas (Nechyba and Walsh, 2004).

Kahn (2001) elaborates on one possible positive outcome of sprawl, which is increased housing affordability and greater equality of housing opportunity across racial lines. The lower income half of the population becomes more able to afford the residence location with the characteristics the household looks for, such as space and availability of good-quality public amenities. Nechyba and Walsh (2004) argue that

North Americans are better off than they were before sprawling cities became common, mainly because urban sprawl has created opportunities for considerably higher levels of housing and land consumption for most households. The costs to these benefits were mentioned at the end of the preceding paragraph; while there may exist some social and economic benefits to urban sprawl, the consequences remain and the environment remains affected. Another argument is that sprawling development ceases to be sprawling in the long-term scheme of things because of development infill¹⁴ (Mills, 1981; Ohls and Pines, 1975).

Considering cities outside of the US, patchy or dispersed land development may not be considered sprawl after all. It is argued that it may be part of a process of diffusion or movement and of coalescence or blending together. The process is composed of two steps: dispersed urban growth and later infilling.¹⁵ This is not uncommon in cities that are going through the transition of land to urban uses (Schneider and Woodcock, 2008).

5. Case Study: San Juan Metropolitan Area, Puerto Rico

This Chapter may very well serve as the main motivation behind writing this thesis. As mentioned before, urban sprawl is a phenomenon that is quite visually perceptible. The aims of this chapter are to portray the image of urban development in Puerto Rico—specifically the San Juan Metropolitan Area (SJMA), recognized by the US Census Bureau as San Juan-Caguas-Guaynabo Metropolitan Statistical Area—through census data, transport data, income data, land-use change data, and land use regulation data, as well as provide for the implications for policy making accordingly. Data was obtained from the US Census Bureau webpage, from the Puerto Rico Open Data Interconnection Portal, from Puerto Rico’s Department of Transportation and Public Works webpage, and from Puerto Rico’s Planning Board website. The final Sub-chapter will be dedicated to the summary and discussion of the case study.

¹⁴ The term development infill refers to building within unused lands within existing development patterns, typically but not exclusively in urban areas (California, 2011).

¹⁵ In urban planning, infilling is the rededication of land in an urban environment (usually open space) to new construction.

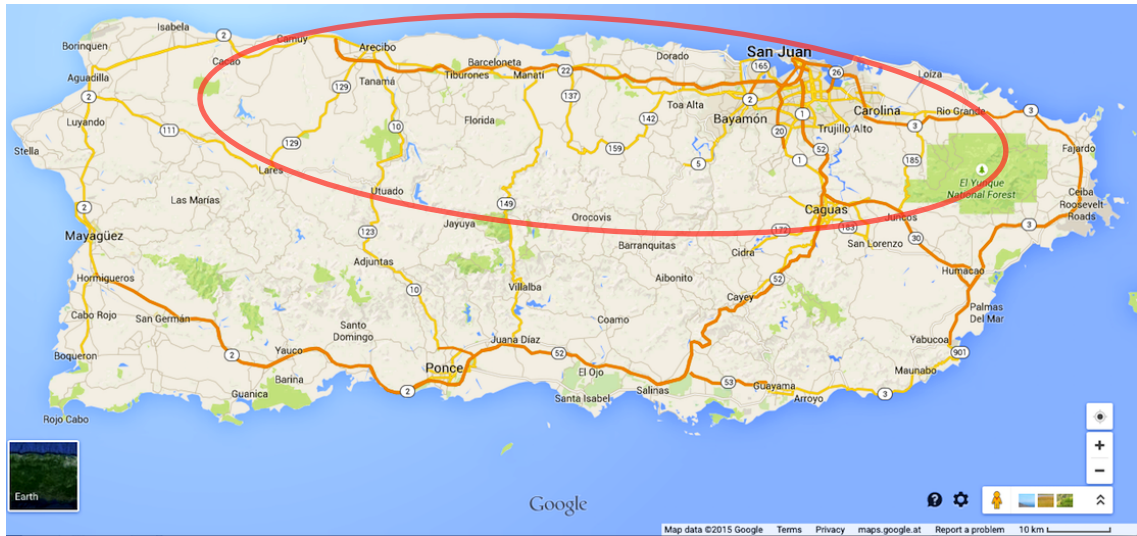


Figure 1: San Juan Metropolitan Area (adapted from Google Maps, 2015)

5.1.Profile

Puerto Rico is an archipelago that has the North Atlantic Ocean to the North and the Caribbean Sea to the South. It is east of the Dominican Republic and west of the Virgin Islands. The main island of Puerto Rico is the smallest and most eastern of the Greater Antilles. It is approximately 160 km long by 56 km wide. With an area of 9,104 km², it is the third largest island in the US. Puerto Rico is mostly mountainous and has large coastal areas in the northern and southern regions. The capital, San Juan, and the metropolitan area under study are located on this large northern coastal area, becoming smaller in extension as it moves inward the island (Rivera, 2015). The SJMA is encircled in red in Figure 1 above. Figure 2 below shows Puerto Rico divided into its metropolitan statistical areas, its micropolitan statistical areas, combined statistical areas, commercial regions, and municipalities (*municipios*). The island is politically divided into 78 municipalities. Forty-one of these municipalities make up the SJMA. Nine out of these forty-one are the most densely populated municipalities of Puerto Rico, according to the US Census Bureau (2014). They are: Cataño, Guaynabo, Bayamón, Toa Baja, Toa Alta, San Juan, Trujillo Alto, Carolina and Caguas. Each municipality contains one urban center, either a city or a smaller town. These urban centers are concentrated on the coastal plains or are restricted to the valleys.

Over the past 60 years or so, Puerto Rico's economy has gone from revolving around agriculture to one focusing more on industry. Puerto Rico's extensive road

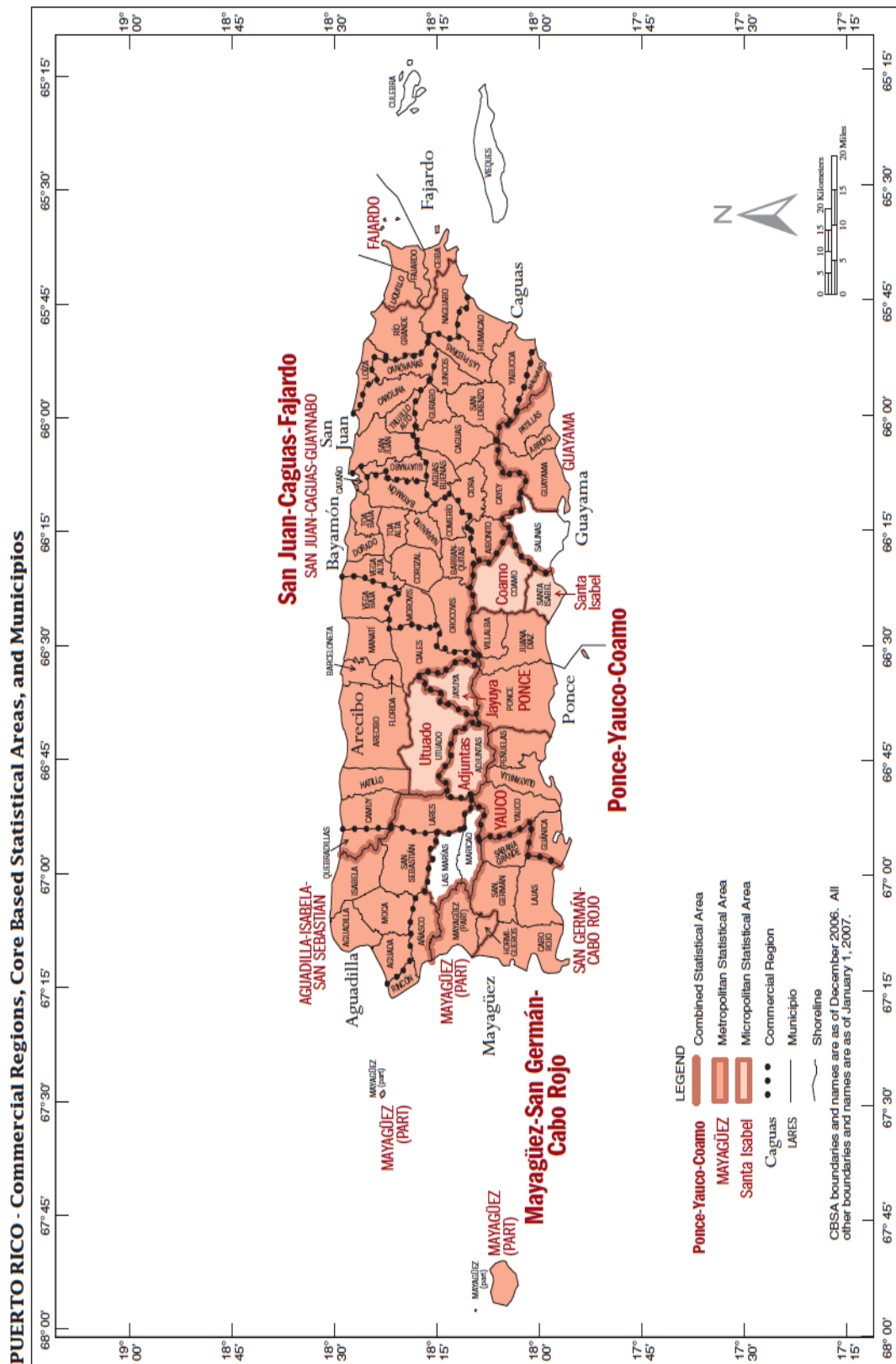


Figure 2: Physical and political delimitations of the SJMA/San Juan-Caguas-Guaynabo Metropolitan Statistical Area (US Department of Commerce Economics and Statistics Administration US Census Bureau, 2015)

network has its origins in the agricultural era (Dietz, 1986). Productive agricultural lands have slowly but surely been converted into urban areas (Helmer, 2004; López et al., 2001). This shift in the economy, as well as an increase in population, paved the way for an increase in the urban areas (López et al., 2001). The visual data obtained for the study (Martinuzzi et al., 2006) shows urban or built-up cover distributed throughout the island as large urban clusters in coastal plains and valleys, and linear developments along highways and routes. Sixty percent of the developments occur in the flat lands, which is where the most productive lands for agriculture are located. In other words, 1/4 of these rich soils have been transformed into urban areas. There is much less urban development in the mountainous areas; only 7% of the total extension of hills and mountains represents developed areas. Within the SJMA there are areas where there is relatively high rates of land consumption and population is relatively low. These are areas dominated by non-residential developments, such as airports, ports, commercial centers, and industries (Martinuzzi et al., 2006).

The following paragraphs will present some insight on the urban lifestyle in San Juan and the surrounding municipalities, as well as a socio-economic framework of Puerto Rico in general. Cities in Puerto Rico, especially those of the SJMA, are built around the automobile. It is no news that cities built around the passenger car are less compact, and thus more sprawling, than cities built around public transportation (Burchfield et al., 2006). The efficiency and reliability of public transportation for SJMA is poor, as governments prefer to spend on building and expanding roads. The poor public transport system—consisting of a 30-route bus lines system, and one 16-stop metro train line that only connects and runs through 3 of the 41 municipalities in the SJMA—does not serve the densely populated cities well. The majority of the population are car owners. In most cases, there are two cars or more per household. Puerto Rico has an extensive system of roads and highways, meaning transportation depends heavily on the car. The capital city is not the only employment center or sub-sector. Going back to a version of Kain's concept of job suburbanization, Bayamón and Caguas are perfect examples of important 'job suburbs'. They are both relatively successful autonomous municipalities.

Puerto Rico is at the moment undergoing a crisis. Headlines in local and US newspapers are all about the recession that has been going on for almost ten years, the credit rating cuts and about the more recent *diaspora* to the US mainland. Puerto Ricans and especially the residents of the SJMA are moving stateside in search for better job opportunities, more public safety, among others (Alvarez, 2015; 2014). The difference between this mass movement and the one that happened in the 1950s is that the people moving back then were manual workers (e.g., to work in the factories of the textile industry), the people moving to the US mainland these recent years are, for the most part, educated professionals (e.g., engineers, professors, doctors, etc.) (Grosfoguel, 1999). The US has experienced some economic growth, but Puerto Rico is stuck with more than 10% rate of unemployment, and a low per capita income (U.S. Bureau of Labor Statistics, 2015). It is no surprise people are choosing to move stateside. There are more Puerto Ricans living in the US mainland than on the island. This mass relocation of people raises the question on whether Puerto Rico can recover economically or not; there are too few hopefuls (Cohn et al., 2014).

Puerto Rico is the third largest municipal debtor of the US, behind California and New York; the disproportion is alarming (Kaske, 2014). Standard & Poor and other financial services companies have lowered Puerto Rico's rating to junk status, taking Puerto Rico out of the bond market (Connor, 2014). The current governor of Puerto Rico has appealed to US Congress for the ability to declare bankruptcy and alleviate the state of debt. The governor has also signed a bill that would increase the island's sales tax from 7% to 11.5% and would also create a new 4% tax on professional services; the sales tax would go into effect July 1, the services tax, on October 1. By June 30 a \$674 million budget cut has to be approved (The Associated Press, 2015).

To offer somewhat of a final opinion on the urban experience in the SJMA, it is not explicit and constantly present like it is in cities like New York or San Francisco. For instance, the banking district (La Milla de Oro, Hato Rey - San Juan, Puerto Rico): it is a failure as city sector because it only operates from 9am to 6pm; this district lacks diversity in programs and services, as it is composed almost solely of office buildings. This makes life in the city unattractive for households. On the other hand we have successful city nuclei, like Miramar and parts of Santurce (both in San Juan) because

they provide variety in services offered and variety in business establishments that are open. The inconsistency by which city life in the SJMA is ruled by is a result of urban planning designed around the automobile and the little regard for the creation of walkable pathways, or circuits of biking lanes, or, more importantly, a reliable and efficient public transport system.

5.1.1.Census data

The 2000 Census reports a 3,808,610 population for Puerto Rico. For the 1990 Census, the population was of 3,522,037 (an 8.1% increase). There is a population decrease for the 2010 Census where population was reported to be 3,725,789. The US Census Bureau projected a population of 4,024,000 people in Puerto Rico for 2015, but this projection is most likely wrong given that there hasn't been any considerable population increase in recent years. As of July 1, 2012, the population density in Puerto Rico was high, with 1,295 inhabitants or more per km², comparable to Maryland, New Jersey, Connecticut, Rhode Island and Massachusetts.¹⁶ 2010 Census results show a population density of 5,180 to 179,923.2 people per km² for 9 main municipalities of the SJMA, the highest compared to the rest of the island.¹⁷ According to the 2010 Census Urban Delineation Program, the percent of the population residing in urbanized areas is from 80% to 100% for all of the SJMA.¹⁸ The Census Bureau found that Puerto Rico's urban population declined from 3,590,994 people in 2000 to 3,493,256 in 2010. This accounts for 93.8% of the total population of 3,725,789. The rural population in Puerto Rico increased between 2000 and 2010 in number and also in percentage of the total population, from 5.5% to 6.2%¹⁹(US Census Bureau, 2015).

The US Census Bureau 2009-2013 American Community Survey 5-Year Estimates provide useful statistics for the SJMA and Puerto Rico as a whole. Since the

¹⁶ See Appendix I.

¹⁷ See Appendix II.

¹⁸ See Appendix III

¹⁹ Note that, for this thesis and according to the US Census Bureau webpage, urbanized areas are different from urban areas. So the decline in urban population matches the percentage range of the population residing in urbanized areas. The percentage range that is presented here for the population of urbanized areas in Puerto Rico is the result of my own calculations using the graphs in Appendix III.

SJMA is the most important metropolitan statistical area and covers basically half of the island, we can take island-wide data and assume it to be very similar to that of the SJMA and vice versa; data for the SJMA can be taken as the rule of thumb for the entire island proportionally to population density, area size and other factors (US Census Bureau, 2015).

Table 4 shows total population according to the 2000 Census, the 2010 Census and population estimates from the 2013 American Community Survey (ACS) and 2012 County Business Patterns (CBP) (US Census Bureau, 2015). On Table 4, the municipalities highlighted in yellow showed a population increase of more than 1,000 in number. This can be interpreted and analyzed in a number of ways. It could mean that people from bigger cities like Bayamón and San Juan have decided to move to these relatively nearby “suburbs” in search of more living space.²⁰

For this case study, data has been taken for the 9 main SJMA municipalities, which coincidentally are the most densely populated throughout the island, and for other 9 municipalities of the SJMA that are less densely populated. These other 9 municipalities were chosen for the study to represent more coastal and/or rural areas. To name and describe a few examples: Arecibo, on the Northern coast, is large in superficial extension; Utuado is near the mountainous area and also large in extension; Río Grande is home to the only tropical rainforest in the US National Forest System, El Yunque (Forest Service, 2015); Cayey is situated along highway 52 (as is San Juan, Caguas and main Southern municipality, Ponce—not part of the SJMA). Cayey also has the fourth university campus (of the University of Puerto Rico) with most enrollment of the SJMA—preceded by San Juan, Bayamón and Carolina.

5.1.2.Income data

According to the US Census Bureau (2015), the average annual wage in Puerto Rico for the year 2010 was \$26,870. According to the World Bank Puerto Rico’s GDP is

²⁰ The group of 9 municipalities with higher population density saw, for the most part, a population decrease. We will refer to this group as Group A. The group of 9 municipalities with lower population density experienced some growth in population. We will refer to this group as Group B. For both groups the higher population numbers have been highlighted in blue. What will be referred to in this thesis as *sprawl alert*, is denoted by the yellow highlights on the table.

at \$103.1 billion and the GNI per capita is at \$19,210, both in 2013 and for current US

Table 4: Total Population of municipalities in groups A and B (CNMP, 2013)

<i>2000 Census</i>			<i>2010 Census</i>	<i>2013 ACS 2012 CBP</i>
	<i>Puerto Rico</i>	3,808,610	3,725,789	3,682,966
	<i>Municipality</i>			
	Bayamón	224,044	208,116	204,725
	Caguas	140,502	142,893	141,600
	Carolina	186,076	176,762	173,994
	Cataño	30,071	28,140	27,669
<i>Higher Population Density</i>	Guaynabo	100,053	97,924	96,670
	San Juan	434,374	395,326	387,336
	Toa Alta	63,929	74,066	74,561
	Toa Baja	94,085	89,609	88,195
	Trujillo Alto	75,728	74,842	73,970
	Arecibo	100,131	96,440	95,185
	Cayey	47,370	48,119	47,700
	Dorado	34,017	38,165	38,303
	Gurabo	36,743	45,369	48,084
<i>Lower Population Density</i>	Loíza	32,537	30,060	29,549
	Rio Grande	52,362	54,304	54,035
	Utua	35,336	33,149	32,593
	Vega Alta	37,910	39,951	39,856
	Vega Baja	61,629	59,662	58,782

dollar (World Bank Group, 2015). From Group A, Guaynabo, San Juan, and Trujillo Alto are the top per capita earners for the past 12 months (for 2013 inflation-adjusted dollars). Table 5 shows the median household income for Puerto Rico and the 18 municipalities of the SJMA that make up Groups A and B. Median household income data was not available for the 2010 Census. However, combining these numbers and estimations with the information from Table 4, we can further describe urban development in the SJMA.

Guaynabo has the largest median household income across the board. This municipality is known for having many gated communities that contain houses with big lots (e.g., large gardens, patios, pools, garages etc). The house market here is also more on the expensive side. According to 2010 Census data 50.3% of owner-occupied units were valued from \$200,000 to \$1,000,000 or more. Total population in Guaynabo does not show to reach the numbers of San Juan, Bayamón and Carolina, where median household income remains below \$30,000. We can conclude that land consumption is more under control in San Juan, Bayamón and Carolina. An important factor to take into account is the fact that Guaynabo is considered mostly residential, and arguably

Table 5: Median Household Income (CNMP, 2013)

		<i>2000 Census (in 2013 US dollars)</i>	<i>2013 ACS 2012 CBP (in 2013 US dollars)</i>
	<i>Puerto Rico</i>	20,149	19,624
	<i>Municipality</i>		
	Bayamón	27,766	24,374
	Caguas	23,098	23,924
	Carolina	29,689	28,674
	Cataño	17,968	18,977
<i>Higher Population Density</i>	Guaynabo	36,644	35,074
	San Juan	24,280	22,754
	Toa Alta	28,148	28,255
	Toa Baja	25,627	23,934
	Trujillo Alto	30,729	31,261
	Arecibo	17,470	16,917
	Cayey	18,806	21,223
	Dorado	23,012	28,306
	Gurabo	22,999	27,459
<i>Lower Population Density</i>	Loíza	15,658	19,085
	Rio Grande	20,979	22,947
	Utua	13,908	14,852
	Vega Alta	18,867	18,184
	Vega Baja	19,459	16,453

provides for better local public amenities when compared to other neighboring municipalities.

As for Group B in Table 5, Dorado has the highest median household income and is also marked in yellow, along with Gurabo and Río Grande, because, correlated with the population growth from 2000 to 2010, shows for sprawling tendencies. People from more densely populated areas in Dorado's vicinity (Toa Baja, Toa Alta, Bayamón) could be moving to take advantage of greener surroundings and calmer lifestyles. A similar situation might be happening from Caguas to Gurabo and from Carolina to Río Grande.

5.1.3.Transport data

No one would argue the fact that most Puerto Ricans drive to their places of work. The estimates of the 2013 American Community Survey (US Census Bureau, 2015) give an idea of how much people in Puerto Rico depend on the car to transport themselves and how much commerces depend on the truck to transport their products. Out of the estimated 1,057,020 workers 16 years and over in Puerto Rico, 945,331 (or 89.4%) used a car, truck or van to get to work. Furthermore, 843,815 drove alone, while only 101,516 carpooled. The remaining 23,612 (or 2.2%) worked at home, 2.7% of the workers 16 years and over was estimated to have used public transportation, 0.2% the bicycle, and 3.5% was estimated to be able to walk to work. For the 2000 Census, out of the 908,386 workers 16 years and over, 790,157 (or 87%) drove a car, truck or van to work; 626,578 drove alone, 163,579 carpooled. 15,964 (or 1.8%) worked at home, 5.2% used public transportation, 0.2% used the bicycle, and 4.1% walked to the workplace. Table 6 presents these numbers in an organized way.

The estimates show a decrease in public transportation use. With somewhat of an increase in median household income, people are more likely and more able to buy a car. Also, as was discussed in Chapter 3, an increase in car availability will increase the tendency to sprawl. Some numbers (not present on the table) stood out in the 2013 American Community Survey data. People in Cataño were estimated to be the ones who used the bicycle to get to work the most; out of the 7,950 workers 16 years and over, 89 (or 1.1%) used the bicycle to get to work. San Juan is the oldest city on the island; it is more densely populated, and residences, establishments and businesses are closer to

Table 6: Public Transportation Users (CNMP, 2013)

		<i>2000 Census (number of users/ workers 16 years and over)</i>	<i>Percentage</i>	<i>2013 ACS (number of users/ workers 16 years and over)</i>	<i>Percentage</i>
	<i>Puerto Rico</i>	47,275/908,386	5.2	28,873/1,057,020	2.7
	<i>Municipality</i>				
	Bayamón	2,985/60,863	4.9	3,186/67,106	4.7
	Caguas	2,487/37,758	6.6	882/46,404	1.9
	Carolina	3,540/55,406	6.4	2,488/62,476	4
	Cataño	678/6,302	10.8	609/7,950	7.7
<i>Higher Population Density</i>	Guaynabo	956/32,746	2.9	1,254/38,203	3.3
	San Juan	14,107/126,576	11.1	12,432/137,667	9
	Toa Alta	717/17,461	4.1	376/25,189	1.5
	Toa Baja	1,567/25,582	6.1	1,043/29,776	3.5
	Trujillo Alto	721/22,780	3.2	500/27,772	1.8
	Arecibo	840/22,449	3.7	149/23,174	0.6
	Cayey	443/10,909	4.1	84/13,864	0.6
	Dorado	349/8,650	4	153/12,135	1.3
	Gurabo	397/9,517	4.2	335/16,005	2.1
<i>Lower Population Density</i>	Loíza	678/5,748	11.8	554/8,387	6.6
	Rio Grande	717/11,780	6.1	308/16,108	1.9
	Utuado	118/5,996	2	12/6,352	0.2
	Vega Alta	505/8,362	6	237/9,481	2.5
	Vega Baja	643/13,719	4.7	180/13,808	1.3

each other. Therefore, more people were able to walk to their places of work; out of the 137,667 workers 16 years and over, 7,689 (or 5.6%) walked to work (CNMP, 2013).

Table 7 shows estimated increases in commute time to work for the 2013 ACS. This shows how car availability is increasing and with it traffic congestion. The numbers presented are not surprising. Bayamón, Caguas and Carolina are located along

Table 7: Average Commute to Work (CNMP, 2015)

		<i>2000 Census (in minutes)</i>	<i>2013 ACS (in minutes)</i>
	<i>Puerto Rico</i>	29	29
	<i>Municipality</i>		
<i>Higher Population Density</i>	Bayamón	35	36
	Caguas	32	33
	Carolina	32	33
	Cataño	31	29
	Guaynabo	28	25
	San Juan	27	26
	Toa Alta	42	41
	Toa Baja	35	36
	Trujillo Alto	36	34
	Arecibo	24	28
<i>Lower Population Density</i>	Cayey	29	29
	Dorado	32	34
	Gurabo	35	35
	Loíza	39	38
	Río Grande	38	39
	Utado	31	30
	Vega Alta	31	34
	Vega Baja	30	33

some of the most peak-hour congested roads in Puerto Rico. It is no surprise that the average commutes in these municipalities remain as some of the longest. What is worthy of noting for Group B on this table is that, since there was a population increase for the 2010 Census and that these are less densely populated municipalities, average commutes remain high because most probably workplaces are located in more urbanized areas. For instance, people living in Dorado might commute to Bayamón for work, people from Río Grande might, in turn, commute to Carolina for work. For both groups of municipalities presented here, we can see that Puerto Ricans suffer one of the

consequences of urban sprawl: regular and habitual traffic congestion. This is the reason for the yellow highlights on Table 7 and Table 8.

Table 8: 60 or more minutes commute to work (CNMP, 2015)

		<i>2000 Census (60 or more minutes commute to work/workers 16 years and over who did not work at home)</i>	<i>Percentage</i>	<i>2013 ACS (60 or more minutes commute to work/workers 16 years and over who did not work at home)</i>	<i>Percentage</i>
	<i>Puerto Rico</i>	47,275/908,386	5.2	140,652/1,033,408	13.6
	<i>Municipality</i>				
	Bayamón	2,471/31,876	7.8	12,692/65,945	19.2
	Caguas	6,058/37,342	16.2	8,242/45,400	18.2
	Carolina	7,858/54,632	14.4	10,428/60,946	17.1
	Cataño	863/6,173	14	985/7,808	12.6
<i>Higher Population Density</i>	Guaynabo	2471/31,876	7.8	2,397/36,871	6.5
	San Juan	10,444/123,351	8.5	11,218/133,139	8.4
	Toa Alta	4,739/17,239	27.5	7,033/25,047	28.1
	Toa Baja	4,844/25,175	19.2	5,622/29,171	19.3
	Trujillo Alto	4,194/22,449	18.7	4,162/26,878	15.5
	Arecibo	1,572/21,981	7.2	2,481/22,706	10.9
	Cayey	1,311/10,672	12.3	2,097/13,516	15.5
	Dorado	1,470/8,509	17.3	2,502/11,863	21.1
	Gurabo	1,794/9,416	19.1	3,386/15,807	21.4
<i>Lower Population Density</i>	Loíza	1,408/5,698	24.7	2,168/8,270	26.2
	Rio Grande	2,894/11,650	24.8	4,036/15,707	25.7
	Utua	915/5,865	15.6	979/6,282	15.6
	Vega Alta	1,307/8,250	15.8	2,177/9,381	23.2
	Vega Baja	1,983/13,492	14.7	2,932/13,755	21.3

As previously mentioned in section 5.1 Profile, the public transport system in the San Juan Metropolitan Area is in need of improvement in terms of reliability and efficiency. The SJMA would greatly benefit from investment in at least one other metro train line. However, expansion plans of the *Tren Urbano* have been abandoned. There is more investment in road infrastructure (Ortiz, 2012). Figures 3 to 5 help illustrate this.

Puerto Rico and the San Juan Metropolitan Area are fully dependent on passenger cars in order for daily social and economic activity to be possible. As can be observed in Figure 4, the metropolitan bus line (known by Puerto Ricans as the AMA - *Autoridad Metropolitana de Autobuses*, Metropolitan Bus Authority in English) does not reach all of the 41 municipalities that make up the SJMA. It's users often complain about how

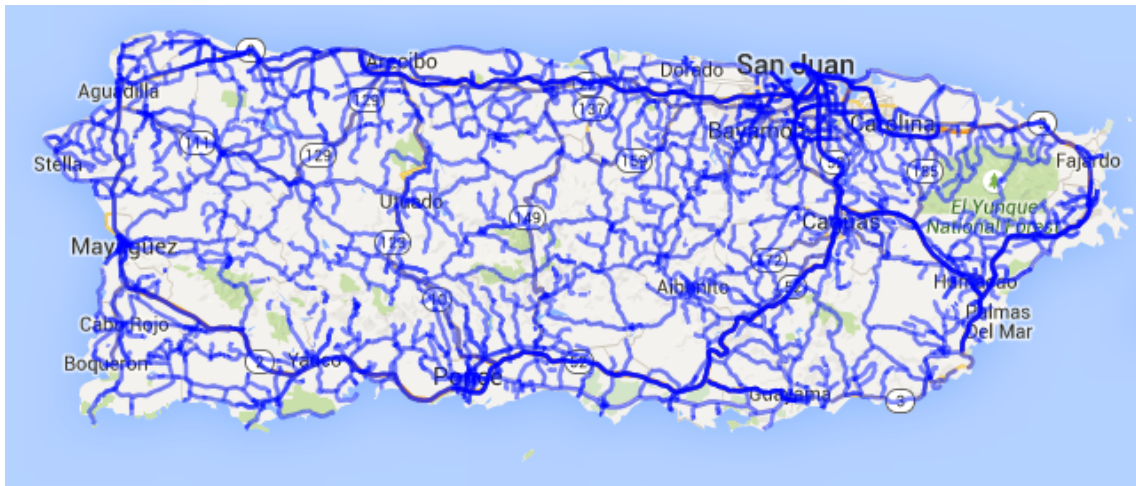


Figure 3: Primary and secondary roads of Puerto Rico (Commonwealth of Puerto Rico, 2014)

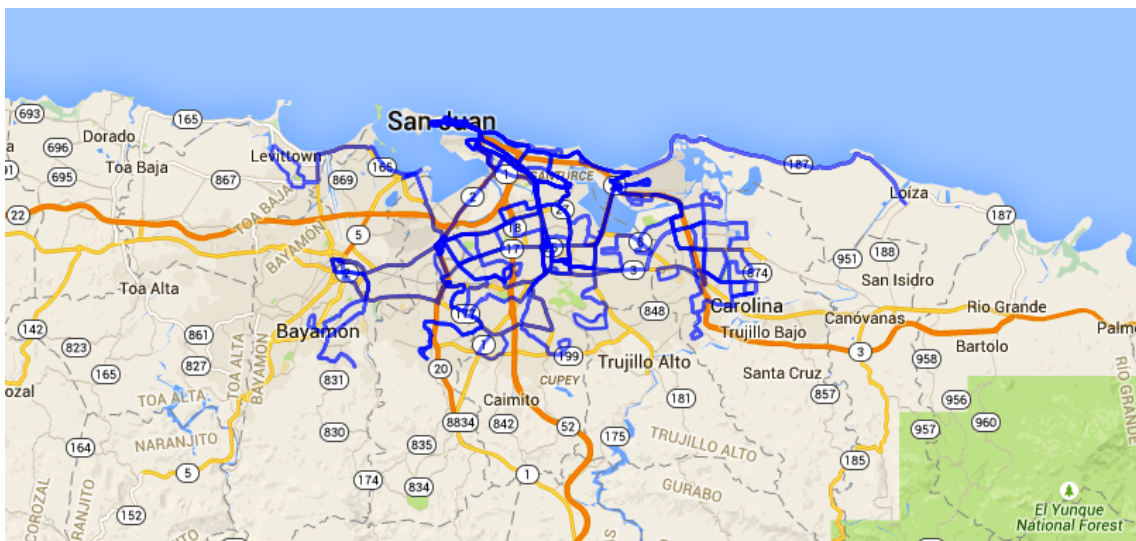


Figure 4: Metropolitan Bus Authority (Commonwealth of Puerto Rico, 2014)



Figure 5: Metro train line (Commonwealth of Puerto Rico, 2013)

stops are too infrequent and about how the system's inefficiency makes the commute very long. This public bus system, together with the metro train line make up ATI (*Alternativa de Transporte Integrado*, Integrated Transportation Alternative in English).

The metro train line shown in Figure 5 (known by Puerto Ricans as the *Tren Urbano*, urban train in English) is the Caribbean's first rapid transit system. The single 16-stop/station line extends 17.2 km of track (Kable, 2015). Way before the planning of the *Tren Urbano*, the regional rail systems that were initiated in the late 19th century (the island still under Spanish rule) continued to be in use under US rule for some part of the 20th century. Without a doubt, it served greatly for the transportation of people and goods throughout the island. The street tramway network in San Juan existed from 1901 to 1946, had more than 32 km of tracks, and transported millions a year. However, during the 1950s agriculture became no longer the principal economic activity on the island, roads and highways were built, expanded or improved, and availability of cars increased. Soon after, consequences arose in the form of severe traffic jams (Pumarada, 1980). The *Tren Urbano* was officially inaugurated in late 2004. The metro train line did not and does not have the projected number of users (Samuel, 2005). A reason for this might be that it runs mostly through suburban areas, meaning it does not transport people to where they need to be. The train has no service to Old San Juan—a major tourist-attracting area—, or Santurce, mentioned before as being an efficient and successful urban nucleus. Both the train and the bus system fails to connect passengers

to the Luis Muñoz Marín International Airport, located in the municipality of Carolina. As mentioned before, the train only connects and runs through 3 of the 9 most important and densely populated municipalities (Bayamón, Guaynabo, and San Juan).

The island-wide low public transportation use—result of the above mentioned factors and characteristic of Puerto Rico, the SJMA, and many other cities in the US—is shown in Tables 6-8. Data were available for all the municipalities of the SJMA. However, presented here are the 18 municipalities this study focuses on. Not surprisingly, San Juan is the municipality that uses public transportation the most. Both the bus lines system and the metro train have the most stops/stations in this municipality, as is pictured in Figures 3 and 4. San Juan, being the capital city, has a better mix of residential and employment areas. Further on, as will be shown later in section 5.1.5, the continuous built-up land cover is larger in San Juan than in Guaynabo or Caguas, for example. This likely means that people that live in San Juan do not commute to other municipalities for work or even recreation. However, San Juan receives daily commuters from Bayamón, Guaynabo, Carolina, Caguas and more.

5.1.4. Land use regulation data

Although during Puerto Rico's industrial development period, there was a decrease in agricultural and farming land, more recent studies show slight changes in this. The 2007 Census of Agriculture (US Census Bureau, 2015) shows a decrease in number of farms, going from 17,659 in 2002 to 15,745 in 2007. Farm land totaled 669,966.4 acres in 2002 and 540,804.1 acres in 2007. The 2010 Census Urban Delineation Program (US Census Bureau, 2015) does not report new urbanized areas for Puerto Rico. There are eight urban clusters in Puerto Rico for the 2010 Census. SJMA is not one of these urban clusters; it is one of the existing urbanized areas.²¹

Regarding land use concerns, in Puerto Rico it is often a case of “conservationists vs. developers”. The coastline is attractive for developers to keep building hotels. However, there is rich biodiversity, which includes bioluminescent lagoons and bays, and mangrove forests which are home to many rare and endemic species. Certainly, large-scale development would affect this biodiversity. Figure 6 shows Puerto Rico's

²¹ See Appendix IV.

natural protected areas. One of the most recent controversies is the case of the Northeast Ecological Corridor, near the capital and stretching along a pristine, undeveloped coastal zone. Issues quickly become political; if one administration is more concerned with conservation, the next administration would be quick in approving construction permits. There have been attempts at consolidating Puerto Rico's land use planning process, for instance the development of an island-wide regulation tool that has been many times delayed (Borak, 2011).



Figure 6: Protected Natural Areas (Commonwealth of Puerto Rico, 2014)

The Puerto Rico Planning Board, created in the 1940s, was for decades in charge of all economic planning, land use zoning and ad-hoc permit granting. In the 1970s this permit granting process was delegated to another government agency (Rules and Permits Administration). Since the late 1990s, major cities take over this task in their own jurisdictions (Junta de Planificación de Puerto Rico, 2015).

Puerto Rico's Planning Board published a draft regulation to implement the public policy promulgated by Act No. 161 of 2009, the "Puerto Rico Permitting Process Reform Act" in 2010. The purpose of this draft and its approval is to establish a unified permitting system that regulates the technical, administrative and legal aspects of construction and use of real property more efficiently and effectively. It is meant to be applied on an island-wide basis, central and municipal administrations alike. With a total of 13 volumes, its scope is quite broad. Significant provisions include the authorization of professionals to validate categorical exclusions and issue ministerial use, demolition, construction, "consolidated environmental" and segregation permits;

also introduced are the so-called “green permits”, which will be issued to efficiently and/or environmentally designed projects and will allow the permittee to avoid paying impact fees and follow a smoother permitting process. Environmental quality and natural resources management is also within the draft’s volumes (Fernández Lugo et al., 2010).

5.1.5. Land-use change data

A tool for policy makers is certainly remote sensing and the data obtained from it. Satellite remote sensing offers an advantage over conventional maps and other visuals, because remote sensing data provides recurrent and consistent observations over large geographical areas, patterns of land cover and land use can be observed, and it is all presented with a synoptic view (Jensen and Cowen, 2009). In another study of the scatteredness of development (Burchfield et al., 2006), data is constructed by merging high-altitude photographs from 1976 and satellite images from 1992. The main focus of the study are the spatial patterns of residential land development, no matter if compact or sprawling. Satellite remote sensing is especially beneficial for environmental considerations, including the consumption of natural resources, like land. Remote sensing technologies provide for a very valuable tool for studying urban issues including and not at all limited to urban sprawl. However, some difficulties arise when mapping urban areas using satellite imagery because of the diversity and heterogeneity of the spectral response (Martinuzzi et al., 2006).

Generally defined, remote sensing is the acquirement of information of an object, area, or phenomenon, through the analysis of data that has been obtained through technologies that do not come into physical contact with said object, area, or phenomenon. More specifically, satellite remote sensing is the acquirement of information of the Earth’s lands and oceans and the atmosphere using sensors that are on “space-borne” platforms (i.e., satellites or space shuttles). The data is obtained through sensors that measure the amount of electromagnetic radiation (EMR, energy in the form of coupled electric and magnetic fields) exiting an object, area, or phenomenon. Valuable information is extracted using mathematically and statistically based algorithms. The electromagnetic energy measured from the objects, areas or

phenomenons being investigated must be calibrated and turned into information using visual and/or digital image processing techniques (Jensen, 1986).

In their study, Martinuzzi et al. (2006) had as resources Landsat ETM+ images, aerial photos, and information from the US Census 2000. The set of images they used included cloud-free parts from 18 individual Landsat ETM+ scenes acquired from 1999 and 2003. They also used NOAA aerial photos from 1999 for further data interpretation. The process followed six major steps: (1) image preparation, (2) mapping of developed lands, (3) analysis of patterns of land development, (4) analysis of land use, (5) analysis of land consumption, and (6) analysis of urban sprawl (Martinuzzi et al., 2006).

To complete step 1 and create a composite image of Puerto Rico, they used two mosaics that complemented each other; the first was made from six images covering 80% of the main island.²² The second mosaic used 12 images (covering another 17% of the island); this one included more spectral variability because images acquired were from multiple dates. The remaining 3% of the island was persistently covered by clouds. For step 2 they mapped the urban/built-up cover separately for each of the two mosaics; for this they used Iterative Self-Organizing Data Analysis Technique (ISODATA) unsupervised classification algorithm. They found 300 clusters in the first mosaic and 60 in the second. To interpret the images they used previous land cover from 1991 to 1992 and aerial photos field knowledge.²³ For step 3, they used a textural filter that evaluates (for a certain developed pixel) the proportion of developed versus non-developed pixels in a surrounding area. High and low-density were the two patterns of urban development that were identified. High-density urban development refers to the urban pixels that are surrounded by more than 50% of developed pixels in a 300m × 300m window. Low-density urban development refers to the urban pixels that are surrounded by less than 50% of developed pixels. They studied the distribution of both types of development related to different topography and changes in slope. In step 4, they integrated the patterns of development in the landscape with census data. This led

²² As mentioned in Chapter 5, Puerto Rico is a group of islands; two municipalities (Vieques and Culebra) are small islands on the eastern coast of the main island of Puerto Rico. They are not included in this thesis or the Martinuzzi et al. 2006 study.

²³ They used as reference the study *Forest conservation and land development in Puerto Rico* of E.H. Helmer (2004).

them to identify three types of land uses: (1) urban, (2) densely-populated rural, and (3) sparsely populated rural. Urban-use refers to the areas where the presence of developed pixels is greater than 20% within the 1km² window. Rural-use refers to the regions where developed pixels represent less than 20%. The rural areas were subdivided according to the Census Urban and Rural Classification for densely and non-densely populated territories. For step 5, analysis of land consumption, they categorized each neighborhood based on the number of people per developed km² compared with the average reported for the island; they estimated the difference between the real population (from the census) and the expected population (from the average of the island) for each of the 900 neighborhoods from the U.S. Census. With this they assume that the areas with higher than expected population will have lower land consumption than areas with lower than expected population. Lastly, to complete step 6, they categorized the relative tendency to sprawl of urban developments by integrating steps 1-5. They identified the limits of urban expansion (territory where sprawl might take place). Outside of this territory (the Sparsely Populated Rural Use), they found, development occurs less well-connected with urban centers. For a visualization of this, refer to Figure 7 below (Martinuzzi et al., 2006).

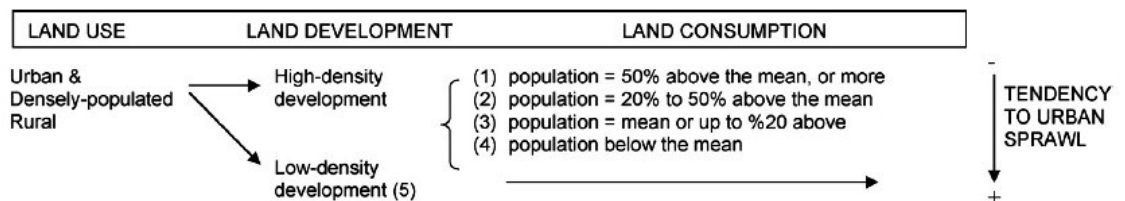


Figure 7: Decision rules for identifying five classes of increasing tendency to urban sprawl based on parameters of land use, land development, and land consumption. (Martinuzzi et al., 2006, 292)

They identified five classes of increasing tendency to sprawl going from lowest tendency (1) to highest tendency (5). Their overall results obtained from the 6 steps are seen in the following figures.

Figure 8 shows the urban/built-up land cover of Puerto Rico which pictures results from step 2 of their study, *mapping of developed lands*. Figure 9 represents steps 3 to 5 of the study: *analysis of patterns of land development, analysis of land use, and analysis*

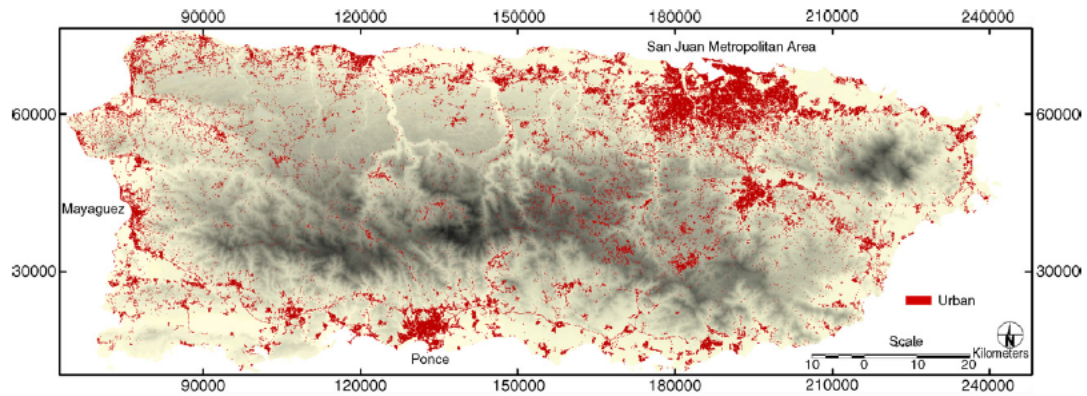


Figure 8: Urban built-up land cover of Puerto Rico (Martinuzzi et al., 2006, 292)

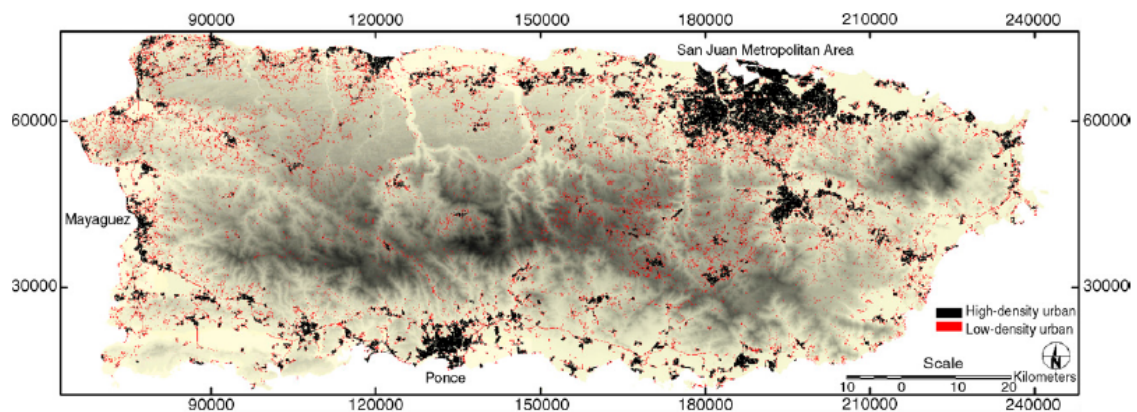


Figure 9: Patterns of urban development in Puerto Rico (Martinuzzi et al., 2006, 293)

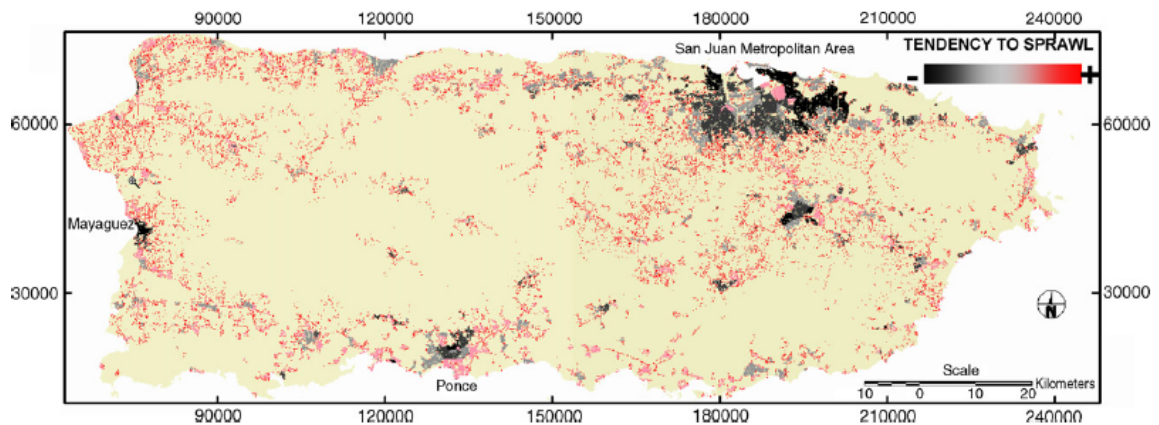


Figure 10: Tendency to sprawl (Martinuzzi et al., 2006, 295)

of land consumption. Basically Figures 8 and 9 describe what has already happened in Puerto Rico in terms of land use and built-up cover. Urban built-up land cover in Puerto Rico concentrates itself in the coastal zones. The relatively large patch of red seen in the central more mountainous area (Figure 8) is actually Caguas, one of the 9 municipalities

sampled for Group A in the case study of this thesis. Caguas—one of the main autonomous municipalities—is the valley between the *Cordillera Central* (Central Mountain Range) and the *Sierra de Luquillo* (the smaller mountain range in the north-eastern part of the island). This urban built-up and cover has high population density almost in its entirety, as seen when doing a side-by-side comparison of Figures 8 and 9.

The edge of the areas that have high population density are, of course, areas with low population density. Both are to be considered urban areas because there is urban built-up land cover. On the edge of the urban areas with low population density, the densely populated rural areas start emerging; on the edge of those are the sparsely populated rural areas. The further inward the island/toward the mountainous center you move, the more rural the land will be. Nevertheless, there is still coastal areas that are free of urban development. This is our main concern.

Figure 10 shows for step 6 of the study: *analysis of urban sprawl*; it is the most important figure as it depicts what could happen in the future, how urban development will likely occur in the years to come. The areas in red are the ones that tend to sprawl the most. Reflecting on what was discussed in Chapter 2 as the indicators of urban sprawl that help define the concept, we know that population density is an important factor, but is certainly not the only one. In fact, residential density is also a significant factor, as are built-up land size and density, continuity, proximity, centrality, nuclearity, etc.

Connecting these indicators and factors with the SJMA data collected and previously presented, it may be concluded that even though there is a slow-down in population growth in Puerto Rico in general there is still risk of sprawl. The densely populated municipalities of Group A of our case study are also going through a consistent population decline; people are choosing to move not only to mainland US but also to the less densely populated municipalities sampled for Group B of our case study, where population is slightly increasing. Those most worthy of mentioning are Dorado, Gurabo and Rio Grande. Recall from Chapter 2 the four-factor sprawl index introduced by Ewing et al. (2002) for Smart Growth America: residential density, mixture of employment, residence, and service facilities, vitalization of inner city, and accessibility to road network. The mixture of employment, residence and service facilities factor

relates specifically to the case study in that the municipalities from Group B have less of this mixture; they are definitely more residential and residences are not proportional to workplaces or employment centers. People from Dorado make a daily commute to Bayamón to get to their places of work, school, or even to enjoy some amenities. The same goes for Gurabo and Río Grande, which make their daily commutes to Caguas and Carolina respectively. Dorado, Gurabo and Río Grande (and the other municipalities in Group B) are actually located in areas that, according to Figure 10, tend to sprawl more. Population density is definitely a good starting point to start analyzing sprawl. Nevertheless, it is important to move forward with that information and combine it with the other indicators/factors like residential density, commuting time lengths and mixed use of land degree.

5.2.Implications for policy making

There has been an overall decrease in population in Puerto Rico. However rural population has increased. This means that people are most likely abandoning urban cores and moving into the suburbs. Urban cores must be more densely populated to reduce tendencies to sprawl. In order to achieve this, city life must be made more attractive. Creation of parks and other recreational areas within the city centers would represent the green, open spaces that push people to the suburbs. In this case, there would be a pull to the city. More safety and crime-reducing measures are also necessary, as crime rates are higher in the city centers. By densifying the cities we are decreasing the quantity of land used. Governments can subsidize regeneration-type development. Through less taxes at the urban centers and higher taxes on low density development, governments would be promoting that investors and developers put their focus on abandoned buildings or improving deteriorating, but still useful and valuable infrastructure.

Median household incomes shown in Table 5 show a slight increase from 2000 Census to 2010 Census. Results in income data correlated with knowledge on the specific lifestyles of certain municipalities may explain some sprawling occurrences that agree with the indicators and causes of sprawl presented in Chapters 2 and 3 respectively. Guaynabo is the richest municipality in the SJMA, but it does not reach the numbers in inhabitants of San Juan, Bayamón or Carolina, where median household

income remains below \$30,000. Land consumption in these three last mentioned is more under control. Guaynabo, benefiting so much from its local revenue is known for having many gated communities that contain houses with big lots. Needless to say, that because public amenities are of considerably better quality in Guaynabo, the housing market is more expensive when compared even with that of San Juan. Another reason for this difference in the prices of houses is that there is less space in San Juan; it is an older city and more populated. With and increase in income people are also more likely to purchase a car. Most households in Puerto Rico own one or more motor vehicles.

Cars are more available than ever to the consumer. From Chapter 3 we know that an increase in the availability of the car will likely increase tendencies to sprawl. Data from the US Census Bureau shows a decrease in public transportation use overall. Average commute times remain high. Going back to Group B on Table 7, we can deduce that people are commuting from their homes—located in less densely populated municipalities/areas—to their workplaces (located in more urbanized areas). The population of the SJMA and all of Puerto Rico for that matter suffer through one of the most enduring consequences of sprawl: traffic congestion. San Juan uses public transportation the most because it is more accessible there than in any other municipality; also, San Juan has a better mix of high and low income households (because it is the capital city). San Juan receives commuters from Bayamón, Guaynabo, Carolina, Caguas and more on a daily basis. People would benefit from government investment in the public transportation system, this in turn, would make city life more attractive. In the short run a better bus routes system can be achieved. In the long run, an expansion of the urban train, reaching successful urban nuclei like Santurce and Old San Juan (where a lot of government agencies are located) would encourage people to enjoy the services and amenities city cores have to offer. Investment in public transportation, by connecting more cities in a more efficient way would alleviate traffic congestion and even improve the tourism industry by providing more options of places to visit (instead of people just staying at the hotel pool and beach).

An island-wide applied land regulation instrument might be the right approach to better regulate land consumption and land use in Puerto Rico. Puerto Rico's government should have in agenda to find some middle ground between development and

environmental conservation to achieve better results. With the fiscal crisis the Commonwealth is going through right now, there will likely be less and less investment in development in Puerto Rico. There are many natural resources that need protecting, and there is a lot of potential for creative low-impact tourism development. It could be further investigated if it would be beneficial and cost-effective to regenerate agricultural lands. Subsidies on farms and agriculture might make lands more agriculture-productive, and thus, reduce sprawl. These subsidies, in turn, will promote an economy of increased local product consumption and exportation.

5.3. Summary and conclusions

The aforementioned policy implications present an ideal scenario, and there is no doubt this would require a lot of time and money. For Puerto Ricans, the principal consequences of sprawl include traffic congestion and reduction of open spaces and fragmentation of habitats, among other things. Sprawl shouldn't be stopped altogether; reserving some land when there is a demand for empty and free space would be a good response for overdevelopment and a gas tax would be the appropriate response to address car pollution (Glaeser and Kahn, 2003).

As a coastal state, Puerto Rico's urban development is slightly different from that of other city types within the US. It does not mean that growth has happened slowly; a city can be bounded by the ocean on one side and still sprawl on the other (Burchfield et al. 2006). In Puerto Rico's coastal zones there is both commercial and residential development. Development is concentrated here and in the valleys more towards the center mountainous area. In the SJMA special movement patterns can be observed through census data. The same way as San Juan receives commuters from all over because its condition as capital city, with more significant employment centers, better universities and schools, more urban life, etc., other important municipalities like Bayamón, Caguas and Carolina receive commuters as well. These are examples of important employment subcenters, and they offer more local public amenities than their smaller neighbors (Dorado, Gurabo and Río Grande, respectively).

Puerto Rico's political division in 78 municipalities is also a detail to be noted. Land-use planning regulation is required for each municipality, but there is no island-wide land-use framework and it is often very political. Burchfield et al. (2006) say

municipal fragmentation has no effect, but I believe it represents a problem for Puerto Rico. There is no reason an island so small should be so sub-divided. Small jurisdictions might have been reasonable political units in a time when transport costs were high. However, it may no longer be appropriate due to the falling transportation costs. Small jurisdictions—Puerto Rico’s municipalities—make decisions which often impose externalities on neighboring jurisdictions which may be costly (Glaeser and Kahn, 2004).

With industrial development, Puerto Rico’s farming and agricultural lands were gravely reduced. This thesis posts the question for further research: Would the bettering of Puerto Rico’s agricultural industry and production better control urban expansion and reduce the consequences to the environment, while simultaneously improving the economy in crisis? Productive agricultural land is more resistant to urban expansion than unproductive land (Brueckner , 2000).

The majority of Puerto Ricans are car owners. The car is not to be considered a luxury good here and its availability and the people’s ability to purchase it has increased, as seen in the US Census numbers of car commuters. In countries where a large share of the population commutes by car, gas taxes will most likely not be taken lightly (Glaeser and Kahn, 2003).

Economic crisis, political instability and unclear development/land use policies do not work in favor of the environment nor the population. Even as population growth has halted, poor planning tendencies are the major cause behind urban sprawl in Puerto Rico and the SJMA.

6. How can policies reduce urban sprawl?

The drivers and causes of urban sprawl discussed in Chapter 3 may, under the right policies, lead to a reduction in urban sprawl and its environmental effects (Nechyba and Walsh, 2004). We have learned how different urban economic models explain and list the causes of sprawl. For instance, how middle-income families have been pushed out of central cities in search for better public school systems, lower crime rates, better infrastructures, etc., thus resulting in sprawl. This chapter will take into consideration the theory and research presented in Chapters 2 through 4 and the information and theory from environmental economics and policy to explain how

policies (or lack of them) contribute to sprawl. Three major targets will be taken into account: population, land use, and transportation in order to reflect better on what has been discussed in previous chapters as far as causes and consequences of sprawl are concerned. The targets²⁴ and instruments of policy that will be presented in this chapter will be linked to the data presented in Chapter 5 as a conclusion as to how policies influence urban sprawl.

6.1.Target of policies

6.1.1.Population

Population growth has notably slowed both globally and in Puerto Rico (US Census Bureau, 2015; US Census Bureau and Demographic Internet Staff, 2011), which plays an important role in achieving sustainability. A smaller global population could experience relatively high individual standards of living, larger populations have to settle for less. Nevertheless, population growth has determined how the products of economic activity are distributed and has been many times considered a source of environmental degradation. On the other hand population growth is often correlated to economic growth; a decreasing population may lead to other types of issues as well. Population density combined with poverty has negative effects on the environment. As the population has grown and the land extension remained the same, production must be intensified on existing lands or marginal lands must be brought into production. Here lies the problem related to urban sprawl: if populations migrate to the marginal, unused and undeveloped lands without considering the long-term feedback effects—for example, vulnerability to storm surges near coastal river deltas and soil degradation over time—the dangers of climate change are intensified. In 2008 more than half of the world's population lived in urban areas. Increasing urbanization or suburbanization affects land use, water pollution, air pollution, trash disposal, poverty and more (Tietenberg and Lewis, 2009). With the instruments of policy that will be discussed in section 6.2, we will see how cities' ecological footprint may be reduced, considering this action against sprawl as an immediate concern.

²⁴ Targets here should be understood as the means to achieve a reduction in urban sprawl.

6.1.2.Land use

The North American lifestyle, very different to the Western European lifestyle, is characterized by the appreciation of open space in the immediate vicinity to the place of residence, by the way people choose to move (mainly the use of passenger cars), by how often it may happen that a household changes residence location, among other things. A key element of this lifestyle is the consumption of large amounts of living space at more affordable prices. Policies can influence these characteristics to go one way or another. The stakes in the policy debate are substantial. The challenge lies in finding policies that favor socio-economic growth without yielding the unwanted results of sprawl, including those that are environmental (bad air quality, loss of landscape).

In the United States, land is treated as property. However, land does not cease to be a resource, and, therefore, it has special characteristics that affect its allocation. Generally, land is allocated to its highest valued use (Tietenberg and Lewis, 2009). Is land more valuable for residential development, industrial use, commercial use or for agriculture? Is it more valuable to keep land in its natural state due to a demand for wilderness-based recreation? Possible sources for the land conversion from agricultural use to residential development use in Puerto Rico could certainly be the increasing urbanization and industrialization that increased the value of non-agricultural land, or maybe the remaining agricultural land became more productive, thus needing less space to produce more food. An important factor to take into account from our case study is that Puerto Rico imports most of the food its inhabitants demand (Fernández et al., 1998).

In most cases, in the absence of any type of government land use regulation, market allocations of land are not efficient. One of the main problems associated with this inefficiency is certainly urban sprawl. Other problems may have their origins or may be closely related to urban sprawl: leapfrogging²⁵, the effects of taxes on land use conversion, incompatible land uses, undervaluation of environmental amenities, among others (Tietenberg and Lewis, 2009).

²⁵ Leapfrogging is when development happens farther out of existing development rather than on the very edge of it (Tietenberg and Lewis, 2009).

As discussed in the previous chapters of this thesis, the government has as one of its functions to provide the public with certain services, such as parks, potable drinking water, sanitation services, public safety, and education. All of which add value to a region, depending on the quality and, in some cases, the quantity. To fulfill this function, the government must sometimes convert (by buying) land that is under private use to public land, creating spaces like parks in lieu of having empty lots that the previous private owner was not able to continue its use. For this conversion to be efficient, the benefits obtained from it must exceed the costs, of course (Tietenberg and Lewis, 2009).

6.1.3. Transportation

Transport is a policy target because of its externalities, mainly environmental effects of emissions and pollution. Transportation subsidies might promote development farther away from centers of economic activity. Households have their choice of residence location and transportation costs are an important factor. If transportation costs are inefficiently low, more distant residential locations will be favored. Reasons of inefficiently low transportation costs are the incomplete internalization of the social cost associated with pollution from car exhaust, and the provision of free employee parking by the employers that lowers the cost of driving to work. Further connected to land conversion, when public open space is highly valued by the household's decision makers, they may be willing to spend more on the commuting costs associated with sprawl in order to take advantage of the larger amount of open space, which is available more cheaply in the areas outside of the city center (Tietenberg and Lewis, 2009).

Traveling by car is and has been the cheaper mode of transportation and has allowed for a dispersed pattern of development, and has, in turn, made public transportation systems meant for masses not viable. Land use patterns must be changed to generate high-density travel corridors, compatible with efficient and effective mass transport use (Tietenberg and Lewis, 2009). For the US and Puerto Rico, this may be achieved more in the long-term scheme of things. Nevertheless, policy makers would be moving in the right direction by making sure that the social costs of transportation are bared by the households that make the residence and mode-of-transportation choices.

6.2. Instruments of policies

6.2.1. Population control

Adding more people to a limited space creates “congestion externalities”. These are higher costs resulting from the attempt to use a resource (land) at an inadequate capacity (i.e., too many drivers trying to use a specific roadway). High population growth makes the problem of income inequality worse. In this sub-section we will approach population control with economics and possible measures to be applied. Extremely low prices on key commodities, like food and education, can lead to an inefficiently high population; if the cost of food is below market levels the *cost of children* is in turn lowered as well. Similarly for the cost of education, if primary education is guaranteed by the state (usually the case) with the funds collected by taxes, households (parents) might not be contributing an amount proportionate to the children in the household.²⁶ The over-population of Earth has been a serious concern for many years now. However, for governments to attempt to control this directly or indirectly is quite challenging, controversial and risky (Tietenberg and Lewis, 2009).

To successfully and democratically control the population there must be a lowering of the desired family size and provisioning of sufficient access to contraceptive methods and family planning information to allow that family size to be reached.²⁷ This is all achieved by assessing how fertility decision-making is affected by the economic environment experienced by the household; basically, the more expensive children become, the fewer will be demanded. This is the *microeconomic theory of fertility* (Tietenberg and Lewis, 2009). This is as far as the discussion on population control will take place in this research, given that rates of population growth are slowing in Puerto Rico and the SJMA. There will be more focus on the policy tools for land use and transportation.

²⁶ What is stated here may be considered more so true for developed economies. There is a theory that contradicts this statement (Todaro’s *vicious circle of poverty*), however, that says that high population growth emerges because of missing security systems and poverty which obligate families to have more children so they can be used for work (Ghatak, 2003).

²⁷ Many of the views and opinions presented here are US-centered. Puerto Rico is a US territory and follows the same economic schemes.

6.2.2. Policy remedies for the market failures in the allocation of land

Zoning is a traditional remedy for the problem of incompatible land uses. It involves land use restrictions regulated by law to create districts or zones that establish permitted and special land uses (residential, industrial, commercial) within those zones. The theory that backs up zoning states that by locating similar land use types together, the negative externalities can be limited or at least reduced. However, zoning can actually promote urban sprawl; by setting strict standards for all property (e.g., requiring large lots per residence/household), zoning calls for lower density (Tietenberg and Lewis, 2009).

Urban growth boundaries have become a popular proposal to limit sprawl. These established boundaries may reduce the urban footprint, but they also drive up housing costs and impose difficulties on lower income households (Quigley and Raphael, 2004). If economists and other researchers of the topic are correct in claiming that the problem with urban sprawl is that it is too much, then a solution lies in changing current public policies (Brueckner, 2000).

Taxes on land (and on the facilities on that land) are another policy tool. For many governments, these taxes represent an important source of revenue for the public administration. For instance, local governments depend greatly on property taxes to fund municipal services such as education. Taxes also have an effect on the incentives to convert land from one use to another, be they efficient or not. In fact, in the US this property tax is the main source of funding for local governments (the local revenue). The two components of a property tax are the tax rate and the tax base. The tax base is the value of the land and it is determined by market value or by an assessor. The latter bases itself on perceived market value and not current use. This means that when a land-intensive activity (i.e., farming or agriculture) is located in a zone under development pressure, the tax assessment may reflect the development potential of the land in question and not its value in farming or agriculture. The value of land that is prone to be developed is usually higher; the tax payments required by this system may raise farming costs, lower net income, and inefficiently favor the conversion of farm and agricultural land to urban or development land (Tietenberg and Lewis, 2009).

Taxes on development work similarly to a congestion toll and governments have the direct power to influence this. The benefits of open space are ignored by the ‘invisible hand’; this causes the conversion of too much land into urban use and expanding the size of cities. The magnitude of the tax would have to be set equal to the value of the open-space benefits that are lost when the land is converted into urban space. The infrastructure and other costs that follow new housing development come from the need of roads and sewers, as well as the need for facilities such as schools, parks, and recreation areas. The payment of this infrastructure is done by the homeowners through the property tax system. However, this infrastructure-related tax is usually less than the infrastructure costs they generate; meaning that the cost of new sewers and schools is shared among all of the city’s residents instead of on those residents who actually require the new infrastructure (Brueckner, 2000).

Property tax adjustments in the form of discounts are sometimes offered by the public administration to protect a current use for land that is in general desired by the public. When property taxes are based upon market value rather than current use, the tax structure can put pressure on the landowner to convert the land. However, this can turn out to be inefficient because the positive externalities of the current use of the land are being ignored (Tietenberg and Lewis, 2009).

Brueckner (2000) discusses possible policy implementation outcomes. If land supply as a resource is limited, then the prices of urban land as well as housing have to go up. As a result of this, consumers would reduce their consumption of residence space, and new homes would be comparatively smaller in size. An ‘attack’ on sprawl would lead to more population density in cities. Zoning regulations and other tools of urban planning allow land use to be channeled toward more attractive results. These tools compliment policies that do tackle the spatial extent of suburban growth. Policies are not designed to limit the character or type of development, but its spatial extent (Brueckner, 2000).

If the public sector administration decides to buy land from its private owner to convert it into public use land (for the provision of public services), the owner of the land would be compensated for giving up ownership and the purchase would assure that the opportunity costs of the land be reflected in the decision to convert the land for

public use. To assure the efficiency of this government action, the benefits obtained from the conversion must be greater than the costs. Otherwise, it should not be changed. This approach might be suitable for reducing sprawl if the repurposing of the land (completed by the government) makes life in the city core more attractive for households. However, the private owner might realize the high value of the land for the public sector and act as a monopolist seller, capitalize on this, and cause an inefficient frustration of the public purpose by raising the costs of the land to a higher level. Under *eminent domain* the government can legally acquire property for a public purpose. First, by condemnation, the transfer of land would be mandatory and not voluntary for the private landowner. Secondly, the compensation to the landowner in this type of proceeding is designed by a legal determination of a fair price and not by an agreement between the private and the public sector involved in the transaction (Tietenberg and Lewis, 2009).

Development impact fees are another policy tool for land use. They are charges imposed on a developer to offset the additional public service costs of new development and are normally applied at the time a developer receives a building permit. The revenues obtained from it, are used to fund the additional services (e.g., water and sewer systems, roads, schools, libraries, and parks and recreation facilities). These fees are supposed to be eventually paid by the people buying the houses in the new development (Tietenberg and Lewis, 2009).

In the area of land use and land conversion, agricultural policies may serve in favor of the mitigation of urban sprawl. Some evidence demonstrates that wherever and whenever agricultural land is productive and, therefore, of high value, cities are more compact in terms of area cover than in regions where agricultural land is unproductive and of little value (Brueckner and Falser, 1983). Policies that aid in the agricultural production of a region might, in turn, help in achieving more desirable extension of cities because productive agricultural land is more likely to withstand urban growth than land that does not produce for the economic growth of a region. There is more sprawl in cities where a large proportion of undeveloped land lays outside of any municipality. Developers often ‘leap frog’ out of municipal zoning and building regulations to avoid putting different municipalities against each other (Burchfield, et al., 2006). This

leapfrogging may be considered the origin of the different municipalities/political divisions/jurisdictions a state might have. A region divided into small jurisdictions makes policy decisions that affect the neighboring jurisdictions, with possible costly externalities. These small jurisdictions no longer make sense because moving around has become easier and cheaper. An example of such measures are land use controls (Glaeser and Kahn, 2003).

Policy makers tend to favor urban growth boundaries rather than the aforementioned development taxes, congestion tolls and impact fees. Urban growth boundaries are more forthright, and are known zoning tools that slow down urban development by prohibiting it in designated areas at the urban edge. This measure might prove to be inefficient because it may restrict the size of cities unnecessarily, yielding disproportionate escalation of housing costs and unjustified increases in population density (Brueckner, 2000). However zoning may be considered one of the most failed policy created to combat urban sprawl because zoning may push development to the fringe of the city (associated with sprawl). On the other hand, gas taxes are ineffective because they have an effect on both drivers on busy roads and drivers on empty roads (Glaeser and Kahn, 2003). Zoning is too restrictive. If a small number of municipalities dominate a metropolitan area through zoning regulations, they may take advantage of this monopoly power and restrict the supply of land, thus increasing property values (Burchfield, et al., 2006).

6.2.3. Policy options for transportation

The main issue being mobile air pollution sources (i.e., motorcycles, cars and trucks), policies such as fuel economy standards, gasoline taxes, and sales quotas imposed on car manufacturers accelerate the introduction of cleaner vehicle technologies. The other way policies try to handle transportation externality issues is by influencing driver choices. This may be attempted by a vast number of policy tools by putting a price on congestion, for instance, to bring the private marginal cost of driving closer to the social marginal cost. Strategies are complicated by the increased demand for cars. It is clear that controlling emissions is not enough; consumer (driver) behavior and choices (also in the residential and employment sector), are extremely correlated to transportation (Tietenberg and Lewis, 2009).

It is known that emissions from mobile sources are more difficult to control. While stationary sources are for the most part large and managed by professionals, mobile sources are small and managed by average consumers. This makes the job of environmental policy makers harder. They largely focus on creating incentives to reduce human-induced sources of carbon emissions. To solely concentrate on controlling emissions from stationary sources is simply not an option, given that mobile sources represent an important part of the three criteria of pollutant, which are ozone, carbon monoxide, and nitrogen dioxide. Mobile sources are also influential for greenhouse gas emissions. As it may be obvious by now, the targets for policy makers are the manufacturers of these mobile sources and the drivers/consumers (Tietenberg and Lewis, 2009).

The policies that address motor vehicle emissions combine control at the point of production and control at the point of use. There are advantages and disadvantages to both. *Point-of-production control* is easier and cheaper because the number of manufacturers is much smaller than the number of users/consumers. However, point-of-production control only affects new vehicles, which make up a small fraction of the total number of cars in use and replace old cars rather slowly. Automobiles are durable; it takes longer to produce emission reductions. Mobile-source pollution involves many times the decisions made by the consumer (what kind of car to drive, where and when to drive it). It is better for the environment if emissions are dispersed (both in time and space) rather than concentrated; it is better if cars are driven in rural areas instead of urban centers. Rush-hours (morning and evening) in traffic also represent unwanted concentrated emissions (Tietenberg and Lewis, 2009).

Air pollution coming from road transport can be reduced by encouraging the production of new, cleaner, more efficient cars, such as hybrids, and also by influencing the decisions the drivers make when choosing the cars they drive and also the places and times they choose to drive. The cars being produced in more recent years are cleaner, therefore the attention of the policy makers is shifting more to the side of the user, who has an insignificant incentive to reduce emissions. Full social costs of road transport need to be internalized in order for a real incentive to exist (Tietenberg and Lewis, 2009).

When the costs of externalities that come from the increased use of cars are correctly internalized, the user/consumer might be influenced to reduce the use of his or her vehicle; for example: fuel taxes and congestion pricing. In conjunction with commuting come several so-called out-of-pocket expenses like vehicle operation and time costs (the monetary value to the commuter of the time consumed while in transit, —mostly wasted). These are the ‘private costs’ of commuting. When the roads the commuter drives on are congested, a cost beyond these private costs is generated. All of these costs tend to be ignored. This is why the author offers the second policy suggestion. A commute that is far too long usually means that cities are too spread out; causing people to commute long distances indirectly leads to sprawl. A *congestion toll* would be the solution to this problem, but there is the political issue that congestion tolls are viewed as net tax increases, generating opposition (Brueckner, 2000).

Taxes on fuel are an example of a policy targeting the consumer; fuel taxes would have to be very high to fully internalize the social costs of road transport and do not take into account the *when and where* factor mentioned before. *Congestion pricing* would be an alternative that does address this factor. Reserved or special lanes that are intended for buses, or for cars that hold a minimum of passengers, electronic toll collection systems, toll discounts, and cordon pricing (fees the driver has to pay in order to park and drive in certain zones of a city) are some examples of congestion pricing. Congestion is effectively alleviated, which is something the consumer definitely desires. As we know, heavy traffic is one of the consequences of urban sprawl. *Private toll roads* aim to make sure that it is the road users the ones that pay the costs of maintaining the roads, rather than all taxpayers bearing the burden as a whole. Some alternatives result differently as desired; it could be that short-run effects are formidable but in the long-run turn out to be counterproductive. Take, for instance, controlling which cars travel and use the roads on certain days using the license-plate number. It just so happens that people end up buying an extra car to travel on those days on which the first car cannot be used. In the long-term scheme of things, land use patterns need to be changed to yield high-density travel roads that favor mass transit use like buses (Tietenberg and Lewis, 2009).

To offer a final analysis of the policy target of transportation, recall the externalities stemming from the increased use of the automobile: detrimental effects on the air quality because of mobile source emissions, costs of road infrastructure not bared solely by the road users. As dependance on the automobile increases so do the costs of congestion externalities. Some vehicle pollution regulations mentioned before have been somewhat successful in curbing emission increases associated with increased driving (Glaeser and Kahn, 2003). Drivers that make use of the roads during peak hours should be adequately taxed to put a stop to the continuously growing welfare costs of traffic delays (Small and Gomez-Ibanez, 1998).

7. Synopsis and Conclusion

The definition of the concept and phenomenon of urban sprawl was the starting point of the thesis. Through the research of several publications and studies, a common ground on what the best measures and indicators of urban sprawl are was achieved. We now know that important and recurring factors are residential/population density, neighborhood mix of homes, shops and others, fragmentation, scatter, accessibility, and built-up land (size and density). Each factor or indicator uses a series of variables. Then we proceeded to discuss the causes behind urban sprawl. With a brief and concise overview of the monocentric and the polycentric city models, it was found that car reliance and transportation costs related causes are most important. Other causes for urban sprawl rely a lot on consumer preferences and behavior. After all, land should be seen as a good and resource. With a growing population, there comes the need of more space to accommodate the people. What was found interesting is the “push and pull” factors that influence the household’s choice of residence location. It is not surprising that the presence local public amenities or lack thereof will either attract people to move to the suburbs or drive people to abandon city cores. Things like a reliable public transportation system, quality public schools, a good business to residence ratio, availability of services, and general public safety are important factors to consider; also for our case study in the San Juan Metropolitan Area in Puerto Rico.

The end of the literature survey chapters is dedicated to the environmental consequences of urban sprawl. Urban development in North America—and in Puerto Rico by default—is mostly sprawling in the sense that most transportation of products

and people is car-/truck-centered. The major environmental consequence resulting from this is the increase in CO₂ and other pollutant emissions and concentrations in the air (air pollution from traffic). Which, in turn, contribute to climate change and affect the quality of life and health of humans. The increase in car usage also leads to severe traffic congestion, which Puerto Ricans (and particularly the residents of the SJMA) suffer habitually.

There are non-environmental consequences of sprawl. When jobs and residences relocate from the city to the suburbs the lower income population that cannot afford a car-centered way of life are further ignored and abandoned. Puerto Rico is struggling to stay afloat from its recession and is severely in debt. To fight this, a recent sales-tax bill was passed, consisting of a 4.5% tax increase. The fiscal recovery that might result from this increase in the sales-tax will displace the impoverished communities. This sort of *gentrification* can be seen in urban nuclei/neighborhoods like Santurce even before the passing of the bill.

The information obtained from the research of census, income, transport, land-use regulation and remote sensing data shaped the profile created of the SJMA. With this profile it was clearer to see which policies would be most effective in creating more attractive urban centers so that households choose their residence location in the cores, thus reducing some of the negative effects of urban sprawl. There were some challenges in this research, as well as limitations of it. Some data for our case study was not available and some conclusions have been made from estimations made by the US Census Bureau. Nevertheless, the main aim of the thesis was achieved. We now have a better idea as to how policy measures influence sprawl in the SJMA and Puerto Rico.

From the profile in Chapter 5 we got an overview of the socio-economic situation in Puerto Rico. We also have an insight into Puerto Rico's most recent history and how land development has come to be in the SJMA. In sum, land that is now considered urban land was once productive agricultural or farming land. Based on this, an interesting point of departure for future research might be to analyze how beneficial it would be to put a subsidy on agriculture, concentrate more on rehabilitating urban cores rather than developing new real estate. Would a new slight shift in the economy of Puerto Rico—going from the sole focus on manufacturing, finance, insurance, real

estate and services to a shared focus on using productive soils for agriculture and farming—really keep urban expansion under control and still bring economic welfare to an island in crisis? The percentage of Puerto Rico's GDP coming from agriculture is by far one of the smallest. This implicates large difficulties in implementing the change. Future research could focus on the long-term changes of coming up with the right steps towards achieving a more agriculturally productive economy.

Even with Puerto Rico's population on the decline, the historically and consistently ineffective planning has been the origin for sprawling in the SJMA and the whole island. There is too much land consumption relative to the small size of the island; there must be a reduction in the urban/built-up land. Reducing the political instability and the unpredictability of development policies in the area will bring more benefits to the environment, the economy and the inhabitants. For the nearer future, the government should incentivize urban regeneration and subsidize the improvement and expansion of the public transportation system of the San Juan Metropolitan Area.

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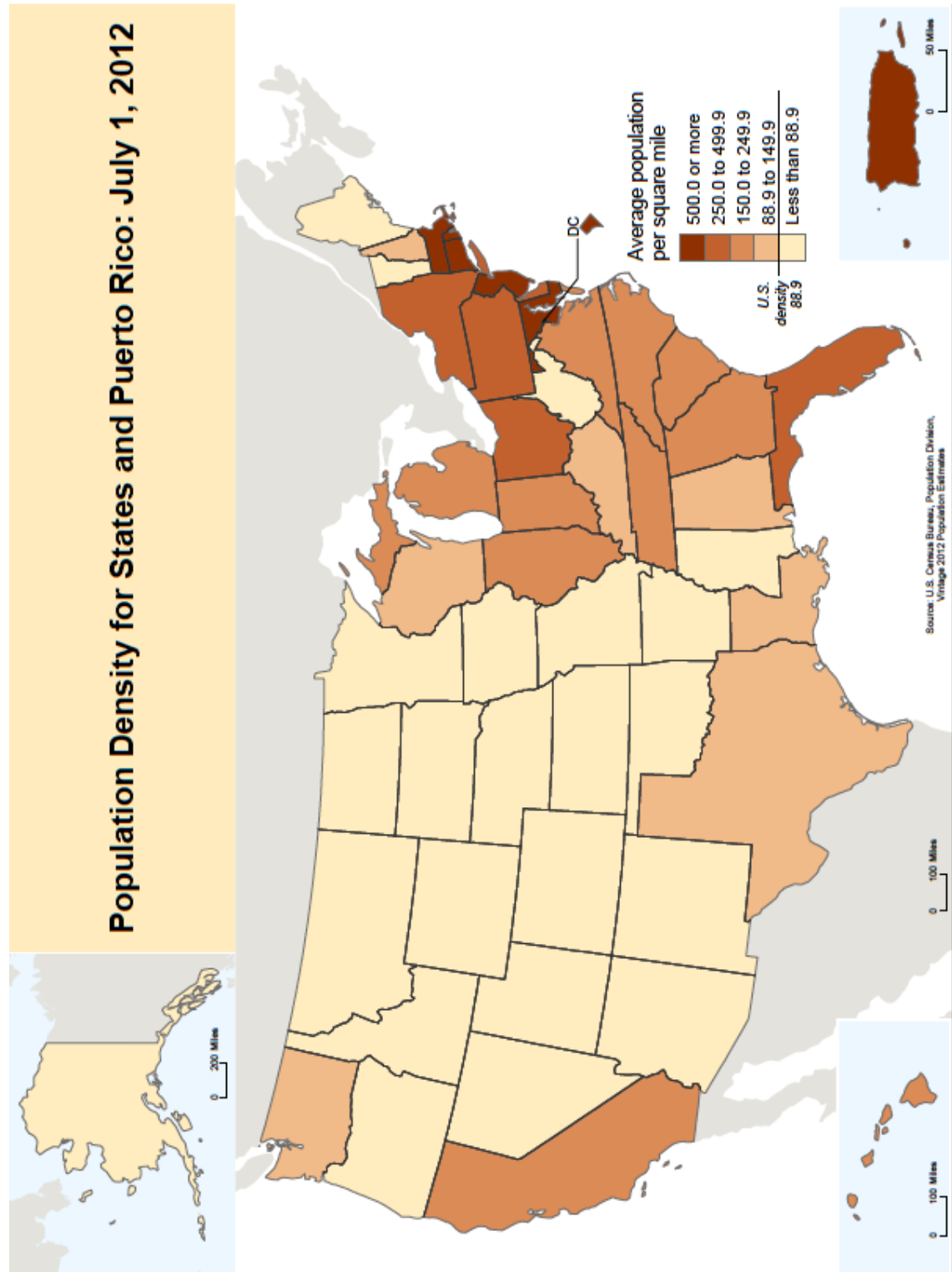
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Appendix I

Population Density for States and Puerto Rico: July 1, 2012

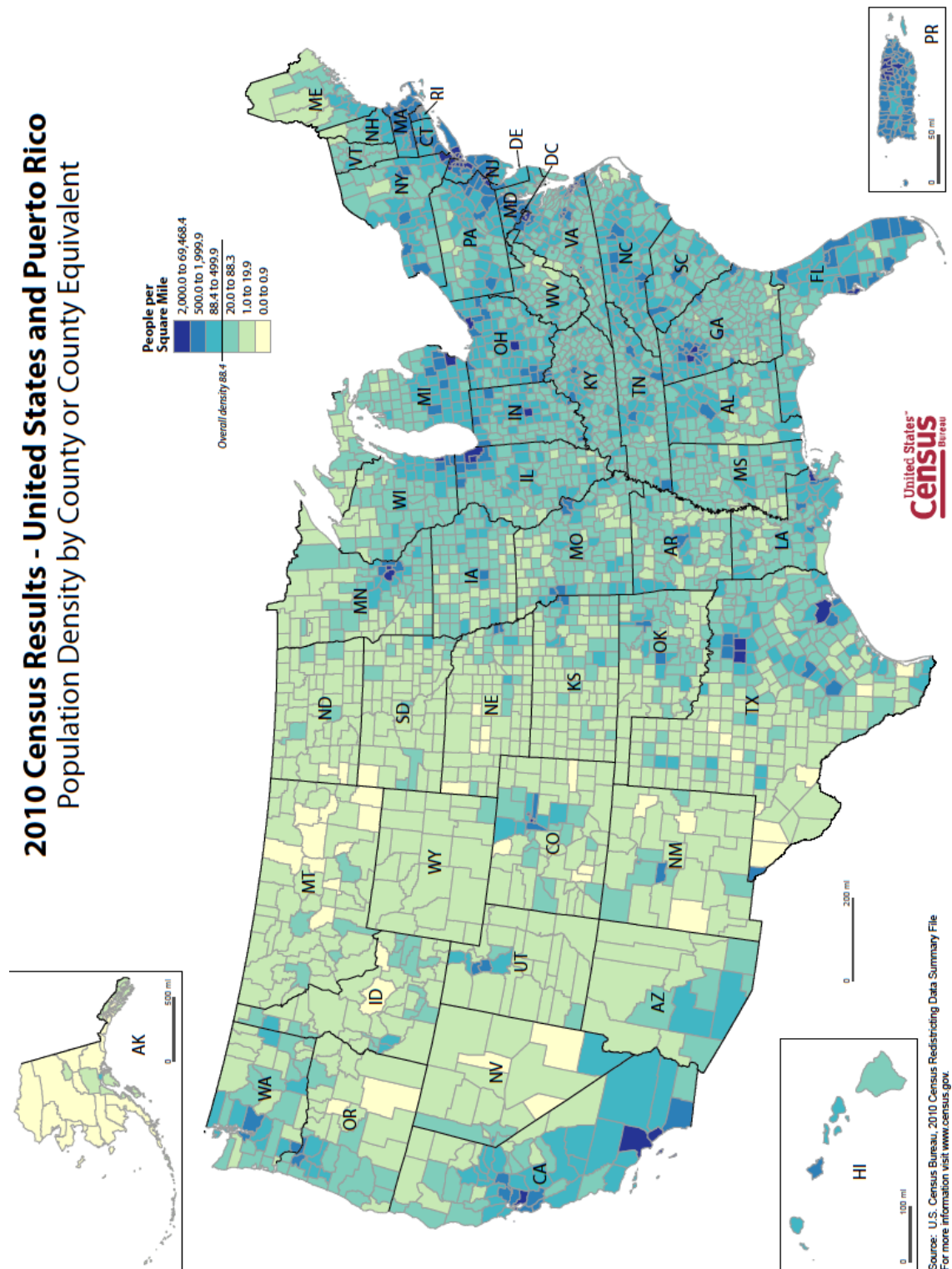
(US Census Bureau, Population Division, Vintage 2012 Population Estimates)



Appendix II

2010 Census Results - Population Density

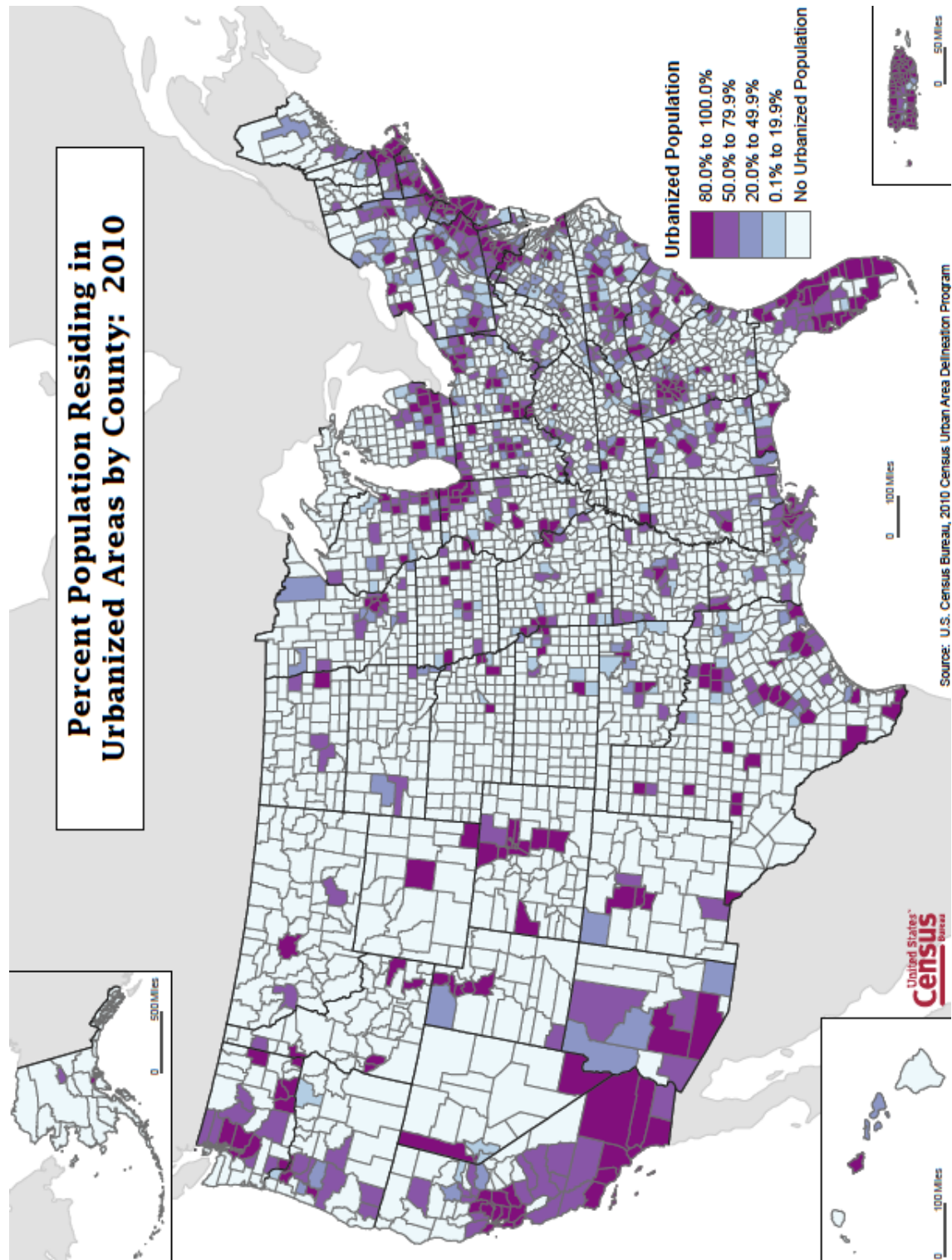
(US Census Bureau, 2010 Census Redistricting Data Summary File)



Appendix III

Percent of Population Residing in Urbanized Areas

(US Census Bureau, 2010 Census Urban Area Delineation Program)



Appendix IV

Urbanized areas and urban clusters: 2010

(US Census Bureau, 2010 Census Urban Area Delineation Program)

