Title

The New Suburbs: Evolving travel behavior, the built environment, and subway investments in Mexico City

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Publication Date
2013

Peer reviewed|Thesis/dissertation

The New Suburbs:
Evolving travel behavior, the built environment, and subway investments in Mexico City

By

Erick Strom Guerra

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

City and Regional Planning

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Robert Cervero, Chair
Professor Dan Chatman
Professor Elizabeth Deakin
Professor Joan Walker

Spring 2013

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ABSTRACT

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Mexico City is a suburban metropolis, yet most of its suburbs would be unfamiliar to urbanists accustomed to thinking about US metropolitan regions. Mexico City's suburbs are densely populated—not thinly settled—and its residents rely primarily on informal transit rather than privately-owned automobiles for their daily transportation. These types of dense and transit-dependent suburbs have emerged as the fastest-growing form of human settlement in cities throughout Latin America, Asia, and Africa. Wealthier and at a later stage in its economic development than other developing-world metropolises, Mexico City is a compelling place to investigate the effects of rising incomes, increased car ownership, and transit investments in the dense, peripheral areas that have grown rapidly around informal transit in the past decades, and is a bellwether for cities like Dakar, Cairo, Lima, and Jakarta.

I begin this dissertation with a historical overview of the demographic, economic, and political trends that have helped shape existing urban form, transportation infrastructure, and travel behavior in Mexico City. Despite an uptick in car ownership and use, most households—both urban and suburban—continue to rely on public transportation. Furthermore, suburban Mexico City has lower rates of car ownership and use than its central areas. In subsequent chapters, I frame, pose, and investigate three interrelated questions about Mexico City's evolving suburban landscape, the nature of households' travel decisions, and the relationship between the built environment and travel behavior. Together, these inquiries tell a story that differs significantly from narratives about US suburbs, and provide insight into the future transportation needs and likely effects of land and transportation policy in these communities and others like them in Mexico and throughout the developing world.

First, how has the influence of the built environment on travel behavior changed as more households have moved into the suburbs and aggregate car use has increased? Using two large metropolitan household travel surveys from 1994 and 2007, I model two related-but-distinct household travel decisions: whether to drive on an average weekday, and if so, how far to drive. After controlling for income and other household attributes, I find that the influence of population and job density on whether a household undertakes any daily car trips is strong and has increased marginally over time. By contrast, high job and population densities have a much smaller influence on the total distance of weekday car travel that a household generates. For the subset of households whose members drive on a given weekday, job and population densities

have no statistical effect at all. Contrary to expectations, a household's distance from the urban center is strongly correlated with a lower probability of driving, even after controlling for income. This effect, however, appears to be diminishing over time, and when members of a household drive, they drive significantly more if they live farther from the urban center. The combination of informal transit, public buses, and the Metro has provided sufficient transit service to constrain car use in the densely populated suburban environments of Mexico City. Once suburban residents drive, however, they tend to drive a lot regardless of transit or the features of the built environment.

Second, how much are the recent trends of increased suburbanization, rising car-ownership, and the proliferation of massive commercially-built peripheral housing developments interrelated? To investigate this question, I first disentangle urban growth and car ownership trends by geographic area. The fastest-growing areas tend to be poorer and have had a much smaller impact on the size of the metropolitan car fleet than wealthier, more established neighborhoods in the center and western half of the metropolis. I then zoom in to examine several recent commercial housing developments. These developments, supported by publicly-subsidized mortgages, contain thousands of densely-packed, small, and modestly-priced housing units. Their residents remain highly reliant on public transportation, particularly informal transit, and the neighborhoods become less homogenous over time as homeowners convert units and parking spaces to shops and offices. Finally, I use the 2007 household travel survey to model households' intertwined decisions of where to live and whether to own a car. As expected, wealthier and smaller households are more likely to purchase vehicles. However, they prefer to live in more central areas where households with cars tend to drive shorter distances. If housing policy and production cannot adapt to provide more centrally-located housing, growing incomes will tend to increase car ownership but concentrate more of it in areas where car-owning households drive much farther.

Third, how has the Metro's Line B, one of the first and only suburban high-capacity transit investments, influenced local and regional travel behavior and land use? To explore this question, I compare travel behavior and land use measures at six geographic scales, including the investment's immediate catchment area, across two time periods: six years before and seven years after the investment opened. Line B, which opened in stages in 1999 and 2000, significantly expanded Metro coverage into the densely populated and fast-growing suburban municipality of Ecatepec. While the investment sparked a significant increase in local Metro use, most of this increase came from people relying on informal transit, rather than cars. While this shift reduced transit fares and increased transit speeds for local residents, it also increased government subsidies for the Metro and had no apparent effect on road speeds. Furthermore, the Metro remains highly dependent on informal transit to provide feeder service even within Ecatepec. In terms of land use, the investment increased density around the stations but appears to have had little to no effect on downtown commercial development, where it might have been expected to have a significant influence. In short, the effects of Line B demonstrate much of the promise and problem with expanding high capacity transit service into the suburbs. Ridership is likely to be high, but so too will be the costs and subsidies, while the effects on car ownership and urban form are likely to be modest.

Individually, each chapter contributes to a specific body of transportation and planning literature drawn from the US as well as developing countries. Collectively, they point to connection between land use and transportation in Mexico City that is different from the connection in US and other rich-world cities. In particular, there is a physical disconnect between the generally suburban homes of transit users and the generally central location of high-capacity public transit. Addressing this disconnect by shifting housing production from the periphery to the center or by expanding high-capacity transit to the periphery would require significant amounts of time and public subsidy. Thus, contemporary policies to reduce car use or increase accessibility for the poor in the short and medium term would do well to focus on improving the flexible, medium-capacity informal transit around which the city's dense and transit-dependent suburbs have grown and continue to grow.

For Luis Matanzo (1978 – 2009),
un abrazo muy fuerte.

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Acknowledgements

This dissertation has been directly supported by a University of California Transportation Center Grant and a Dean's Normative Time Fellowship. An Eisenhower Fellowship, the University of California Transportation Center, the Department of City and Regional Planning, and the Volvo Center for Future Urban Transport have also supported me and my research over the past four years.

Numerous individuals have helped me in the development, analysis, proposal, and writing of this dissertation. First and foremost, I would like to thank my advisor and dissertation chair, Robert Cervero. Throughout my PhD program, Robert has consistently provided good advice, quick and thoughtful feedback, and a regular stream of research, work, and funding opportunities. His support has been a tremendous benefit throughout this process. I also owe a debt of gratitude to each of my other committee members. Betty Deakin has helped draw me back from the weeds of analysis to consider the big picture and broader policy implications. Joan Walker has been generous with her time and has regularly helped me to improve my model specifications and interpretations. She also taught what may have been my favorite course at Berkeley. Dan Chatman has provided support and guidance since I first began applying to PhD programs. It has been a pleasure and an asset to start with him at Berkeley.

I would also like to acknowledge Tony Gomez-Ibanez, who has been a mentor and inspiration throughout the years, and Chris Zegras, whose course on land use and transportation, more than anything else, set me on this path. While there are many other teachers and mentors to whom I am grateful, this dissertation owes a special debt to those at Roxbury Latin, who helped me learn to write. I apologize for the more onerous passages and paragraphs; you could only do so much. Finally, my love and gratitude goes out to a very special group of teachers. Thanks, Mom, Dad, Frank, Kim, and Lynn. Mikey, I don't know if you're technically a teacher, but odds are you will be one and I love you too.

In addition to an overall thank you for all my colleagues and classmates, I am particularly grateful to Ian Carlton, Andrea Broaddus, Wei-Shiuen Ng, and Elisa Barbour for their help as I prepared my dissertation proposal, grant applications, and written materials for my qualifying exams. My writing group, Rebecca Sanders Carlton, Allie Thomas, and Jake Wegmann, has had a key hand in improving my dissertation outline, conceptual thinking, and the writing of key passages throughout the text. They also greatly improved the quality of my job applications and talks to good effect. Matt Glaser and Lillian Lew-Hailer helped tremendously with copy edits. Conversations and friendships with Liming Wang, Manish Shirgaokar, Daniel Sherman, Diego Canales, Jin Murakami, and Oscar Sosa Lopez have also contributed to this dissertation. Additional thanks to Liming and Manish for being great office mates. Paavo Monkkonen has been generous with time, advice, data, and email conversations about contemporary housing development in Mexico.

In Mexico City, I am extremely grateful to the administration and staff at CTS-EMBARQ for welcoming me so kindly and generously lending me a place to work and sleep. I am particularly grateful to Salvador Herrera. This dissertation, in its current form, would probably not have been possible without him. My visits to Mexico City certainly would have been less fun and less productive. Thank you also to Adriana Lobo, David Uniman, and Leonardo Lopez Ruiz at CTS-EMBARQ. Amado Crôtte and Julia Gamas generously provided me with data and documents pertaining to the Mexico City Metro and the 1994 household travel. Enrique

Betancourt and Maria Luz Bravo kindly shared their home, conversations about Mexico City, and meals with me.

Lastly, I want to thank friends who have had little or nothing to do with this dissertation. Extra thanksgivings, a seemingly unending stream of birthdays from February to April, and bachelor parties both real and contrived have kept me happy and well-fed. To my closest friend, Lillian Lew-Hailer, thank you for helping me to keep my priorities straight and encouraging me to treat this process like a job. Living with you and Marla is a real treat.

Chapter One. Introduction

1.1 Introduction

This dissertation investigates the relationship between land use and travel behavior in Mexico City. While the geographic scope of the investigation is metropolitan in scale, the focus is suburban. Sometime between 1990 and 2000, the number of metropolitan residents living outside of the boundaries of Mexico City's Federal District surpassed the number within it. Despite a strong centralization of jobs and economic activity, Mexico City has become a primarily suburban metropolis. As in the United States and Europe, Mexico City's new suburban majority has spread in tandem with the mass proliferation of the internal combustion engine. Whereas automobile ownership and single-family homes characterize suburbanization in the rich world, crowded minibuses and densely populated urban environments are what will capture the attention of a visitor to Mexico City's new suburbs.

Using a mixed-methods approach that relies on qualitative narrative, informal interviews, site observation, descriptive statistics, urban mapping, and statistical modeling, I frame, pose, and test three interrelated questions about Mexico City's evolving urban landscape and the nature of households' travel decisions: (1) how has the influence of the built environment on travel changed as more households have moved into the suburbs and car use has increased?; (2) how much are the recent trends of increased suburbanization, rising car-ownership, and the proliferation of massive commercially-built peripheral housing developments interrelated?; and (3) how has one of the first and only suburban high-capacity transit investments influenced local and regional travel behavior and land use? A better understanding of evolving travel behavior in the densely populated urban periphery will help predict the transportation needs and likely effects of land and transportation policy in these communities and others like them in Mexico and throughout the developing world.

1.2 Motivation

Over the past half-century, hundreds of millions of people have moved from rural to urban areas. Recently, the global urban population surpassed the rural population. Developing countries, with ninety-five percent of the world's recent urban growth, are driving this ongoing phenomenon (UN-HABITAT, 2008). More than three in four children born today will live in a city in a developing country.[1] Many will migrate to cities from rural areas, but even more will be born and raised there. Figure 1.1 graphs the United Nations' population estimates and projections for rural communities and more-developed and less-developed countries, which include those in Africa, Asia (excluding Japan), Latin America, the Caribbean, Melanesia, Micronesia and Polynesia. The majority of this urban growth, furthermore, has been suburban. The peripheral areas of most developing-world cities are growing much faster than central cities, which are losing population in many cases. These new suburbs are becoming the predominant form of human settlement around the world. They are the geography where the success or failure of transportation policies aiming to reduce pollution, increase economic productivity, improve

[1] Author's calculation based on the 2007 World Urbanization Prospects (United Nations Population Division, 2007).

public health, and provide access to jobs and services for the poor will have the largest global consequences.

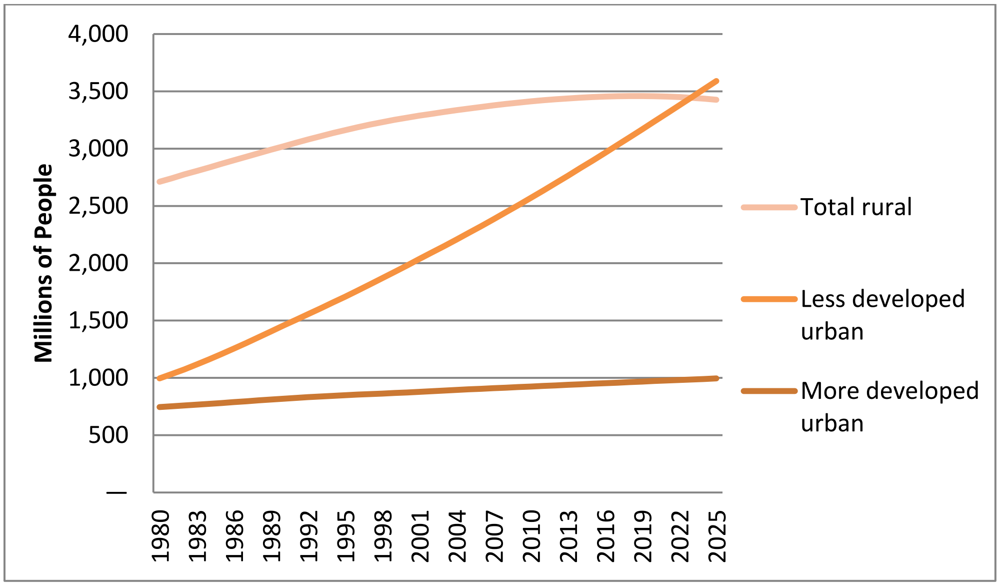

Figure 1.1 Global population estimates and projections (United Nations Population Division, 2007)

Mexico City, which is at a later phase in its economic development than most other developing-world cities, is an ideal place to study the relationship between land use and transportation in these new suburbs. Income is strongly correlated with urbanization, suburbanization, car ownership and use, and urban infrastructure and services. Table 1.1 compares Mexico City's income and car ownership rates to national rates, as well as the average of upper- and lower-middle income countries as defined by the World Bank (2012). Mexico City also has a vast, dense, and fast-growing suburban fringe. Nearly all of the city's recent growth has occurred in peripheral areas, where the total vehicle fleet has doubled in the past ten years. The suburbs already house more than 11 million people and the suburban population is growing at 2% per year. By contrast, population growth in the central areas has stagnated and even declined in some districts. Many suburban municipalities, like Ecatepec and Nezahualcóyotl, are among the largest and most densely populated in the metropolis.

While Mexico City's overall size—just over 20 million inhabitants in 2010—makes it distinct from the small and medium-sized cities that are growing the fastest, large cities are also growing quickly and represent a disproportionate and often growing share of national social, economic, cultural, and educational production. The UN predicts that the number of cities with more than 5 million residents will increase from 44 in 2000 to 75 in 2025; the number with over 10 million, from 16 to 27 (UN-HABITAT, 2008). For these, Mexico City provides a compelling case in which to investigate the effects of rising incomes, increased car ownership, and transit investments in the dense, peripheral areas that have grown rapidly around informal transit in the past decades. As Ward (1998, p. 279) stated as a justification for his study of the metropolis: "…if the consequences of megacity growth are dire, they will first come unstuck in Mexico City." While nothing appears to have come unstuck—the city of 20 million appears to function similarly as to when it had only 5 million residents—findings and policies from Mexico City can inform policy makers and researchers interested in land use and transportation in the new suburbs in other large, fast-growing cities.

Table 1.1 GDP per capita, urbanization, and car-ownership in lower- and upper-middle income countries

	GDP per Capita (2011 PPP)	Percent Urban (2010)	Cars / 1000 people (2009)	Motor Vehicles / 1000 people (2009)
Mexico City Metropolitan Area	$21,306*	100%	267	299
Mexico	$15,340	78%	191	276
India	$3,650	30%	12	18
Lower-middle-income countries	$3,758	34%	21	33
China	$8,442	45%	34	47
Upper-middle-income countries	$10,867	57%	84	99
United States	$48,442	82%	439	802

Sources: World Bank (2012), INEGI (2012a). *Author's estimate based on Gross Census Value Add by municipality and GDP by State.

1.3 Overview and outline

The body of this dissertation consists of four interconnected chapters. In Chapter 2, I review the history and recent trends in urban population growth, land use, and travel behavior in Mexico City. This provides critical context, makes the case for the relevance and applicability of findings from Mexico City to other cities, and frames three separate-but-interrelated chapters that form the dissertation's research core. Each of the core research chapters contains its own background and literature sections. Although I strive to avoid repetition, I intend each chapter to be self-contained as well as to contribute to the overall thrust of the dissertation. As such, I summarize relevant sections of the background chapter when essential to each chapter's set-up or discussion. On several occasions, I repeat a table, figure, or some text to prevent the reader from having to flip back several chapters to view the relevant information. Where additional information may be desired, but would require lengthy discussion, I refer the reader to sections of the background chapter or another author's work. In Chapter 6, I provide a brief summary and synthesis of key findings from previous chapters and their implications for public policy.

1.4 Research contributions

This dissertation makes at least six principal contributions to the academic and policy literature about the relationship between land use and transportation. First, each research chapter contributes to academic knowledge about the empirical relationship between the built environment and travel behavior in an understudied part of the world. While there is an abundance of policy and institutional literature on transportation planning in the developing world, data limitations have tended to constrain statistical analyses.

Second, the dissertation frames and focuses these analyses around the world's fast-growing suburbs, which have received even less attention. Perhaps contrary to expectation, I find that Mexico City's suburban neighborhoods have not been driving the rapid increase in car ownership or use. In fact, households in the suburbs are less likely to drive than similar households in more central areas, even after controlling for income. However, once such households drive, they drive significantly longer distances. While suburban high-capacity transit investments appear to concentrate housing around them and encourage local transit use, a single investment is insufficient to offset larger metropolitan land-use and transportation trends.

Third, I frame each chapter within the context of findings from the US and other wealthy countries. Many existing findings from rich cities do not translate well to poorer, dense cities that have grown around different transportation technologies, namely shared taxis, buses, and informal transit. For example, my findings and several other studies have found that the farther households live from the downtown, the less likely they are to drive or own a car. Furthermore, high-capacity transit investments appear to have significantly different land use impacts than in large, dense US cities. In particular, they tend to concentrate housing development around stations, but do little to promote downtown commercial development. Unlike in New York or San Francisco, the people who use Mexico City's Metro system largely do not work in commercial office buildings. As a result, the Metro does not encourage commercial development in the same way. This influence is likely to hold in other cities, where the car remains the mode of choice for wealthy urbanites.

Fourth, although it is never the direct subject of my analysis, informality in the land use and public transportation systems plays an important role in the interpretation and conclusions of each chapter. The new suburbs of Mexico City, many of which began as informal settlements, have grown around informal transportation. Even in new commercially-built housing developments, informal transit continues to provide access to the city for most residents, while informal conversions of housing units to shops and other commercial uses provide access to local services and everyday needs. Policy makers, however, tend to view the informal as a policy villain at worst and a necessary backwardness at best. One of my first and most memorable interactions with a transportation professional in Mexico City involved him declaring his disgust at the inefficiency, ugliness, and low-quality of a privately-owned minibus, filled to capacity and providing service to a nearby Metro station. If we could only replace it all with BRT! However, the demand-responsiveness of the informal has allowed Mexico City's suburbs to grow with a much lower ecological footprint than would have otherwise been possible. It has also provided jobs, mobility, and access to opportunities for millions.

Fifth, each chapter makes individual contributions to the specific literature on which it builds. Chapter 3, for example, provides one of the very few quantitative comparisons of individual-level statistical models of car use across time in a single city. I find that the influence of local population and job density on car use has increased over time, while many socioeconomic characteristics have remained the same. As more households drive, however, the influence appears likely to diminish, since density has a much stronger effect on whether a household drives than how much. Chapter 4 makes the case that wealthy households have a strong preference for car-ownership, but also for central housing locations and shorter overall trips. It also provides strong evidence that the city center, rather than the periphery, has driven recent increases in the metropolitan car fleet and decreases in aggregate density levels. Chapter 5 provides much-needed and timely documentation of the effects of high-capacity transit investments into the new suburbs. It also provides some evidence that lower-cost bus rapid transit (BRT) systems are likely to run into many of the same financial problems as subways and other metro systems as BRT expands beyond the most productive transit corridors.

Finally, this dissertation tells three stories about the interaction between land use and transportation in a developing-world city that is wealthier and more urbanized and has higher car-ownership rates and better infrastructure than most other developing-world cities. It thus provides a picture of the likely future direction of similar albeit poorer Latin American, African, and Asian cities where rising incomes are contributing to rapid urban expansion and the proliferation of private cars. This picture suggests that although car-ownership rates and use are likely to rise, public transportation will remain an important—and likely the predominant—form of urban transportation. Nevertheless, even aggressive expansion in formal high-capacity transit—Mexico City has one of the world's largest and most used metros—is unlikely to meet the growing global demand for urban mobility. Policies that improve medium-capacity transit services like *colectivos*, Mexico City's privately owned and operated minivans and minibuses, and that encourage more central housing production, particularly for poorer households that are most reliant on transit, have an important role to play in transportation and land-use planning, even in those cities where policy makers choose to invest heavily in urban BRT or rail systems.

Chapter Two. Land Use and Transportation in the Mexico City Metropolitan Area

2.1 Introduction

In this chapter, I provide background information on the history and current trends in demography, land use, and transportation in Mexico City. This lays the foundation for developing, analyzing, and interpreting the findings presented in later chapters. While it is apparent that Mexico City's suburbs are not a new phenomenon—many grew rapidly in the 1950s, 60's, and 70s—I refer to them collectively as the new suburbs, due to their new status as the predominant form of human settlement in Mexico City and stark differences with the low-density, car-dependent suburbs of the United States. In addition to providing context, the purpose of this chapter is threefold.

First, I demonstrate that Mexico City, much as is widely assumed, has experienced rapid change over the last century. In particular, it has grown to become one of the world's largest population and economic centers. Although, the city has been continuously large and central since at least the 15th century—it was the Aztec capital and as large as the largest Spanish cities when the conquistadors arrived—rapid expansion began at the turn of the 20th century when the city had approximately 500,000 residents and was surrounded by lakes and farmland. This growth is critical to the central hypothesis of Chapter 3, that cross-sectional analyses of the influence of land use on travel behavior may poorly represent future influence in cities where demand for travel is increasing rapidly, but transportation supply remains constrained—a state that characterizes many medium and large developing-world cities. The rapid growth in informal transit and informal suburban settlements from the 1940s to 1990s and more recent growth in private car ownership and large-scale privately-constructed housing developments serve as the backdrop for Chapters 3 through 5 and help frame Chapter 4's central question: to what extent are the growth in commercial housing development, rising car ownership rates, and suburbanization interrelated?

The chapter's second purpose is to explore and explain the historical relationship between land use and transportation in Mexico City. Citing Adams (1970) in an analysis of metropolitan development and transportation in the United States, Muller (2004) identifies and describes four defining eras: the Walking-Horsecar Era (1800-1890), the Electric Streetcar Era (1890-1920), the Recreational Automobile Era (1920-1945), and the Freeway Era (1945-present). In each era, personal mobility, defined by the dominant transportation mode, shapes land use and the physical form of the metropolis. While Mexico City underwent the first two eras during roughly the same time periods, the city has since sharply diverged from the American metropolitan experience. Privately operated buses, informal collective taxis, and dense informal suburbs have defined Mexico City's modern metropolitan era. Informal transit and dense, informal suburbs have been mutually self-supporting; ubiquitous and market-responsive informal transit providers enabled Mexico City's flat, uniform, and dense urban form. Furthermore, although car ownership and large private housing developments have increased at roughly the same time, these two trends are not directly related. Car ownership and use has increased most rapidly in the wealthier boroughs just outside of Mexico City's center. Like the informally developed suburban neighborhoods that preceded them, large-scale private housing developments rely on informal public transit to provide access for the majority of their residents and reflect that reliance in their uniform, flat, high density. These findings have implications for the relationship between density and travel (Chapter 3), the future of car ownership in Mexico City (Chapter 4), and the effects of high capacity suburban transit investments (Chapter 5).

Third, this chapter provides the contextual framework for considering lessons from findings derived in Mexico City and applying them to other cities. This will be particularly relevant for the concluding paragraphs (Chapter 6), as well as the individual conclusions drawn from each chapter. While aspects of the work have general implications, the findings are most relevant for other large, developing-world cities with high-density suburbs that have grown around buses and minibuses like Dakar, Libreville, Lagos, Cairo, and Lima, to name a few.

2.2 Mexico City Metropolitan Area

Mexico City is located above and around a network of lakes—now mostly filled or drained—in the Valley of Mexico, an elevated plateau in the Trans-Mexican Volcanic Belt, which runs across the center of the United States of Mexico (Figure 2.1). When the Spanish first entered the city in 1519, the then Aztec capital Tenochtitlan, built on an island in Lake Texcoco, was the most populous city in Mesoamerica. Throughout colonial rule and independence, the city has remained the political and cultural capital of Mexico. The Mexican Government designated the capital as a Federal District, whose boundaries define what is commonly referred to as Mexico City. The metropolis, however, has extended far beyond this area to incorporate parts of the states of Mexico and Hidalgo.

Appendix A maps and provides a list of the jurisdictional boundaries of the Metropolitan Zone of the Valley of Mexico (*Zona Metropolitana del Valle de México*) which includes the 16 boroughs (*delegaciónes*) of the Federal District and 59 surrounding municipalities (*municipios*) of the states of Mexico and Hidalgo (INEGI, 2005). At the time of the 2010 census, just over 20 million people resided in this area, which housed roughly a fifth of the country's total population and generated a quarter of gross domestic product (GDP).

Within the existing English-language literature, there is inconsistency in both the delineation and terminology used for the metropolitan area. Ward (1998) refers to the entire metropolis as Mexico City and distinguishes between a metropolitan area, which only includes contiguous urbanized areas, and a larger metropolitan zone. Aguilar and Ward (2003) refer to the Metropolitan Area of the City of Mexico and use the official Spanish acronym, ZMVM. Wirth (1997) uses the Spanish acronym as well as metropolitan Mexico City. Crôtte el al. (2011; 2009a, 2009b) alternate between Mexico City Metropolitan Area (MCMA) and Mexico City metropolitan area. They use it primarily to refer to the official metropolitan zone, although they occasionally draw their data from a smaller area. Monkkonen (2011a) uses Mexico City metropolitan area and the Metropolitan Area of the City of Mexico. Throughout this dissertation and unless otherwise noted, I will use the terms Mexico City and Mexico City Metropolitan Area (MCMA) interchangeably. Both refer to the official metropolitan area, the Metropolitan Zone of the Valley of Mexico, as designated by the National Institute of Statistics and Geography (INEGI, 2005). When referring to the area within the designated Federal limits, I will specify the area as the Federal District.

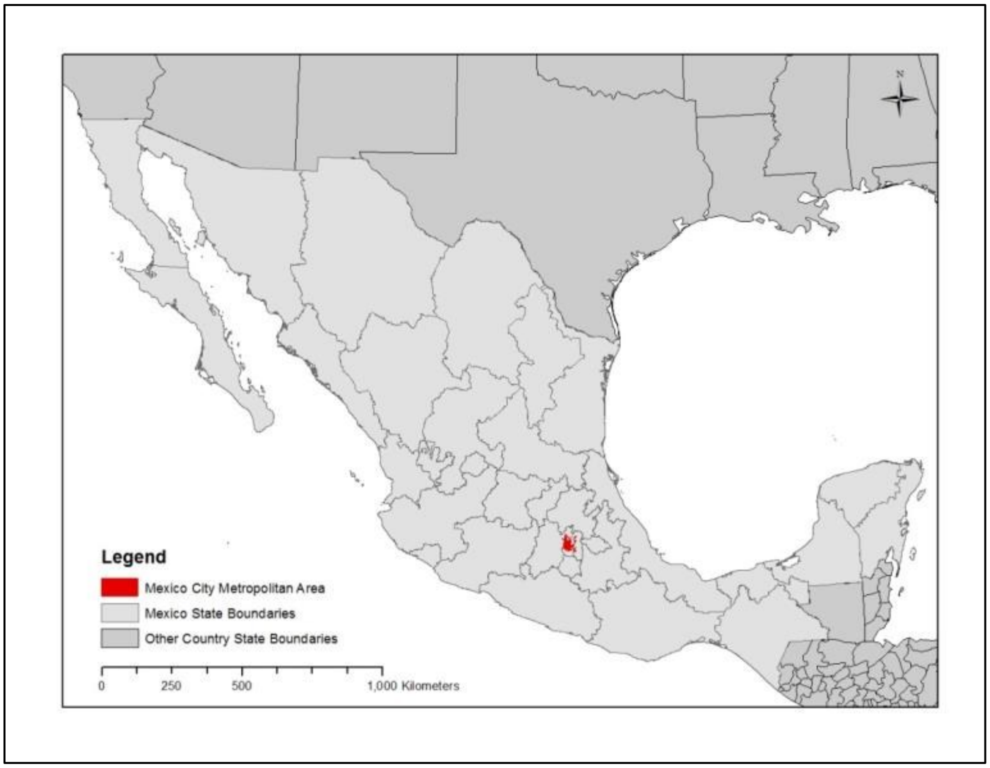

Figure 2.1 Mexico City Metropolitan Area

Within Mexico City, I will also refer to the urban center and four concentric urban rings. These rings surround the original urban center, which consists of 4 boroughs in the Federal District. The first ring contains the 6 boroughs, where the city expanded rapidly during the 1940's and 1950's. The fourth ring contains the most remote municipalities of the states of Mexico and Hidalgo, which began to grow rapidly in the 1980s and 1990s. Appendix A provides a list, taken from Suárez-Lastra and Delgado-Campos (2007a, 2007b), of the boroughs and municipalities associated with each ring. These urban rings differ from those provided by Ward (1998, p. 48) which, for example, include several early suburban expansions like Nezahualcóyotl into the northeast in the first ring. Figure 2.2 maps the borders of the urban center, four urban rings, and regional highway network. I use urban areas (*localidades urbanas*), another geographic designation, to screen the non-urbanized areas of the metropolis (See Appendix A). The urban rings emanate radially, following the regional highway network and topography.

2.3 Land use in Mexico City

Over the past half century, the Mexico City Metropolitan Area has become less centralized and ever more expansive. Currently, more than half of the population lives outside of the Federal District. Although physical expansion has outpaced population growth, peripheral neighborhoods, particularly poor ones, often have population densities as high as or higher than the center of the city. Economic activities, however, have remained far more centralized. Social segregation, furthermore, has become more pronounced as the scale of the city and size of its neighborhoods have increased. In this section, I look at the socioeconomic and demographic trends that have had a profound influence on the city's land use and urban form. Understanding these trends, as well as the contemporary form of the city, is critical to interpreting findings about the relationship between land use and transportation in future chapters.

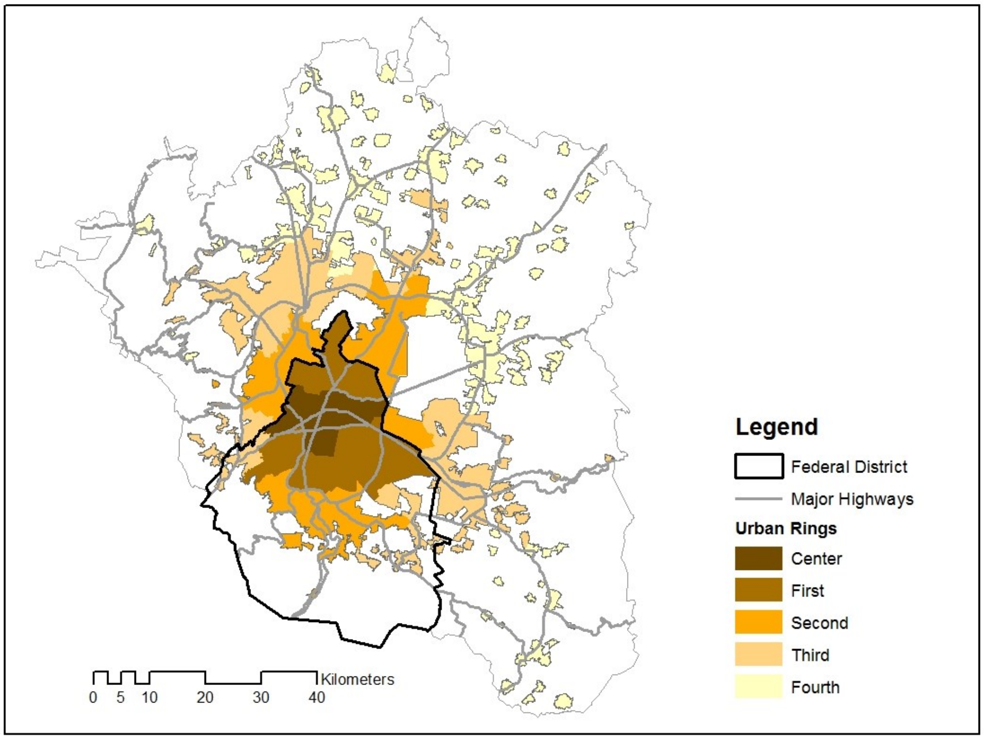

Figure 2.2 Mexico City's urban rings

2.3.1 Population growth

From 1700 to the turn of the 20th century, the population and geographic extents of Mexico City remained fairly stable (Ward, 1998, p. 42). With the advent of the electric trolley, low-cost urban taxis, and industrialization in the capital, Mexico City began to grow rapidly during the first three decades of the 20th century. The number of people living in Mexico City tripled between 1900 and 1940 and has increased more than tenfold since then (INEGI, 2012b). At the time of the 1940 Census, 1.64 million people, 8 percent of the national population, lived in Mexico City. All resided within the limits of the Federal District, much of which remained rural. By 1980, more than one in five Mexicans lived in Mexico City. Of these 13.7 million metropolitan residents, approximately 36% lived outside of the Federal District. Most growth within and outside the Federal boundaries has been on lands that were recently rural or part of the city's former network of lakes. Over the past two decades, the percent of the national population living in the MCMA has declined slightly to 18%, but the city has remained nationally dominant with over 20 million residents. The three next largest urban agglomerations, metropolitan Guadalajara, Monterrey, and Puebla, collectively had about half of Mexico City's population in 2010.

Figure 2.3 graphs the city's population by urban ring from 1950 to 2010. The central city continued to grow throughout the 1950's and 60's, but began to lose population in the 1970's. By 2010, each urban ring was more populous than the center. The first and second urban rings grew most rapidly during the 1960's and 70's and have since leveled off. Early urban expansion in the first urban ring followed the major commercial avenues of the city. Much of the rapid growth of the 60's and 70's, by contrast, occurred in informal settlements in the east and northeast along the highway to the city of Puebla. Nezahualcóyotl and Ecatepec, in particular, absorbed large shares of population growth, growing from around 40,000 to 800,000 residents between 1960 and 1970. By the 1980's, population growth began to decline in the first and, to a lesser extent, second urban rings. The third and fourth rings have continued to grow rapidly and are absorbing most of the city's population growth. Figure 2.4 maps the average annual population growth rate (AAGR) by municipality and borough between 2000 and 2010. Growth has been fastest in the far periphery, particularly in the north, east, and southeast.

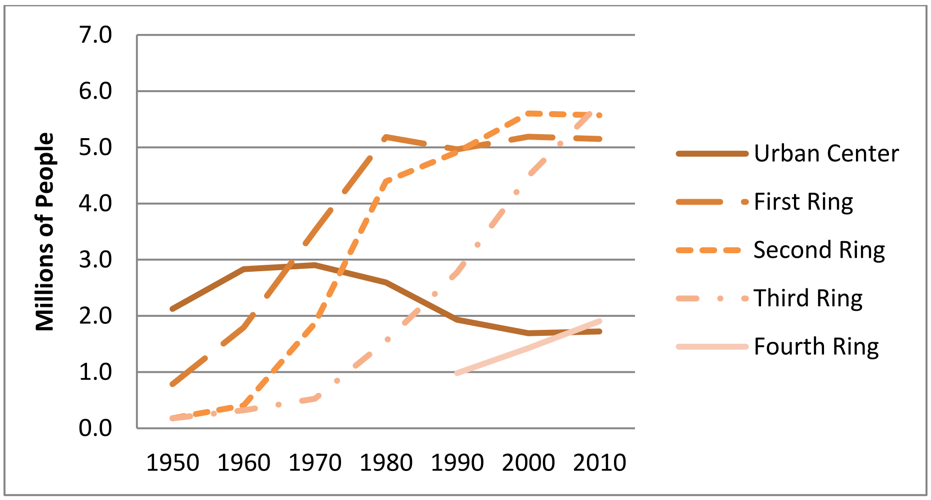

Figure 2.3 Mexico City's Metropolitan Population by Urban Ring, 1950 to 2010.

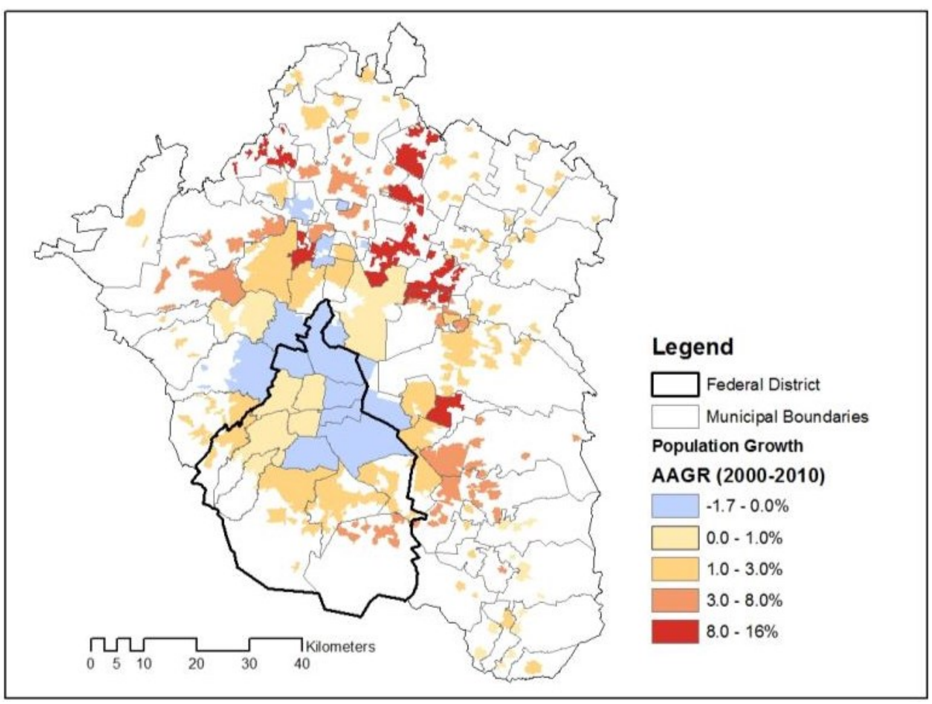

Figure 2.4 Mexico City's Metropolitan Population Growth by Municipality, 2000 to 2010.

In the past two decades, population growth rates have begun to slow significantly. Average annual metropolitan growth rates dropped from 1.8% between 1990 and 2000 to 0.9% between 2000 and 2010. Earlier projections of the city reaching a current population of more 25 million residents appear to have been quite exaggerated (Ward, 1998). Current forecasts have the population growing at an average annual rate of 0.7% from a current 20 million to 21 million by 2025 (Suárez Lastra & Delgado Campos, 2007b).

2.3.2 Housing

Housing growth has largely mirrored population growth, with some notable differences. For example, average population per housing unit, after rising in most areas from 1950 to 1960, has declined steadily in all urban rings since 1970 (Figure 2.5). As a result, the rapid population growth in the urban periphery has sparked an even faster growth in housing units, while the number of housing units in the center has declined less rapidly than the population. Dowall and Wilk (1989) divide the housing market into three sectors: the private, public, and popular. While both popular and private housing are private, they distinguish the private sector, as housing constructed legally by commercial agencies for sale or rental. The popular sector includes legal and illegal units, self-build housing, and rental accommodations from petty landlords. In general, it is defined by some degree of informality in legal status or construction. Ward (1998) refers to both housing types as private, but distinguishes between formal and informal markets. In addition to suburbanization, five major trends have defined the evolution of the housing market in Mexico City over the last half century: (1) the rapid growth of informal housing settlements throughout the second half of the 20th century, (2) an increase in public housing provision since the 1970s, (3) a shift from rental to ownership properties, (4) increased infrastructure and service provision to informal settlements, and (5) a recent, but pronounced shift from informal housing to large-scale commercial housing developments as the principal form of new housing production for moderate- and low-income households.

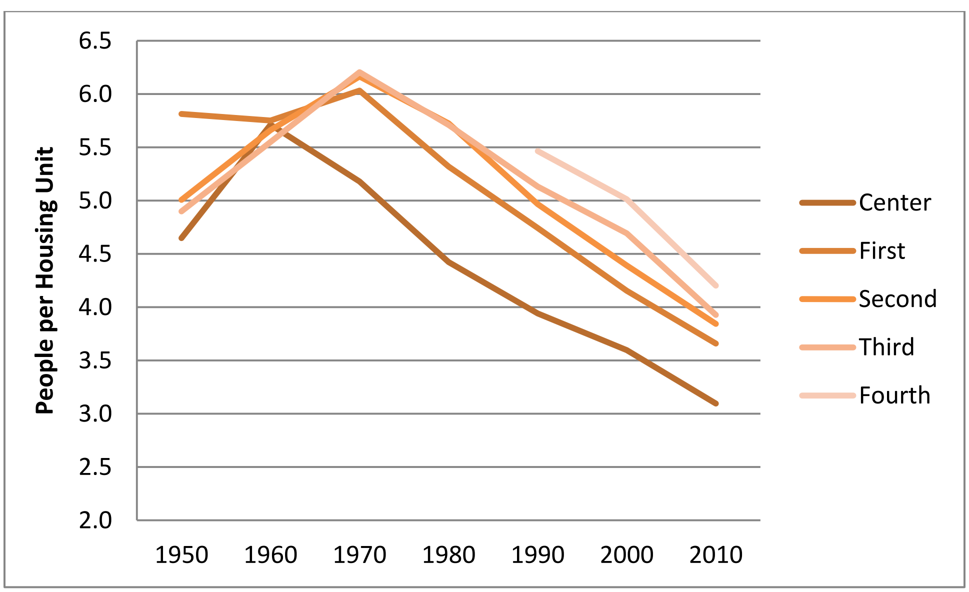

Figure 2.5 Mexico City's average people per housing unit, 1950 to 2010.

First, the most notable trend in Mexico City's housing system over the past half century has been the rapid growth of private housing—often self-built on lands with informal or no title—for low and low-to-middle income families. Between 1950 and 1980, this type of housing, virtually non-existent at the turn of the 20th century, comprised 65% of the total metropolitan housing production. Over the same period, the private commercial housing sector declined to under 15% of the total production (Dowall & Wilk, 1989). Much of this new housing was built on communally owned farmland (*ejidos*), drained lakebeds, or peripheral lands at the foot of mountains or on other unstable land. Generally, land conversions have gone through one of three physical and legal processes. The most common involved the gradual and often illegal subdivision of *ejidal* lands for sale to private home-owners or petty landlords. Over time, the state expropriated the land and resold it to tenants, thus granting them full legal tenure. Although extensively documented, land invasions played a much smaller role than informal sales in the conversion of *ejidos* and other peripheral lands to urban neighborhoods (Dowall & Wilk, 1989; Ward, 1998, Chapter 2). Like in the first arrangement, the government eventually expropriated the land and converted it to grant legal private tenure. The third mechanism involved the taking of undeveloped *ejidos* by the state for resale, generally to private developers, and often at a discounted price. This mechanism was more commonly used for public housing or private middle- and high-income housing developments (Dowall & Wilk, 1989).

Second, the public sector has become significantly more involved in the production and finance of housing. Public housing accounted for approximately 5% of annual housing production in the 1950s. This increased to 9% in the 1960s and 18% in the 1970s (Dowall & Wilk, 1989). In 1963, with the creation of the Housing Finance Program (PFV), public housing provision switched from producing rental units to subsidizing for-sale units (Dowall & Wilk, 1989; Ward, 1998). This primarily served lower-middle and middle income households, who could afford the subsidized mortgages. Established in 1973, the Institute of National Workers Housing Fund (INFONAVIT) quickly came to dominate subsidized housing provision in Mexico City. According to Ward (1998, p. 62), the program produced as many housing units during its first 3 years than all other public programs in the prior four decades. Dowall and Wilk (1989) also attribute the program with increasing public housing provision, but attribute a more modest 45% of public housing production in the 1970s to the fund. INFONAVIT requires employers to pay 5% of all salaried workers wages into the fund. In its early years, the program collected 54% of its funds in Mexico City, where 44% of credits were distributed to build one third of the national fund's total housing production (Dowall & Wilk, 1989).

In the early 1990s, the fund—although never directly involved in housing construction—ceased to be active in selecting eligible sites and rationing available mortgages. Instead, it provided mortgage financing directly for privately produced housing. Peralta and Hofer (2006) attribute this shift to a desire to move away from the political cronyism and corruption that characterized the construction and distribution of public housing and an overall shift to market-based policies in the years following the 1982 economic crisis. Between 2000 and 2005, the fund provided an annual 400,000 mortgages in all of Mexico, compared to 150,000 per year in the 1980s (Monkkonen, 2011b). The Popular Housing Fund (FONHAPO), founded in the early 1980's to improve housing conditions for poor households, provides housing for families ineligible for INFONAVIT due to informal employment and low wages. Public agencies funded 75% of all housing loans by value—and even more by volume—in Mexico between 1995 and 2005 (Monkkonen, 2011b). Although Mexico City, due to its size, received a large share of total financing, it was only the 68th most financed out of 151 metropolitan areas in terms of the percent of new housing that was financed (correspondence with Monkkonen, 2012).

Third, there has been a marked shift away from rental properties to for-sale properties. Sparked by rent control ordinances in the 1950s and 1960s (Davis, 1994; Dowall & Wilk, 1989; Ward, 1998), the percentage of rental units dropped from 80% in 1960, to 57% in 1970, and 36% in 1980 (Dowall & Wilk, 1989). As mentioned earlier, the public housing sector also moved away from providing rental accommodations in the 1970s. In 1980, rental properties included the older, generally rent-controlled, multifamily apartments in downtown, newer low-quality rental construction near downtown, and—the most numerous—units owned by petty landlords in large irregular settlements in the periphery (Ward, 1998, Chapter 2). Large-scale private developers, previously active in downtown apartment construction, shifted production almost entirely to for-sale units in the periphery (Dowall & Wilk, 1989). Currently, approximately 30% of housing stock is in the rental sector and Mexico City has the 40th highest share of its housing stock in rental properties out of Mexico's 128 largest metropolitan areas. Monkkonen (2011b) found that decreasing proportions of rental properties corresponded with increasing levels of socioeconomic segregation in the 128 metropolitan areas between 1990 and 2000.

Fourth, the percentage of housing serviced with sewerage, electricity, and piped water has increased rapidly. Two underlying trends have contributed to this shift. First, informal settlements have been upgraded and provided with basic services, often through a concurrent process of gaining legal tenure (Varley, 1987; Ward, 1998). In fact, residents often viewed legalization, and the accompanying integration into the property tax system, as a prerequisite for the government to install infrastructure (Varley, 1987). Second, and related to the fifth housing trend, most new housing, built by large private developers, includes basic infrastructure like piped water, sewer, electricity, and phone hookups. The percentage of homes with piped water in Mexico City increased from 60% to 69% between 1970 and 1980; with sewerage, from 75% to 86%; and with electricity, from 93% to 97% (Ward, 1998, p. 226). In recently built informal settlements, service connections increased even more quickly. For example, in Nezahualcóyotl in 1970, 40% of households lacked electricity, 68% lacked pipe water, and 41% lacked sewerage. By 1980, more than 95% of households had electricity and sewerage, although only 60% had piped water (Ward, 1998, p. 227). In the past two decades, this trend has continued. From 1990 to 2010, the percentage of households with sewerage increased from 79.9% to 96.9% in the State of Mexico (including areas outside of the MCMA) and from 93.3% to 99.2% in the Federal District. Electricity rates, already above 90% in 1990, increased more modestly (see Table 1.1). In general, service rates have been highest in the Federal District, although rates in the State of Mexico remain significantly higher than across the nation.

Table 2.2 Percentage of housing with infrastructure service connections (1990 – 2010)

	Sewerage		**Piped Water**		**Electricity**	
	1990	2010	1990	2010	1990	2010
National	62.0%	89.1%	77.1%	88.7%	87.5%	98.2%
State of Mexico	79.9%	96.9%	83.6%	92.2%	93.8%	99.2%
Federal District	93.3%	99.2%	95.7%	97.5%	99.3%	99.9%

Source: INEGI (2011a)

Fifth, in recent years the principal form of housing production has shifted away from self-built incremental housing in informal settlements to large-scale private commercial developments of for-sale properties on privately owned tracts, often in the most peripheral areas of the city. Looking at the amount of loans made each year and the quality and age of housing construction across censuses, Monkkonen (2011a) estimates that this transition occurred in the early years of the 21st century. Several factors made this rapid change possible. First, as discussed earlier, the government funding agencies began providing more loans and distributing them more fairly. Concurrently, the national government legalized the sale of *ejidos*, which made large tracts of land available for commercial development. In agreement with State governments, it also worked to simplify housing construction regulations and facilitate private production (Monkkonen, 2011a). Finally, economic growth and an increase in the number of salaried workers led to an increased funding pot from which to provide loans. Figure 2.6 shows a view of a neighborhood of informal self-built houses in central Ecatepec, a municipality in the northeast of the MCMA, 15 kilometers northeast of downtown. Figure 2.7 shows a typical recent development, Los Héroes Ecatepec, approximately 10 kilometers north of the location of the previous photograph.

Figure 2.6 Traditional informal neighborhood in municipality of Ecatepec (2012)

Figure 2.7 Commercially produced housing development, Los Héroes Ecatapec (2012)

While the effect of the shift to commercial-housing development on the quantity of new housing units is clear, the effects on quality and social equity are less clear. Looking at two large (over 10,000 unit) developments in Ixtapaluca, a suburban municipality in the State of Mexico, Peralta and Hofer (2006) identify size, lack of security, insufficient social and physical infrastructure—including required ones such as piped water—poor transportation, monotony, and poor construction as endemic problems of the new type of popular housing construction. In general, however, the program has provided greater social and physical infrastructure—often at a lower monetary cost, nearly always at a lower time cost—than the self-constructed houses in informal developments.

Despite serving previously unmet demand by middle and lower-middle income households, the principal funding mechanism, INFONAVIT, has been criticized as regressive since the poorest salaried employees still contribute 5% of their salary, even if they make too little to qualify for a mortgage (Monkkonen, 2011a; Peralta & Hofer, 2006). Spatially, INFONAVIT also tends to favor areas with higher shares of formal employment, in particular northern cities, at the expense of the poorer more rural areas of the south (Monkkonen, 2011a, 2011b). Using logistic regressions and nearest-neighbor covariate matching estimator, Monkkonen (2011a) found that, across the 51 largest Mexican cities in 2000, households with access to social benefits—a proxy for access to formal employment and housing benefits—were 9% to 12% more likely to own a fully constructed home with basic infrastructure than a comparable household without access. The sample was limited to households in homes that were constructed between 1995 and 2000.

2.3.3 Urban expansion and contemporary urban form

As its population has increased, Mexico City has also expanded geographically. The urbanized area of the city grew from 118 square kilometers in 1940 to 746 square kilometers in 1970 and 1,250 square kilometers in 1990 (Ward, 1998, p. 57). In 2000, the city covered 1,658 kilometers (Angel, Parent, Civco, & Blei, 2010) and has continued to expand. Suárez-Lastra and Delgado-Campo (2007b) estimate that the metropolis will expand an additional 380 to 560 square kilometers by 2020. Figure 2.8, taken from the Lincoln Institute of Land Policy's Atlas of Urban Expansion (Angel et al., 2010), maps Mexico City's geographic growth over the past 200 hundred years. As with population growth, physical expansion did not commence in earnest until the 20th century. Up until the 1950, the vast majority of urban territory remained in the Federal District. Throughout the 70's and 80's, in particular, the metropolis absorbed large quantities of former agricultural land and drained lakebeds in the State of Mexico. Urban expansion has been radial with development shaped by the surrounding mountain ranges and lakes and concentrated along regional roads to the northwest, northeast, southwest, and southeast.

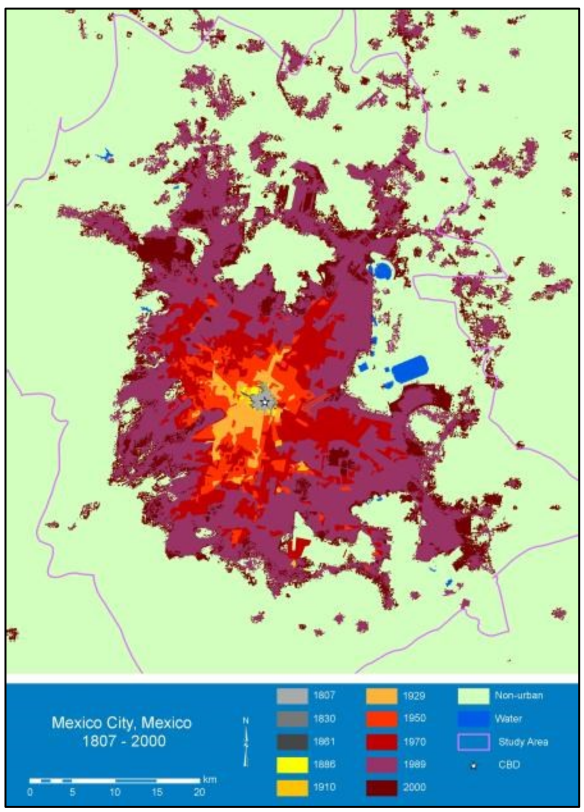

Figure 2.8 Mexico City's urban expansion (1800 to 2000)
Source: Lincoln Institute of Land Policy's Atlas of Urban Expansion (Angel et al., 2010)

With population decreasing in central areas and increasing rapidly in the periphery, suburban expansion in Mexico City has been dense. Many of the most densely populated neighborhoods are outside of the Federal District, particularly in the bordering municipalities of Ecatepec and Nezahualcóyotl. Figure 2.9 maps the population per hectare in AGEBs in 2005.[2]

[2] AGEBs are roughly equivalent to US Census Tracts. For a full description, see Appendix A.

The Metro system and Federal boundary serve as geographic references. Darker areas correspond with densely populated areas. Many of the least densely populated areas are on the suburban fringe as expected. However, density is often lower because the area has empty lots or undeveloped land, not because units or yards are larger. High-density two-to-three story construction characterizes the majority of Mexico City's urban development and nearly all of it outside of the Federal district. This has resulted in a uniformly dense city. Figure 2.10 graphs the cumulative percentage of Mexico City's total population living on the percent of urbanized land. A perfectly flat city, where all residents lived in similarly dense neighborhoods would look like a straight 45 degree line. In Mexico City, approximately 29% of people live on the most densely populated 10% of the land. By contrast, in the New York, San Francisco and Los Angeles urban areas, 66%, 67%, and 40% of people respectively live in the most densely populated areas (Eidlin, 2005). The least densely populated 50% percent of land houses 15% of the MCMA's residents, compared to about 5% for the three American metropolises. Two-thirds of all people live in neighborhoods with densities between 100 and 300 people per gross hectare (Figure 2.11). The average neighborhood density is 166 people per hectare in the Federal District and 126 people per hectare in the State of Mexico. In terms of total population per urbanized land, the Federal District has a density of 110 people per hectare; the State of Mexico, 81 per hectare. For comparison, the five boroughs of New York City have around 100 people per hectare while greater New York has only around 17 people per hectare (Eidlin, 2005).

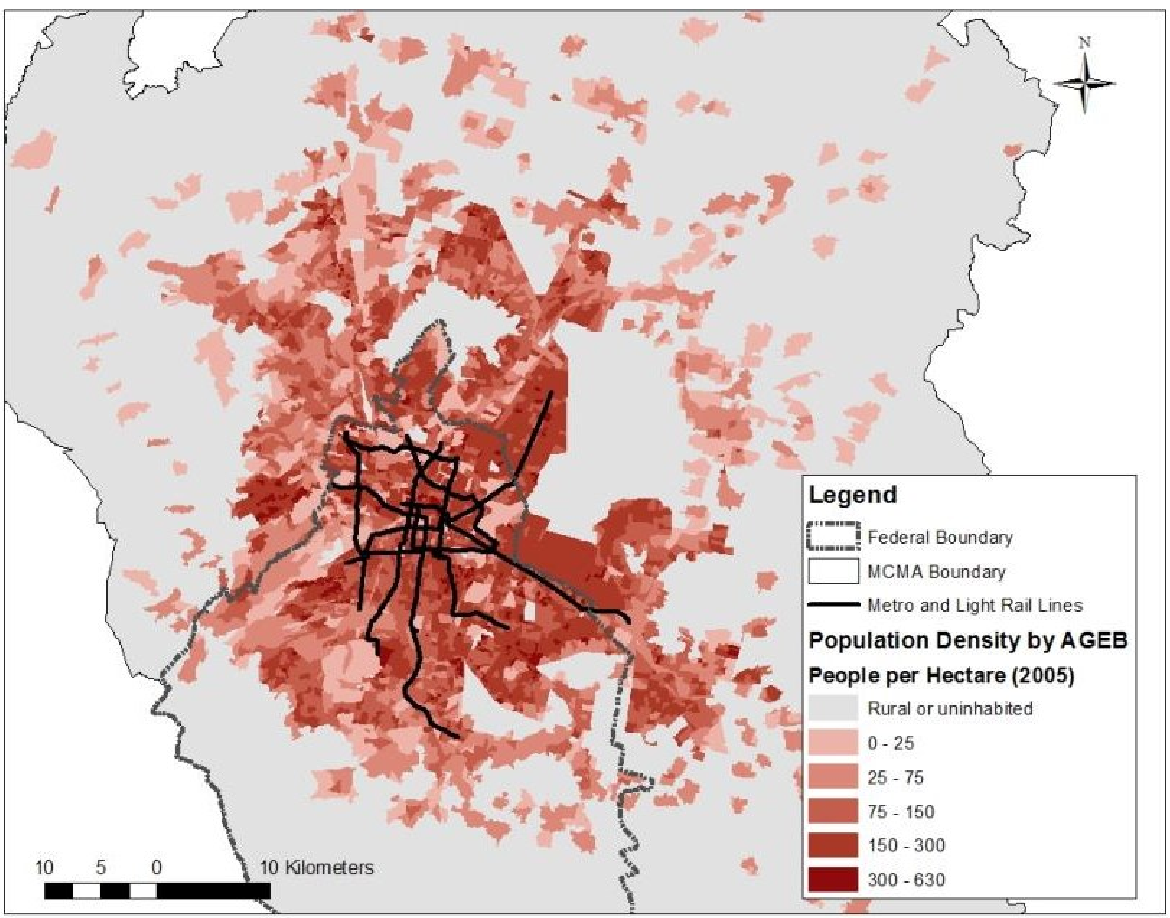

Figure 2.9 Population per Hectare in 2005 by AGEB (Census Tract equivalent)

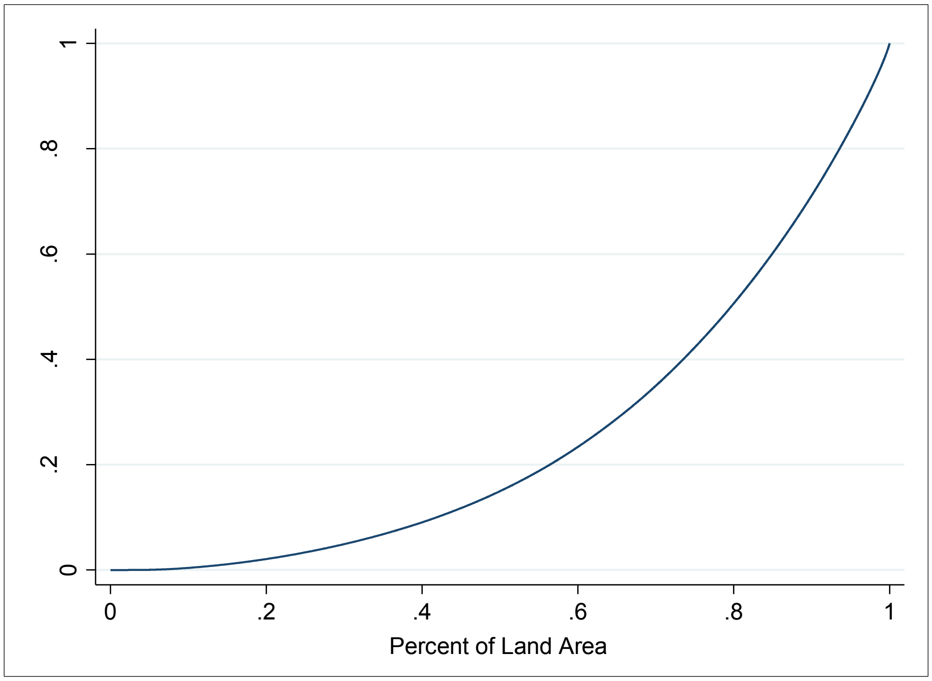

Figure 2.10 Percent of population living in percent of land area

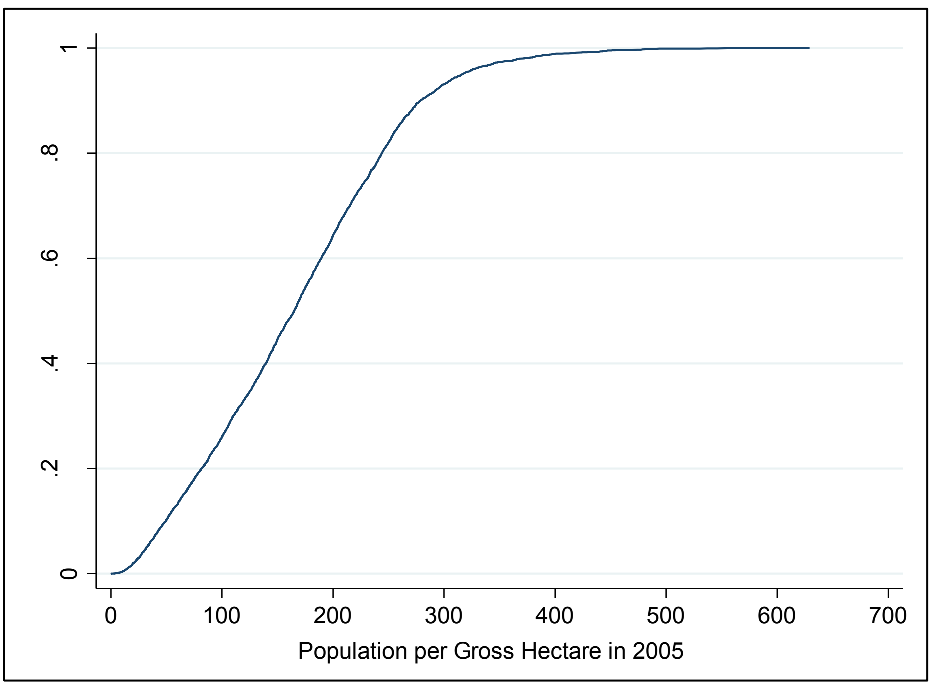

Figure 2.11 Cumulative percent of population living in neighborhoods by density

New commercial developments do not appear to be changing this trend. Monkkonen (2011c) found that new commercial housing developments in Mexico are no more peripheral and no less dense than traditional self-build neighborhoods. While remote and initially homogeneous, the developments are quite different from prototypical American sprawl. They tend to be densely populated—even more so than informal developments—rely heavily on public transportation, and become more self-sufficient over time as residential properties are converted into shops (Monkkonen, 2011c).

While much of the process of population and housing expansion and decentralization has been market-driven, several policies and one natural catastrophe have strengthened the trend. Campbell and Wilk (1986) encouraging decentralization has been the dominant objective of urban policy and planning in Mexico City. Rent control ordinances in the 1940's froze rents in central locations of the Federal District and halted the private production of rental properties in central Mexico City (Davis, 1994; Dowall & Wilk, 1989). In 1954, a ban on subdivisions in the Federal District and several surrounding municipalities further discouraged centralized growth, while promoting it in municipalities where the law did not apply (Dowall & Wilk, 1989; Ward, 1998, p. 50). Ernesto Uruchurtu, the Federal District's mayor from 1952 to 1966, actively pursued policies to limit growth within his jurisdiction with the result of accelerating growth in the surrounding municipalities of the State of Mexico (Davis, 1994, Chapter 4). Finally, although all four central boroughs lost population between 1970 and 1980, the 1985 earthquake wrought particular devastation in the historic center (Davis, 2005). This further encouraged the ongoing process of decentralization and may have even been a pretext for policies to encourage it (Campbell & Wilk, 1986). The worst-hit borough, Cuauhtémoc, lost more than a quarter of its residents between 1980 and 1990. Despite the quick reconstruction and repair of around 48,000 housing units benefiting 260,000 people through the two-year Popular Housing Reconstruction program (Kreimer & Echeverria, 2011), the four central boroughs lost over 650,000 residents between the two census periods. Prior to the earthquake the number of housing units in the center had, in fact, been increasing. In the 21st century, the Federal District's Bando 2 policy has prohibited housing and commercial development in nine of the most remote boroughs of the Federal District while encouraging new development in the center. This has helped to centralize growth within the Federal District, but also pushed more of it into the State of Mexico (Delgadillo Polanco, 2008; Vassalli & Yescas Sánchez, 2009).

2.3.4 Social and spatial inequality

Throughout Mexico City's periods of urban expansion, different socioeconomic groups have tended to move in different directions (Dowall & Wilk, 1989; Ward, 1998). The poor have generally moved to unstable and flood-prone areas with limited infrastructure, particularly the eastern and northeastern periphery, while the middle class and wealthier residents occupied areas with stable soils and gentle slopes in the southern and western areas of the city (Dowall & Wilk, 1989). While the poor and rich have never lived side by side in Mexico City, growth and expansion have magnified the scale of segregation (Ward, 1998, Chapter 2). Poor neighborhoods, particularly on the urban fringe, tend to be physically large and uniformly poor. Ward's (1998, p. 76) diagram of the socioeconomic geography of Mexico City still largely holds (Figure 2.12). Wealthy neighborhoods predominate in the western and southwestern suburbs of the Federal District, while the majority of the State of Mexico is inhabited by the working class. The downtown area has experienced an influx of young professionals and artists over the past decade and has become significantly more mixed in terms of income and social class.

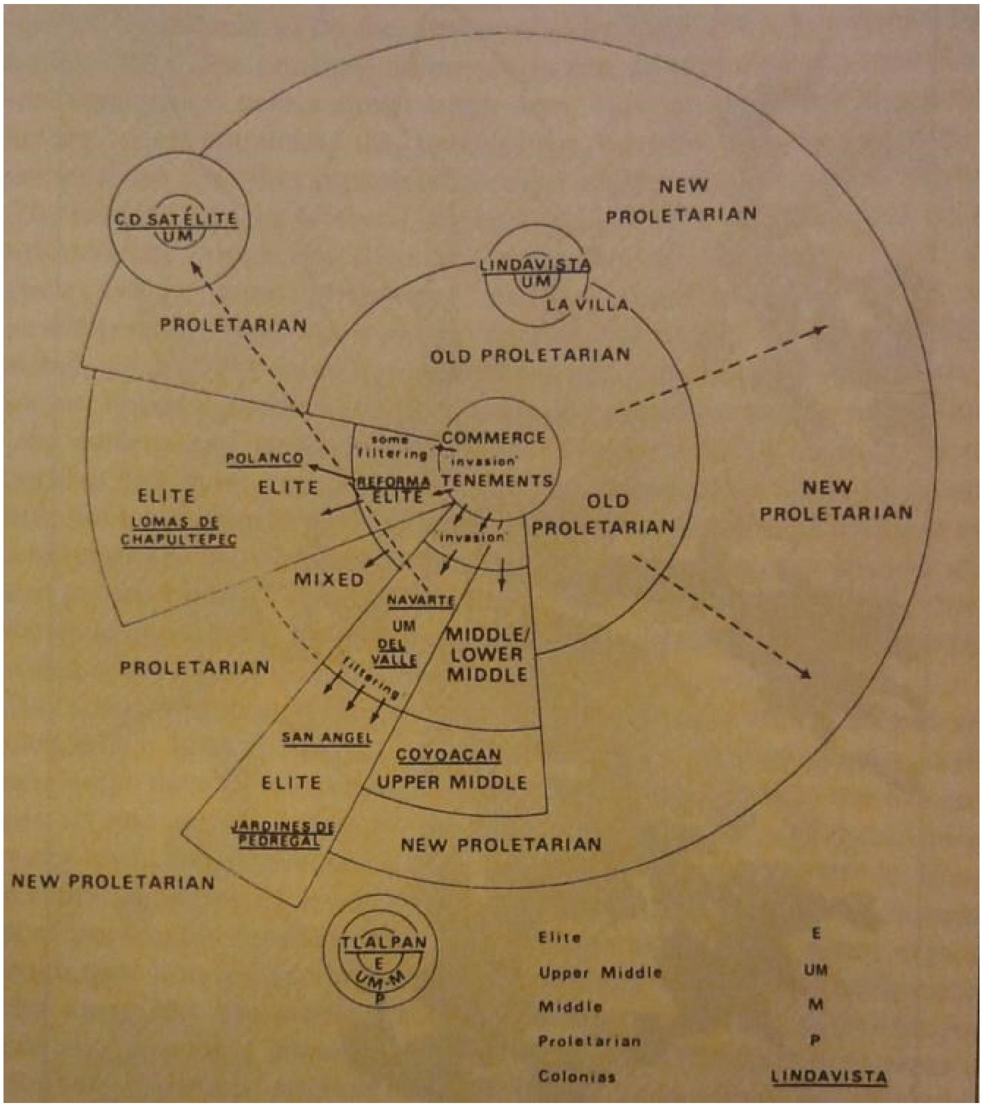

Figure 2.12 Diagrammatic representation of 'Ecological' areas of Mexico City. Reprinted from Ward (1998, p. 76)

The recent shift to private commercial development has also increased spatial segregation. In a study of the 128 largest Mexican cities, Monkkonen (2011b) found that higher percentages of mortgage financed homes between 1990 and 2000 were strongly associated with increased socioeconomic segregation over the same time period. By contrast, the incremental upgrading of informal neighborhoods was associated with decreased segregation. Of the 128 cities in 2000, Mexico City was the 38th most segregated, as measured by the distribution of income groups across all AGEBs.

Figure 2.13 maps the average household income by borough and municipality from the 2007 household travel survey (INEGI, 2007a). Perhaps the two most notable trends are the higher incomes in the wealthier western half of the city and the high concentration of wealthy households in the Federal District. The poorest municipalities are in the fast-growing eastern fringe.

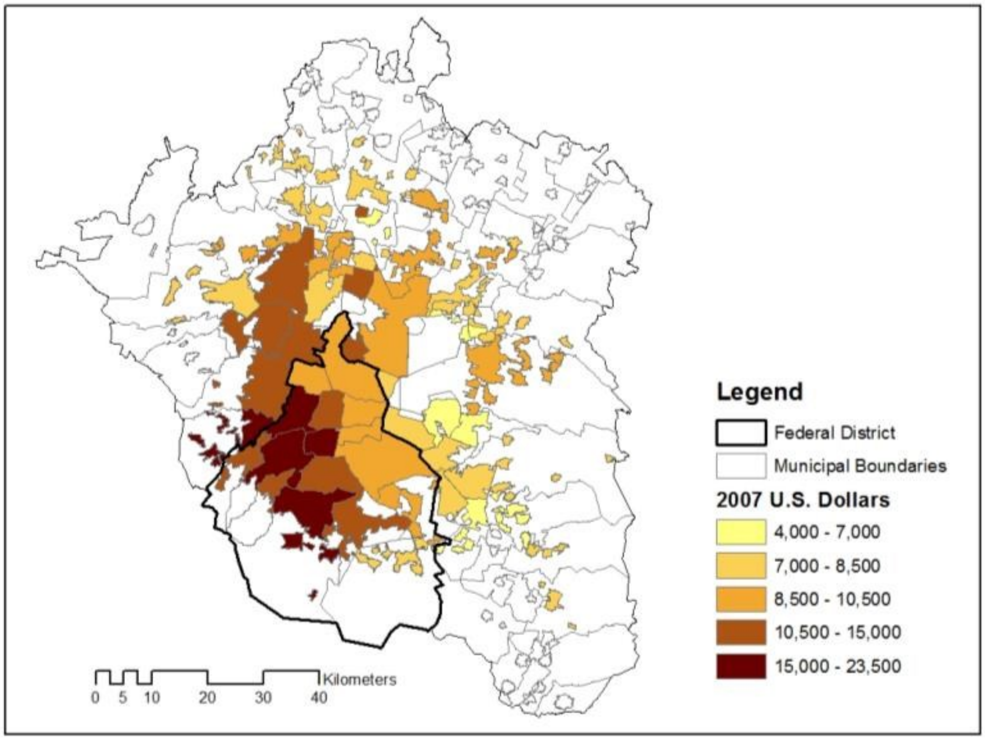

Figure 2.13 Average household income by borough and municipality (INEGI, 2007a)

2.3.5 Economic activity and jobs

Despite population growth in the suburbs, jobs and economic activities have remained highly centralized. Approximately one quarter of all Mexican jobs are in Mexico City. Although the percentage of national jobs in the MCMA declined from 26% in 1998 to 23% in 2008, the total number of jobs increased from 3.9 to 4.7 million—twice the average annual population growth rate over the same time period (INEGI, 2012a). Within the metropolitan area in 2008, eighty-two percent of Gross Census Value Added (GCVA)[3], a measure or economic production, and 70% of jobs were located within the Federal limits. Figure 2.14 graphs the number of jobs in Mexico City from 1998 to 2008. The number of jobs in the center has remained fairly stable, while those in the first and second rings have absorbed the most job growth. The fast-growing fourth urban ring contains less than five percent of all jobs.

Table 2.3 compares the number of jobs and housing units and the ratio of jobs to housing units in 1998/2000 and 2008/2010. Only the urban center has more jobs than housing units, although the ratio has declined in the past decade due to an increase in the number of units downtown. The number of jobs in the urban rings has been growing more quickly than the number of housing units. Nevertheless, both the absolute number and the relative number of jobs

[3] Gross Domestic Product (GDP) figures were not available at a fine enough resolution to calculate metropolitan GDP. The total GCVA for the Federal District and the entire State of Mexico was 62% of GDP for the same geographic area in 2008. GCVA is equal to total economic production minus the cost of all inputs, excluding capital depreciation (INEGI, 2011b). This differs from Gross Value Added, which equals GDP minus production taxes, plus production subsidies.

in the peripheral urban rings remain small. The center and first urban ring have over 60% of jobs and nearly three-quarters of GCVA. The urban center, despite its smaller geographic area, contains a third of all jobs and one half of all economic activity, as measured by GCVA. The productivity of central workers has also increased more rapidly than in the periphery. GCVA per employee increased by 133% from 1998 to 2008 compared to 83%, 55%, 78%, and 57% for rings 1 through 4 respectively.

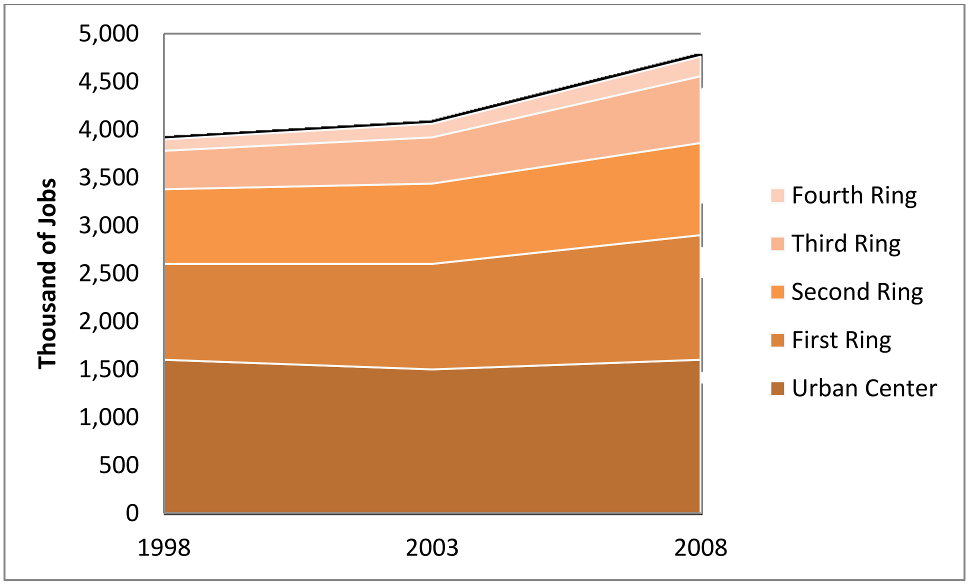

Figure 2.14 Thousands of jobs in MCMA by urban ring

Table 2.3 Ratio of Jobs to Housing Units in 1998/2000 and 2008/2010

Urban Ring	1998 Jobs (millions)	2000 Housing (millions)	**Ratio**	**Percent of GCVA[1]**	2008 Jobs (millions)	2010 Housing (millions)	**Ratio**	**Percent of GCVA[1]**
Center	1.60	0.47	**3.40**	**0.49**	1.59	0.55	**2.85**	**0.48**
First	1.04	1.23	**0.84**	**0.24**	1.29	1.38	**0.93**	**0.25**
Second	0.78	1.26	**0.62**	**0.15**	0.96	1.44	**0.67**	**0.18**
Third	0.40	0.96	**0.42**	**0.09**	0.69	1.47	**0.47**	**0.07**
Fourth	0.12	0.29	**0.41**	**0.02**	0.20	0.45	**0.45**	**0.02**

1. Gross Census Value Added, a measure of economic output

Within each urban ring, however, there is significant variation in job locations across municipalities. To normalize for the geographical differences, I map the number of jobs per square hectare of urbanized land in each municipality and delegation in 2008 (Figure 2.15). Employment densities are somewhat higher in the western half of the city. The strongest concentration, however, is in the three western boroughs of the urban center. Job densities are significantly lower in the outer periphery, while most of the second and third ring municipalities have densities that range from 5 to 25 jobs per hectare. The most rapid job growth, however, has been in peripheral municipalities, albeit from a significantly lower base (Figure 2.16). The number of jobs in two of the three densest central boroughs declined from 2003 to 2008. Nevertheless, these remain the dominant areas of employment.

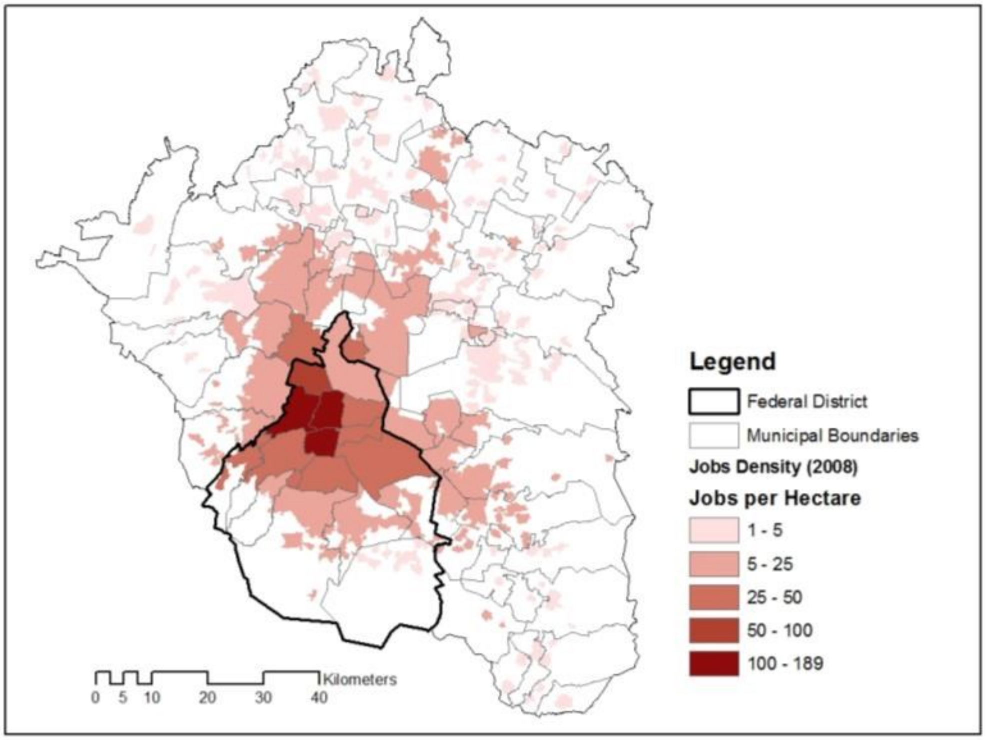

Figure 2.15 Jobs per hectare of urbanized land in municipalities and boroughs in 2008

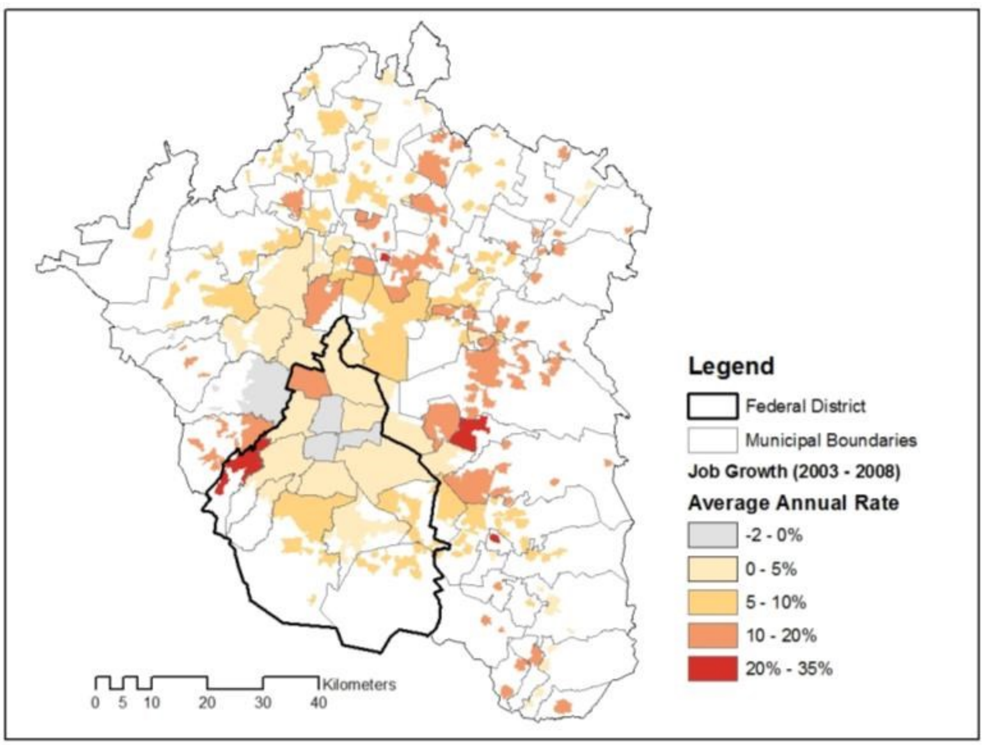

Figure 2.16 Average annual job growth by municipality and borough (2003 to 2008)

In addition to the concentration of jobs, there is significant variation in the types of jobs that locate in different parts of Mexico City. Prior to 1950, most industry located either near the downtown railways or to the immediate northwest in the borough of Azcapotzalco. Davis (1994) refers to a period of "urbanization-led industrialization", where significant public funds were pumped into infrastructure, parks, and industry in the Federal District. With the appointment of mayor Uruchurtu in 1952, large infrastructure and downtown development plans came to a halt. Allied with small shop-owners, he worked to remove street vendors and improve local transit with construction projects or street widening. Public funds continued to flow into the Federal District, but primarily into parks, boulevard beautification, and drainage systems (Davis, 1994). Throughout the 1950's and 60's industrial manufacturing moved outside of downtown to bordering municipalities, such as Naucalpan, Tlalnpantla, and Ecatepec, in the State of Mexico (Ward, 1998).

In recent years, the relative importance of service jobs has increased across Mexico City and, indeed, the country of Mexico. This process, however, has been particularly pronounced in the Federal District. Table 2.4 demonstrates some of the key economic differences across the Federal District, State of Mexico, and country of Mexico. The location quotients are equal to the percentage of aggregate GDP accounted for by the sectors of interest in the Federal District and State of Mexico divided by the equivalent percentage for the country as a whole. For example, the Federal District is approximately half as reliant on manufacturing as the nation as whole, while the State of Mexico is 50% more reliant. The Federal District, by contrast, is significantly more reliant on the government and high-end service jobs, like finance and information technology. These sectoral differences have remained stable or increased over the past decade.

Table 2.4 Industry Location Quotients in the Federal District and State of Mexico

Location	Industry	2003	2010
Federal District	Manufacturing	0.59	0.53
Mexico State	Manufacturing	1.49	1.53
Federal District	Finance, IT, Professional Services	2.52	2.50
Mexico State	Finance, IT, Professional Services	0.71	0.66
Federal District	Government	1.63	1.79
Mexico State	Government	0.88	0.84
Federal District	Real Estate & Construction	0.72	0.70
Mexico State	Real Estate & Construction	1.12	1.15

Source: INEGI (2012a)

2.4 Transportation in Mexico City

Transportation has played a major role in Mexico City's urban expansion. In particular, the rapid growth in informal neighborhoods coincided with a rapid increase in privately operated informal minivans and minibuses, referred to as *colectivos*. Over the past several decades, furthermore, car ownership and use have risen dramatically in Mexico City. Travel times, delays, and trip distances have all increased over the same period. While high-capacity public transportation, like the Metro and BRT, has managed to maintain mode share, road-based public buses and informal transit have seen significant losses in mode share over the past 10 years. Although the majority of households, and nearly all of the poorest households, continue to rely on public transportation to meet their daily needs, increasing car use will tend to increase the economic, environmental, and social costs of the current transportation system. The poor, less able to sort to preferred locations, will suffer the brunt of these costs.

2.4.1 Public transportation

Since the first mule-drawn trolleys of the early 20th century, the relationship between the public sector and private providers of public transportation has been complex and, at times, contentious. With the exception of a brief period between September 25th, 1981 and April, 7th 1994, the government has relied on concessions to private consortiums to operate most public transportation routes. These concessionaires provided access to most of the fastest-growing parts of the metropolis, particularly areas in the less heavily regulated State of Mexico. At the same time, the public sector has provided high capacity transit in the form of the Metro, the first 42-kilometer phase of which was completed in 1972, and more recently publicly owned and privately operated commuter rail and bus rapid transit (BRT) lines. The Federal District and State of Mexico also provide public bus services. This section looks at the history and use of the most common forms of public transportation.[4]

Just as the history and relationship between informal and formal transit are complex, so too is the contemporary use of public transit. Nearly all trips are multimodal, making it difficult to present mode share neatly. For example, of the 19% of weekday trips that relied on the Metro in 2007, 69% also used *colectivos* and 20% used a public bus or trolleybus. A little over one percent also relied on BRT or light rail. Only17.5% of Metro trips relied exclusively on the Metro and walking. Due to this complexity, researchers either estimate mode share for public transportation by legs or by primary mode. This makes the comparison of public mode share—and indeed number of trips, since some authors use trips segments while others use trips—across years and studies unreliable, as will be discussed below.

In 2007, 62% of trips used public buses, *colectivos*, light rail, or the Metro. A significant portion of the 2.5% of trips that listed "other" as a mode described the mode as a school or university bus and a further 6% used taxis. Table 2.5 reports the percentage of total trips that used each mode by itself, or in combination with another public transportation mode, taxi, or car. With the exception of *colectivos*, most types of public transportation rely on one or more additional modes. Even unimodal bus and *colectivo* journeys, however, rely on transfers. While the survey is not particularly well-suited to recording these unimodal trip segments, a quarter travelers reported them. However mode share is reported, two attributes are apparent. One, most people rely on public transportation. Two, informal transit provides the lion's share of service and is an important feeder for the Metro and public buses. Unlike with public transportation, most car trips are unimodal.

Table 2.6 presents official mode share statistics from 1986 to 2007. Although roughly accurate, these data are likely inconsistent. The number of total trips varies tremendously and

[4] Public, here, refers to the capacity and public nature of the service, rather than the ownership and operation. Despite similarities with private cars, taxis are often referred to as a form of public transportation and will be discussed in this section. While the separation between modes, particularly between public buses and privately operated *colectivos*, is not always entirely clear-cut, particularly from a historical perspective, I conform to the modal specification used in the 1994 and 2007 metropolitan travel surveys.

may refer to trips in some years, but trip segments in others. The drop in the share of trips by car from 1986 to 1989, in particular, indicates that 1989 data may use segments, while 1986 data use trips. Furthermore, only the 1994 and 2007 data were collected using large-scale household travel surveys. The collection methods for intermediate years are not reported. The lower percent of trips using cars in 2007—21% compared to 29% from the table above—indicates that the mode share refers to the percent of trip segments. Similarly in 1994, 24% of trips used a personal car, compared to 17% of trip segments. The 2007 household travel survey reported 22 million trips and 31 million trip segments.

Table 2.5 Percent of all trips relying one public transportation modes for part or all of a trip

	Percent of trips using mode	Percent of trips using mode exclusively	Percent unimodal
Metro	19.0%	3.0%	15.9%
Colectivo	51.6%	32.4%	62.8%
Bus / Trolleybus	12.9%	4.2%	32.8%
BRT	1.1%	0.2%	18.7%
Light rail	0.5%	0.0%	3.5%
Taxi	8.1%	6.1%	74.9%
Personal Car	28.8%	28.5%	99.0%

Table 2.6 Mexico City Metropolitan Area mode share* (1986 – 2007)

Mode Share	1986	1989	1994	2000	2007
Metro	0.19	0.20	0.16	0.14	0.14
Autobus	0.42	0.19	0.10	0.09	0.10
Colectivo	0.06	0.36	0.53	0.54	0.46
Taxi	0.06	0.06	0.03	0.06	0.06
Light rail / Trolleybus / Metrobus	0.03	0.03	0.01	0.01	0.02
Personal Car	0.24	0.16	0.17	0.16	0.21

*Source: SETRAVI (2010). While mode share reports trip segments in most years it appears to report the percent of total trips in 1986.

Trolleys, buses, and colectivos

Three forms of animal-powered transportation dominated Mexico City at the turn of the 19th century: mule-drawn trolleys, walking, and personal horses and horse-drawn carriages. With electrification, overhead cables replaced mules and electric trolleys became the dominant form of mass transportation. By 1917, the foreign-owned and -financed Mexico Trolley Company operated fourteen electric trolley lines, which served the vast majority of vehicular trips in Mexico City (Navarro, 1984). In 1914, the first of a series of strikes by trolley drivers and electric workers paralyzed urban transportation with significant urban and national political repercussions (Davis, 1994, Chapters 1–2; Islas Rivera, 2000, Chapter 6). First organically and later with state support and subsidies, entrepreneurs began to provide public transportation services with converted cars, trucks, and buses (Davis, 1994, Chapters 1–2; Islas Rivera, 2000, Chapter 6; Navarro, 1984; Wirth, 1997). Over the next 20 years, bus drivers' unions and collectives grew into a social and political force (Davis, 1994) and privately operated buses—along with shared-ride taxis, one of two predecessors to today's *colectivos*—became the city's principal form of transportation. By 1940, there were five times more buses than trolleys serving the city. Their advantage stemmed in large part from their ability to serve newly urbanized areas quickly and efficiently (Navarro, 1984). In 1945, the Mexican government expropriated the trolley system, the final remnants of which closed in the 1980s (Wirth, 1997). Simultaneously, the government expanded trolleybus services, but they have never captured a significant share of travel. In 1979, there were 400 trolleybuses in operation, carrying just fewer than 600,000 passengers per day.

While bus-drivers associations' political influence helped them to secure route concessions and subsidies, it also became a liability. In the 1970s, most private bus routes had operating expenses that were between 110% and 130% of fare revenues (Navarro, 1984). This led operators to shorten routes, raise fares without permission, and lobby for additional subsidies (Navarro, 1984; Wirth, 1997). In September 1981, Federal District mayor Hank González revoked all private bus route concessions within the city and gave them to the publicly owned Ruta 100, a previously private bus route which had been converted to public control nine years earlier (Islas Rivera, 2000, Chapter 6). Officially, the policy was claimed to promote efficient transportation and support the drivers' unions, since they were losing money on intercity routes (Davis, 1994; Islas Rivera, 2000). Unofficially, the Hank González administration opposed the politically powerful Bus Drivers Alliance (*Alianza de Camioneros*) (Islas Rivera, 2000; Ward, 1998; Wirth, 1997). In support of this view, Islas Rivera notes that no transportation plan, prior to the handover, ever mentioned it. Davis (1994, p. 243), by contrast, argues that the policy largely fit with Hank González's urban transportation policies, which included investment in the Metro and the widening of urban arterials, and benefited the Bus Drivers Alliance, who were allowed to keep the longer, and more lucrative routes between the Federal District and State of Mexico.

The immediate consequence of this policy was to drastically reduce bus service in Mexico City. Between 1979 and 1982, the number of bus routes dropped from 534 to 114, although the number of vehicles and passengers declined more slowly (Islas Rivera, 2000, p. 260). Despite an increase in routes, the decline continued steadily. By 1994, the number of daily bus passengers roughly halved from 5.6 to 2.9 million. In terms of mode share, bus use dropped from 42% in 1986 to 19% in 1989 and 10% in 1994 (SETRAVI, 2010). The system also required significant subsidies. In the early 1990's, Ruta 100 required more public subsidy than the Metro, but carried fewer passengers (Wirth, 1997). In 1995, after strikers demanding higher fares blocked public roads with Ruta-100 buses, the Federal District government dissolved the agency.

In 1994, a year before its closing, just 8.7% of trips relied on the Ruta-100 for at least part of the journey. In 2000, the Federal District reopened a public bus system (RTP, 2012). In 2007, just 1.7% of trips used the system. Over the same time period, the share of trips using suburban buses in the State of Mexico increased from 4.7% to 9.6%. Faster population growth, limited Metro service, and no public takeover all likely contributed to this significant difference across the Federal District boundary.

In the shift from private to public bus operations and back again, *colectivos* emerged as the dominant form of transportation in Mexico City. These informal, though now highly formalized and regulated minibuses (*microbúses*) and minivans (*combis*), are a hybrid of the shared taxis, *peseros*, and private bus operators that emerged from the trolley strikes of the early 20th century and the coinciding mass production of rubber-tired vehicles powered by internal combustion engines. *Colectivos'* tremendous growth in the 1970s and 1980s matches the rapid population growth in informal suburban neighborhoods in the second and third urban ring (See

Figure 2.3). With the formal concession of transit routes to *colectivo* operators in the Federal District in 1969, though only on routes feeding Metro stations (Cervero, 1998), the number of registered vehicles throughout the metropolis surged. By 2006, there were a total of 276,000 registered *combis* and *microbúses* in Mexico City (SETRAVI, 2010, p. Table 2). The fastest growth occurred during and immediately after the public takeover of bus service in the Federal District. The percent of metropolitan trip segments by *colectivo* increased from 6% in 1986, to 36% in 1989, and 52% in 1994 (Table 2.6). While drivers initially competed with public bus service, they also expanded service into newly growing parts of the city without public transportation (Cervero, 1998; Islas Rivera, 2000).

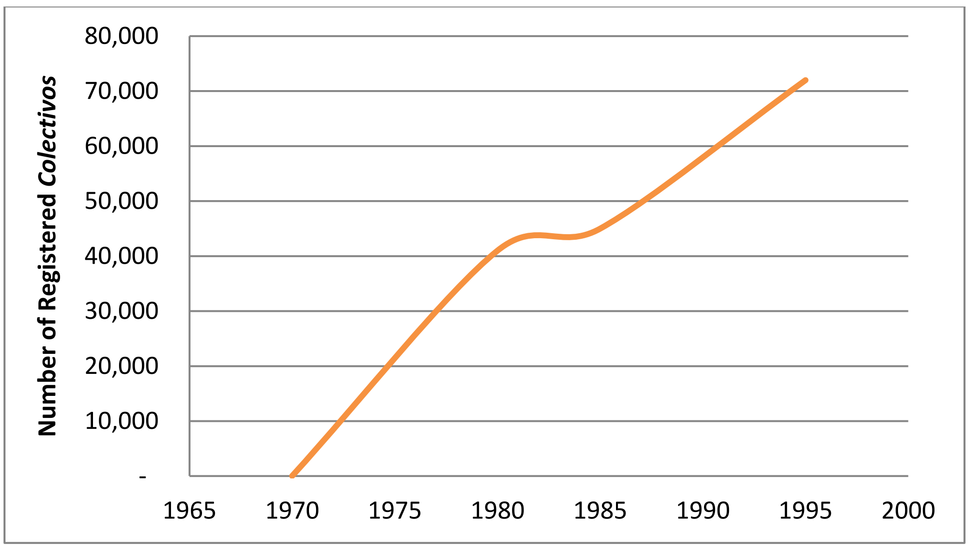

Figure 2.17 Registered *colectivos*, 1970 to 1995 (Wirth, 1997)

Wirth (1997) and Ward (1998) both treat *colectivos* (along with personal cars) as villains in the contemporary transportation system. Wirth, in particular, accuses them of cheating, corruption, overcharging, destroying the public bus system, and serving the interests of an elite powerful few. Nevertheless, *colectivo*s have managed to provide mass public transportation where and when the public sector was unable or unwilling. While there is a tendency to view the closing of Ruta 100 and expansion of *colectivos* as an expression of the neoliberal policies of the decades following Mexico's 1982 economic crisis, the private provision of public transportation has been the rule, rather than the exception, in Mexico City for the past 100 years. Islas Rivera (2000) and Cervero (1998) take a more nuanced view and articulate the major pros and cons of *colectivos*. They provide flexible, demand-responsive service that tends to be faster, have more seats per passenger, more frequent headways, and easier loading and unloading than buses. They also serve as the primary feeder for the Metro system. On the other hand, they provide inadequate peak hour service along major corridors, wait for vehicles to fill before leaving during the off-peak, and are significantly more expensive than public buses and trains. This higher fare—the average *colectivo* expenditure was five pesos per trip in 2007, compared to the Metro's flat fare of two pesos—however, has also allowed *colectivos* to operate without direct public subsidies.

Although *colectivos* generate more pollution, congestion, and traffic collisions per passenger than contemporary public buses, BRT, or the Metro, they generate far lower social costs than private taxis or personal cars. They also provide a vital service, particularly for poorer residents in suburban areas without good access to high-capacity transit. It is worrisome that *colectivos* lost significant mode share from 1994, when 61% of trips used a *colectivo*, to 2007, when only 52% did. Nearly all of this travel has been absorbed by personal cars, rather than high-capacity transit. Figure 2.18 maps metropolitan residents' reliance on *colectivos* by municipality and borough. Suburban municipalities remain particularly reliant on *colectivos*, while central residents use them far less frequently. Even in the center, however, residents use *colectivos* for a fifth to a third of trips.

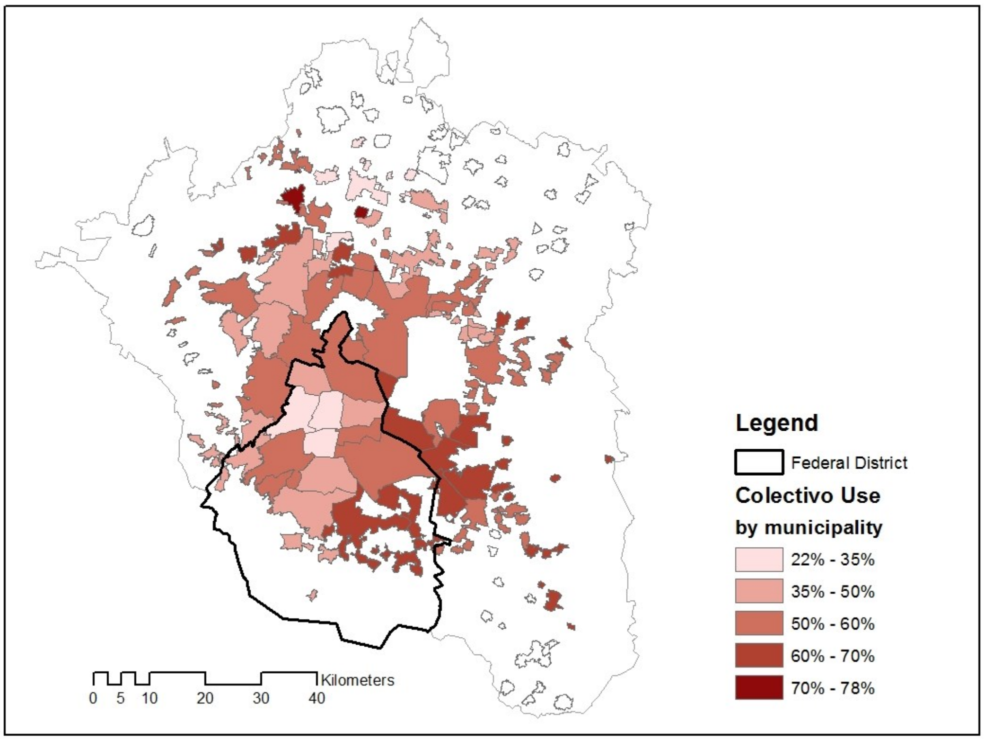

Figure 2.18 Percent of trips using *colectivos* by home municipality/borough of trip maker

Taxis

As with private cars, taxi mode share has increased in recent years. In 1994, 3.6% of trips used a taxi, compared to 8.1% in 2007. The lower rate in 1994, however, may be something of an anomaly. With the exception of 1994, taxi mode share has remained fairly consistent from 1986 to 2007 (Table 2.6). Taxis tend to serve middle-income and wealthy households for shorter trips. The average taxi trip distance was 43% as long as other trips. Despite serving far fewer trips and shorter distances, the taxi fleet at 155,000 was more than half the size of the *colectivo* fleet in 2007 (SETRAVI, 2010). The vehicles also circulate without passengers and create far more pollution and congestion than higher capacity vehicles. In 2006, the taxi fleet generated 1.75 times more greenhouse gas emissions than the *colectivo* fleet (SETRAVI, 2010).

The Metro

The first 13 kilometers of Mexico's City's Metro, the primarily rubber-tire high-capacity transit system, opened in 1969, barely one year after construction began (Navarro, 1984; Sistema de Transporte Colectivo, 2012). Originally deemed too expensive and complicated due to Mexico City's unstable soils and frequent earthquakes, the planning and implementation of the Metro was a prominent cause of the *Ingenieros Civiles Asociados*, a large Mexican engineering, construction, and infrastructure conglomerate, in the 1950s and 1960s. President Díaz Ordaz, a Metro supporter, initially planned to open the first three lines in time for the 1968 Mexico City Olympics. Political opposition from mayor Uruchurtu, however, delayed the opening. Uruchurtu longed for a smaller, less chaotic Mexico City and feared that the Metro would contribute to the growth and expansion of the city (Davis, 1994, Chapter 4). He favored policies to improve bus service and decentralize development away from the Federal District. After crippling bus service strikes in 1965, however, his policies began to lose support and Metro plans moved forward (Davis, 1994, Chapter 4). Over the next forty years, the Metro has expanded in fits and starts, often based on the mayor and president's support or opposition. President Echeverría, for example, worried about the Metro's impact on foreign debt. As a result, the initial Metro lines did not increase until the enthusiastic support of mayor Hank González helped to double the system's length in the late 70s and early 80s (Davis, 1994, Chapters 6 & 7).

Table 2.7 provides figures on the length of the Metro and the total number of annual boardings from 1979 to 2013. By 1973, the initial system was saturated and carrying 50% more passengers than the recommended maximum (Navarro, 1984). Accidents and assaults proliferated on the initial investment (Davis, 1994, Chapter 7; Navarro, 1984). Between 1979 and 2010, the system length quadrupled, while ridership has only increased about 40%. Passengers per kilometer and per station have decreased accordingly. The most recent expansion, Line 12, opened at the end of 2012. The system, nevertheless, has remained extremely crowded as passengers travel longer distances.

Table 2.7 Mexico City Metro system length and ridership (1979 – 2013)

	1979	1983	1988	1992	1995	2000	2005	2010	2013
Annual boardings (millions)	1,022	1,241	1,476	1,436	1,474	1,393	1,441	1,410	-
System length (km)	43	86	135	158	178	190	201	201	226
Passengers (millions per km)	24	14	11	9	8	7	7	7	-
Stations	49	85	121	135	154	167	175	175	192
Passengers (millions per station)	21	15	12	11	10	8	8	8	-

The Metro is busy day and night, particularly during the long morning and evening peaks and particularly on the original three central lines. The share of trips using the Metro has declined since the 1980s, although precise figues depend on how mode share is divided. Of the nineteen percent of vehicular trips that involved the Metro in 2007, 69% also involved a *colectivo*. Another 14% of Metro trips not counting those that also used *colectivos*, involved public buses, light rail, BRT, and other vehicular modes. Figure 2.19 maps the Metro system, 2005 station boardings, and percent of trips that used the Metro on any segment by the home municipality or borough of the trip maker in 2007. The eastern and northeastern suburban municipalities with some Metro service have the highest rate of Metro use in Mexico City. The western suburbs, which are wealthier and lack Metro lines, have the lowest Metro use. In all areas, terminal stations are particularly busy, since they draw from a wide catchment area fed by *colectivos* and buses.

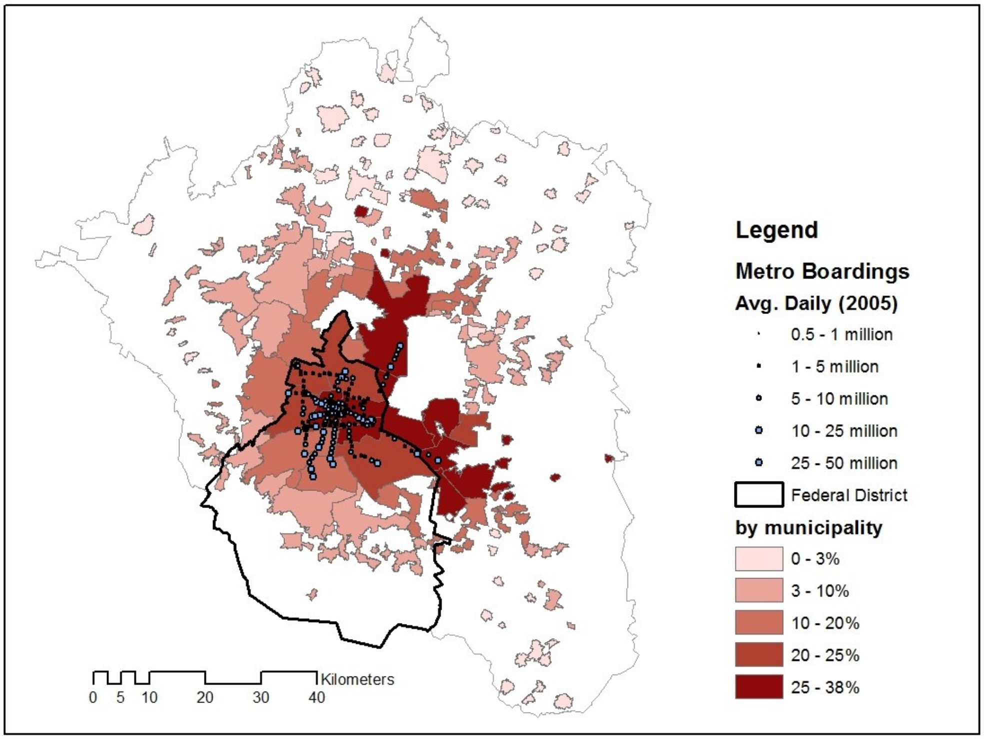

Figure 2.19 Percent of trips using the Metro by home municipality/borough of trip maker

The Metro provides high-capacity trunk-line service in the center of the metropolis while *colectivos* provide feeder and local service throughout the city, including densely populated suburban areas with narrow and congested road networks. This combined service has made Mexico City one of Cervero's (1998) case studies for well-integrated transit and land use. In this respect, the Metro has been a success. In other respects, it has struggled. The Metro has neither decongested urban streets nor promoted urban development. The first is fairly unsurprising. Transit systems rarely reduce road congestion, but allow an increase in multimodal accessibility within the service area. As to development, the Metro has likely increased land values and development around stations in poor neighborhoods, but decreased it or had no effect in wealthier areas (Navarro & González, 1990). The types of workers associated with downtown development do not ride the Metro. Davis (1994, p. 232) notes that the centrally located residents, who ought to benefit most from the Metro, tend not to use it due to perceptions of danger or associations with the working class. For an overview of social hierarchies and the Metro, as well as a direct taste of several authors' extreme distaste for the Metro, The Mexico City Reader offers a collection of contemporary essays on the Mexico City Metro (Gallo, 2004, sec. 3).

Ward (1998), however, notes that it remains the least expensive form of transportation and carries more and a greater share of passengers than any other Latin American subway system. If the Metro is crowded or unsafe, furthermore, it is much less so than other forms of public transportation (Wirth, 1997). It is also the fastest form of public transportation and one that has not slowed with increasing congestion. Low, flat fares, however, have come at a price. By 1981, the Metro was the largest debt-producing item on Federal District's budget (Davis, 1994, p. 249). Citing a budget report, Crôtte, Graham, and Noland (2011) indicate that Metro subsidies accounted for 82% of the Federal District's transportation expenditures in 2008. In 2010, Metro fares were increased from two to three pesos. After adjusting for inflation, however, this remains lower than the 1995 one-peso fare. In 1996, fare revenues covered about 40% of operating, maintenance, and debt-financing costs (Islas Rivera, 2000, Chapter 7). After the 50% fare increase in 2010, the Metro agency printed tickets indicating that the real cost of providing the 3 peso trip was 9 pesos (Sistema de Transporte Colectivo, 2012).

Light Rail

Like the city's trolleybuses, discussed above, the Federal District government owns and operates the city's 13-kilometer light rail line. The line opened in 1986 and provides high capacity transit access from Tasqueña, the southernmost Metro station of Line 2, to neighborhoods in the south and two important cultural and tourist destinations: Aztec Stadium and Xochimilco. The line carried some portion of half of one percent of metropolitan trips in 2007. Of these, 97% also relied on some other vehicular mode. Both the light rail and trolleybuses run routes from the former electric trolley system.

Bus Rapid Transit

In the face high Metro subsidies, the government has reoriented its investment policy toward developing a BRT network, operated by the private sector. Due to lower investment costs, high capacity, and a higher success rate in covering operating costs, BRT has been touted as the appropriate technology for high-capacity transit in developing countries (Fouracre, Dunkerley, & Gardner, 2003; Gwilliam, 2002; Hidalgo, 2005). Mexico City's first BRT line, Metrobus 1, opened in 2005 and was extended in 2008. Since then, three other lines have opened for a total of 95 kilometers in the Federal District. Table 2.8 provides the opening dates, average daily ridership, and length of the Federal District's four BRT lines. A single BRT line opened in 2010 and provides service from Ciudad Azteca, a shopping mall and the terminal Metro station of the Line B northeast extension, 16.5 kilometers to the north. Along with the commuter rail, described below, it is the only high-capacity transit line providing service into Mexico City's currently fastest-growing neighborhoods

Indeed, the first Metrobus lines have covered operating expenses and provided sufficient revenues to finance private operation. When the first line opened, however, a standard fare cost twice as much as a Metro fare, but only covered twenty kilometers. One percent of metropolitan trips used Metrobus 1 in 2007. Of these, 80% relied on some other transit mode. Relative to the Metro, Metrobus 1 carries about six thousand fewer passengers per day per kilometer of right of way. Each new Metrobus investment, furthermore, carries fewer passengers than the previous. The fourth line, which goes to the airport and charges an additional 25 pesos for direct access to the terminals, has done particularly poorly. Given free transfers, each trip on a new line is less likely to add new fare revenue. Metrobus 5, which will run north from the San Lázaro Metro station, provides parallel service, three-quarters of a kilometer west of Line 4 of the Metro. As the BRT system expands, it is likely to face many of the same challenges as the Metro system. While its investment costs are likely to remain lower than the Metro, its current operating performance is more related to higher fares and lower spatial coverage than to technology.

Table 2.8 Metrobus lines (Gobierno del Distrito Federal, 2013)

	Length (km)	Daily passengers	Passengers per km	Opening
Metrobus 1	30	440,000	14,667	2005
Metrobus 2	20	170,000	8,500	2009
Metrobus 3	17	140,000	8,235	2011
Metrobus 4	28	50,000	1,786	2012

Commuter rail

Like the BRT system, Mexico City's nascent commuter rail system is privately operated. Unlike Metrobus 1, the first commuter rail line, which opened in 2008 and provides 25.6 kilometers of service from the Buenavista Metro station terminal into the northern suburbs, has not been able to cover operating costs, despite fares ranging from 6.5 to 15 pesos per trip depending on trip distance. At 134,000 average daily user in 2012, the line is well short of the projected 193,000 users and the operator has claimed that the government has failed to provide adequate feeder service (Cruz Serrano, 2012b). The additional five planned suburban commuter lines appear unlikely to move forward in the near future due to operating losses on the first line (Cruz Serrano, 2012a, 2012b).

2.4.2 Non-motorized transportation

For all its size, Mexico City is a walking city. Streets and sidewalks, not just in the city center but also in the suburbs, are full of pedestrians. In addition to walking trips, the high share of multimodal public transit trips encourages walking. While the Mexico City household travel survey does not provide data on walking trips, Zegras et al. (2000) conservatively estimate that 15% of trips are by foot based on 10% rates from Buenos Aires, 20% from Santiago de Chile, and 30% from São Paulo. In addition to failing to collect data on walking, urban policy has also placed far less emphasis on pedestrian infrastructure than highways or public transportation. Pedestrian bridge crossings are commonly built to prevent pedestrian crossings from delaying traffic. They are rarely used, however, since they send pedestrians far out of the way and make them ascend and descend stairs to cross a street. As a result, many major pedestrian crossings, particularly in the suburbs, offer almost no protection for pedestrians. Figure 2.20 shows a typical pedestrian bridge crossing at the northern terminal BRT station of the Metrobus 3. The striped at-grade crossing is blocked by a metal gate, which pedestrians climb over or squeeze past. The rarely used metallic pedestrian bridge more than quadruples the walking distance to cross the street.

Figure 2.20 Pedestrian bridge crossing at Tenayuca Metrobus station (2012)

The photo also shows numerous bicycles chained around the station; a common site throughout Mexico City's peripheral, particularly terminal, high capacity transit stations. Nevertheless, bicycles remain a niche transportation mode in Mexico City. In 2007, 2% of trips relied on bicycles. This, however, doubled the recorded mode share from 1994. Despite the visible sign of bicycle-to-transit transfers, more than 99% of reported bicycle trips were unimodal. At 3%, cycling rates in the State of Mexico are three times higher than in the Federal District. In 2010, the Federal District government launched EcoBici, a bike-sharing program with over a thousand bikes at a hundred stations. In 2012, the system, which quickly reached the maximum number of subscribers, expanded to 250 stations, concentrated in the four central boroughs of the Federal District (Ecobici México, 2013). This program has coincided with the construction of new bike lanes and cycle tracks.

2.4.3 Personal Cars

While public transportation still accounts for most trips in Mexico City, the car fleet and the percent of trips by car have been growing steadily. Between 1980 and 2010, the number of registered cars more than doubled from 1.8 million to 5.4 million. This growth has been particularly pronounced in the urban center. Figure 2.21 graphs the number of registered cars and light duty trucks per thousand people in all urban rings between 1980 and 2010. Between 2000 and 2010, there were 1.7 new cars and light duty trucks for each additional person in the metropolis. While the fourth urban ring accounted for 27% of population growth in the last decade, it accounted for just 6% of the growth in vehicle fleets. In 2007, approximately 29% of trips were by car, up from 24% in 1994. Chapters 3 and 4, which focus on car use and ownership, contain additional information, maps, and graphics about the distribution of car ownership and use. In general, patterns of car ownership closely mimic the patterns of income distribution. While suburban households are less likely to own a car or drive one than residents of the Federal District, once they drive, they drive significantly longer distances.

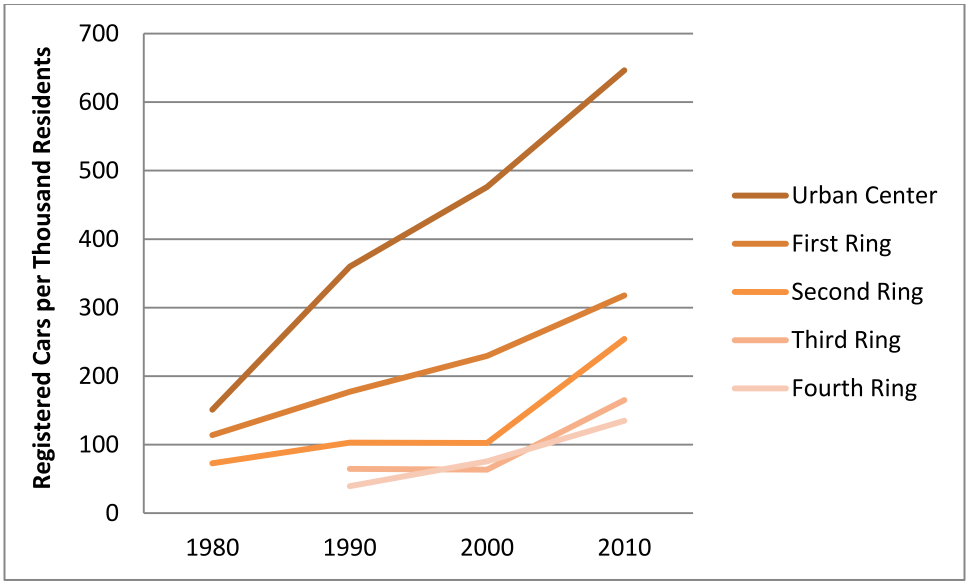

Figure 2.21 Number of registered cars per thousand residents by urban ring

The rapid growth in personal cars began in the 1940's and has had serious implications for public transportation speeds, congestion, and local and global pollution. Although Wirth (1997) claims that average bus speeds dropped from fourteen kilometers per hour in 1982 to just six in 1994, the drop is likely exaggerated. I estimate that the total door-to-door travel speed of public transportation trips dropped from 11.2 to 10.8 kilometers per hour between 1994 and 2007. Overall driving speeds dropped more significantly from 14.5 to 13.2 kilometers per hour, but maintained a speed advantage over public transportation. In 2006, private cars emitted more than half of all road-based green-house gas emissions, including from freight vehicles and public transportation (SETRAVI, 2010, p. 30). Although local air quality has improved significantly, high altitude and surrounding mountains have made Mexico City particularly vulnerable to local pollution. In 2002, the city exceeded local ozone standards on four out of five days (McKinley et al., 2005). Local pollution, rather than congestion, motivated the metropolitan *Hoy No Circula* law, which bans cars from driving one day per week. Smog tests are strictly enforced with high official penalties and smaller, but frequent, informal ones.

In addition to hindering car use, several government policies have also encouraged the shift to car-ownership and use. Between 1952 to 1982, the government spent nearly $70 billion (in 2013 dollars) on 470 kilometers of highway (Wirth, 1997). Mayor Hank Gonzales' *ejes viales*, high-capacity linear roadways, displaced 25,000 housing units and 145,000 people. The Periférico, a high-capacity ring-road completed in 1962, was double-decked in 2006. Other regional urban highway rings connect Mexico City to the surrounding states of Hidalgo, Morelos, and Querétaro. A national network of privately operated toll roads have further added to regional road capacity. Currently, the Federal District government is building another elevated highway, designed to improve access to Santa Fe, in the western half of the city.

Motorcycles

Although there appears to have been a recent bump in the number of scooters and motorcycles on the road, motorcycle use is even less common than bicycle use. In both 1994 and 2007, motorcycles accounted for less than a half percent of all trips. The dearth of motorcycles makes Mexico City a poorly suited case city for two-wheeler cities like Ho Chi Min City, Ouagadougou, or Phnom Peng.

2.5 Geography of travel

As population growth has moved to the periphery and economic production has remained centralized, the geography of travel in Mexico City has shifted. Average trip distances increased from 9.1 to 9.9 kilometers from 1994 to 2007. Combined with slower speeds, average trip durations have increased even more, from 46 to 52 minutes. The average one-way work-trip increased from 52 to 58 minutes. Although the central parts of the city attract more trips of all types than other areas, the work-trip is particularly centralized. From 1994 to 2007, trip-making has become less centralized. Nevertheless, 57% of all trips and 62% of all work trips had a destination in the urban center or first urban ring in 2007.

Table 2.9 and Table 2.10 show the percent and total number of non-home-destination trips by home location and destination location.[5] Of these, 24% were reported as work or work-related trips in 1994 and 27% in 2007. In both years, the urban center is the most self-contained geography, with 71% and 68% of trips (83% and 82%, if journey-home trips are counted) remaining in the area in 1994 and 2007. With the exception of the fourth urban ring, each additional ring is less self-contained. Outside of its own residents, very few metropolitan citizens traveled to the fast-growing fourth urban ring. Even including residents, just 2% of trips went to the fourth ring in 1994 and 4% in 2007. Households living in the Federal District tend to be entirely bounded by the Federal limits for their daily travel. By contrast, residents of the State of Mexico regularly travel to the Federal District.

Table 2.9 Non-home-bound trips by home location and destination (1994)

	Home location					
Destination location	Urban Center	First Ring	Second Ring	Third Ring	Fourth Ring	Total
Urban center	70.5%	34.1%	23.8%	17.7%	8.7%	34.0%
First ring	21.4%	55.3%	26.2%	15.9%	10.3%	32.5%
Second Ring	6.8%	8.8%	46.3%	19.4%	10.1%	21.8%
Third Ring	1.2%	1.7%	3.5%	45.9%	15.5%	10.3%
Fourth Ring	0.1%	0.1%	0.2%	1.2%	55.4%	1.5%
Millions of trips	1.99	3.56	3.39	1.99	0.23	11.16

[5] In 1994 and 2007, 46% and 45% of trips had a reported purpose of returning home.

Table 2.10 Non-home-bound trips by home location and destination (2007)

	Home location					
Destination location	Urban Center	First Ring	Second Ring	Third Ring	Fourth Ring	Total
Urban center	68.2%	30.9%	21.5%	16.5%	6.7%	27.3%
First ring	22.7%	56.7%	22.6%	15.7%	6.0%	30.0%
Second Ring	6.7%	9.2%	50.3%	18.1%	9.2%	22.9%
Third Ring	2.2%	3.1%	5.0%	47.6%	16.1%	15.6%
Fourth Ring	0.2%	0.2%	0.5%	2.0%	62.0%	4.2%
Millions of trips	1.32	3.55	3.41	3.08	0.66	12.01

This pattern is even more pronounced for work trips (Table 2.11 and Table 2.12). Forty percent of all work trips went to the four central boroughs of the Federal District in 1994. This decreased to 33% in 2007, although the total number of work trips to the urban center remained constant. In 2007, the center attracted three times more work trips than it generated. Figure 2.22 maps the percent of work trips with a destination in one of the four central boroughs. Despite heavy centralization, the likelihood of traveling to the center for work decreases with distance throughout the city and suburbs. There is, furthermore, no clear distinction between the wealthier western suburbs and the poorer eastern ones in terms of central work locations.

Table 2.11 Journey to work by home location and destination (1994)

	Home location					
Destination location	Urban Center	First Ring	Second Ring	Third Ring	Fourth Ring	Total
Urban center	66.8%	43.2%	34.0%	25.1%	13.3%	40.1%
First ring	22.4%	43.4%	26.0%	21.0%	9.8%	29.8%
Second Ring	9.1%	11.0%	35.7%	21.0%	9.2%	20.3%
Third Ring	1.6%	2.3%	4.0%	31.2%	19.4%	8.4%
Fourth Ring	0.1%	0.1%	0.3%	1.7%	48.3%	1.5%
Millions of trips	0.80	1.60	1.57	0.92	0.10	4.99

Table 2.12 Journey to work by home location and destination (2007)

	Home location					
Destination location	Urban Center	First Ring	Second Ring	Third Ring	Fourth Ring	Total
Urban center	65.0%	37.5%	28.7%	22.9%	9.2%	32.8%
First ring	22.9%	48.0%	24.1%	18.6%	7.0%	28.8%
Second Ring	9.1%	10.2%	40.5%	19.6%	12.5%	21.3%
Third Ring	2.8%	4.0%	6.2%	36.8%	20.6%	13.8%
Fourth Ring	0.2%	0.3%	0.6%	2.2%	50.7%	3.3%
Millions of trips	0.62	1.73	1.67	1.50	0.28	5.81

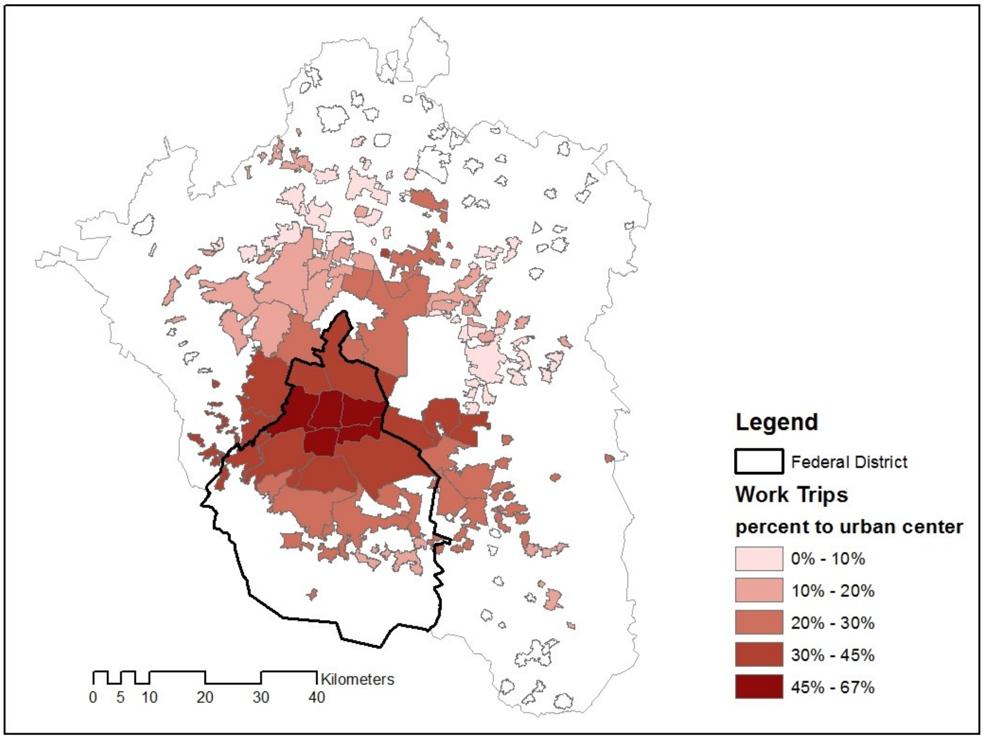

Figure 2.22 Percent of work trips with a destination in the urban center in 2007

These geographic differences help explain wealthier households' strong preference for the combination of central living and car ownership. In 2007, the average commute to work by car for someone in the urban center was less than two-thirds of the average public transit commute by someone in the State of Mexico (47 minutes compared to 73 minutes). For all trips, the trip durations are 33 minutes and 66 minutes. Given the average of 1.9 trips per day, that amounts to an hour of savings each day. Although central transit trips are shorter and faster in the center than in the periphery, they are still slower than car trips. Similarly car trips in the periphery take much longer than car trips in the center. People who put a high value on their time, due to wealth or preference, have a strong incentive to live in central locations and drive. People who do not, due to poverty or other circumstances, tend to get priced out of the best transit locations and live in less accessible areas of the city. This disconnect between transit infrastructure and transit riders helps drive the multimodal nature of transit use and is perhaps the defining feature of transportation and land use connection in Mexico City's suburbs. It helps explain the relationship between the built environment and car use (Chapter 3), the connection between commercial suburban housing developments and car ownership (Chapter 4), and the effects of suburban Metro investments (Chapter 5).

Chapter Three. The Built Environment and Car Use in Mexico City: Does the Relationship Change over Time?

3.1 Introduction

Despite a long and lively debate, something of a general consensus about the influence of the built environment on car use has emerged in the United States in recent years: small increases in density, land use diversity, and other quantifiable aspects of the built environment tend to contribute to statistically significant, but smaller decreases in households' propensity to own and use cars. However, most of our understanding of how the built environment influences individuals' travel decisions comes from cross-sectional studies in American or European cities. To what extent is this average relationship stable across places and over time? In particular, how does the relationship between the built environment and car use differ in the lower income, high-density, and transit-rich urban areas that characterize Mexico City and much of the developing world? As households become wealthier, how is the relationship likely to evolve?

3.2 The built environment and travel behavior

Much ink has been spilled over the influence of the built environment on travel behavior. Researchers, urbanists, and practitioners have long held that different aspects of the built environment, particularly dense concentrations of people and jobs, are essential to successful public transportation, high walking and bicycling rates, and lower car ownership and use. While academics have questioned the extent, nature, and even the direction of this relationship (Boarnet & Crane, 2001; Crane, 1996, 2000), something of a general consensus has emerged in the United States in recent years: marginal increases in density, land use diversity, and other quantifiable aspects of the built environment correspond with and likely cause statistically significant—but much less than proportional—marginal decreases in car travel (Boarnet, 2011; Brownstone, 2008; Ewing & Cervero, 2010; National Research Council, 2009). As Boarnet (2011, p. 208) puts it, "While the question of causality cannot be definitively answered with only cross-sectional data, the preponderance of evidence, theory, and common sense all argue that there is a causal relationship."

In this section, I briefly review the theoretical and empirical foundations of this consensus, in particular the role of a behavioral approach to understanding how individuals make travel decisions and appropriate econometric model specification. I then focus on why the average causal relationship between the built environment and travel behavior varies across geographies, why the relationship is likely stronger in developing-world cities and how it may change over time in rapidly evolving cities.

3.2.1 How the built environment influences travel

The built environment primarily influences travel behavior through its influence on the relative cost and availability of different travel alternatives for achieving day-to-day activities. For example, a traveler likely faces shorter distances, more congestion, higher car-insurance fees, greater difficulty finding parking, higher gasoline prices, better public transit, and a more pleasant walking environment in a dense, compact city than in a sparse and sprawling one. For a given activity, the traveler is likelier to choose to walk, bike, or take transit in a compact city than in a sprawling one. The relationship, however, is more complicated than this simplified example of mode choice for a specific trip. The built environment also influences trip frequency, time of travel, trip chaining activities, and even the type of person making the trip, the types of trips being made, and personal travel preferences. The built environment, furthermore, is something of a nebulous term. It encompasses land use, transportation infrastructure, open space, and even design features like tree plantings, block size, and building form. These various aspects of the built environment, moreover, are highly interrelated and statistically correlated with one another (Cervero & Kockelman, 1997; Ewing & Cervero, 2001).

Contemporary evaluations of the influence of the built environment on travel tend to focus on which aspects—particularly what scale—of the built environment influence which aspects of travel, how the influence occurs, and which research methods are most appropriate (Boarnet, 2011; Brownstone, 2008; Crane, 2000; Ewing & Cervero, 2010). In a review of early scholarship, Crane (2000) divides the literature into four categories based on methods and theory: (1) hypothetical simulations, (2) descriptive analyses, (3) *ad hoc* multivariate analyses, and (4) multivariate analyses based on economic theories of individual travel demand. The first, he dismisses for circular logic, "[t]he studies essentially ask: 'if a trip becomes shorter, will people travel as far? (p. 6)" Although he acknowledges the contributions of descriptive and *ad hoc* statistical models, he criticizes them for failing to explain individual behavior and thus missing important pathways of influence and potentially including spurious correlations (e.g., poorer American households drive less and also tend to live in denser areas). Finally, he advocates situating empirical analyses of the influence of land use on travel behavior within a robust theory of individual travel demand. As in other areas of empirical analysis of consumer choices, the rapid increase in computing power and the availability and reliability of individual-level data has made this shift possible (McFadden, 1974, 2001). Contemporary study of the influence of the built environment on travel behavior focuses almost entirely on individual or household choices. Individuals and households make travel decisions, not cities or Census Tracts; they are the correct ecological unit for analyzing behavior.

3.2.2 Toward a generally accepted model specification

Boarnet and Crane (2001) present three model specifications, based on individual behavior, for considering the influence of the built environment on travel behavior:

1) ***a* = *f* (L, y, s)**. That is, an individual's travel behavior is a function of the built environment, income, and socio-demographic factors.
2) ***a* = *f* (L, y, s, p)**. That is, an individual's travel behavior is a function of the built environment, income, socio-demographic factors, and the price of travel alternatives.
3) ***a* = *f* (y, s, p*)**; ***p* = *f* (L)**. That is, an individual's travel behavior is a function of income, socio-demographic factors, and the price of travel alternatives as estimated by exogenous built environment and other variables in a two-stage estimation procedure.

The authors argue for the third specification, since the built environment primarily influences travel behavior through its influence on relative travel prices (including time costs).

They furthermore argue that the specification corrects for the endogenous relationship between travel price and the chosen behavior.[6] The broad framework has conceptual appeal and has encouraged study into how the built environment influences travel behavior and what this says about public policy. For example, Chatman (2008) and Cervero and Murakami (2010), looking at individuals' non-work travel behavior in Northern California and a cross-section of vehicle miles traveled in 370 American urbanized areas respectively, conclude that increases in population density will have limited influence on travel behavior if public policy reduces congestion through road construction or other means.

Nevertheless, the third specification is problematic for at least two reasons. First and foremost, it demotes the built environment from the public policy of variable of interest (i.e., the treatment) to a statistical technique (i.e., the instrument) for removing endogeneity from some other treatment variable (in their example, price). A good instrument variable is of no policy interest on its own and is uncorrelated with the outcome except by means of some treatment that is of interest (Angrist & Pischke, 2008, Chapter 4; Cameron & Trivedi, 2005, Chapter 4.8). In a commonly cited paper on instrument variables, Angrist and Krueger (1990) use the quarter in which a child is born—a variable that is of no policy interest but is correlated with years of schooling due to compulsory school attendance requirements—to attempt to cleanly identify and estimate the influence of years of schooling on wages. Second, even if a researcher is strictly concerned with price as a policy variable, land use is not a particularly good instrument. While it fulfills the first property of a good instrument—it is clearly correlated with travel price—it almost certainly does not fulfill the second—that it only influence travel behavior through its influence on price. If built environment variables were, in fact, good instruments, then the reduced form equation (the first specification) would provide accurate, unbiased estimates of the influence of the built environment on travel behavior.

Analysts have generally not adopted the proposed two-stage approach (Boarnet, 2011). Instead, the previously-mentioned consensus has emerged from a body of empirics that, despite methodological differences, generally relies on a functional form that bears the closest resemblance to Boarnet and Crane's (2001) second specification. As such, results will generally produce measures of the built environment's influence on travel, independent of the travel time and cost variables that are also included, as Zegras (2004) notes in his study of the influence of urban form on household vehicle kilometers traveled (VKT) in Santiago de Chile. To avoid the potential endogeneity between choices and reported travel times and prices, analysts commonly use zone-to-zone estimates of time and price (Small & Verhoef, 2007, p. 21; Zegras, 2004).

Finally, no discussion of a generally accepted model specification is complete without reference to residential self-selection. In his review of the literature for the National Resource Council's (2009) Committee for the Study on the Relationships Among Development Patterns, Vehicle Miles Traveled, and Energy Consumption, Brownstone (2008, p. 2) dismisses the empirical findings of studies that do not control for it because, "The observed correlations between higher density and lower VMT may just be due to the fact that people who choose to live in higher density neighborhoods are also those that prefer lower VMT and more transit or

[6] Endogeneity occurs when a variable included in a model is correlated with the model's error term. Travel price is thought to be endogenous because the choice made influences the price that the person making the choice faces. Therefore omitted variables (such as personal preferences) that influence travel choice may bias and distort the estimated parameter for travel price.

non-motorized travel." In general, studies that have attempted to correct for residential self-selection have found that it has a relatively small (Mokhtarian & Cao, 2008) or statistically insignificant (Bhat & Guo, 2007; Brownstone & Golob, 2009) effect. Chatman (2009) also finds a small influence, but unlike other studies finds that residential self-selection may lead to underestimates of the influence of the built environment on travel as well as the much-discussed overestimates.

Based on a sample of studies, Brownstown (2008) and Brownstone and Golob (2009) conclude that including a rich set of household socio-demographic control variables appears to account for most, if not all, residential self-selection bias. The extent to which self-selection matters, moreover, depends on the extent to which households are able to locate to preferred locations. Levine (2006, Chapter 7) argues that zoning regulations restrict many households from living in denser locations and that self-selection is an important pathway through which changes in the built environment can affect travel behavior. Finally, the built environment also likely influences preferences which, in turn, influence residential selection (Weinberger & Goetzke, 2010). For example, a New Yorker who relies on and prefers transit moves to downtown Austin for a job, but finds that she now relies on and prefers a car more than she had expected. The next time that she moves, this newfound preference for driving is likely to influence the neighborhood that she selects.

3.2.3 Toward generally accepted empirical findings

Two general findings have emerged from the large body of literature on the built environment and travel. First, regional-scale measures of the built environment, such as job accessibility and distance to the downtown, have larger impacts on households' car use and mode choice decisions than neighborhood ones, like local population density (Boarnet, 2011; Ewing & Cervero, 2001, 2010; Handy, 1992). Second, uniformly increasing neighborhood population density or other measures of the built environmet is likely to have small aggregate influences on US car use. In a meta-analysis of empirical findings, Ewing and Cervero estimate an elasticity of vehicle miles traveled (VMT) with respect to neighborhood population density of -0.07. Brownstone and Golub (2009) find that a 40% increase in residential neighborhood densities in California correlate with a 4.8% reduction in VMT (implying an elasticity of around -0.12). Looking at household travel choices from 114 American metropolitan areas in 1990, Bento, Cropper, Mobarak, & Vinha (2005) found that individual measures of the built environment had VMT elasticities of under -0.10.

Despite similar empirical findings, conclusions have varied. Brownstown (2008) and Brownstone and Golob (2009), for example, conclude that reducing car use through changes in settlement patterns would require dramatic and unlikely changes in development practice that, even if implemented, would have little effect on travel or fuel consumption. By contrast, Ewing and Cervero (2010) and Bento et al. (2005) argue that, taken together, various aspects of the built environment have larger and more important influences on travel behavior and that the built environment has an important role to play in reducing the amount that Americans drive.

3.2.4 The influence of the built environment across places and over time

The influence of marginal changes in population density and other aspects of the built environment on VMT and other travel behavior outcomes almost certainly varies by place and by time. In this section, I consider why the influence of the built environment on travel behavior is likely stronger in developing-world cities than US cities. I compare this theory to empirical findings from both contexts and then consider how and why the magnitude of the influence may change over time in a rapidly evolving metropolis.

Above or below a certain threshold, the built environment is likely to have little or no effect on travel. Consider distance to the urban center, a common built-environment measure that is thought to influence whether someone drives. It is not physically possible to live closer to the urban center, than in it. Furthermore, beyond a certain distance, there is no reason to expect that distance from an urban center has much influence on travel behavior. Car travel is likely as easy and other forms of travel, likely as difficult, whether someone lives 50 miles or 100 miles from an urban center. More abstractly, if the built environment constrains no one from driving, no changes to the built environment can possibly make more people drive. Several studies have attempted to identify the minimum threshold for the built environment to influence travel behavior across neighborhoods and cities.

Looking at data from the 1990 and 1995 Nationwide Personal Transportation Surveys, Pickrell (1999) observes that reductions in household car use do not occur until zip code residential densities reach 15 people per gross hectare (4,000 per square mile) and do not decline with much significance until densities reach 29 people per gross hectare (7,500 per square mile). The data sample mean is below 8 people per hectare (2000 per square mile), well below the point where density begins to influence travel. In a cross-sectional study of 58 high income cities around the world, Newman and Kenworthy (2006) identify a similar threshold of 35 jobs and people per gross hectare (14 per acre). In Mexico City and most other developing-world metropolises, job and population densities are significantly higher than this minimum. Even the least dense neighborhoods of the far periphery had an average of 54 people per hectare, well above Pickrell or Newman and Kenworthy's minimum thresholds. This suggests that the influence of the built environment on travel may be significantly higher in the dense metropolitan areas of the developing world than sparsely settled US metropolitan areas.

The influence of the built environment, furthermore, depends on the relative desirability of travel options, independent of the built environment. According to a utility-based theory of individual travel behavior, the built environment—or any other determinant of travel behavior for that matter—ought to have the strongest impact when the relative utility of travel options is closest. For example, if a traveler is indifferent between driving a car or taking the bus, any small change in the cost or convenience of either mode will likely influence mode choice. By contrast, even significant changes to the cost or convenience of bus will be unlikely to influence the traveler's mode choice, if the time-savings and convenience of driving significantly outweighs the benefits of the bus. Barring some radical non-linear differences in a population—everyone above median income drives, everyone below takes the bus—the built environment is likely to have the strongest influence on aggregate mode choice where roughly the same proportion of individuals chooses each option. A policy designed to reduce driving will generally have a much larger effect in a city where 50% of households drive than a city where 90% or 10% of people drive. Again, this suggests that the influence of the built environment may be stronger in the developing-world than in the US, particularly as car use increases over time. It is unsurprising that uniformly increasing residential densities to discourage US car use on a national scale, where almost 85% of all trips are made by car (U.S. Department of Transportation, 2009), is expected to have only a small impact on behavior.

Although few empirical studies have looked at the influence of the built environment on travel behavior in the developing world and results are inconclusive, the built environment's influence on travel does appear to be somewhat stronger in denser, poorer cities. In a model of car ownership and use in Santiago de Chile, Zegras (2010) estimates that the collective influence of the built environment variables on car travel is around twice that estimated in Ewing and Cervero's (2010) meta-analysis. A doubling of residential densities, by contrast, correlates with a much lower 3.6% reduction in VKT. The model, however, also included a number of other neighborhood-scale variables such as land use diversity, intersection type, and the density of pedestrian plazas that are generally not included in models. Collectively, these generate a cumulative elasticity of around -0.10. Distance to the central business district (CBD) and to the city's subway have a much larger estimated impact. A halving of distances to both correlates with a 45% reduction in household VKT. Despite significant differences in density and travel behavior in the two cities, Zhang (2004) finds a similar marginal impact of neighborhood population density on the probability of driving to work in Boston and Hong Kong (elasticity of around -0.04). He finds a stronger influence on non-work car use in Hong Kong (elasticity of -0.11 compared to -0.04) and of job density for both work and non-work mode choice. The Boston model, however, includes additional built environment variables that are likely correlated with density, such as land use mix, distance to transit, and the percent of cul-de-sac intersections at origins and destinations, making a direct comparison difficult.

Several recent econometric analyses indicate that, in addition to being slightly stronger, the influence of the built environment on travel may be somewhat different in developing-world cities. In particular, there appears to be an inverse relationship between household vehicle ownership and suburban household location in several developing world metropolises, even after controlling for income and other demographic variables. Including a full set of socioeconomic controls, Shirgaokar (2012) finds that households that live outside of the central area in Mumbai, India tend to generate more VKT but are less likely to own vehicles. Srinivasan et al. (2007) do not look at VKT but similarly find that more peripheral households in Chennai, India are less likely than more central ones to own or use cars or two-wheelers. Looking at car ownership—again in Santiago de Chile—Zegras and Hannan (2012) produce similar model results.

With much denser built environments and fewer drivers, the built environment appears to exert a stronger influence on travel behavior than in most US cities. It is unclear, however, whether this influence is likely to increase or decrease over time in the rapidly changing cities of the developing world. On the one hand, as the metropolis expands, more residents tend to live in less dense neighborhoods of the periphery. On the other hand, rising incomes and car use may strengthen the constraining influence of the built environment, since more people are competing for scares road space and parking. Since nearly all studies of individual travel behavior provide only a single cross-sectional snapshot, there is little in the way of existing findings to support an increase or decrease of the influence of the built environment. In a rare exception, Zegras and Hannan (2012) model car ownership in Santiago de Chile in 1991 and 2001. They find notable changes in household behavior over the period and estimate that the influence of neighborhood population density on ownership doubled over the time-period while the influence of land use diversity decreased significantly. The effect of proximity to the subway went from having a statistically insignificant effect in 1991 to decreasing the probability of car ownership in 2001. While the modeling structure does not allow for direct comparison of the parameter estimates—they reject the hypothesis that preferences have remained stable but do not normalize parameter estimates across the two years—it is nevertheless clear that the estimated influence of the built environment on car ownership changed significantly in the span of just ten years.

Identifying differences in the magnitude of relationship between the built environment and travel behavior over time and across places is a promising avenue for future empirical study. Absolute differences in the built environment and relative differences in the utility of available travel options are likely to produce some cities and neighborhoods where changes to the built environment can have significant behavioral impacts on travel and others where the impacts will be negligible. National, state or local policies that attempt to influence travel through uniform changes in the built environment are less likely to bear fruit than policies targeted to cities and neighborhoods where individuals are most likely to respond.

3.3 Land use and transportation in Mexico City

US cities look quite different from much of the world, particularly the developing world where most cities, towns, and rural areas are significantly denser and more compact and most households are poorer and own and use fewer cars. Given the comparison with findings from US cities, it is important to acknowledge some key similarities and differences related to the built environment and travel behavior in Mexico City or other cities in Latin America, Africa, and Asia. Below, I provide summary statistics about land use and car ownership by income group and geographic location (Table 3.1 and Table 3.2)[7].

Car ownership rates, although much lower than in any US metropolis, increase systematically with income. Household incomes are also much lower. Unlike in many US metropolises, the wealthiest households tend to choose housing in central locations with marginally lower population densities and greater access to jobs and amenities. The lowest income households are more likely to live in peripheral locations. Collectively, these decisions have led to wealthier central districts with denser concentrations of jobs and people and higher car ownership rates and poorer peripheral ones with lower densities and car ownership.

Table 3.1 Land use and car ownership by income quintile in 2007

Income Quintile	Poorest	Second	Third	Fourth	Richest
Estimated average monthly income in 2007 dollars	$206	$381	$603	$943	$2,511
Percent of households with a car	22%	27%	39%	52%	73%
Average cars per household	0.25	0.30	0.45	0.63	1.11
Average distance to downtown in kilometers	19.4	20.6	18.8	18.1	16.9
Average people per hectare	169	165	170	172	154
Average jobs per hectare	28	26	31	32	39

[7] For a map and definition of the urban center and four urban rings, see Appendix A, the previous chapter, or Suárez Lastra and Delgado Campos (2007a).

Table 3.2 Land use and car ownership by geographic location in 2007

Urban Ring	Center	First	Second	Third	Fourth
Estimated average monthly income in 2007 US dollars	$1,237	$955	$877	$813	$689
Average distance to downtown in kilometers	5.4	12.1	17.6	27.2	39.5
Percent of households with a car	47%	44%	43%	40%	40%
Average cars per household	0.63	0.57	0.57	0.51	0.49
Average people per hectare	189	204	172	132	53
Average jobs per hectare	123	34	20	11	5

With 20 million residents, Mexico City is best compared to New York (population, 19 million) and Los Angeles (population, 18 million) in terms of US metropolitan areas. Despite the many differences between the New York and Los Angeles regions in terms of urban form (see Eidlin (2005) for a discussion) Mexico City has a higher concentration of jobs in central locations and a far denser and flatter population distribution than either. Two-thirds of all residents live in neighborhoods with densities between 100 and 300 people per gross hectare (40 and 120 per gross acre). Many of the densest of these neighborhoods are in peripheral locations, despite the lower average densities of the most peripheral (Figure 3.1). With large segments of the population living in dense, lower income, suburban neighborhoods, Mexico City is far more reliant on public transportation than any US metropolis. Two thirds of vehicular trips in 2007 used some form of public transit (INEGI, 2007a). Over half of all trips involved at least one leg on a privately operated minibus, a form of transportation which serves only niche populations and geographies in the US.

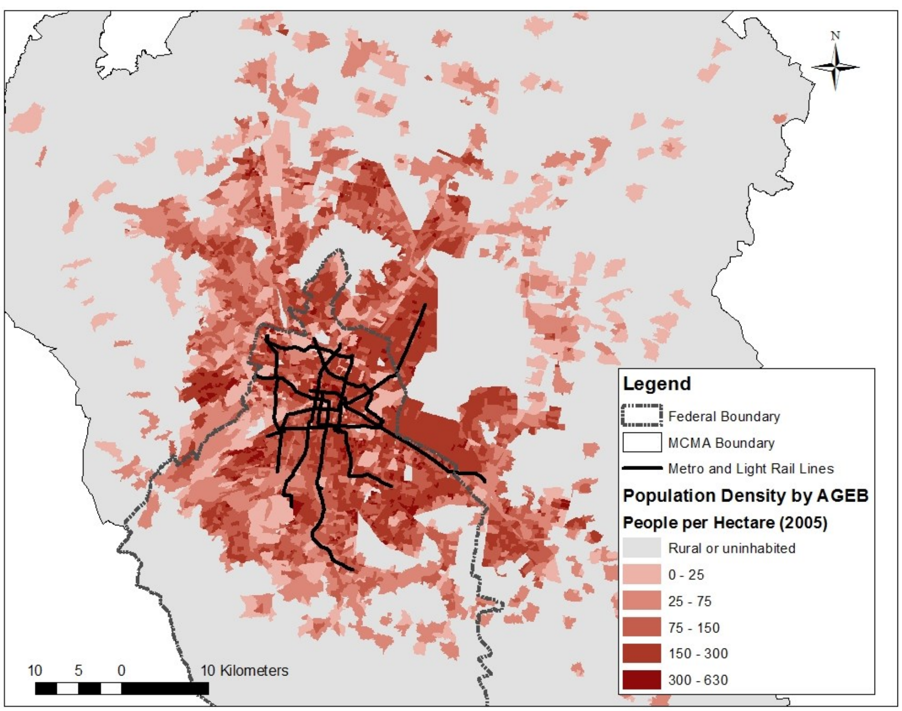

Figure 3.1 Population per hectare by AGEB in 2005, Mexico City Metropolitan Area

3.4 Data and model specification

In this study, I rely primarily on data from two metropolitan-area household travel surveys conducted in 1994 and 2007. The surveys contain information on approximately one percent of all households, household members, and their vehicular travel on an average weekday in the Mexico City Metropolitan Area.[8] Both surveys provide geographic location codes for household location, origin, and destination to the AGEB (*Área Geográfico Estadística Básica*)—roughly the equivalent of a US Census Tract—and survey expansion factors, which estimate the proportion of the total number of households and trips that each sample household and trip represents. For additional survey documentation, see INEGI (2007b). I combined these data with transportation infrastructure and Census shapefiles from the National Statistics and Geography Agency (INEGI) and the Secretary of Transportation and Highways (SETRAVI).

3.4.1 Descriptive statistics

Table 3.3 provides the sample means and standard deviations of the travel, socioeconomic, built environment, and travel time variables used in this chapter's models. Unfortunately, I was only able to obtain partial results from the 1994 travel survey. Specifically, the dataset included information on all household members who took a vehicular trip on the survey date, but nothing on household members, who did not. Due to this limitation, I calculated household-level statistics from the available information on individuals who took trips during the survey day for both 1994 and 2007 and used these in the statistical models. This led to an underestimate of several household-level variables such as the number of people, children, and workers per household. For example, the average number of household members who took vehicular trips in 2007 was approximately one half the reported total household size. Children between 6 and 10 were even less likely to travel; only about a seventh of those recorded in the 2007 household survey were reported to have taken vehicular trips. The income of travelling household members, by contrast, was less biased (on average 15% lower), since most income-earning household members took trips on the survey day. This data limitation also biased the overall sample. Approximately 15% of the households in 2007 reported not taking any vehicular trips. These households, on average, were poorer and owned fewer cars.

Of the households that reported any trips, the proportion reporting at least one car trip increased five percent from 32% to 34% between 1994 and 2007. The number of car trips and average VKT per household increased more substantially (by 16.8% and 18.5% respectively). I did not have data on household-level car ownership in 1994, but aggregate car-ownership rates grew from 37% to 43%. The number and composition of household members taking vehicular trips appears to have remained fairly stable across the two samples. Slightly more non-worker household members reported taking trips in 2007 than in 1994.

Two income estimates were available for 2007: a survey-provided estimate of total household income and my calculation made by summing all travelers reported income by household. Only the latter was available in 1994. The consistent traveler-based estimate indicates that inflation-adjusted household income shrank by 15% across the two time periods. The inconsistent estimate reports stable household income. It is unclear, however, how much this

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[8] No information was provided for pedestrian trips.

reflects different reporting standards across the two years or changing household income. Nearly twenty percent of households reported no income for any travelers in 2007, compared with no households in 1994. For consistency across the two years, I used the traveler-based measure of income across the two years in my statistical models. These tended to produce better model fits than the survey-provided estimates of household income in 2007. The National Household Survey of Income and Expenditures (2011c) confirms a national decline in household income between 1994 and 2007, but only of 5%. Connolly (1999), using the same survey for 1977 and 1992, found that household income declined by 18% in the Mexico City Metropolitan Area, compared to 2% for the nation as a whole. Nationally, although inflation-adjusted GDP per capita increased by 21% between 1994 and 2007, adjusted for purchasing power parity, GDP per household declined (World Bank, 2012).

In terms of geography and the built environment, a greater share of the sample lived in more distant and less dense neighborhoods in 2007 than 1994. Distance to the Zócalo is the road-network distance to the central Zócalo, the historical, geographical, social, and political center of Mexico City. The four central boroughs surrounding the Zócalo accounted for half of the MCMA's Gross Census Value Added, a measure of economic output, and 34% of metropolitan jobs in 2008 (INEGI, 2012a). A decrease in density in the urban center and a substantial increase in the proportion of the sample in the fourth urban ring, which has been growing rapidly for the past two decades, drive the aggregate changes in neighborhood population density and distance to the downtown. Density measures exclude large open spaces and terrain features but not local streets, parks, or plazas from the land area. Between the two time periods, gross densities in the third urban ring increased from 98 to 124 people per hectare, despite the aggregate decrease. Jobs per hectare in households' municipality of residence also decreased slightly from 35 to 34 per hectare. The percent of the sample living near subway or light rail stations decreased while the percent living near major highways increased. The average duration of car trips—a measure or car accessibility—increased fourteen percent from 36 to 42 minutes. This is likely due to growing congestion and longer distances traveled. Despite the increase, cars offered an average 30% speed advantage over other modes of transportation in Mexico City in 2007. For additional information on data sources and calculations, refer to Appendix B.

3.4.2 Model forms and specifications

I estimate models for three distinct types of household car use: whether a household drives at all, how many vehicle kilometers a household generates, and how many VKT households that drove on the survey day generate. Socioeconomics and the built environment influence these choices differently. For example, wealth tends to increase the probability that a household generates any VKT, but may have a smaller influence on total VKT, since wealthy households are better able to locate close to their jobs and other destinations. Similarly, if density makes parking more difficult, density may have a bigger influence on whether a household drives than how much it drives.

The discrete choice of whether a household generates any car trips is a particularly important one. Nearly two-thirds of trip-making households did not produce any VKT in 1994 or 2007. While this is less common than examining the influence of the built environment on car-ownership (see (Bhat & Guo, 2007; Kitamura, 1989; Zegras & Hannan, 2012)), it has advantages. Car travel, not ownership, creates most of the car's social costs such as congested city streets, traffic fatalities and injuries, inequality of physical access to opportunities and services, and local and global pollution. Furthermore, some households that do not own cars have members who rely on private cars, while many who own cars do not use them every day.

Table 3.3 Sample data descriptive statistics: dependent, policy, and control variables

	1994 Trips Data		2007 Trips Data		2007 Household Data	
	Mean	**sd**	**Mean**	**sd**	**Mean**	**sd**
Trip Variables						
Household owns car	-	-	-	-	0.445**	0.50
Household generates car trips	0.32	0.47	0.34	0.47	-	-
Number of car trips	1.22	2.50	1.43	2.78	-	-
Vehicle Kilometers Traveled	10.4	22.9	12.0	26.5	-	-
Socioeconomic Variables						
Estimated average monthly income in 2007 pesos	10,599	12,123	9,061*	19,245	10,574	18,890
Household size	2.21	1.310	2.23	1.24	4.07	1.78
Workers in household	1.42	0.82	1.38	0.90	1.72	1.03
One or two-worker household	0.87	0.34	0.79	0.41	-	-
Three-or-more-worker household	0.10	0.29	0.10	0.30	-	-
Number of children in household (Age 6 to 10)	0.08	0.33	0.10	0.35	0.73	0.96
Mean traveler age	33.6	10.6	36.2	12.6	-	-
Built Environment Measures of Household's Neighborhood						
Population per hectare in AGEB	180	101	168	91	-	-
Jobs per hectare in municipality	35	47	34	41	-	-
Kilometers to Zócalo	15.5	8.6	17.6	10.1	-	-
Within a kilometer of a major highway	0.34	0.48	0.35	0.48	-	-
Within a half kilometer of transit	0.05	0.22	0.05	0.21	-	-
Accessibility Variables						
Average home-based travel time by car (minutes)	36.5	6.0	42.4	6.6	-	-
Number of observations	22,950	-	39,185	-	39,185	-

*Number of observations is 31,827 **Number of observations is 39,061. The difference with the previously mentioned aggregate car-ownership figure (43%) is accounted for by the survey expansion factor.

Table 3.4 compares the relationship between car-ownership and whether and how many VKT a household generated in 2007. Only 61% of households that owned a single car reported using it on the day of the survey. This is likely at least partially a result of the metropolitan area's *Hoy No Circula* law, which prohibits cars from operating one weekday per week based on license plate numbers. Stiff penalties also discourage drivers from using any vehicles which have not passed semiannual emissions tests.

The discrete decision of whether to drive either precedes or coincides with the more continuous choice of how much to drive on an average weekday. To assess underlying socioeconomic and environmental factors that influence this choice, I used the Biogeme software package (Bierlaire, 2003, 2009) to estimate a binomial logit model. For a description of the model form and estimation procedures, see Ben-Akiva and Lerman (1985, Chapter 4). In order to evaluate changes across the two time periods, I pooled the 1994 and 2007 datasets, and performed likelihood ratio tests to establish whether the models could be combined and whether separate parameter estimates for predictor variables improve the model fit or provide significantly different results. Since the dependent variable of a discrete choice model is utility and utility has no absolute value, the size of parameter estimates increases with the variance of the error terms over the two time periods. To correct for these scalar differences, it is necessary to estimate an additional parameter that rescales the parameter for one of the model years. Ben-Akiva et al. (1994) describe early work, challenges, and benefit of combining datasets. Train (2009, Chapter 3.2) describes the estimation procedures. Without correcting for scale, the parameter estimates from the two years are not directly comparable.

Table 3.4 Average daily car trips and VKT per household by number of cars in 2007

Number of cars	Generates car trips	Number of car trips	VKT	Percent of households in sample
0	0.07	0.18	1.1	54.3
1	0.61	2.30	11.5	34.2
2	0.87	4.95	22.4	8.9
3 or more	0.94	6.67	27.1	2.6

In addition to this discrete choice, I also model how the built environment and socio-economic factors influence how much each household drives. Since most households do not generate any VKT, ordinary least squares (OLS) regression produces biased estimates of behavior. In particular, it will tend to undervalue the influence of variables that have a strong influence on the choice not to drive at all. To avoid this bias, I estimate standard censored Tobit regression models—with left censoring at zero—for 1994 and 2007. The Tobit model jointly estimates the probability that a household drives and the estimated VKT, given that it produces any. For a complete description of modeling procedures and estimation, see Wooldridge (2010, Chapter 16).

Finally, to help disentangle the relative influence of the built environment and other variables on whether and how much to drive, I estimate OLS regressions of household VKT for the one-third of households that drove in 1994 and 2007. Both the Tobit and OLS regression models were estimated using Stata, version 11.

3.5 Model results

In general, the influence of the built environment on car use has increased over time, although not exclusively. Most of the built environment's influence on VKT occurs through its influence on the discrete choice of whether to drive, rather than the continuous choice of how much to drive. For the subset of driving households, the built environment exerts a much smaller influence. Distance to the city center tends to decrease the probability of driving at all but increase the amount that households drive. Over time, however, the distance to the city center appears to have a decreasing effect on the probability of driving and an increasing effect on the amount driven.

3.5.1 Discrete choice of whether households generate any VKT

Table 3.5 presents the results of four discrete choice models of whether a household generates any VKT. The first two models use the data from 1994 and 2007 respectively. As previously mentioned, however, the parameter estimates are not directly comparable. Nevertheless, there are some clear differences across the two years in terms of which variables are statistically significant and the relative weights of individual parameter estimates. In the third model, I pool the data and introduce a scale parameter for 1994, but constrain all parameter estimates to be equal across the two time periods. The scale is statistically significant and greater than one, indicating greater variation in the error term in 1994. This suggests more variation in unobserved attributes, such as personal preference, or possibly less reliable data.

However, a chi-squared likelihood ratio test of the log likelihoods from the two separate models against the pooled data model indicates with greater than 99.99% confidence that preferences have not remained stable over time and not all parameter estimates should be constrained to be equal. To arrive at the fourth model, I systematically relaxed the equality constraint for each parameter estimate across years and tested whether the unconstrained model outperformed the constrained one. This final model has six unconstrained and five constrained parameters. A likelihood ratio test against the first two models fails to reject the null hypothesis that the models should not be combined and indicates that the data can, indeed, be pooled. The final scale parameter again indicates that the variance in the 1994 error term is systematically larger than in 2007.

Across the two time periods, the influence of population and job density on car use increases, while that of distance to the Zócalo decreases. Gross population and job densities appear to be increasingly important disincentives to driving. Across both survey years, the further households live from the center of the city, the less likely they are to drive, even after accounting for income. This relationship is the opposite of what is found in US cities and I will discuss this finding further in section 3.6. Other relationships move in the generally expected direction. Households within a kilometer of a major highway are more likely to drive, while those within a half-kilometer of a Metro or light rail station are less likely to drive. This influence is not statistically different between the two time periods. Using the methodology described in Guerra, Cervero, and Tischler (2012), I tested multiple catchment areas before settling on the preferred distance measure. With the preferred distances included, neither the relationship between living within one and two kilometers of a highway nor a half and whole kilometer from a transit station has a statistically significant influence on whether a household chose to drive in 1994 or 2007.

Table 3.5 Binomial logit models predicting whether households generate car trips

	1994 Model		2007 Model		Joint Fixed		Joint Flexible	
	Par.	T-test	Par.	T-test	Par.	T-test	Par.	T-test
Population per hundred square meters (1994)	-0.16	-8.06	-	-	-0.12	-11.64	-0.12	-7.73
Population per hundred square meters (2007)	-	-	-0.15	-8.99	"	"	-0.15	-9.03
Jobs per hundred square meters (1994)	-0.14	-3.30	-	-	-0.08	-3.53	-0.11	-3.4
Jobs per hundred square meters (2007)	-	-	-0.20	-4.41	"	"	-0.20	-4.48
Log of household income	**1.59**	**52.22**	**1.18**	**47.15**	**1.12**	**55.66**	**1.18**	**47.98**
Kilometers to Zocalo (1994)	-27.70	-9.35	-	-	-13.60	-10.00	-20.40	-8.95
Kilometers to Zocalo (2007)	-	-	-10.40	-5.68	"	"	-10.50	-5.71
Within a kilometer of a major highway	**0.17**	**4.94**	**0.11**	**3.80**	**0.11**	**6.11**	**0.12**	**6.21**
Within half kilometer of a Metro station	**-0.30**	**-3.93**	**-0.20**	**-2.97**	**-0.21**	**-4.87**	**-0.22**	**-4.92**
Average home-based travel time by car (1994)	-1.22	-6.18	-	-	-0.70	-8.11	-0.90	-6.01
Average home-based travel time by car (2007)	-	-	-1.39	-9.18	"	"	-1.40	-9.26
Household size (1994)	0.07	4.19	-	-	0.10	10.25	0.05	4.65
Household size (2007)	-	-	0.17	11.47	"	"	0.17	12.77
Mean age of household members	**0.06**	**7.06**	**0.04**	**5.81**	**0.05**	**10.22**	**0.04**	**9.08**
Mean age of household members (squared)	**-0.66**	**-5.95**	**-0.37**	**-4.95**	**-0.46**	**-8.67**	**-0.42**	**-7.71**
Number of children in household (1994)	0.40	7.27	-	-	0.37	12.53	0.29	7.32
Number of children in household (2007)	-	-	0.40	9.27	"	"	0.41	9.91
Number of workers in household	**-0.47**	**-17.37**	**-0.35**	**-16.23**	**-0.33**	**-22.63**	**-0.35**	**-22.18**
Car trip constant (1994)	-14.50	-42.63	-	-	-10.50	-48.00	-10.6	-43.69
Car trip constant (2007)	-	-	-10.40	-38.89	"	"	-10.5	-40.02
1994 Scale	-	-	-	-	1.44	14.85	1.35	9.49
Observations	22,950		31,827		54,777		54,777	
Adjusted rho square	0.276		0.218		0.240		0.242	
Final log likelihood	-11,506		-17,236		-28,854		-28,743	

*Indicates that a variable is not statistically different from zero at the 95% confidence interval. Built environment variables refer to the household's home location
All T-statistics are robust. Bold text indicates that the parameter estimates are constrained to be equal in the final model.

Between 1994 and 2007, both the average duration of car trips and its influence on car travel increased. Households appear to have become more sensitive to car accessibility over time. I also estimated models using the ratio of car travel to other modes of travel. The findings were similar but did not fit the observed patterns of behavior as well.

The number of workers and the average age of households continue to have a similar effect in 2007 as in 1994, while the number of children and total household size appear to exert a somewhat different effect. As expected, more household members and more children tend to lead to a higher probability of generating car trips. Perhaps surprisingly, the probability of driving decreases with the number of workers. Results, however, should be approached with caution. Household size, for example, measures the number of household members who took a vehicle trip on the day of the survey, not the actual household size. As mentioned in the data section, household composition figures are proxies, rather than actual measures.

3.5.2 Household VKT generation

Table 3.5 compares the results of the Tobit models of households' VKT generation and the OLS models of VKT generation for the one-third of households who actually drove. Standard errors are clustered by home neighborhood to account for unobserved neighborhood-level correlations. Since the Tobit regressions capture the joint influence of the probability of driving and how much to drive, they provide more reliable estimations of how changes in policy or demographics will likely influence VKT. The OLS models, despite only reflecting the behavior of a third of the population, give insight into how the built environment affects drivers differently from non-drivers on a given weekday and how behavior may change as more households drive.

In Mexico City, most of the influence of the built environment on VKT occurs through the discrete choice of whether or not to drive. Once members of a household already drive on a given weekday, population density, proximity to transit and the highway, have little to no statistical impact on how much they drive. By contrast, distance from the city center exerts a similar influence on VKT for driving households as that found in US cities: driving households on the periphery tend to drive more than more central driving households. Figure 3.2 and Figure 3.3 demonstrate this phenomenon spatially with maps of the percent of households in a municipality that drove at all on a given weekday and the average VKT of households that drove. By 2007, the influence of household location on whether and how much a household drives (the Tobit regression) result in a statistical wash: peripheral households are less likely to drive but, when they do, they drive more. The car accessibility measure similarly flips signs across the Tobit and OLS regressions. Once a household already generates VKT, it tends to generate the most VKT in the least car-accessible areas.

As with the built environment, household composition appears to exert a smaller influence on VKT for households that choose to drive. Income, in particular, exerts a much larger influence on whether a household drives than how much they drive. The sample of driving households, however, is different from the total sample of households and likely has different preferences. Specifically, they prefer driving. It is unsurprising that the households that choose to drive should be less sensitive to household composition, income, or the built environment. Nevertheless, the influence of job and population density on driving is increasing over time, while the influence of distance from the center is decreasing.

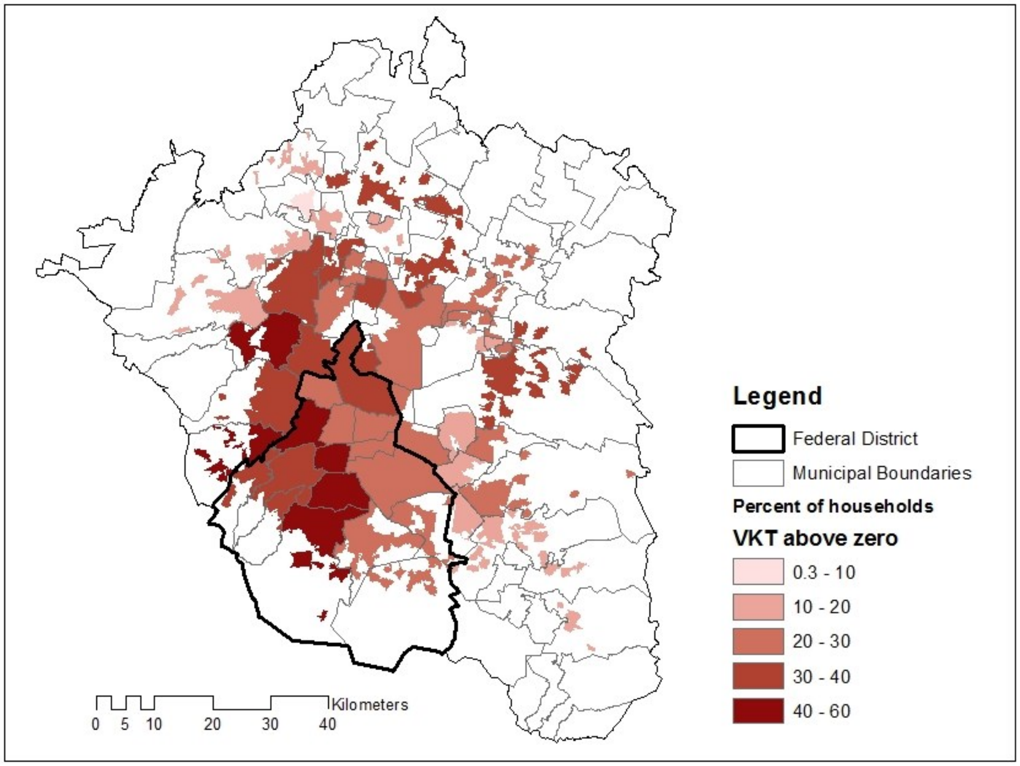

Figure 3.2 Percent of households that generated VKT in 2007

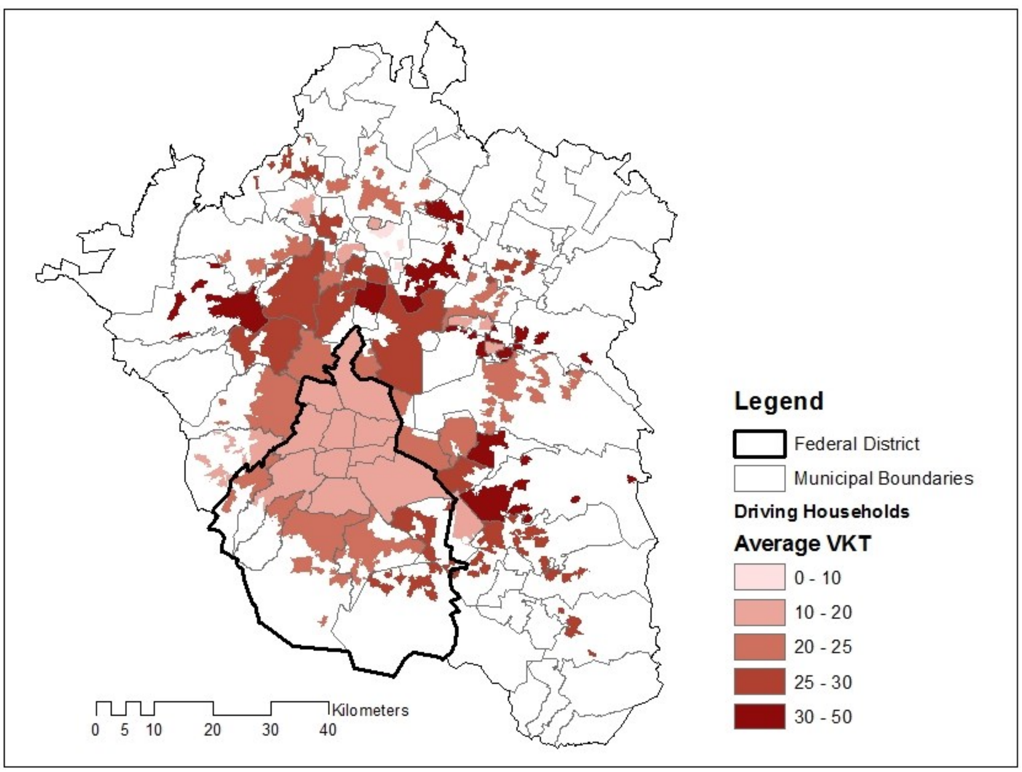

Figure 3.3 Average daily VKT per driving household in 2007

Table 3.5 Tobit and OLS regression models predicting household VKT (for all households and subset of non-zero-VKT households)

	Tobit regression of VKT of all households		OLS regression of VKT of driving households only	
	1994	2007	1994	2007
Population per hundred square meters	-1.41***	-2.08***	-0.056	-0.027
	(-4.60)	(-5.73)	(-0.24)	(-0.09)
Jobs per hundred square meters	-2.58***	-3.90***	-0.889	-0.330
	(-4.31)	(-4.62)	(-1.91)	(-0.48)
Log of household income	19.89***	18.92***	4.487***	4.715***
	(37.22)	(38.74)	(12.59)	(14.20)
Kilometers to Zócalo	-0.149**	0.00616	0.432***	0.381***
	(-2.83)	(0.15)	(8.63)	(9.52)
Within a kilometer of a major highway	2.608***	2.220***	0.499	0.687
	(4.74)	(3.68)	(1.06)	(1.28)
Within half kilometer of Metro station	-3.439**	-2.721*	-0.316	-0.365
	(-3.22)	(-2.25)	(-0.48)	(-0.43)
Average home-based travel time by car	-0.123*	-0.209***	0.286***	0.327***
	(-1.99)	(-3.71)	(4.40)	(5.42)
Household size	2.789***	5.030***	3.329***	4.164***
	(10.51)	(17.35)	(12.52)	(15.09)
Mean age of household members	0.794***	0.632***	0.0119	0.0583
	(6.16)	(5.55)	(0.10)	(0.56)
Mean age of household members (squared and divided by 1000)	-8.14***	-5.89***	0.121	0.0627
	(-5.17)	(-4.62)	(0.09)	(0.06)
Number of children in household	6.032***	8.844***	2.470**	4.801***
	(7.03)	(9.42)	(2.79)	(4.61)
Number of workers in household	-5.314***	-5.104***	-0.400	-0.684
	(-10.36)	(-12.49)	(-0.54)	(-1.60)
Trip taken outside of MCMA control	-16.98***	-3.310***	-5.299	-0.48
	(-5.26)	(-3.76)	(-1.74)	(-0.62)
Constant	-199.2***	-190.0***	-48.41***	-54.56***
	(-30.20)	(-31.15)	(-10.47)	(-11.92)
Sigma	26.18***	33.05***	-	-
	(35.95)	(50.31)	-	-
Observations	22,950	31,827	7,326	10,163
Left-Censored Observations	15,624	21,664	-	-
Pseudo R-sq	0.0635	0.0466	-	-
Adj. R-sq	-	-	0.131	0.147

Robust clustered t statistics in parentheses

* p<0.05, ** p<0.01, *** p<0.001

The final reported variable, a dummy control to indicate whether a household took any trips out of the MCMA has the expected sign. The distance of these trips are unknown and thus do not contribute to the measure of household VKT.

3.5.3 Model limitations

Four limitations may influence the reported findings. Where possible, I tested whether these limitations were likely to influence model results and found that they did not. First, the data sample excludes households that did not take any vehicular trips on the survey day. As discussed earlier, 15% of all surveyed households did not take a vehicular trip on the day of the 2007 survey. These one in six households either took only pedestrian trips, took no trips, or failed to report vehicular trips. Presumably, the 1994 sample excludes a similar, though perhaps slightly larger, portion. Since the built environment likely affects whether households take any vehicular trips, parameter estimates are almost certainly biased toward the behavior of trip takers. This would tend to lead to small underestimates of the influence of the built environment on travel since dense built environments likely encourage pedestrian trips. Testing this across 2007 models that excluded and included non-trip-taking households, I found that parameter estimates were slightly smaller, but elasticity estimates were larger, due to the higher proportion of non-driving households in the sample.

Second, missing data also required the use of proxies for household attributes, such as the number of children or composition of workers. Unless the unobserved household attributes are also correlated with other attributes, the omission should not influence other parameter estimates. Alternating between the proxy variables and the actual household attributes in the 2007 models, where both were available, I found no indication of statistically significant bias.

Third, I find some indication that data quality, particularly reported income, varies across surveys. Since income is almost certainly correlated with household composition and where a household chooses to live, poorly reported income may cause some of the differences between the two models. Modeling car use with both sources of income from the 2007 survey did not change any parameter estimates, other than the influence of income, by more than two standard errors. What changes did occur, furthermore, did not move in any systematic direction across (i.e., in the 2007 discrete choice model, the influence of population density became stronger, while the influence of job density became weaker).

Fourth and finally, the models do not correct for residential self-selection. While this is an undeniable limitation, previous studies have tended to find small or insignificant influence of residential self-selection when they include a rich set of socio-economic variables. Furthermore, accurately correcting for residential self-selection by either structural equation modeling (see (Bhat & Guo, 2007; Brownstone & Golob, 2009)) or instrument variables (see (Boarnet & Sarmiento, 1998; Zhou & Kockelman, 2008)) requires the data and error term to conform to a set of difficult to fulfill properties. The assumption that these properties have been fulfilled is no less problematic than the assumption that residential self-selection does not bias the parameter estimates. No instrument variable is preferable to a bad instrument variable.

3.6 Influence of the built environment on travel behavior across places and over time

Four trends emerge from the series of models presented in the previous section. First, the constraining influence of population density, job density, and congestion is, in general, a bit stronger than in the US and strengthening over time. Unlike in US studies, however, the influence of job density is much weaker than that of population density. This is likely a result of the high concentration of jobs in the center, where households are likelier to own and use cars. Second, the influence of geographic location is changing as more households drive and drive longer distances. Third, most of the influence of the built environment on VKT occurs through its influence on whether to drive at all, rather than on how much to drive. Finally, as more households drive, the influence of the built environment on total VKT may decline.

In this section, I look at how elasticity estimates compare across the models and are changing over time. I also discuss why this may be happening and the likely implications for public policy and future travel behavior in Mexico City. Table 3.6 presents the elasticity estimates—the proportional changes in behavior expected from a marginal change in the dependent variables—of the relationship between five built environment variables and the different measures of car use. For the discrete choice models, I use the non-pooled estimations (Models 1 and 2 from Table 3.5) and estimate elasticities by sample enumeration (Moshe Ben-Akiva & Lerman, 1985, Chapter 6). This produces smaller elasticities than looking at the behavioral responses of the average individual.

Tobit and OLS elasticities are estimated based on changes for the average traveler, which is equivalent to sample enumeration for linear models. Despite measuring different aspects of the same behavior, car use, elasticities differ significantly across the discrete choice, Tobit, and OLS models. Of note, local built environment variables have a much stronger influence on whether households drive than how much they drive. For example, the influence of neighborhood population density on the discrete choice of whether to drive is nearly four times stronger than the joint influence on whether and how much to drive. The discrete choice elasticities are just above the common range from US studies (-0.05 to -0.12), while the Tobit elasticities are just below the range. Similarly, proximity to transit and the highway has a stronger influence on whether a household drives than how much it drives. For households that do drive, the distance to the downtown is the only built environment variable that has a statistically significant influence on VKT generation.

Table 3.6 Elasticities with respect to whether a household generated car trips and how much they drove in 1994 and 2007

	Drove at all		Total VKT		VKT of subset of driving households	
Variable	1994	2007	1994	2007	1994	2007
Population Density	-0.138	-0.139	-0.040	-0.044	-0.005	-0.002
Job Density	-0.027	-0.034	-0.014	-0.016	-0.021	-0.006
Distance to Zocalo	-0.207	-0.110	-0.036	0.001	0.329	0.304
Within a kilometer of a major highway	0.032	0.021	0.014	0.010	0.011	0.012
Within half kilometer of Metro station	-0.009	-0.004	-0.003	-0.001	-0.001	-0.001

A grey highlight indicates that the estimated variable was not statistically different from zero with 95% confidence.

This influence, however, runs in a different direction from the discrete choice models. When peripheral households in Mexico City do drive, they drive more than central ones. Yet peripheral households in Mexico City are less likely to drive after accounting for income, local population densities, and other measures than more central households. This corroborates similar findings about the influence of geographic location on vehicle ownership in Chennai (Srinivasan et al., 2007) and Mumbai, India (Shirgaokar, 2012) and Santiago de Chile (Zegras & Hannan, 2012). The most likely explanation is that households that favor car use put a high value on accessibility and travel time. As a result, these households also prefer to locate in the most central locations, which have the best accessibility. Households in the periphery, moreover, tend to travel longer distances, which may make car travel prohibitively expensive. In relative terms, there is no cost difference between choosing driving over transit for a ten- or twenty-kilometer trip, if car trips are twice as expensive as a transit trip. In absolute terms, however, the difference between the car trip and the transit trip is two times larger for the longer journey.

Differences in suburban environments also help to explain this behavioral difference. An American household that lives far from downtown tends to face long trips, free parking, uncongested streets, and extremely poor, if even extant, public transportation. While suburban households in Mexico City also tend to have to take longer trips, these trips take place on highly congested streets where frequent, relatively inexpensive public transportation is available. They also have many closer destinations for non-work travel. Flexible and lightly enforced land use regulations allow local shops and businesses to be extremely demand-responsive. Most daily needs are within walking distance of most households in Mexico City's dense suburban neighborhoods. With the exception of longer average trips, most of the environmental features of distant US neighborhoods do not hold in Mexico City or most of the developing world.

3.7 Conclusion

This study confirms findings that the built environment influences whether and how much people drive. It also contributes to a growing body of literature that suggests that this relationship may be stronger and, in some respects, quite different in developing-world cities than the US. As more households drive, however, the relationship may move in the direction of findings from US cities since the built environment appears to exert only a limited influence on how much VKT household members generate once they drive.

In addition to supporting common planning practices such as improving transit access, limiting highway expansion, and increasing or maintaining local densities, the findings have less commonly referenced implications for policy makers concerned with slowing the increase in car use and its associated externalities in Mexico City and similar developing-world cities with fast-growing and dense peripheries.

First, most of the influence of the built environment on travel occurs through the choice of whether, rather than how much, to drive. Policies designed to reduce the likelihood that households drive on an average day are likelier to bear fruit than policies designed to reduce the amount that they drive—particularly in the suburbs, where once households drive, they drive a lot more than similar but more centrally located households. Viable alternatives to car use are therefore imperative. While this suggests continued investment in high-capacity public transit like BRT, commuter rail, and subway into the suburbs, improving informal transit travel speeds is even more important. In 2007, more than half of vehicular trips relied on informal transit for at least a portion of the journey. Of the nineteen percent of trips that involved the Metro, more than three-quarters also involved informal transit or public buses. If increasing car use slows travel for all road users, it may produce a vicious cycle that makes road-based transit less and less tenable, since these modes are at least as affected by growing traffic congestion as car travel.

Second, Mexico City has a number of advantages that allow dense concentrations of people to have a strong impact on whether people drive, including those living in the suburbs. Specifically, local shops and informal transit are extremely sensitive to local demand. Tightening or enforcing existing land use regulations will likely hinder this demand-responsiveness and have unintended consequences for household travel behavior. Similarly, increased controls or slower speeds on informal transit may promote an already ongoing shift toward car ownership and use.

Finally, peripheral households—after controlling for neighborhood population density and a number of socioeconomic variables, including income—are less likely to use cars. Once suburban households drive, however, they drive more than urban ones. Given similarities with recent findings in India and Chile, the effect of suburban housing location on car ownership and use in the developing world merits further study. While it is unlikely that increasing the number of people living in the periphery will cause fewer people to use cars, it is nevertheless clear that distant suburbs with dense, diverse land use patterns and good public transit do not produce the same travel behavior as the uniform, lightly populated suburbs of US cities. This is not simply a result of lower incomes or different family structure.

This also has implications for US suburbs, where land use and public transportation (including taxis) are highly regulated. There is nothing inherent about the distance from a city center and car dependency. US suburbs are, therefore, potentially viable places for encouraging shifts to more sustainable travel behavior. This is encouraging, since most Americans live in suburban areas. However, unless land use and transportation regulations allow supply to respond flexibly to local demand, suburban densification will likely do very little to reduce car use. More worryingly, if developing-world cities begin to adopt and enforce US-style zoning regulations, residents of fastest-growing parts of the world may soon find that they need a car for most trips.

Chapter Four. Two Cars and a Garage? Suburbanization, Commercial Housing Development, and Growing Car Ownership in Mexico City

The previous chapter examined how the relationship between the built environment and car use has been changing over time in Mexico City. One finding of particular note is that households in the periphery are, all things being equal, less likely to drive than more central households. Once they do drive, however, they drive a lot more. In this chapter, I zoom in to look more closely at contemporary peripheral housing production and the growth in the metropolitan car fleet. This leads into the following chapter where I examine the impacts of a recent suburban Metro investment on travel behavior and housing location. Given the continued rapid growth in suburban locations with low car ownership and use rates, understanding the effects of high-capacity transit investments can help demonstrate the extent to which investment policy can help shape future growth and travel choices.

4.1 Introduction

As discussed in Chapter 1, the vast majority of recent and projected global population growth is happening in developing-world cities. Three trends have accompanied much of this growth: suburban expansion, a shift to privately-built large-scale commercial housing developments, and a rapid increase in vehicle fleets. To what extent are these trends interrelated and similar to post-war US patterns of suburbanization? Will the fastest-growing parts of the world's fastest-growing countries follow the US suburban model of a free-standing home with two cars and a garage in newly-built, single-use, low-density suburban neighborhoods? Mexico City, which is generally wealthier, more suburbanized, more reliant on commercially developed housing, and more reliant on private cars than other developing-world cities, provides a compelling case of the likely future development of similar, but poorer peer cities.

I first disentangle urban growth and car ownership trends by geographic area. The fastest-growing areas tend to be poorer and have had a much smaller impact on increasing car fleets than wealthier, more established neighborhoods in the center and western half of the metropolis. I then zoom in to several recent commercial housing developments. These are massive and dense with large numbers of modestly sized units. They remain highly reliant on public transportation, particularly informal transit, and become less homogenous over time as homeowners convert units and parking spaces to shops and offices. Finally, I model households' joint decision of where to live and whether to own a car using the 2007 household travel survey. As households become wealthier and smaller, they are more likely to purchase vehicles. However, they also increasingly prefer living in more central areas where households with cars tend to drive shorter distances. If housing policy and production cannot adapt to provide more central housing supply, growing incomes will increase car ownership, but concentrate more of it in areas where car-owning households drive the longest distances.

4.2 Suburban expansion, the housing transition, and increasing car ownership in developing-world cities

As discussed in Chapter 1, the vast majority of recent global population growth has been in developing-world cities. The United Nations estimates that the number of urban dwellers in the developing world will increase from 2.6 billion in 2010 to 4.0 billion in 2030. These 1.4 billion people account for 98% of the net total projected increase in global population.

This section reviews the literature related to three of the trends that are accompanying this urbanization: (1) suburbanization, or a rapid growth in the urban periphery that is often accompanied by declining population in the center, (2) a shift away from public housing and informal self-build housing construction to publicly subsidized mortgage markets and the commercial development of housing, and (3) the rapid increase in car fleets and car use. While some of this literature is descriptive, the majority analyzes either the causes or the impacts of the three trends. I briefly summarize a selection of the global literature, before focusing on studies that look specifically at Mexico and Mexico City. The purpose is neither to provide a comprehensive review of these somewhat disconnected bodies of literature nor to summarize all the potential causes and consequences of suburbanization, commercial housing developments, or growing auto-mobility. Rather, it is to confirm that the three trends are somewhat commonplace across a variety of developing-world cities and that Mexico City, where it is systematically different, tends to be wealthier, more suburbanized, more reliant on commercially developed housing, and more reliant on private cars. Mexico City is ahead of the trends and provides a compelling case of the likely future development of similar, but poorer peer cities.

4.2.1 Suburban expansion

As the global urban population has increased, so too has the process of suburbanization; most metropolitan areas are expanding geographically more quickly than the population is growing (Angel et al., 2010; Angel, Sheppard, & Civco, 2005; J. Liu, Zhan, & Deng, 2005). Although cities in the developing world have population densities that are three times higher than in the rich world, average densities have been declining by around 1.7% per year. Based on satellite imagery of 120 cities, Angel et al. (2005) estimate that this will correspond to a tripling in developing-world cities' urban footprints between 2000 and 2030. A more recent estimate, based on satellite imagery of over 3,500 cities, projected a slower but still rapid increase in urban footprints, from three hundred thousand square kilometers in 2000 to seven hundred and seventy thousand square kilometers by 2030 (Angel, Parent, Civco, Blei, & Potere, 2011). They find that total population, per-capita income, fuel prices, and arable land per capita explain most of the variation in land consumption across cities. They conclude that these findings support the classical economic model of urban spatial structure developed and refined by Alonso (1964), Mills (1967), Muth (1969), Wheaton (1976), and Brueckner (1987), among others. In short, global suburban expansion fits the trends observed and theories developed in the United States and Europe: higher incomes and lower transportation costs lead to increased land consumption as more households opt for larger suburban homes on larger parcels.

Mexico City, like many other cities, experienced tremendous population growth in the 20th century. The number of residents tripled between 1900 and 1940 and has increased more than tenfold since then (INEGI, 2012b). Figure 4.1 maps the jurisdictional boundaries of the Mexico City Metropolitan Area and delineates an urban center and four concentric urban rings, as defined by Suárez-Lastra and Delgado-Campos (2007a, 2007b). As discussed in Chapter 2, the urban center consists of the four central boroughs of the Federal District. The first ring contains the six boroughs, where the city grew during the 1940's and 1950's, while the fourth ring contains the most remote municipalities of the states of Mexico and Hidalgo, which began to grow rapidly in the 1980s and 1990s.

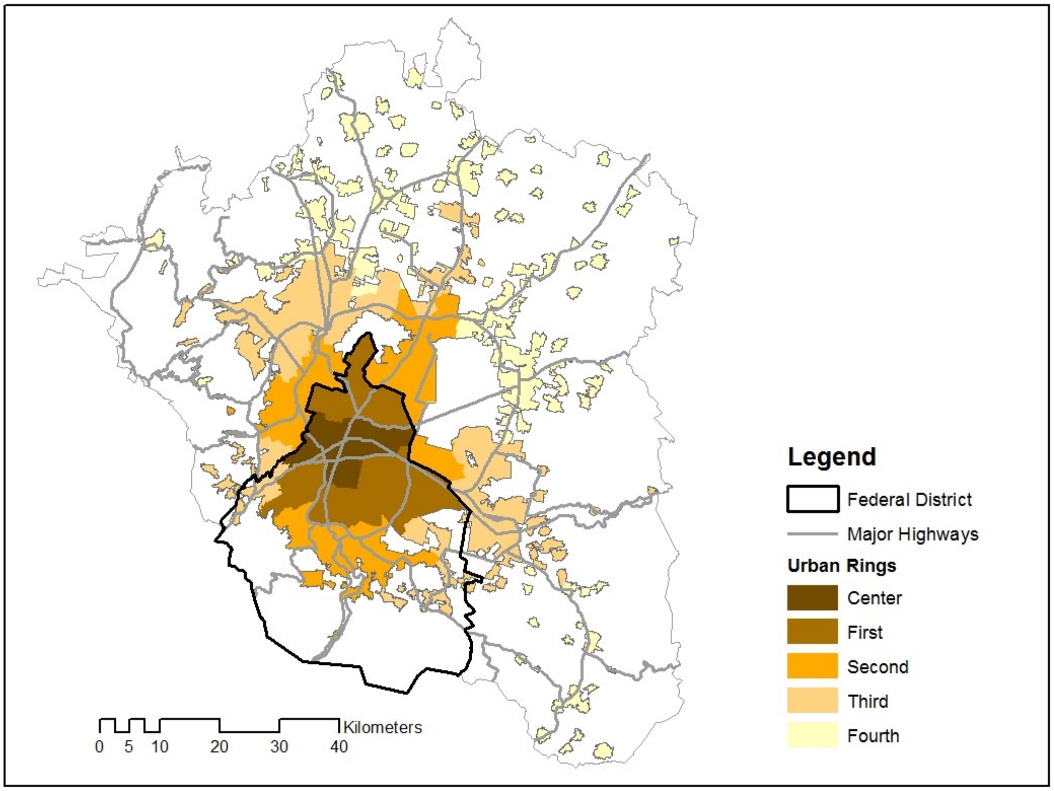

Figure 4.1 Mexico City's urban rings

Figure 4.2 graphs the city's population by urban ring from 1950 to 2010. The central city continued to grow throughout the 1950's and 60's, but began to lose population in the 1970's. By 2010, each urban ring was more populous than the center. The first and second urban rings grew most rapidly during the 1960's and 70's. Early urban expansion into the first urban ring tended to follow the major commercial avenues of the city. Much of the rapid growth of the 60's and 70's, by contrast, occurred in illegal settlements in the east and northeast along the highway to the city of Puebla. Nezahualcóyotl and Ecatepec, in particular, absorbed large shares of population growth, growing from around 40,000 to 800,000 residents between 1960 and 1970. By the 1980's, population growth began to decline in the first and, to a lesser extent, second urban rings.

Mexico City has long passed its period of tremendous population growth. Average annual metropolitan growth rates dropped from 1.8% between 1990 and 2000 to 0.9% between 2000 and 2010. Current forecasts have the population growing at an average annual rate of 0.7% from a current 20 million to 21 million by 2025; a far cry from earlier projections of 26 to 30 million residents (Ward, 1998, p. 47). Nevertheless, the third and fourth rings have continued to grow rapidly and are absorbing nearly all of the city's population growth. Since 1970, the average number of people per housing unit has declined throughout the metropolis (Figure 4.3).

Metropolitan occupancy rates declined from six per unit in 1970 to four per unit in 2010. The urbanized area of the city grew from 118 square kilometers in 1940 to 1,658 square kilometers in 2000 (Angel et al., 2010; Ward, 1998, p. 57). Figure 2.8, taken from the Lincoln Institute of Land Policy's Atlas of Urban Expansion (Angel et al., 2010), maps Mexico City's geographic growth over the past two hundred years. Suárez-Lastra and Delgado-Campo (2007b) estimate that the metropolis will expand an additional 380 to 560 square kilometers by 2020. This equates to a projected urban expansion that is 4 to 7 times higher than population growth.

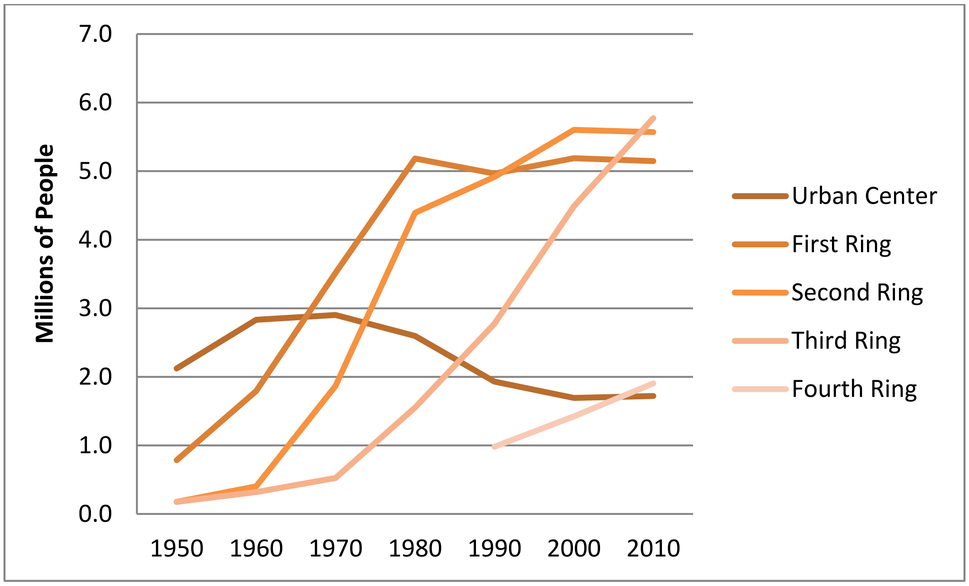

Figure 4.2 Mexico City's metropolitan population by urban ring, 1950 to 2010.

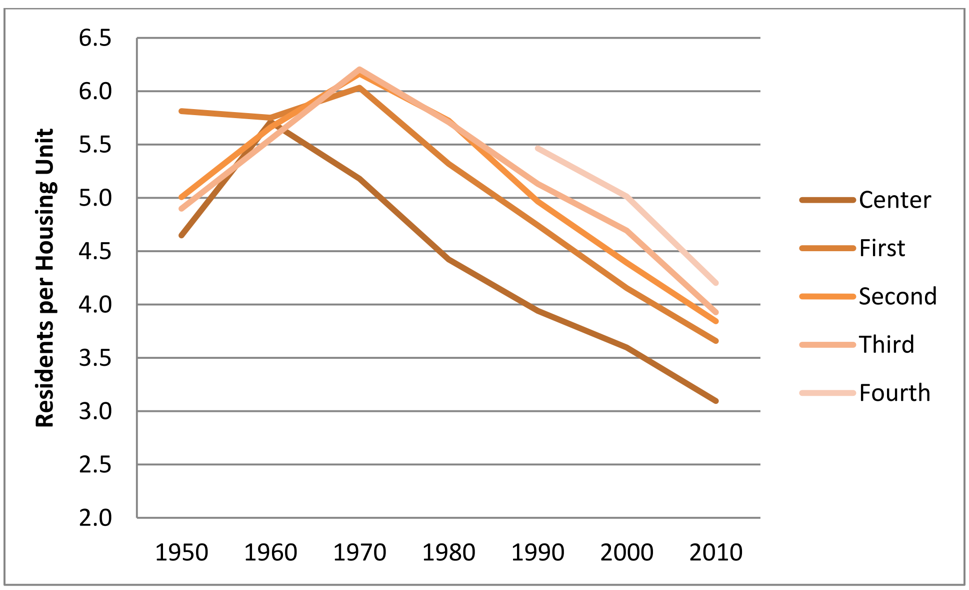

Figure 4.3 Mexico City's average people per housing unit, 1950 to 2010.

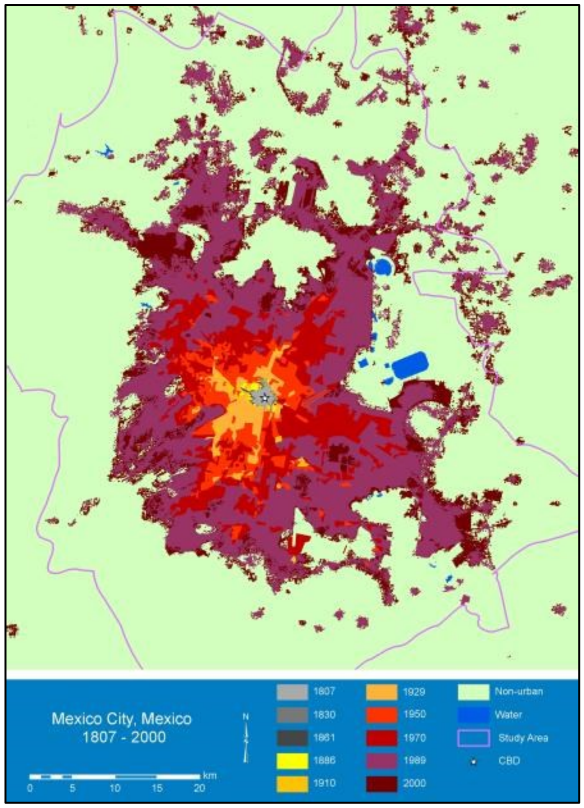

Figure 4.4 Mexico City's urban expansion (Angel et al., 2010)

4.2.2 Market-based housing transition

In recent years, there has also been a notable shift in suburban housing production and consumption in many developing-world cities. Specifically, fewer households are relying on the informal, largely self-built housing in illegal or quasi-legal settlements that typified earlier periods of urban expansion. Instead more are purchasing private homes and condominiums in large-scale private commercial developments backed by government-subsidized mortgages.[9] Researchers have attributed this shift to governments' inability to provide sufficient public housing, a dislike of informal settlements, and a general shift toward pro-market, neoliberal policies, led by the World Bank and International Monetary Fund, among others (Gough & Tran, 2009; Monkkonen, 2011a; Peralta & Hofer, 2006; Sheng, 2012; Soliman, 2012; X. Q. Zhang, 2000). The existing literature tends either to note the shift's success in expanding access to credit and increasing housing production and quality, analyze negative social impacts, or both.

Few researchers have estimated the extent that commercially constructed housing contributes to overall housing production in developing-world cities. Monkkonen's (2011a, 2011b) work in Mexico is a notable exception. Looking at the number of loans made each year and the quality and age of housing construction across censuses, he estimates that the annual production of private commercial housing surpassed new informal housing units in the early

[9] In the case of communist countries like China and Vietnam, private commercial housing has primarily replaced public soviet-style apartment blocks (Gough & Tran, 2009; Huong & Sajor, 2010; X. Q. Zhang, 2000).

years of the 21st century. Several public policies—in particular, a restructuring of the Institute of the National Workers' Housing Fund (INFONAVIT), the legalization of communal farmland (*ejido*) sales, a simplification of housing construction regulations, and active political engagement with private developers—facilitated the rapid shift in housing production. An increase in the share and wages of salaried employment, 5% of which is paid into housing funds, also contributed. Between 1995 and 2005, public agencies funded 75% of all housing loans by value—and even more by volume—in Mexico. INFONAVIT accounted for 81% of these publicly-financed loans (Monkkonen, 2011b). For a more detailed discussion of this transition in Mexico, see Chapter 2 or Monkkonen (2011a). In general, the new housing construction has been praised for serving the previously unmet demand of many middle and lower-middle income households or criticized for regressive funding mechanisms, architectural monotony, and poor social and physical infrastructure.

Despite the notable shift in housing production, the existing stock of informal housing on the periphery far outnumbers the new supply of privately constructed homes. Indeed, the most notable trend in Mexico City's housing system—and perhaps its urbanization—during the 20th century has been the rapid growth of informal, often self-built housing for low-to-middle income families. From 1950 to 1980, this type of housing, virtually non-existent at the turn of the 20th century, comprised 65% of total metropolitan housing production. Over the same period, the private commercial housing sector declined to under 15% of the total production (Dowall & Wilk, 1989). Informal housing production remains an important and integral part of most developing-world cities' housing markets (Roy & AlSayyad, 2004; Soliman, 2012). In many cities, it remains the predominant form of housing production, particularly for low income households. For example, Balaban (2011) observes that many long-term squatters have replaced shacks with multi-story apartment buildings in Turkish cities, but the ownership and production systems have remained informal. Nevertheless, commercially constructed private housing is a notable and growing part of the suburban landscape of many developing-world suburbs.

4.2.3 The growth in car ownership

Finally, there has been tremendous recent global growth in the number of cars, trucks, and motorcycles. Sperling and Gordon (2009) predict that motor-vehicle fleets will double in the next two decades. Households in developing-world cities, particularly Chinese ones, are driving this trend (Sperling & Clausen, 2002). In 2009, China surpassed the US as the world's largest car market (The Guardian, 2010). Between 1991 and 2003, the number of cars per thousand people grew fivefold in China and doubled in India (Pucher, Zhong-ren Peng, Mittal, Yi Zhu, & Korattyswaroopam, 2007). From 2009 to 2010, the total fleet of registered cars increased by 8.7% in Asia and 8.4% in Latin America, compared to 0.2% in the US and 1.2% in Western Europe ("WardsAuto," 2012). Analyzing a cross-section of developing and high-income cities and nations, Ingram and Liu (1999) found that higher incomes contributed to both urbanization and car ownership. As countries become wealthier, they also become more urbanized and more reliant on private cars. In 1980, a sample of developing cities had an average of 60 motor vehicles per thousand residents compared to 482 in high-income countries (Ingram & Liu, 1999).

At that time, Mexico City had 124 cars and light-duty trucks per thousand residents. By 2010, it had 267. Between 2000 and 2010, there were 1.7 new cars and light duty trucks for each additional person in the metropolis; a total increase of 2.4 million cars. Nevertheless, fifty-seven percent of households did not own a car in 2007. Of those that did, 76.6% owned only one car, 18.5% owned two cars, and 4.9% owned three or more cars. Table 3.1 gives the breakdown of car ownership and use by income group in 2007. Car use and ownership rise notably with income group. For graphical representations of recent growth in the fleet of cars and light-duty trucks see Figure 4.7 and Table 4.3.

Table 4.1 Car ownership and use by income quintile in 2007

Income Quintile	Lowest	Second	Third	Fourth	Highest	Average
Estimated average monthly income in 2007 dollars*	$206	$381	$603	$943	$2,511	$906
Percent of households with a car	22%	27%	39%	52%	73%	43%
Average cars per household	0.25	0.30	0.45	0.63	1.11	0.56
Average daily vehicle kilometers traveled	2.6	3.7	5.9	7.9	15.8	6.5

*10.93 Mexican pesos per dollar

In an evaluation of *Hoy No Circula*, a policy to ban cars from roads one day per week by license plate number, Eskeland and Feyzioglu (1997) found that fuel consumption and car purchases increased not only despite, but also because of, the policy. Households purchased multiple vehicles for the days that they could not otherwise drive. Given that only 10% of households own more than one vehicle, however, it is unlikely that the policy sparked as many secondary vehicle purchases as the authors suggest. Furthermore, 39% of households with one vehicle did not drive it on an average weekday in 2007. It is likely that fuel consumption and car ownership would have grown even more rapidly without the policy. In time series analyses of aggregate subway use, car registrations, and fuel consumption, Crôtte, Noland, and Graham (Crôtte et al., 2009a, 2009b) estimated that car ownership and use rose in lockstep with income and that subway fares and investments had no statistically measurable impact on this growth. In short, car ownership and use have continued to rise with income despite investments in public transportation and somewhat strict rationing of car use.

4.3 Are the trends interrelated?

It is easy to assume, based on US experience, that suburbanization, car ownership, and mass-produced commercial housing developments are moving hand-in-hand. This assumption is implicit in discourses about the environmental dangers of letting developing-world cities become as car-dependent as the US. Yet, the average suburban expansion in a developing-world city bears little physical or socioeconomic resemblance to the average US suburb. Although there are many examples of high-income gated suburban communities, the suburbs are generally poor and densely populated. Perhaps in part for this reason, many researchers working in these areas, opt for terms like peri-urban, peripheral, or fringe development rather than suburban, which tends to evoke affluence in English. Little work explores the relationship between new developing-world suburbs and automobility. A better understanding, however, is a key component to crafting effective transportation and land use policies in the fastest-growing neighborhoods of the world.

In order to disentangle the three trends, I first look at the geographic distribution of car ownership and population growth. Since, it is difficult to differentiate new commercial developments from older informal ones using aggregate data, I then zoom in to look more closely at several recent commercial developments. Finally, I jointly model the effect of income and other socioeconomic factors on whether a household chooses to own a car and where they choose to reside. How will growing incomes and shrinking households tend to influence suburbanization and car ownership?

4.3.1 Suburbanization and car ownership trends by urban geography

Neither suburban expansion nor growing car ownership has occurred uniformly throughout metropolitan Mexico City. In this section, I analyze recent trends by urban ring and municipality. Several key points emerge. First, recent suburbanization—although generally on large plots of former agricultural land—has largely been a process of high-density construction around existing neighborhoods rather than low-density leapfrog development. Second, the total car fleet and the number of cars per thousand people are growing throughout the city, particularly the suburbs. Third, although car ownership and population have grown most rapidly in the third urban ring, there is wide variation within this ring and others. Most population growth has been in the densely populated suburbs to the east and northeast, where car ownership rates are among the lowest. Car ownership and use are highest in the slow-growing and wealthy western half of the city. These trends largely reflect the city's income distribution. Finally, absolute car ownership is rising rapidly—although from a low base—in the city's poor and fastest-growing neighborhoods.

As stated in section 4.2.1, Mexico City's urban footprint has expanded rapidly in recent years and population density has declined in aggregate. Nevertheless, recent suburban expansion has largely been a process of infill and dense development in or around existing urban areas. Average neighborhood population density in the third and fourth urban rings increased by 49% and 67% from 1990 to 2005 (Table 4.2).

Table 4.2 People per hectare in Agebs by urban ring in MCMA in 1990 and 2005

Urban Ring	In average neighborhood		In average person's neighborhood*	
	1990	2005	1990	2005
Center	185	161	220	193
First	194	193	208	206
Second	151	150	185	174
Third	78	116	101	131
Fourth	27	45	39	55

*The average person's neighborhood has a higher density than the average neighborhood, because more people live in the densest neighborhoods.

The density of the average person's neighborhood also increased, although less rapidly. Between 2000 and 2010, these peripheral rings absorbed more than 100% (due to losses in other rings) of the total net increase in the metropolitan population. In the first and second urban rings, which lost a modest amount of population between 2000 and 2010, densities remained fairly constant. Between the 2000 and 2010 censuses, the urban center experienced its first population increase since the 1960s. Incomplete geographic data, however, prevented the estimation of neighborhood population densities in 2010. Figure 4.5 maps the change in average neighborhood population density by municipality between 1990 and 2005. Sections of each municipality that were not part of an urban locality in 2010 are screened in white in order to give a more accurate representation of the metropolis' urban geography (See Appendix A). Growth in neighborhood densities has been most pronounced in the northern and eastern suburbs, particularly Chalco and Ixtapaluca, where average densities more than doubled from thirty four to eighty and forty eight to one hundred and thirty four people per hectare respectively.

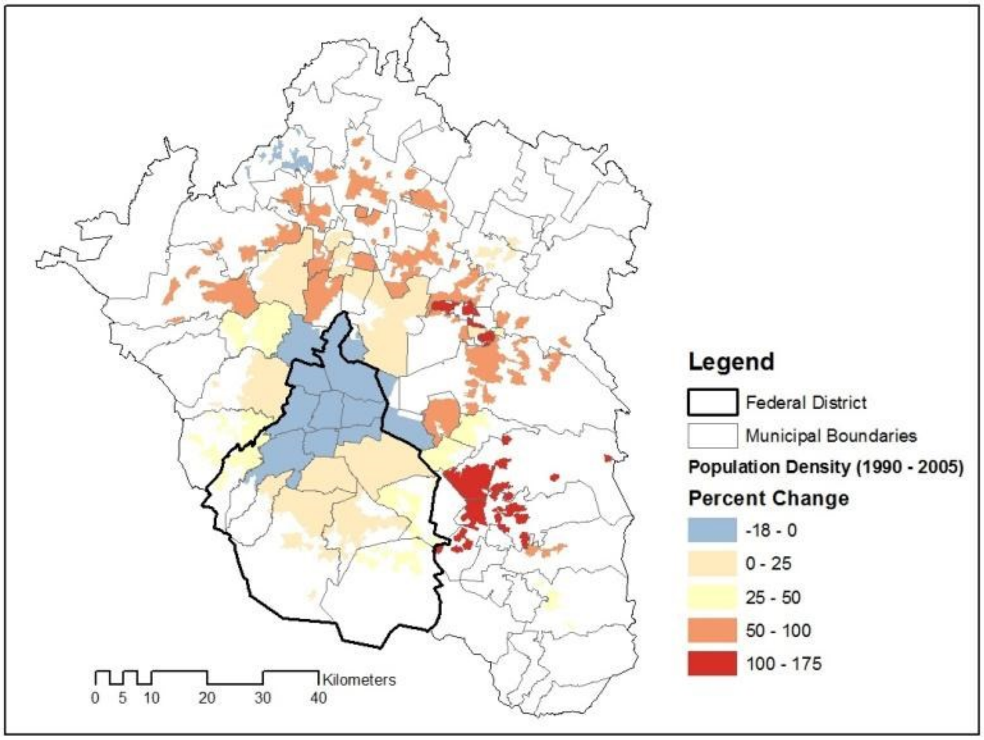

Figure 4.5 Change in average neighborhood densities by municipality (1990 – 2005)

Unlike changes to the total population and population density, vehicle fleets have increased throughout all areas of the city (Table 4.3 and Figure 4.6). Total car fleets and the number of cars per thousand people grew most rapidly in the second and third urban rings. The total vehicle fleet, however, remains highly concentrated in the center. In 2010, more than half of all cars were registered in the urban center and first urban ring. Just 34% of the population resided there. Despite rapid growth in the second and third rings, the most distant neighborhoods have played a much smaller role in increased car fleets. The fourth urban ring accounted for 27% of metropolitan population growth between 2000 and 2010, but only 6% of new cars. In 2010, there were 647 registered cars per 1000 people in the urban center compared to 135 in the fourth ring. While this difference partially reflects registrations to businesses, which are highly concentrated in the downtown, household-level survey data confirm lower vehicle ownership rates outside of the center. Figure 4.7 maps the proportion of households in each municipality that had one or more cars or light duty trucks in 2007. Ownership rates are highest in the western parts of the metropolis, with significantly lower rates in two of the downtown delegations and most of the peripheral suburbs. Even in the most auto-dependent municipalities, only two-thirds of households reported owning a car in 2007.

Table 4.3 Growth in cars and light duty trucks by urban ring (2000 – 2010)

Urban Ring	Total Car Fleet					Cars / 1000 People		
	2000	2010	AAGR*	New Cars	% of New	2000	2010	AAGR*
Center	805,818	1,112,704	4%	306,886	13%	476	647	4%
First	1,190,869	1,635,888	4%	445,019	18%	230	318	4%
Second	574,670	1,416,733	15%	842,063	35%	103	254	15%
Third	285,458	953,075	23%	667,617	28%	64	165	16%
Fourth	107,983	256,705	14%	148,722	6%	76	135	8%

*Average Annual Growth Rate (INEGI, 2012c).

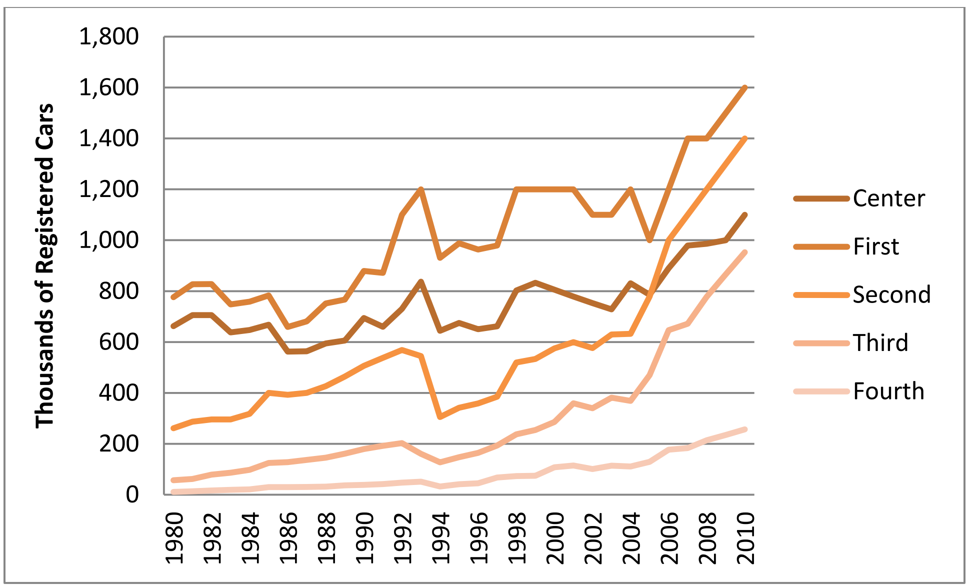

Figure 4.6 Thousands of registered cars and light-duty trucks by urban ring (INEGI, 2012c)

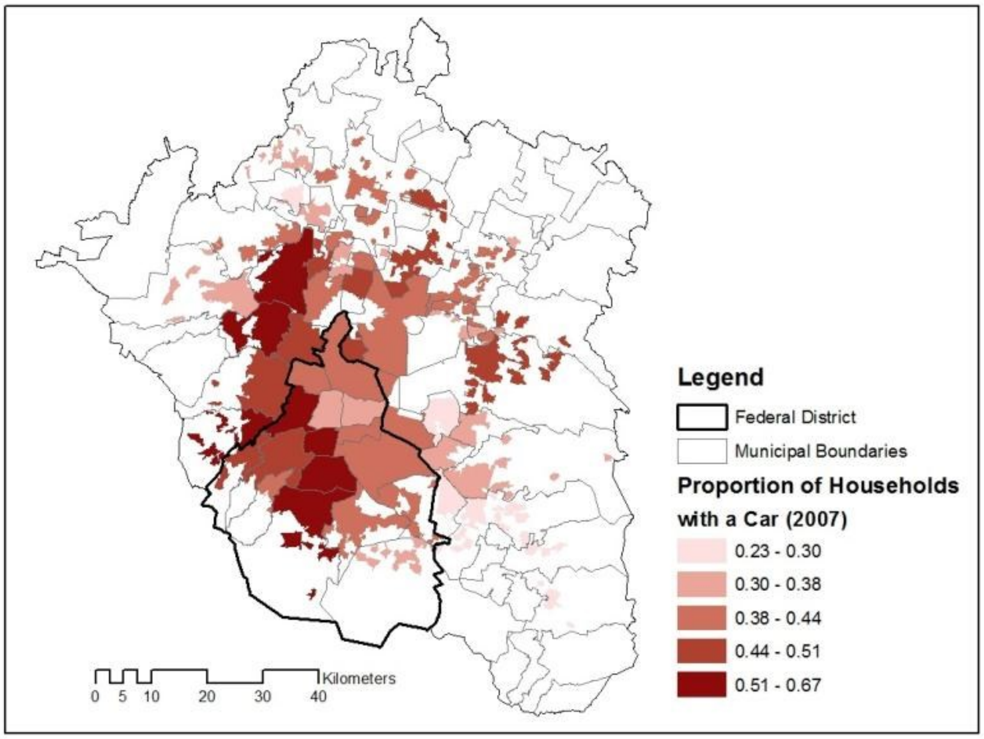

Figure 4.7 Proportion of households with one or more cars by municipality in 2007

As expected, income plays a strong role in both household location and vehicle ownership. Figure 4.8 maps the metropolis by average household income in 2007. I opt to use average instead of median household income for two reasons. First, household income is derived from a sample of households in which each sampled household represents between nine and eight hundred and twenty actual households. Second, there is significant variation in income levels across neighborhoods in each municipality and delegation. These result in significantly less variation in median income across municipality and produce maps that do a worse job of revealing the wealthiest and poorest parts of the city than average income. In general, the wealthiest parts of the city, whether central or peripheral, are in the western half of the city. These tend to have high car ownership rates and low population growth rates. The poorest neighborhoods are in the eastern and northeastern parts of the city, where growth rates are fastest and car ownership is lowest. Nevertheless car fleets and ownership rates are growing quickly, albeit from a low base, in poorer areas. The number of registered cars and light-duty trucks grew nearly fivefold in the five poorest municipalities between 2000 and 2010. While the poor, dense neighborhoods of the northern and eastern suburbs have the lowest vehicle ownership rates, they also represent the greatest source of potential future demand.

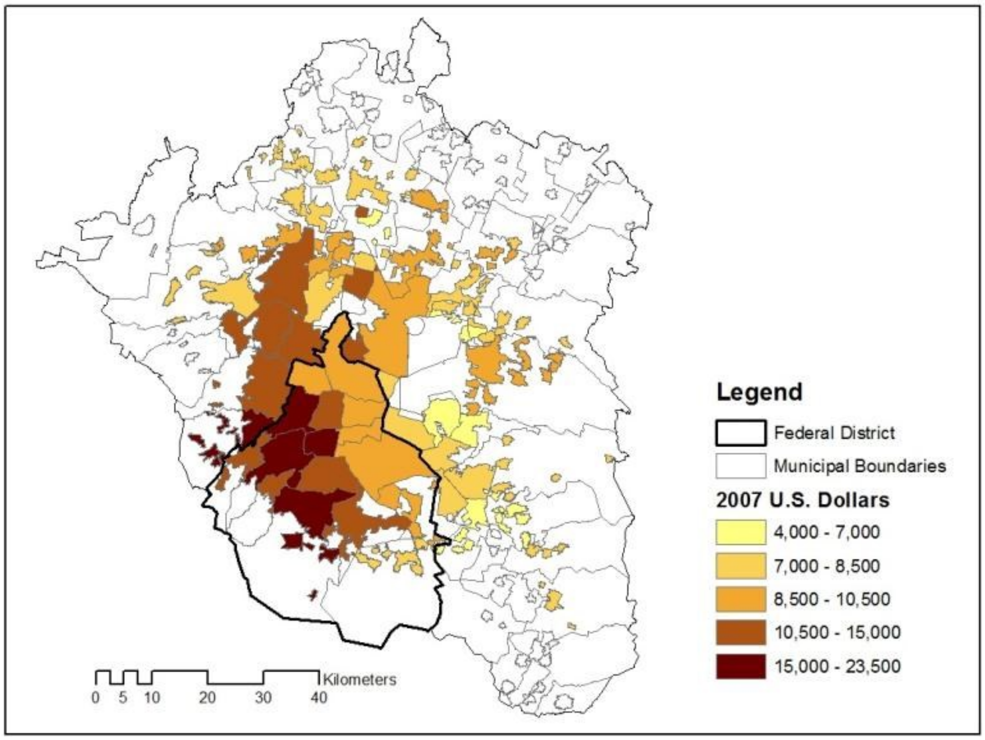

Figure 4.8 Average household income by municipality in 2007

4.3.2 Mexico City's emerging Levittowns

Just as aggregate trends mask geographic variation, trends by urban ring or municipality mask significant variation across individual neighborhoods and households. Furthermore, it is difficult to differentiate between large commercially-built housing developments and other forms of suburban expansion with existing datasets. In this section, I look more closely at recent commercial housing developments in the periphery. Mexico's large commercial housing builders—Urbi, Geo, Homex, Sadasi, and Sare—build a full range of housing products from humble 25 square-meter town homes to luxury high-rises and exclusive gated communities. The developments that have driven recent suburban expansion, however, are massive and primarily provide small housing units to low and moderate income households. As suburbs, they are more akin to mass-produced US developments like Levittown and Lakewood—although the units are smaller and more tightly packed their either US development—than suburban garden communities. Most come with a single exterior parking space. Households often use this area for small commercial enterprises or building additions instead of parking. As residents create additional access points, open shops, and expand their residences, the developments more closely resemble traditional informal developments. Although cars are a visible and growing presence, the majority of households continue to rely on informal transit, generally in *colectivos*, for the majority of daily needs. These also provide direct connections to mass public transit such as the suburban commuter train in the north, Line B Metro in the northeast, and Line A to the east.

Between 1990 and 2005, average neighborhood population densities increased more quickly in Ixtapaluca, located about 30 kilometers east of downtown, than any other municipality in Mexico City from 48 to 131 people per hectare. Over the past two decades, the region's population has grown an average of 12% per year. Large-scale, high-density private commercial developments accounted for nearly all of this growth. In a study of two such developments, Geo's Villas de Santa Barbara and Hacienda Las Palmas, Peralta and Hofer (2006) report that the municipality approved a total of eight commercial housing developments, containing 68,625 units, between 1992 and 2002. That is three-quarters of all new housing units between the 1990 and 2010 censuses, and twice the number of new units between 1990 and 2000. Figure 4.9 provides an aerial view of Ixtapaluca with commercial housing developments outlined and named. Even at 8,000 feet, these developments are easy to identify. Different building materials and paint leads to a browner color than the gray cement of informal developments. As in the US, there is a great diversity in the size, quality, and urban form of new suburban subdivisions, even within one municipality. The largest developments, which have over 10,000 units, are uniform and mass-produced with home sizes ranging from twenty five to a hundred square meters.

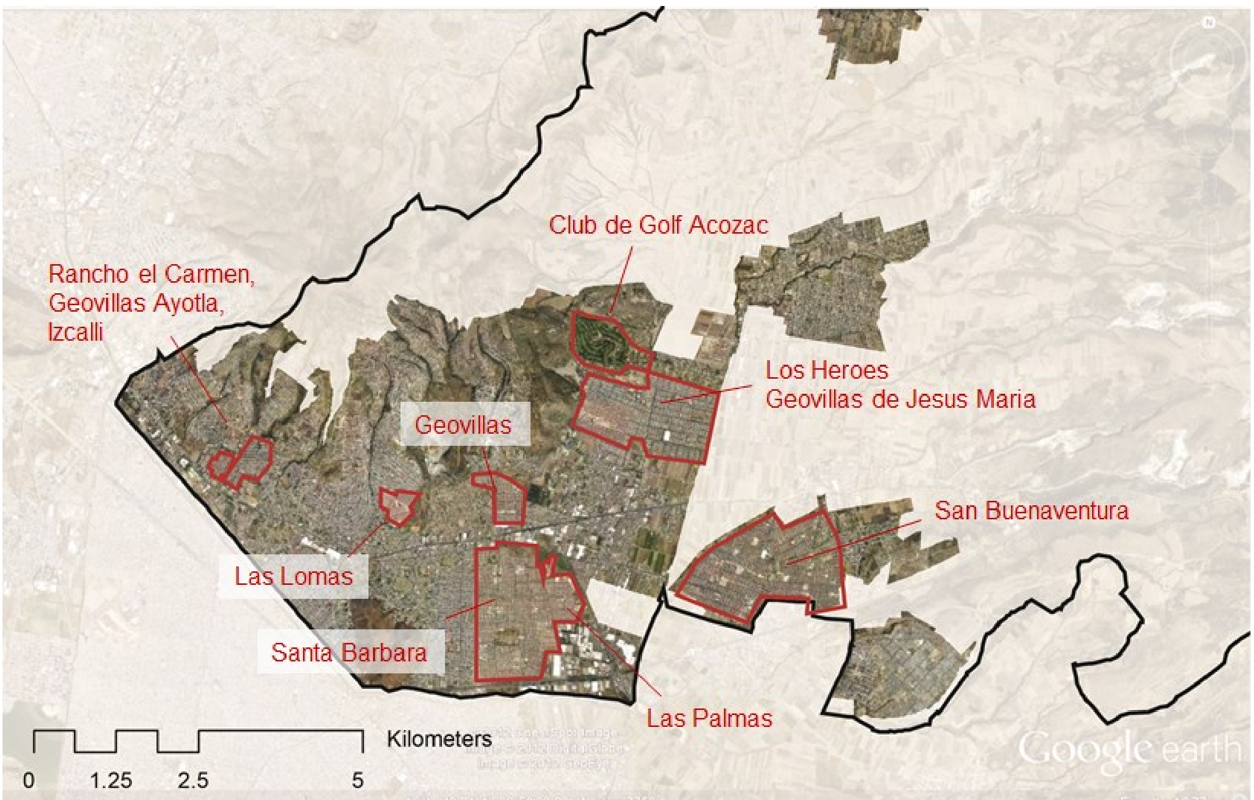

Figure 4.9 Large-scale contemporary developments in Ixtapaluca, State of Mexico

Figure 4.10 shows the interior layout of Sare's three self-described "social interest housing" types in Tecamac ("SARE," 2012).[10] All variations of the same two-story row house construction, the units range from around twenty five to fifty square meters with one to three bedrooms. Each has a single exterior parking space on the narrow front yard. These units are common throughout recent large-scale housing developments, where they are mas-produced in straight uniform blocks (Figure 4.11). In most developments, a large open space, school, or

[10] In addition to social interest housing, the company's website advertises downtown apartments, vacation homes, and exclusive residential developments.

gymnasium serves as the only break to the long blocks of row houses. The six-phase Los Héroes development in northern Ecatepec and Tecamac contains tens of thousands of units. Figure 4.12 shows the exterior of a typical twenty-five square meter unit. New homes in the most recent phase of Los Héroes Tecámac, which includes some three-story six-unit apartmet buildings, cost between 350,000 and 535,000 pesos ($27,000 to $41,000) ("Grupo SADASI," 2012).

Figure 4.10 Typical housing unit floor plans

Figure 4.11 Aerial view of Los Héroes (Ecatepec and Tecamac, State of Mexico)

Figure 4.12 Typical housing unit exterior, Los Héroes Ecatepec

Over time, the commercial developments become less homogenous and come to resemble informal neighborhoods more closely. Some home-owners convert all or part of their units to commercial enterprises. Enclosing the exterior parking area and opening a small shop is quite common. Others expand their living area, either vertically, horizontally, or both. Some extend an additional bedroom above an open or closed garage space. Figure 4.13 shows workers in the process of installing a new room or garage in a recently constructed neighborhood in Los Héroes. In older neighborhoods on arterial streets, commercial conversions are quite common (Figure 4.14). In an analysis of 128 urban areas in Mexico, Monkkonen (2011c) found that Mexican commercial housing developments tend to be densely populated—even more so than informal developments—rely heavily on public transportation, and become more self-sufficient over time as residential properties are converted into shops. Some developments attempt to formalize these informal practices. For example, Ara's Citara development—branded "the city as it ought to be"—advertises its own van and taxi service, 30% discounts on commuter rail tickets, and a shopping area within four hundred meters of every home ("Casas ARA," 2012). Homes range from forty to seventy-five square meters and sell for between 290,000 and 535,000 pesos ($22,000 to $41,000).

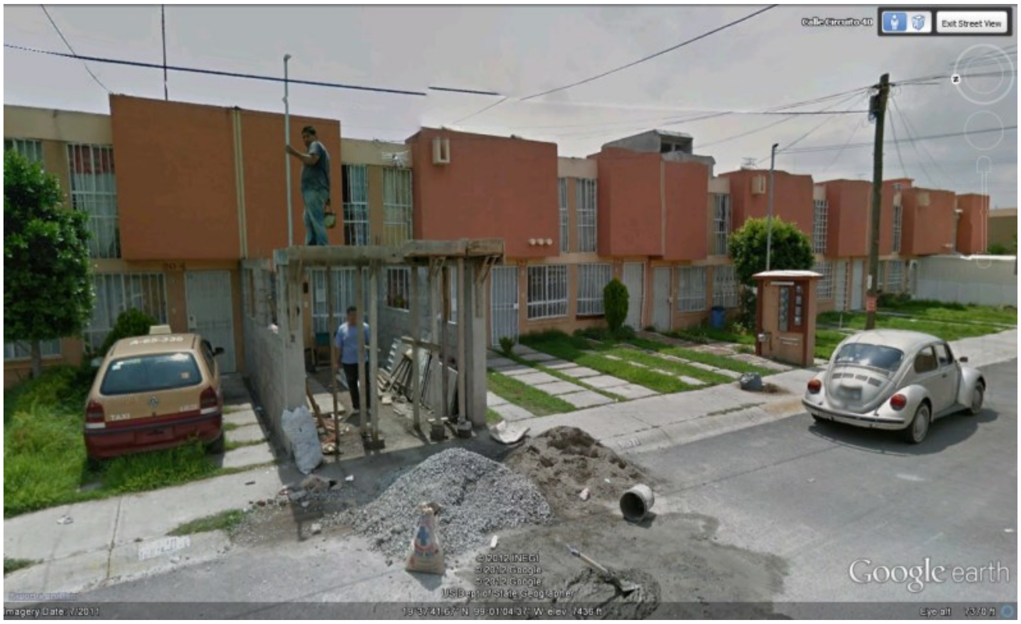

Figure 4.13 Reuse of parking space underway (Ecatepec, State of Mexico)

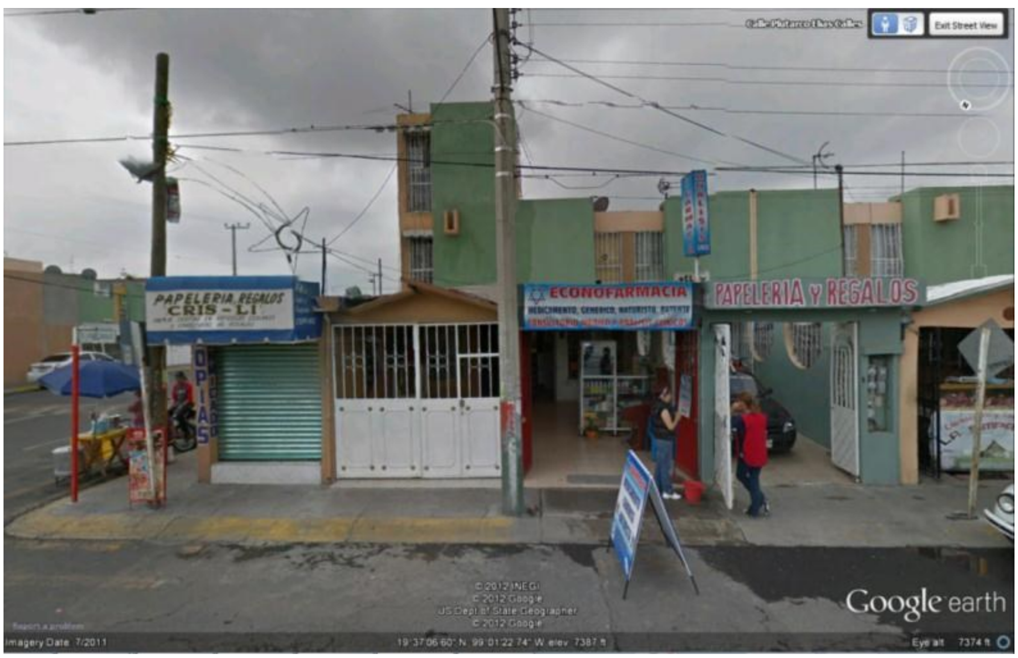

Figure 4.14 Commercial reuse of parking spaces and housing units (Ecatepec, State of Mexico)

4.3.3 The effects of income and household size on household's car ownership and location decisions

As incomes increase and household sizes shrink, how will households respond? To address this question, I jointly model households' car ownership and location decisions as a function of socioeconomic variables. In the model, each household faces ten discrete decisions: whether to own a car and in which urban ring to reside. The probability that a household chooses any one alternative is the estimated probability that the utility of that alternative is higher than the utility of the other nine alternatives. In order to account for unobserved relationships across the alternatives, I use a mixed logit model with random error components. It is unlikely that car-owning households do not vary in some systematic way, such as a preference for driving, across the five different urban rings. Similarly, many households living in the urban center likely share certain features with other central households that also influence household location choices, such as where their members were born, regardless of whether they own cars. Written formally the estimated utility of each choice alternative for each household is:

$$Uij = \alpha_j + \beta X_{ij} + \gamma_{ijc} + \delta_{ijr} + \epsilon_{ij}$$

Where:

- α_j are alternative specific constants for the choice alternatives.
- βX_{ij} is the vector of estimated parameters multiplied by the column vectors of household attributes (household income, size, and composition).
- γ_{ijc} are zero-centered, normally-distributed random error components for car-owning households.
- δ_{ijr} are zero-centered, normally-distributed random error components for the five urban rings.
- ϵ_{ij} is the type-1 Gumbel-distributed random error term.

Table 4.4 provides descriptive statistics about the ten choice alternatives and socioeconomic data considered for the model. Data for the model come from the metropolitan area's 2007 household travel survey. The survey contains information on just over 50,000 households—including income, household size and composition, and geographic location at a resolution equivalent to a US Census Tract—and 200,000 weekday trips—including the geographic location of origins and destinations, trip purpose, trip duration, trip time, out-of-pocket expenses, and mode of travel. It also includes expansion factors that represent the proportion of total households and trips in the metropolitan area that each surveyed household and trip represent. For more information, see Appendix B. I dropped households that did not report income from the model. On the whole, the excluded households were more likely to live in the urban center and less likely to live in the first urban ring. They were also 10 percentage points less likely to own a car. It is unclear, however, if this reflects a fundamental difference in ownership or a difference in reporting preferences. Households, who prefer not to report income, are probably more likely not to report other factors, such as car ownership.

Table 4.5 reports the results of the final model estimated using the Biogeme software package (Bierlaire, 2003, 2009). Random error components were simulated by taking 8,000 quasi-random Halton draws from a zero-centered normal distribution. I began by taking 1,000 draws and doubled the number until parameter estimates remained consistent across estimations. For a full description of estimation procedures, see Train (2009, Chapter 6).

Table 4.4 Descriptive Statistics of Choice Sets and Socioeconomic Variables

Choice Set				
Geography	*Has Car*		*Observations*	*Percent of Sample*
Center	No		2,688	6.26
Center	Yes		2,296	5.35
First ring	No		7,259	16.92
First ring	Yes		5,943	13.85
Second ring	No		7,018	16.35
Second ring	Yes		5,215	12.15
Third ring	No		6,141	14.31
Third ring	Yes		3,939	9.18
Fourth ring	No		1,468	3.42
Fourth ring	Yes		946	2.2
Continuous Predictor Variables				
Variables	*Mean*	*Std. Dev.*	*Min*	*Max*
Reported monthly income (2007 USD)	$937	$1,682	$9	$91,491
Average age of adults (18 to 59)	36.3	7.5	18	59
Household members	4.12	1.74	1	23
Children under 11	0.77	0.97	0	12
Adults over 59	0.33	0.62	0	5
Number of workers	1.72	1.01	0	11
Categorical Predictor Variables				
Variables			*Observations*	*Percent of Sample*
Multiple households in housing unit			1,669	3.89
Maximum Educational Attainment in Household				
High school			9,964	23.22
Technical degree			5,122	11.94
College or professional degree			13,577	31.64
Masters or doctorate			1,162	2.71

As expected, a household's probability of car-ownership rises systematically with income. The log of income significantly improves model fit over a linear model and indicates that income has a diminishing influence on car ownership as it increase beyond a certain point. The distribution of the log of income, furthermore, matches a normal distribution much more closely than income, which has a long tail of wealthy households. I also included a dummy variable for whether a household has any members with a college education or higher. This removes some of the effect of income and I opt to include it in the model, as a proxy for social status. Households from better-educated social classes are more likely to own cars and less likely to use public transit than otherwise similar households from social classes with lower educational attainment. Educational attainment may also capture some of the effects of accumulated wealth exclusive from monthly income. Income and educational attainment also significantly influence where a household chooses to reside. Wealthier, better educated households prefer centrally located residences and disfavor more remote urban rings.

Household composition also influences residential location. Household with higher average working-age members are less likely to live in the second, third, and fourth urban rings than in the center and first ring. Households with members who are 60 years-old or older also prefer central living; as do smaller households. Households with children under 11 are most likely to live in the center or third and fourth urban rings.

Despite the expected correlations, few of the random error components proved statistically significant. This indicates that the included covariates do a good job of capturing non-random variation in preferences across the available choices. Despite insignificance, I opt to include the random error components in the final model, due to the potential for non-random correlations across choices and to allow more flexible substitution patterns between choices when predicting the outcome of changes in income or household size.

Table 4.5 Mixed logit model of households' joint location and car ownership decisions

	Parameter	Robust Std. err.	Robust t-test	
Car Ownership				
Log of reported monthly income	0.757	0.016	47.27	
Maximum education: college or higher	1.150	0.024	47.46	
Urban Geography (relative to urban center)				
Reported monthly income				
First urban ring	-0.284	0.029	-9.81	
Second urban ring	-0.427	0.0247	-17.27	
Third urban ring	-0.502	0.0311	-16.16	
Fourth urban ring	-0.632	0.0362	-17.48	
Maximum education: college or higher				
First urban ring	-0.319	0.0679	-4.70	
Second urban ring	-0.660	0.0415	-15.89	
Third urban ring	-0.894	0.0647	-13.8	
Fourth urban ring	-0.938	0.0651	-14.4	
Average age				
First urban ring	-0.004	0.003	-1.420	*
Second urban ring	-0.011	0.002	-4.510	
Third and fourth urban ring	-0.015	0.003	-5.470	
Has a child under 11				
First urban ring	-0.108	0.028	-3.820	
Second urban ring	-0.091	0.026	-3.460	
Third urban ring	-0.027	0.027	-1.010	*
Fourth urban ring	-0.006	0.034	-0.170	*

Has an adult over 59				
First urban ring	-0.124	0.075	-1.660	*
Second urban ring	-0.391	0.041	-9.600	
Third urban ring	-0.846	0.074	-11.420	
Fourth urban ring	-0.670	0.064	-10.440	
Household size				
First urban ring	0.239	0.016	15.01	
Second urban ring	0.322	0.016	20.29	
Third urban ring	0.344	0.017	19.81	
Fourth urban ring	0.392	0.020	20.06	
Random Error Components**				
Car ownership	-0.010	0.017	-0.570	*
First urban ring	-0.954	0.671	-1.420	*
Second urban ring	-0.389	0.470	-0.830	*
Third urban ring	-0.594	0.605	-0.980	*
Fourth urban ring	-0.188	0.932	-0.200	*
Adjusted rho-square	0.123			
Initial log-likelihood	-98811			
Final log-likelihood	-86653			
Number of Halton draws	8,000			

*Parameter estimate is not significant at the 95% interval **Random error component draws taken from zero-centered normal distribution

To give a better sense of the relative magnitude of car-ownership and household location shifts that continuing trends are likely to generate, I estimate the influence of rising incomes and shrinking households on aggregate household preferences. Table 4.6 presents the predicted aggregate response of an across-the-board 10% increase to household income. The number of households owning one or more car would increase by approximately 3.4%. This implies a lower demand elasticity of car ownership than commonly found. However, it only includes the shift from zero to one or more cars, not the total increase in car purchases. Furthermore, the models include additional household covariates, such as composition, age, and educational attainment that are also correlated with income.

In addition to demand for car ownership, housing demand in the urban center would also increase with income, matched by corresponding declines in the third and fourth urban rings and marginal changes in the first and second rings. Decreasing average household sizes are also likely to shift housing demand to more central locations. Table 4.7 estimates the aggregate response to a randomly selected 10% sample of households losing one household member. Again, increased central demand is offset by a decrease in peripheral demand.

Unlike vehicle supply, however, housing supply is quite sticky, particularly in the short run. Without a major shift in the predominant form of contemporary housing typology—the small row house in massive, peripheral developments—the shift in housing preferences is likely to influence average prices by geography more than settlement patterns. Already, however, developers are struggling to sell units in some of the most peripheral developments. Many households have reached the limit of how far they are willing to live from the center and this limit will likely decrease if household incomes increase or household sizes continue to shrink.

Table 4.6 Effect of 10% increase in household income on car-ownership and housing location

	2007	Simulated	Change
Owns			
Car	42.7%	44.2%	3.36%
Urban Ring			
Center	11.6%	11.9%	2.91%
First	30.8%	30.9%	0.54%
Second	28.5%	28.4%	-0.43%
Third	23.5%	23.2%	-1.08%
Fourth	5.6%	5.5%	-2.11%

Table 4.7 Effect of reduction in household size to 10% of households on car-ownership and housing location

	2007	Simulated	Change
Owns			
Car	42.7%	42.7%	-0.04%
Urban Ring			
Center	11.6%	11.9%	2.70%
First	30.8%	30.8%	0.14%
Second	28.5%	28.4%	-0.49%
Third	23.5%	23.3%	-0.65%
Fourth	5.6%	5.6%	-1.00%

4.4 Conclusion

Looking at suburbanization trends and recent commercial housing developments, it is clear that these neighborhoods are not the driving force behind decreases in urban density or increased car-ownership rates. Over time, furthermore, the neighborhoods become more diverse, as residents convert housing units and parking spaces into shops and other commercial spaces. Whereas automobile ownership and single-family homes have characterized suburbanization in the US, crowded minibuses and densely populated neighborhoods are more characteristic of Mexico City's suburbanization, including in recent commercially constructed developments. If it is true that the primary mode of transportation during a neighborhood's growth influences its future settlement and transportation patterns (Muller, 2004), then the densely packed suburbs serviced by informal transit providers are unlikely to evolve to look like their US counterparts, which grew around the automobile or streetcars.

As households become wealthier and smaller, however, demand for car ownership will increase. So too will the demand for more central housing locations. While the car industry is prepared to meet increased demand, the housing industry is not. The current housing development model almost entirely encourages new supply on large tracts of open land, which primarily exist in the periphery. If the metropolitan demand for central housing is not met, the third and fourth urban rings are likely to continue to grow rapidly, as will car ownership and use in these neighborhoods. This has serious implications for pollution, congestion, and households' commute times and travel expenditures. Thirteen percent fewer households own cars in these two most remote rings than in more central areas. When the more remote households do drive, however, they generate 43% percent more VKT than other metropolitan households.

Thus, while it is unlikely for Mexico City's periphery to evolve to resemble US suburbs in terms of land use and transportation, this area also has the potential to increase the city's overall VKT significantly. Increased congestion will not only harmfully impact drivers, but also the majority of the population who rely on road-based informal transit. Public policies to encourage low-cost housing production in more central areas and give priority to informal transit can help offset this risk.

Chapter 5. Mexico City's Suburban Land Use and Transit Connection: The Effects of the Line B Metro Expansion

The previous two chapters explore the relationship between urban form and car use and between car ownership and commercially-built suburban housing developments. Both chapters provide insights into the relationship between public transportation and land use in Mexico City's suburbs. In 1994 and 2007, households in neighborhoods within a half kilometer of transit stations were statistically less likely to drive than other similar households. Moreover, both population density in the suburbs and the constraining influence of density on car use increased over the same time period. After accounting for income and other socioeconomic variables, suburban households were less likely to own or use cars than more central ones. Once peripheral households start to drive, however, they tend to drive significantly farther than their otherwise similar but more centrally-located counterparts. With many densely populated neighborhoods, lower than average incomes and car ownership rates, and high transit use, but little in the way of high-capacity transit, Mexico City's suburbs are an important place to consider public investments in high-capacity transit, like rail and bus rapid transit. In this chapter, I look at how one of the first and only suburban Metro investments in Mexico City has influenced suburban form, transit use, and the cost, distance, and duration of households' trips in around the new Metro stations and in the surrounding municipality.

5.1 Introduction

Over the past two decades, governments and development agencies have invested significanly in high-capacity transit, like subway and bus rapid transit (BRT), in Asian, Latin American, and African cities. Beijing went from having just two subway lines in 2000 to having the world's longest metro system and, every year, dozens of new BRT lines open in cities around the world. Concerns over economic competitiveness, congestion, sprawling development, pollution, and accessibility for the poor and middle class have driven these investments. Despite the increased production of high-capacity transit—also called mass rapid transit (MRT)—far less research has evaluated its impact in developing-world cities than in American and European ones. Most of the existing literature, furthermore, is either descriptive or recommends a specific technology based on costs and maximum passenger loads during peak hours. There is a small, and almost entirely cross-sectional, body of empirical work focused on determinants of mode choice on existing systems or the relationship between proximity to rail or BRT and land values. Even less work narrows to investigate the land use and travel impacts of transit investments in the suburbs, where developing-world cities are growing most rapidly and which tend to be poorer and more densly populated than in Europe or the US. Yet, transit investments' impacts almost certainly vary in areas with different spatial patterns, land use regulations, travel habits, and income levels.

To help fill this research gap, I look at the effects one of the earliest suburban high-capacity transit investments in Mexico City: Line B of the city's 225-kilometer Metro network. Over the past half century, the Mexican government has invested heavily in high-capacity public transit, particularly the Metro, and more recently BRT and commuter rail. Although several recent investments have been in the fast-growing periphery, service outside of central areas of the Federal District remains quite sparse. Line B, which opened in 1999 and 2000, significantly expanded Metro coverage into the densely populated and fast-growing suburban municipality of Ecatepec. Average annual system-wide Metro boardings, however, have remained fairly steady despite high residential densities, low incomes, and low car ownership in the investment's service area. Why has a well-used investment into a dense and largely transit reliant-community, failed to spark a notable increase in aggregate transit ridership? To what extent has it influenced local land use patterns and travel behavior around the investment and downtown? What do findings imply for current Metro, commuter rail, and BRT investment plans in Mexico City and other parts of the world?

5.2 The influence of high-capacity transit on travel behavior and land use

The effects of high-capacity transit investments are strongly related to the city and neighborhood where they are built. Perhaps the most common expression of the land use and transit connection is that of the critical relationship between dense settlement patterns and high transit use and successful transit systems. In this section, I provide an overview of findings about the relationship between land use and high-capacity transit. I focus on findings from the US, where numerous studies have been conducted, and the developing world, where fewer studies have been published but geographic and socioeconomic differences may lead to different outcomes. In both contexts, dense and diverse land use patterns tend to encourage both high transit use and economically efficient transit systems. In both contexts, furthermore, new rail and BRT investments draw many riders from existing transit like conventional bus and informal transit. Some are drawn from cars, but the effect is smaller and new investments have tended to have negligible impacts on total vehicle travel by car.

In terms of influencing development and settlement patterns, high-capacity transit tends to have the largest impact in places where real estate markets are strong, regulation is light, and the accessibility benefits of new service are high. In the US, these conditions have been most prevalent in downtown areas, which have tended to benefit the most from transit. In places like Mexico City, however, real estate markets, land use, and regulations are different, particularly in suburban neighborhoods, which are much more densely populated and have much higher rates of transit use than in the US. Furthermore, the white-collar workers associated with downtown commercial developments rarely use transit in Mexico City. One of the largest concentrations of office towers is in the notoriously transit-inaccessible Santa Fe. As a result, new investments are likely to have a different effect on land use than in US cities, where transit and downtown office development have often gone hand in hand.

5.2.1 Land use and high-capacity transit

Various aspects of a city's form influence whether and how much people use transit. Cervero and Kockleman (1997) divided the built environment's influence on travel into three categories: density, diversity, and design. Since then, researchers have added at least two more "D's", destination accessibility and distance to transit, to measurable categories of the built environment that influence travel (Ewing, Meakins, Bjarnson, & Hilton, 2011). While precise causal relationships are complex and intertwined (Cervero & Kockelman, 1997; Holtzclaw, Clear, Dittmar, Goldstein, & Haas, 2002), dense, diverse land uses with pedestrian friendly design tend to increase transit ridership by increasing the speed, convenience, and reliability of transit while reducing the attractiveness of driving, due to congestion and higher parking and other costs. People who prefer transit, due to income constraints or personal preference, may also tend to live in dense areas (Cervero, 2007; Chatman, 2009; Mokhtarian & Cao, 2008).

More than any other measures, dense concentrations of people and jobs are strongly correlated with high transit use. This empirical relationship holds in studies of transit systems and cities (Gomez-Ibanez, 1996; Guerra & Cervero, 2011; Z. Liu, 1993; Taylor, Miller, Iseki, & Fink, 2009), neighborhoods (Baum-Snow & Kahn, 2000, 2005; Holtzclaw et al., 2002), transit stations (Cervero, 2006; Guerra et al., 2012; Kuby, Barranda, & Upchurch, 2004) and individuals and households (Ewing & Cervero, 2010; Frank, Bradley, Kavage, Chapman, & Lawton, 2008; M. Zhang, 2004). In the above studies, a doubling of residential densities around transit is associated with an increase between twenty to sixty percent in system-level and station-level transit use. Estimates of the influence on individual mode choice have tended to be smaller. In a meta-analysis of individual-level transit use, Ewing and Cervero (2010) found that a doubling of a household's neighborhood population density related to just a seven percent increase in the probability of using transit. However, halving the distance to the nearest transit stop corresponded with 29% more transit trips, thus confirming the strong relationship between transit use and dense concentrations of people around transit. Increases in job density, job accessibility, and central city jobs generally have a slightly stronger, but similar effect (Cervero, 2006; Ewing & Cervero, 2010; Guerra et al., 2012; Guerra & Cervero, 2011).

Most empirical studies focus on the marginal effects of density on transit use in cities that already have some transit. Below a certain threshold, however, marginal changes in land use are unlikely to have any influence on transit use. Pickrell (1999) found that population density appeared to exert no influence on US households' travel behavior in neighborhoods with fewer than twelve people per acre. In a cross-sectional study of 58 higher income cities around the world, Newman and Kenworthy (2006) identified fourteen jobs and people per gross acre as a similar threshold. High-capacity transit needs even denser concentrations of people and jobs. Pushkarev and Zupan (1977), estimated that cities with more than twelve housing units per acre and downtowns with more than fifty million square feet of office space could support metros and subways, while cities with more than nine units per acre and downtowns with twenty to fifty million square feet of office could support lower-cost light rail systems. In a more recent study of 23 systems over time, Guerra and Cervero (2011) confirmed that rail cost-effectiveness increases with job and population density and estimated that heavy rail systems, like metros and subways, tend to outperform light rail in densities above 28 jobs and people per gross acre. Comparing car, bus, and rail travel, Meyer, Kain, and Wohl (1965) concluded that heavy rail was the most cost-effective technology for moving people in the high-density cities of the East Coast, but the least cost-effective in medium and low density cities, where the US was primarily growing.

In developing-world cities, however, these minimum density thresholds exist even in many of the most remote neighborhoods. In Mexico City, for example, the average population density in the surrounding State of Mexico is 51 people per gross acre, well above threshold densities established in the US for the highest capacity transit. Generally poorer than US cities, however, most developing-world cities and their residents have difficulty financing high-capacity transit. Perhaps as a result, a significant portion of the literature on developing-world cities focuses on what type of high-capacity transit is most cost-effective, given limited resources (Fouracre et al., 2003; Gwilliam, 2002; Hidalgo, 2005).

Finally, the relationship between land use and high-capacity transit is more nuanced than the simplification that high-density and high transit use go hand in hand. In a case study survey of a dozen global cities with successful transit systems, Cervero (1998) describes the commonality across the vastly different but high-performance systems as the close fit between the transit system and land use patterns. Either the city adapted to the transit system, the system adapted to changing land use patterns, or both. Although all of the cities studied were denser than the average American city, density alone was not the defining characteristic. This is particularly relevant to dense, developing-world cities trying to promote successful transit systems.

5.2.2 High-capacity transit, mode choice, and congestion

There is an ongoing debate about the extent to which transit investments limit or reduce congestion and private vehicle travel. Duranton and Turner (2009) find that road traffic tends to expand or contract to conform to road capacity. Transit systems, although they allow more travel within urban areas, do not reduce vehicle travel per road mile. In a study of rail investments over time in 16 US cities, Baum-Snow and Khan (2005) found that most, though not all, rail patrons were drawn from buses. While rail users saved significant amounts of time on commutes, investment had negligible impacts on travel times by car. Fouracre et al. (2003) similarly state that high-capacity transit in the developing-world tends not to attract drivers but bus and informal transit users. In time series analyses of car use and Metro boardings in Mexico City, Crôtte, Graham, & Noland (2011, 2009a) find little to no modal switching when fuel prices and Metro fares change. They hypothesize that either Metro fares are too low to make much of a difference or that Metro users are transit dependent and thus unresponsive to changes in price. In any case, this suggests that improved rail service, like reduced fares, is unlikely to limit car use.

Nevertheless, proximity to rail and BRT stations has been strongly associated with a higher probability of using transit and a lower probability of car ownership and use in US and developing world cities (Ewing & Cervero, 2010; Zegras, 2010; M. Zhang, 2004). Households within a half kilometer of the Metro were less likely to drive than other households in Mexico City in 1994 and 2007 (Chapter 3). In a recent study of a 2003 transit strike in Los Angeles, Anderson (2012) found that, although transit has only limited influence on vehicle travel, it has a very strong influence on congestion and delays, which increased by 47% during the strike.

Despite apparent differences, general findings are not inconsistent. In Mexico City, new rail investments likely attract most riders from bus and informal transit. Where they do attract drivers or reduce informal transit routes, newly available road-space will likely be filled quickly. Despite failing to reduce car travel, a sudden system closure, like the one in Los Angeles, would likely cause significant congestion and delays. Nevertheless, public transportation officials predicted that the Line B investment would cut road traffic by fifty percent (Wirth, 1997).

5.2.3 Transit's land use impacts

Unlike the influence of land use on transit, the measured influence of transit on land use has been far less uniform. High-capacity transit investments have tended to have large impacts on urban form, where the accessibility benefits are large, government regulations and financing are supportive of development, and the real estate market is strong. In US cities, these conditions have been most prevalent in downtown locations, and indeed transit has tended to have the largest development impacts in downtown locations (Cervero & Landis, 1995, 1997; Giuliano, 2004; Huang, 1996; Porter, 1998).

Cervero and Landis (1997) evaluated the San Francisco Bay Area Rapid Transit (BART) system two decades after its opening and found that BART played a small, but not inconsequential, role in shaping growth and spatial development, although the impacts were localized rather than regional in nature. The system helped strengthen San Francisco's downtown core and encouraged development around some of the suburban stations. However, the authors also found faster population growth away from BART stations than around them. They identified local opposition to construction and weak real estate markets as the key impediments to development around stations outsider of San Francisco. Porter (1998), reviewing the influence of new rail transit on development in nineteen US regions, found that the real estate market was the primary deterrent to new development despite strong political support. In California, the expected fiscal impact of new housing has led many communities in California to avoid zoning for residential development around stations (Boarnet & Crane, 1997, 1998). Parking requirements and the desire to keep park-and-ride spots have also constrained development (Cervero, Arrington, Smith-Heimer, Dunphy, & Others, 2004). In addition to a tendency to have a stronger influence on downtown development, new rail transit has primarily influenced land use and transit use in cities that are already dense. Investigating changes to Census Tracts around new transit stations in sixteen cities using the 1970 to 2000 Censuses, Baum-Snow and Kahn (2005) found significant variation in impacts. In particular, the effects of new rail on transit use, population density, and home values were much larger in denser, more centralized cities like Boston and Washington, D.C. than in cities like San Jose and Buffalo.

Fouracre et al. (2003) and Gwilliam (2002) identify increased development and economic activity downtown as important impacts of high-capacity transit in developing-world cities. Suburban neighborhoods in developing-world cities, however, also tend to have strong, though often informal, real estate markets particularly for housing, light and weakly enforced regulations, and high transit mode share, which indicates that improvements to travel speeds from high-capacity transit will have large accessibility benefits. This suggests that transit may have large and significant land use impacts in suburban neighborhoods. Since many rail and BRT riders access stations by local bus or informal transit, however, these impacts may be diffuse and insufficient to spark new housing or commercial development.

Whether or not new development occurs, transit investments ought to influence land values, if they improve accessibility. Hedonic price models (Rosen, 1974) of the relationship between land values and proximity to rail transit are perhaps the most common measure of rail transit's influence on urban land. Studies in both US and developing-world cities have tended to find—though certainly not exclusively found—a positive relationship between rail and BRT access and commercial and residential sales prices and rents (Cervero & Kang, 2011; Cervero & Landis, 1995; Chalermpong, 2007; Hess & Almeida, 2007; Lewis-Workman & Brod, 1997; McMillen & McDonald, 2004; Nelson, 1999; Pan & Zhang, 2008; Rodríguez & Targa, 2004; Voith, 1993; Weinberger, 2001).

5.3 Informal transit, the Metro, and the Line B expansion

The Mexico City Metropolitan Area is dense and has high transit ridership. The average neighborhood population density is 145 residents per hectare, while the average person lives in a neighborhood with 165 people per hectare (59 and 67 people per acre respectively). Approximately two thirds of all trips rely on public transportation. In this sense, Mexico City conforms to the most commonly referenced and strongest aspect of the transit and land use connection. The majority of residents and households, however, rely on *colectivos*, privately owned and operated minibuses and minivans that provide public transportation services. These types of services and the route associations that manage them have been a prominent form of the urban and political landscape since a series of trolley strikes beginning in 1914 prompted entrepreneurs to convert Ford model T's for passenger transit (Davis, 1994, Chapter 2; Islas Rivera, 2000, Chapter 6). Over time, the scope and scale of privately-provided informal transit has expanded. On an average day in 2007, 11.3 million trips, 52% of all vehicular trips, relied on *colectivos* for at least part of the journey. Thirty two percent relied exclusively on this mode.

By comparison, the city's publicly owned and operated subway system, the Metro, is a newcomer and light-weight. The first 13 kilometers of the now 225-kilometer network opened in 1969 (Sistema de Transporte Colectivo, 2012). Over the past three decades, it has carried about four million trips per weekday. Although most Metro trips are multimodal, Islas Rivera et al. (2011) estimate that the Metro was the primary mode for fourteen percent of trips in both 1994 and 2007. The Metro, busy day and night, particularly during the long morning and evening peaks, provides high-capacity trunk-line service in the center of the metropolis while *colectivos* provide feeder and local service throughout the city, including densely populated suburban areas with narrow and congested road networks. This combined service has made Mexico City a case study for well-integrated transit and land use (Cervero, 1998). Of the nineteen percent of vehicular trips that involved the Metro in 2007, 70% also involved a *colectivo*. Large *colectivo* transfer hubs are common around subway stations, particularly terminals (Figure 5.1). Another 14% of Metro trips involved public buses, light rail, and other vehicular modes.

Since the Metro opened, most population growth has been in areas without Metro service, outside of the Federal District. From 1970 to 2010, the Federal District has accounted for just 17.5% of the increase in total metropolitan residents. At the time of the 2010 Census, 56% of metropolitan residents lived in the surrounding states of Mexico and Hidalgo. These residents are particularly reliant on informal transit. Nevertheless, 18% of their trips—just a little below the metropolitan average—also involve the Metro. As a result, average daily boardings are particularly high at terminal stations (Figure 5.2).

Figure 5.1 ***Colectivo*** **transfer station next to suburban Metro station, Ecatepec (2012)**

Despite rapid peripheral development, the government has only recently begun to invest in suburban high-capacity transit. Of the only eleven Metro stations in the State of Mexico, eight are on Line B, which provides Metro service into the northeast. The 24-kilometer Line B opened in two phases in 1999 and 2000 at a total investment cost of $1.3 billion in 2013 US dollars (Gwilliam, 2002, p. 113). It runs underground from east to west along the northern half of the center of the Federal District before emerging and expanding northeast into Ecatepec along the *Avenida Central*. As in many peripheral municipalities, residents of Ecatepec are poorer, have lower car ownership rates, and live in more densely populated neighborhoods than the metropolitan average. The municipality has also grown rapidly over the past four decades. As one of the earliest of the very few suburban high-capacity transit investments in Mexico City, Line B can shed light on the likely effects of future suburban Metro, BRT, and commuter rail expansions.

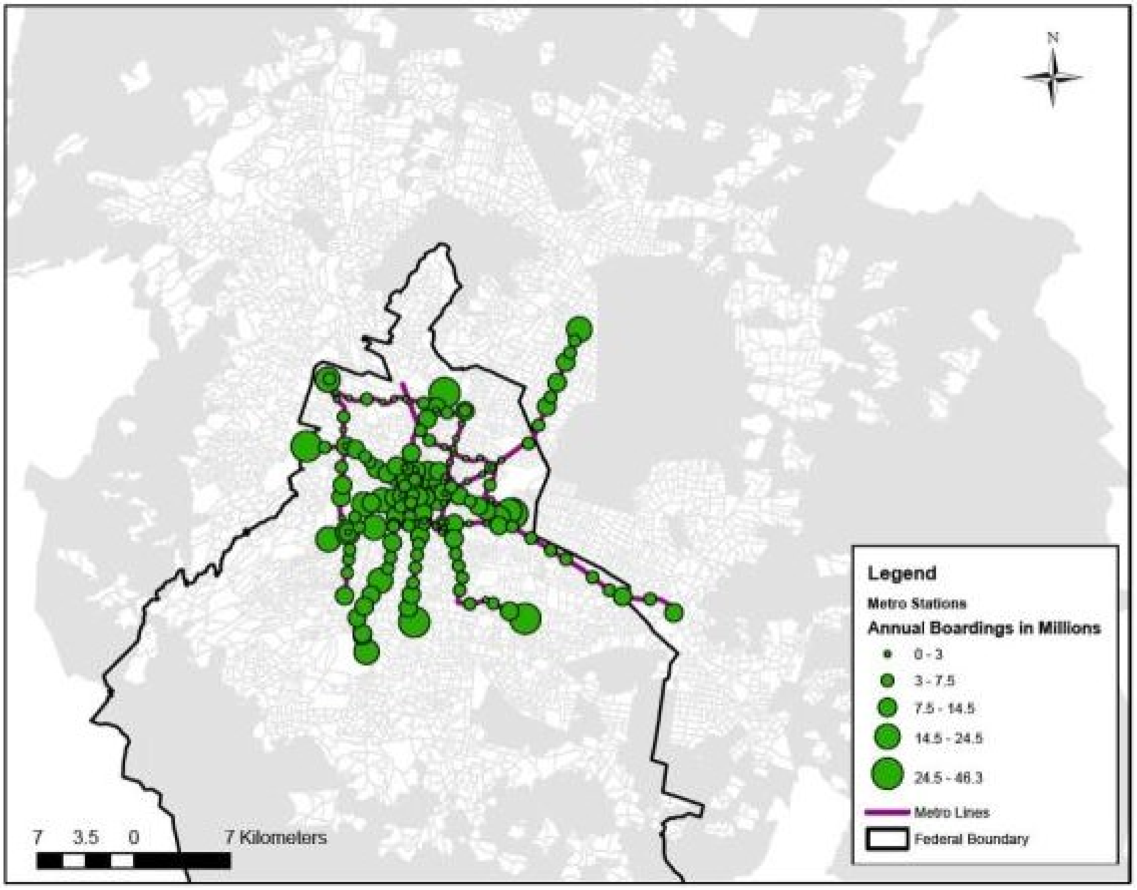

Figure 5.2 Annual boardings (millions) by Metro station in 2005

5.4 Measuring the impacts of the Line B Metro expansion

Between 1994 and 2007, the two most recent years in which the National Statistics and Geography Agency conducted large-scale household travel surveys in the Mexico City Metropolitan Area, three high-capacity transit investments opened: Metrobus 1, the city's first BRT line which runs form 30 kilometers along the central *Avenida de los Insurgentes*, Line 8, which runs southeast, and Line B. Neither of the two other investments is close enough to Line B to have had much of an influence on local settlement or travel patterns there. Both furthermore expanded service in the Federal District rather than outside of it.

To explore the effects of the suburban portion of Line B, I compare travel behavior and land use measures across the two time periods at six urban geographies: (1) within a kilometer of a suburban station of Line B, (2) in the surrounding municipality of Ecatepec, (3) in boroughs and municipalities that are a similar distance from the downtown (4) in the State of Mexico, (5) in the entire metropolitan region, and (6) within a kilometer of any metro station[11]. This allows me to disentangle effects of the Line B station from other regional and local trends and make a

[11] Residents are considered to be within one kilometer of the station if the centroid of their neighborhood is within a kilometer of the geographic center of the station. I use AGEBs, Census-Tract equivalents, as the measure of neighborhoods.

compelling case for how the Line B has influenced travel behavior and settlement patterns. Sample averages are weighted by survey expansion factors, which estimate the total number of metropolitan trips that each sample trip represents. Table 5.8 provides the number of trips recorded by the 1994 and 2007 household travel surveys at each of the six geographies analyzed. Figure 5.3 maps these geographies. For the number of people living in each geography and gross neighborhood population densities (Section 5.4.2), I use the full counts from the 1990 and 2005 Censuses.

Table 5.8 Total sample of trip by geographic analysis unit

Geography	1994	2007
1 km from Line B	1,157	1,518
In Ecatepec	10,278	15,552
1 km from Metro	24,910	40,266
2nd Ring	41,336	66,157
In Mexico State	49,792	102,498
In MCMA	125,738	231,514

To test whether the changes in travel behavior are statistically different across geographies, I fit statistical models for each outcome presented in the following section. Predictor variables include dummy variables for the year, geography tested, and an interaction between the year and geography. Rather than report the results of the several dozen statistical models, I indicate whether the change in outcomes over time across two geographies is statistically significant with 95% or more confidence. For discrete binary outcomes, such as whether a trip uses the Metro, I use a binomial logit model. For continuous variables, such as the average trip speed, I use ordinary least squares regression. For joint discrete and continuous outcomes, such as car vehicle kilometers traveled (VKT), I use a Tobit model. Finally, for the number of segments on a *colectivo*—the only count variable—I use Poisson regression. All models are estimated using R, version 12.15.1.

5.4.1 Influence on travel

Average annual Metro boardings have fluctuated around 1.4 billion for the past three decades (Figure 5.4). After a period of modest decline from 1994 to 1999, annual boardings appear to increase as a result of the opening of Line B. At the end of 1994, however, the devaluation of the Mexican peso triggered an economic crisis. Furthermore, the Metro more than doubled its fares from 40 centavos to 1 peso in December, 1995 (Wirth, 1997). It is extremely difficult, if not impossible, to disentangle the effects of the Line B on aggregate annual Metro boardings from these simultaneous shocks. Nevertheless, any effect on aggregate ridership appears to have been modest.

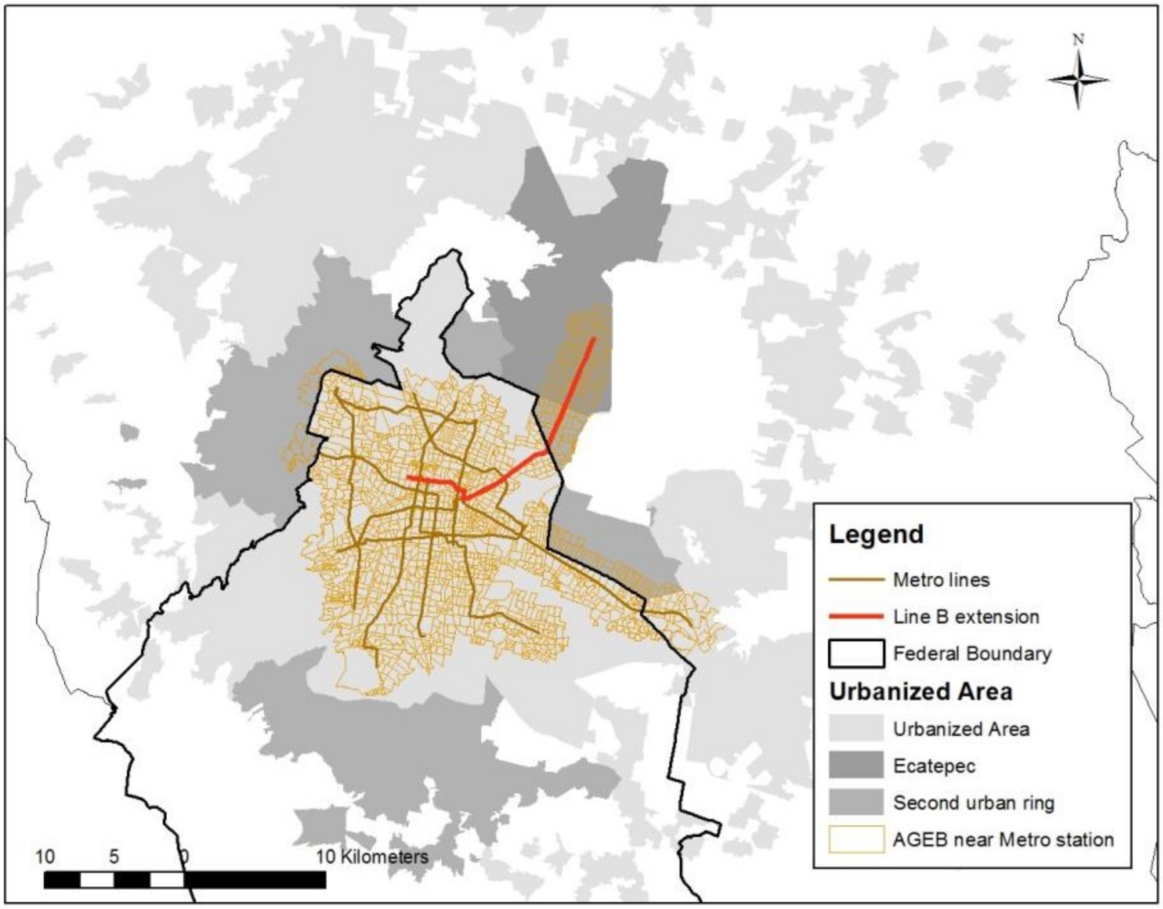

Figure 5.3 Geographic areas of analysis for study

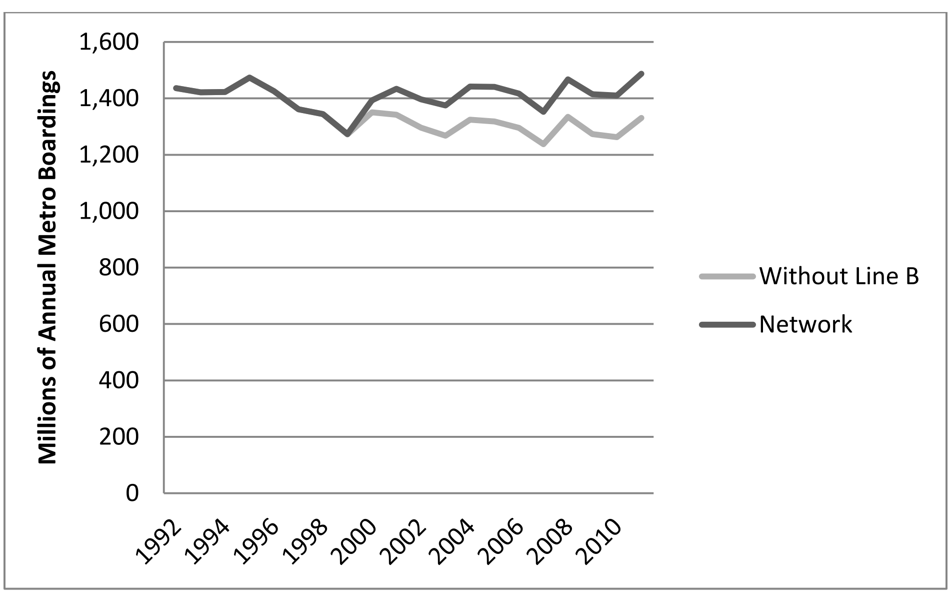

Figure 5.4 Metro system annual boardings in millions (1994- 2011)

By contrast, the effect on local ridership has been pronounced. The proportion of trips by residents of Ecatepec using the Metro increased 11% from 0.24 in 1994 to 0.27 in 2007 (Table 3.1). This increase is statistically different from the changes in Metro use in the second ring, which increased 1%, and the rest of the State of Mexico, which saw a decline in Metro mode share. Growth in Metro use of residents within a kilometer of the new stations was even more pronounced with a near doubling in mode share from 1994 to 2007. This was statistically greater than the growth in all other geographies reported. The proportion of trips using only the Metro and no other vehicular modes increased dramatically, although from a very low base. Nevertheless, residents near Line B were more than twice as likely to use the Metro as average metropolitan residents and eight times more likely to rely exclusively on the Metro. While it is likely that investment attracted new residents, who prefer to rely on transit, data limitations prevent the analysis of differences in behavior between new and long-term residents.

Table 5.9 Proportion of average weekday trips relying partially or exclusively on the Metro in 1994 and 2007

	Metro and other mode		Percent		Metro only		Percent	
Geography	1994	2007	Change		1994	2007	Change	
1 km from Line B	0.24	0.43	82.6%		0.01	0.24	3697.2%	
In Ecatepec	0.24	0.27	11.2%	*	0.01	0.04	392.6%	*
1 km from Metro	0.24	0.30	26.3%	*	0.10	0.14	47.5%	*
2nd Ring	0.18	0.19	1.3%	*	0.00	0.02	373.2%	*
In Mexico State	0.19	0.18	-3.7%	*	0.00	0.01	252.1%	*
In MCMA	0.18	0.19	3.3%	*	0.02	0.03	25.7%	*

*The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better.

The increase in Metro use has primarily come from *colectivos*, although Line B also appears to have had a smaller, localized impact on car use. The total proportion of trips using *colectivos* declined between 1994 and 2007 in all six geographies studied (Table 5.10). So did the average number of *colectivo* segments per trip. This change was statistically more pronounced around the Line B stations than in other geographies. Ecatepec also had a statistically significant reduction in *colectivo* use. In contrast with informal transit mode share, private car use increased in all geographies (Table 5.11). This growth was particularly pronounced in Ecatepec and throughout the rest of the State of Mexico. Relative to the rest of Ecatepec, the area near Line B saw a smaller percent increase in car use, but the difference was not statistically significant. If the Line B has had any effect on car use, it has marginally constrained its growth in a localized area of a municipality where car use has been rising rapidly. The growth rate in car use around Line B was statistically higher than around other Metro stations and higher than the metropolis on average. More residents of Ecatepec also rely on bus service in Ecatepec than the rest of the metropolis and suburbs (Table not presented). This likely reflects a shift in state-run bus services to connect with the new Metro line.

Table 5.10 Proportion of average weekday trips relying using *colectivos* and average number of *colectivo* segments per trip in 1994 and 2007

	Used *Colectivo*		Percent		*Colectivo* Segments		Percent	
Geography	1994	2007	Change		1994	2007	Change	
1 km from Line B	0.74	0.29	-61.3%		0.95	0.32	-66.4%	
In Ecatepec	0.76	0.52	-31.7%	*	0.98	0.60	-38.6%	*
1 km from Metro	0.46	0.37	-19.9%	*	0.55	0.43	-22.6%	*
2nd Ring	0.69	0.55	-20.9%	*	0.89	0.69	-22.2%	*
In Mexico State	0.69	0.54	-21.6%	*	0.87	0.65	-25.0%	*
In MCMA	0.61	0.52	-16.1%	*	0.78	0.64	-17.7%	*

*The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better.

Table 5.11 Proportion of average weekday trips relying on cars and average per capita vehicle kilometers traveled (VKT) per trip in 1994 and 2007

	Car Trips		Percent		VKT per Passenger		Percent
Geography	1994	2007	Change		1994	2007	Change
1 km from Line B	0.21	0.29	37.6%		1.42	1.77	24.3%
In Ecatepec	0.14	0.21	50.7%		1.04	1.53	46.7%
1 km from Metro	0.29	0.31	7.5%	*	1.04	1.27	21.9%
2nd Ring	0.22	0.29	32.9%		1.13	1.53	35.6%
In Mexico State	0.19	0.26	36.1%		1.14	1.59	39.2%
In MCMA	0.24	0.29	21.3%	+	1.10	1.47	33.2%

*The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better. +Significant at the 90% confidence level.

The Line B investment appears to have had some influence on average travel speeds, but only for trips by public transportation (Table 5.12). Although the difference was not statistically different from any other geography, average travel speeds declined more quickly around Line B, than away from it. By contrast, the speed of trips by public transit (including bus, Metro, and *colectivo*) increased at a statistically significant rate around Line B, as well as around all other Metro stations and in Ecatepec. The rest of the city saw a four to five percent decrease in average speeds by all modes, including public transportation. In addition to increasing transit travel speeds, Line B has had a direct impact on consumers' finances. The inflation-adjusted average cost of transit per trip and per kilometer decreased by close to one-third (Table 5.13). This change is significantly greater than changes over time at all other geographies, where cost per trip increased. The cost per kilometer increased in the metropolis as a whole, but decreased by 14% around Metro stations. This decrease around Metro stations was significantly smaller than the decrease around Line B. In addition to trips speeds and costs, Line B also influenced destination locations, but I will discuss this impact in the following section on land use.

Table 5.12 Average trip speeds in kilometers per hour (KPH) for all trips and by public transportation in 1994 and 2007

Geography	Avg. speed (KPH) 1994	2007	Percent Change	Avg. transit speed (KPH) 1994	2007	Percent Change	
1 km from Line B	14.02	13.17	-6.1%	12.97	13.33	2.7%	
In Ecatepec	12.87	12.59	-2.1%	12.40	12.43	0.3%	*
1 km from Metro	10.79	10.36	-4.0%	9.72	9.77	0.6%	*
2nd Ring	11.85	11.28	-4.8%	11.05	10.59	-4.1%	*
In Mexico State	13.00	12.38	-4.8%	12.49	11.93	-4.5%	*
In MCMA	11.91	11.36	-4.6%	11.16	10.75	-3.7%	*

*The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better.

Table 5.13 Average total expenditure in inflation-adjusted 2007 pesos on public transportation per trip and by kilometer in 1994 and 2007

Geography	Total Cost 1994	2007	Percent Change		Cost per km 1994	2007	Percent Change	
1 km from Line B	6.62	4.65	-29.8%		0.85	0.56	-34.3%	
In Ecatepec	7.25	7.48	3.2%	*	0.90	0.95	5.7%	*
1 km from Metro	3.85	3.92	1.9%	*	0.97	0.84	-14.0%	*
2nd Ring	6.03	6.59	9.2%	*	1.01	1.03	1.6%	*
In Mexico State	7.04	8.00	13.7%	*	0.98	1.04	5.3%	*
In MCMA	5.59	6.34	13.3%	*	0.97	0.95	-2.5%	*

*The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better.

5.4.2 Influence on urban form

Perhaps the most notable influence of the Line B on metropolitan form is that it increased the proportion of residents of the State of Mexico living near the Metro by about five times (Table 5.14). Despite this large suburban increase, a smaller proportion of all Metropolitan residents lived close to Metro stations in 2005 than in 1990. As shown in the previous chapter, most recent population growth has occurred in large, commercially constructed housing developments on the periphery. Furthermore, population density has decreased around most other Metro stations, as indeed it has in most of the Federal District. In sum, the metropolis has grown much more rapidly away from the Metro than around it. While the Line B appears to have significant local effects these are quite modest in relation to overall trends in settlement patterns.

To visualize where localized effects are likely to have occurred, I map the density of trips using Line B by household location (Figure 5.5) and by destination location for non-home trips (Figure 5.6). Most Line B users live within three kilometers of the line and use it to travel to central locations in the Federal District. That said, there are some concentrations of homes that rely Line B in the Federal District as well as some destination hubs near stations in Ecatepec. Nevertheless, the primary land use effects of the Line B most likely relate to housing in the northeast and commercial uses in the central area.

Table 5.14 **Residents per hectare and the percent of residents within one kilometer of the Metro in 1990 and 2005**

	Residents per Hectare		Percent of residents within 1 km of transit	
Geography	1990	2005	1990	2005
1 km from Line B	162	189	0%	100%
In Ecatepec	141	154	0%	8.1%
1 km from Metro	190	168	100%	100%
2nd Ring	151	150	1.8%	5.4%
In Mexico State	109	126	0.4%	2.5%
In MCMA	143	145	16.5%	13.9%

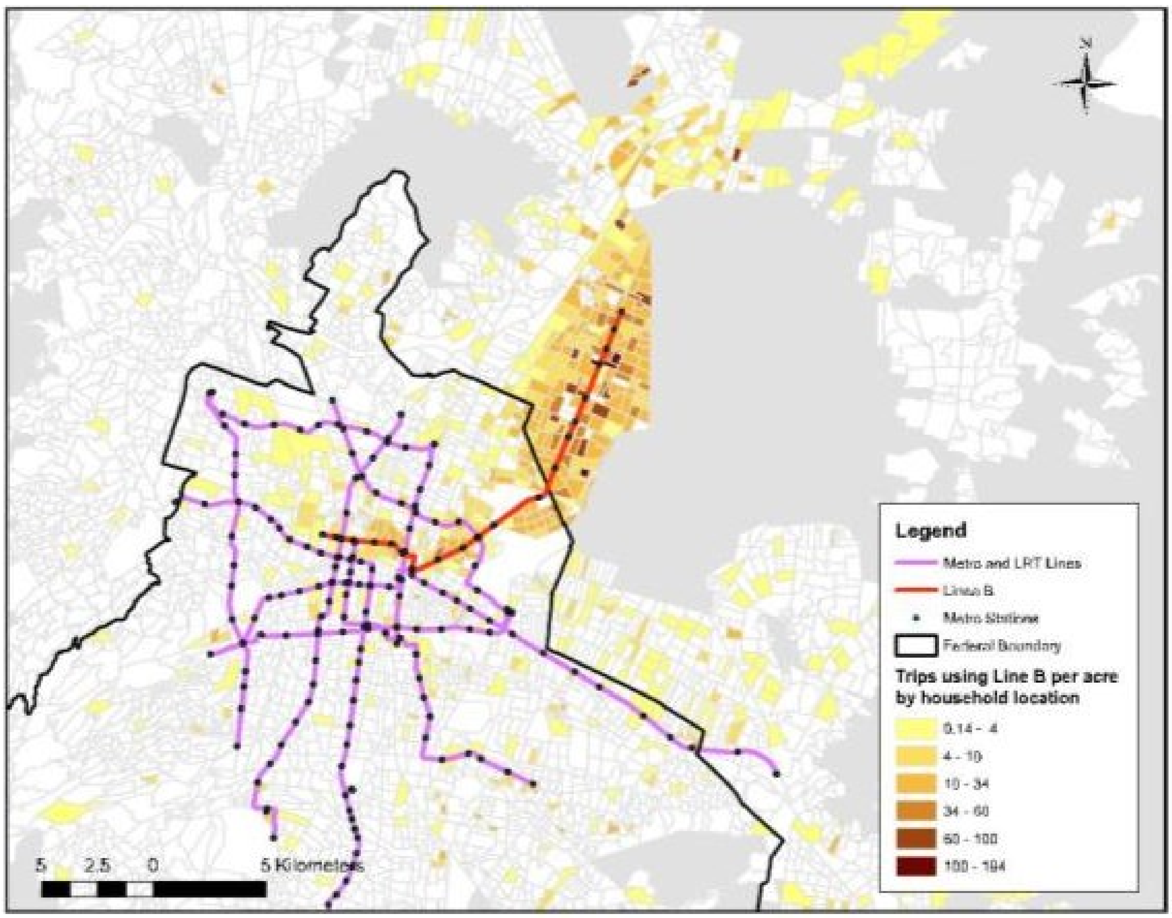

Figure 5.5 Trips using Line B per acre by household location of trip maker

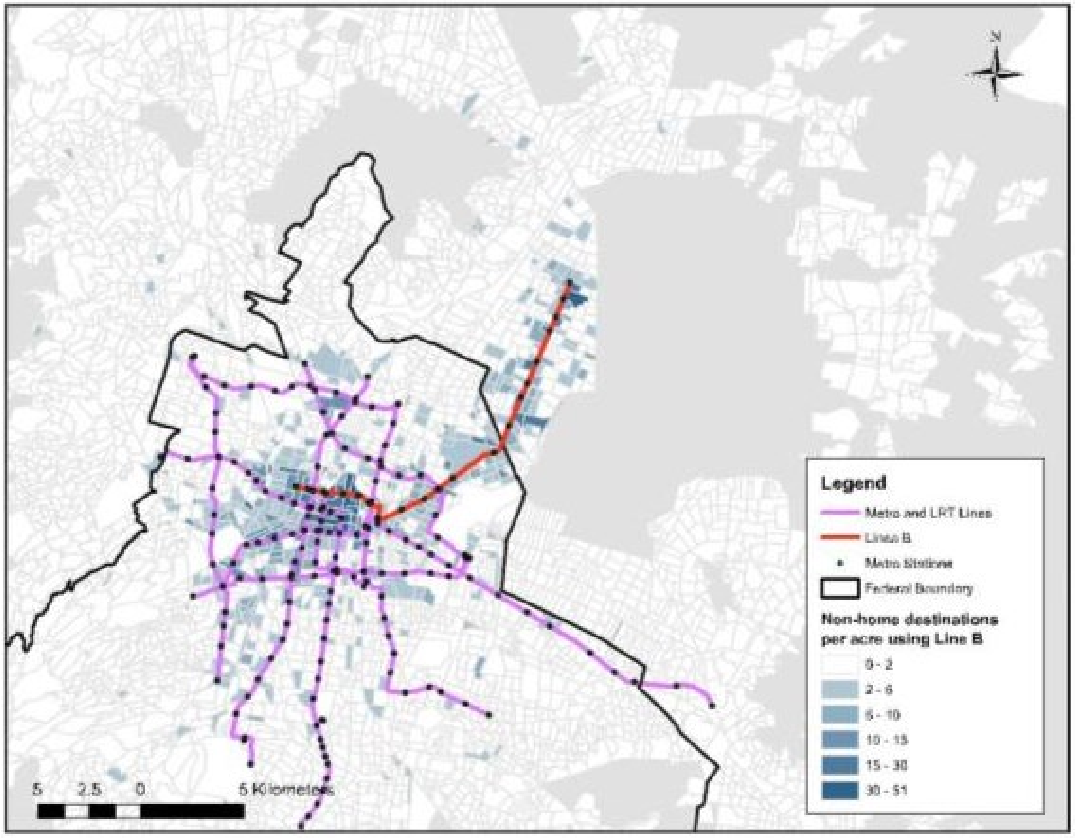

Figure 5.6 Non-home trip destinations using Line B per acre

Indeed, residential densities increased significantly more for households living around the Line B than for households in other geographies (Table 5.15). Figure 5.7, taken from an overpass above Ecatepec station, shows the typically dense two- and three-story residential and commercial developments that are common around Line B and throughout much of Ecatepec. Average household incomes decreased more than the rest of Ecatepec but less than around other Metro stations. In addition to losing residents, neighborhoods around Metro stations have likely lost some wealthier households and attracted poorer ones who put a greater value on good transit access. Nevertheless, households around Metro stations in 2007 remained wealthier than the metropolitan average. Unfortunately, due to data limitations in 1994, I was unable to look at changes in rent or home values over time.

The Line B's influence on trip destinations, and thus likely impact on central urban form, is less pronounced. In general, the proportion of all trips, including work trips, to the urban center—measured here as the four most central boroughs of the Federal District—decreased from 1994 to 2007. This decline has been less pronounced around the Line B, where the proportion of work trips to the center actually increased. If the Line B has had much impact on central commercial space, it has likely been small and difficult to quantify. In short, the investment appears to have spurred significant residential growth around stations but probably had limited impact on central development. That said, the increased number of residents, coupled with increased central work trips, led to an even larger overall uptick in the total number of central trips. Despite this, the land use effects are questionable. Metro users do not tend to work in the large commercial developments, often associated with downtown growth around transit, and are therefore unlikely to influence this type of construction. I did not, however, have sufficient commercial land use data to address this question more directly.

Figure 5.7 View of commercial and housing development from Ecatepec Station, Line B (2012)

Table 5.15 People per hectare in average household's neighborhood and average household income in 1994 and 2007

	People per hectare		Percent		Monthly Income**		Percent	
Geography	1994	2007	Change		1994	2007	Change	
1 km from Line B	165	211	27.8%		10,309	10,175	-1.3%	
In Ecatepec	158	172	8.8%	*	7,825	8,453	8.0%	+
1 km from Metro	210	188	-10.3%	*	13,569	12,210	-10.0%	
2nd Ring	176	171	-2.9%	*	10,032	10,251	2.2%	
In Mexico State	148	149	0.4%	*	9,209	9,176	-0.4%	
In MCMA	173	165	-4.5%	*	10,954	10,534	-3.8%	

*The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better. +Significant at the 90% confidence level.

**Note that income estimation methods differ across the two years. For a full description of the discrepancies, see Chapter 3.

Table 5.16 Proportion of trips and work trips with destinations in the four most central boroughs of the Federal District in 1994 and 2007

Geography	All Trips 1994	All Trips 2007	Percent Change		Work Trips 1994	Work Trips 2007	Percent Change	
1 km from Line B	0.17	0.17	-0.6%		0.43	0.45	4.4%	
In Ecatepec	0.14	0.12	-12.7%		0.34	0.29	-12.5%	
1 km from Metro	0.59	0.51	-12.9%		0.58	0.54	-6.5%	
2nd Ring	0.13	0.12	-7.7%		0.34	0.29	-15.7%	+
In Mexico State	0.12	0.10	-15.6%	+	0.30	0.25	-18.0%	*
In MCMA	0.26	0.20	-23.7%		0.40	0.33	-18.3%	*

*The change in value from 1994 to 2007 is statistically different from the change that occurred within a kilometer of Line B at the 95% confidence level or better. +Significant at the 90% confidence level.

5.5 Conclusion

The primary influence of the Line B has been to reduce the travel times and costs of public transportation around the investment and throughout Ecatepec. Residents in neighborhoods within a kilometer of stations saved 1.5 minutes and 2 pesos per trip on average public transit trips relative to 1994 and even more relative to changes in other geographies. Lower costs and faster speeds have encouraged a significant increase in Metro use and population density around the investment. On an average weekday in 2007, residents of Ecatepec generated 65,000 more Metro trips than in 1994. In terms of mode, the Line B has drawn primarily from *colectivos* with little observable influence on car use. That said, high-capacity transit creates less congestion, less pollution, and fewer collisions per trip than informal public transportation. Perhaps most importantly, it provides high-quality service during peak hours, when congestion significantly reduces travel speeds for other modes.

Despite providing improved service to downtown, the Line B has likely had only a limited centralizing effect. In this respect, the land use impacts of Line B have differed significantly from those observed in US cities, where new investments have primarily encouraged downtown commercial development. Although the Line B has encouraged more centralized trips, particularly work trips, this effect is not always statistically significant. Even if the effect on travel were significant, a strong impact on urban form would be unlikely. The wealthy white-collar workers associated with high rise commercial development rarely use transit and the investment appears only to have influenced transit speeds. This conforms to Navarro and González's (1990) observation that the Metro likely increased land values in poor neighborhoods but decreased them or had no effect in wealthy areas. As a public policy, suburban Metro expansions appear an ineffective tool for reducing congestion or promoting downtown development, but an effective one for improving travel for low and moderate income households.

It also appears to be an effective way to maintain and increase Metro mode share. Like Ecatepec, many suburban municipalities have lower household incomes and car ownership rates than the metropolitan average. These municipalities, furthermore, are becoming more densely populated over time and continue to absorb most metropolitan growth. Despite the promise of higher ridership, expanding high-capacity transit into the suburbs faces significant challenges. First, providing similar Metro coverage per capita in the State of Mexico as in the Federal

District would require at least new 230 kilometers of Metro. At the same cost per kilometer of the Line B, that would cost $12.4 billion in 2013 US dollars. Given lower population densities in the most peripheral neighborhoods, the actual amount of track and stations needed for equivalent service would be even higher.

Second, without radical and unpopular changes in fare policy, Metro expansions will increase the already burdensome operating subsidy that goes to the Metro. Fare revenues cover around half of operating expenses (Gwilliam, 2002) and a standard fare covers less than a third of the total cost of providing the service (Sistema de Transporte Colectivo, 2012). Expanding high-capacity transit service will have a relatively smaller effect on ridership and fare revenues than on costs. In Ecatepec, 24% percent of trips already used the Metro in 1994. In 2007, this figure increased to 27%. Given the flat fare system, however, only new trips are likely to generate any new revenue. Even residents of remote municipalities in the third and fourth urban ring (see previous chapter for urban rings), well outside of the Metro service coverage, used the Metro during 14% percent of weekday trips in 2007. Each new suburban investment will reduce the overall ratio of fare revenue to capital and operating costs, as well as raising the total costs. As a result systematic attempts to increase Metro coverage will require changes to fare policy or greater subsidy. Given that the Line B reduced costs for transit users and increased travel speeds, there may be an opportunity to increase fares in conjunction with new investments.

In the face of high and rising costs, the government has reoriented its investment policy toward developing a BRT network. Due to lower investment costs, high passenger volumes, and a higher success rate in covering operating costs, BRT has been touted as the appropriate technology for high-capacity transit in developing countries (Fouracre et al., 2003; Gwilliam, 2002; Hidalgo, 2005). Since 2005, four BRT lines have opened in the Federal District and one in the State of Mexico. Indeed, the first line has covered operating its expenses and provided sufficient revenues to finance its private operation. The experience of the Line B, however, provides a cautionary tale for the future of BRT in Mexico City. When Metrobus 1, the first BRT line, opened, a standard fare cost twice as much as a Metro fare, but only covered thirty kilometers. Relative to the Metro, Metrobus 1 carries about six thousand fewer passengers per day per kilometer of right of way. Each new Metrobus investment, however, carries fewer passengers. The number of daily passengers per kilometer of the system is only around half of the initial investment (Gobierno del Distrito Federal, 2013). Furthermore, given free transfers, each trip on a new line is less likely to add new fare revenue. As the BRT system expands, it is likely to face many of the same challenges as the Metro system. While its investment costs are likely to remain lower than the Metro, its current operating performance is more related to higher fares and lower spatial coverage than to technology.

Mexico City's transit system, in general, and the effects of the Line B, in particular, offer lessons for other medium and large Latin American, Asian, and African cities with similarly dense suburban environments. Even massive investments in high-capacity public transportation are unlikely to offset the need for informal transportation, particularly for low and moderate income residents, who live outside of the service area. While the Line B reduced residents' use of *colectivos* in the direct catchment area, more than half of trips in Ecatepec in 2007 continued to use them. New high-capacity transit both compliments and competes with informal transit. While high-capacity transit investments may replace informal transit on trunk lines, feeding these lines will remain a critical function for low and medium capacity transit.

Improving informal transit has a major and somewhat neglected role to play in improving public transportation and reducing car use in Mexico City as well. Despite the significant loss in the overall informal transit mode share—62% of trips used at least one *colectivo* in 1994, compared to 52% in 2007—more than half of all trips continue to rely on *colectivos*. As a result, even minor improvements, such as safer, more comfortable vehicles or lane or signal priority, will tend to have fairly large and widespread economic benefits. Most of the growth in the share of trips using personal cars, furthermore, appears to have come from *colectivos*. Flexible informal transit does a much better job of connecting a wide array of origins and destinations than centrally focused high-capacity transit. It therefore has a better chance of competing with the private car than the Metro or BRT. In the absence of an extensive reorientation of new commercial and housing development away from the periphery and toward transit or massive and costly expansion of the network, the Metro is unlikely to be able to compete with many of these trips. Like the Line B, individual suburban expansions will likely concentrate housing development and encourage a shift from informal to formal transit in the immediate vicinity, but do little to change overall development patterns or stem the increase in private car use.

Chapter Six. Conclusions

Densely populated suburban neighborhoods that rely on privately provided informal transit in minivans and minibuses have emerged as Mexico City's predominant form of human settlement. Some of these settlements developed informally over the past half-century, while others were built rapidly by the large commercial housing developers that have come to dominate housing construction in the 21st century. Despite cosmetic, historical, geographic, and physical differences, together they have provided the lion's share of low- and moderate-income housing production in recent years. Over time, furthermore, the two types of settlement have become more similar, as residents of informal settlements gain legal title and infrastructure, and residents of commercially produced housing developments build additions and convert units and parking spaces to shops and other commercial uses.

The previous four chapters have investigated the relationship between land use, transportation, and travel behavior throughout Mexico City, with an emphasis on these suburbs. Chapter 2 explored the recent demographic, economic, and political trends that have contributed to the Mexico City's emergence as a primarily suburban city and the metropolis' contemporary urban form and travel patterns. Chapters 3 through 5 then framed, posed, and explored three questions about Mexico City's evolving urban and suburban landscapes and the nature of household travel decisions:

(1) How has the influence of the built environment on travel changed, as more households have moved into the suburbs and car use has increased?
(2) How much are the recent trends of increased suburbanization, rising car-ownership, and the proliferation of massive commercially-built peripheral housing developments interrelated?
(3) How has one of the first and only suburban high-capacity transit investments influenced local and regional travel behavior and land use?

In this concluding chapter, I briefly synthesize and summarize the findings of these three chapters and two principal implications for land use and transportation policy. Each previous chapter contains a more detailed summary of the findings and policy implications that are specific to the chapter's principal research question and analysis.

6.1 Summary of key findings

Suburban Mexico City has far lower rates of car ownership and use than central areas. The further a household lived from downtown in 1994 and 2007, the less likely its members were to drive a car, even after controlling for income and other household attributes. This effect, however, has diminished over time. Furthermore, once members of a household drive, they drive more as their distance from downtown increases. Similarly, high job and population densities substantially decreased the probability of driving at all, but have had a much smaller influence on how many kilometers of vehicle travel a household generates. Looking only at households with driving members—a little less than a third of the total sample—neither job nor population density had a statistically significant influence on total kilometer of household vehicle travel. The combination of *colectivos*, public buses, and the Metro has provided sufficient transit service to constrain car use in the densely populated suburban environments of Mexico City. Once suburban residents begin to drive, however, they tend to drive a lot, regardless of the features of the built environment.

The recent shift from informal development to massive commercially-constructed housing developments in the suburbs does not appear to have produced radically different travel behavior. Despite available parking, most residents do not own cars and continue to rely on public transportation, primarily *colectivos*. Residents frequently convert parking spaces to residential additions, shops, or offices. Furthermore, wealthier households have a strong preference for more central housing locations, as well as for car ownership. Average travel times in central locations are significantly lower than in peripheral ones within and across modes. With readily available parking and long distances from other parts of the city, however, the new commercial developments represent a large and growing potential source of vehicle travel. This is particularly so, if suburban incomes increase, but policy or market conditions prevent new more centrally located housing supply.

Given the potential for large increases in suburban vehicle travel, understanding the effects of high-capacity transit investments into the suburbs is particularly important. To that end, I looked at how one of the few suburban Metro investments influenced land use and travel behavior from 1994 to 2007. The investment sparked a significant increase in Metro use in its immediate vicinity. Most of this increase, however, appears to have come from *colectivos*, rather than cars. While this shift reduced transit costs and increased transit speeds for local residents, it also increased government subsidies for the Metro. The Metro furthermore has remained highly dependent on *colectivos* to provide feeder service. In terms of land use, the investment increased population density around suburban stations but appears to have had little to no effect on downtown commercial development, where it might also have been expected to have a significant influence. In short, the investment shows much of the promise and problem with expanding high capacity transit service into the suburbs. Ridership is likely to be high, but so will subsidies, and the effect on car ownership and urban form are likely to be modest.

6.2 Policy implications

Two principal policy themes recur throughout this dissertation. First, there is a physical disconnect between the homes of most transit users and the location of most high-capacity public transit. This stems from the strong preference of households that most value accessibility to purchase cars and live in central housing locations, where jobs and other social and cultural activities are concentrated, but transit supply is also best. Households that value accessibility less, often due to lower incomes but also due to preferences, are most likely to live in the periphery and use public transportation. This suggests three potential strategies for improving public transportation in Mexico City. The first is to increase high-capacity transit into the suburbs. Chapter 5 demonstrates the likely effects of such a policy: increased local suburban densities, increased subsidies, lower costs and higher speeds for users, and decreased, though still significant, reliance on *colectivos*. The second is to increase the number of employment and other destinations in the suburbs. Since many suburban residents work in low-wage service industries, whether informal or formal, that locate near wealthier centralized households, this may be unrealistic. Neither a wealthy household nor an office is likely to relocate to the suburbs for low-wage workers or janitorial staff. The third is to reorient new low- and moderate-cost housing developments away from the periphery and toward areas that already have good transit supply. Findings from Chapter 4 indicate that households are likely to have a strong preference for this policy. Central land, however, is more expensive and its availability more constrained. It is unclear how much financial support such a policy to increase central housing supply for low and moderate income households would require. Nevertheless, results from the housing location model in Chapter 4 and the analysis of impact of the Metro's Line B on the cost of public transit trips indicate that most households would be willing to spend more on central than peripheral housing. In any case, the current policy of building low-cost housing on the periphery and investing in most high-capacity transit in the center has its own direct and indirect public costs.

Second, there is a need to focus transportation policy on improving *colectivos*. This form of privately operated and flexible, medium-capacity transit provides service to more people in Mexico City than any other form of transportation. It is also the type of transportation around which most of the city's dense and transit-dependent suburbs have grown and continue to grow. Across-the-board marginal improvements to *colectivo* travel speeds and reliability would likely have a greater economic impact than any of the currently proposed transportation infrastructure investments. These economic benefits, furthermore, would be far more widely spread and primarily benefit the poor and working class. Nevertheless, current policy debates and prescriptions focus almost exclusively on cars, the Metro, and BRT. Given the potential financial and time costs of executing either a significant increase in suburban high-capacity transit or a reorientation in contemporary housing policy, *colectivos* are likely to remain the primary form of public transportation in the foreseeable future. They are almost certainly the car's chief competitor for suburban households on the verge of car ownership. As such, the significant drop in *colectivo* use between 1994 and 2007, largely ignored, should be viewed with alarm. Without intervention, increasing suburban car use will continue to lower road-based transit speeds, thus also increasing travel times, operating costs, and eventually fares, and further decrease transit use.

Although based on the study of Mexico City, findings from this dissertation offer insights for many cities throughout the developing world. Few cities can boast of as much high-capacity transit or as much public transit use, both absolute and as a share of trips, as Mexico City. With more than 200 kilometers of high-capacity transit, a fifth of metropolitan trips relied on the Metro, BRT, or light rail in 2007. Nearly all of these trips, however, also relied on some other form of public transit, most often *colectivos*. The Metro line, commuter rail line, and four BRT lines that have opened in the last five years do not appear to have had much of an effect on high-capacity public transit mode share. This is not to say that these lines should not be built. It does, however, indicate that the many cities around the world that are highly reliant on informal, medium capacity transit to serve their dense and fast-growing suburbs are unlikely to stop the proliferation of cars or the need for informal transit by investing in high-capacity transit lines. This is particularly the case where wealthy households have a preference for central housing locations, as well as for cars. Improving informal transit, the car's primary competitor, is an essential strategy for improving accessibility for the poor and constraining the rapid rise in global car ownership and use.

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Appendices

Appendix A: Geographic units

Boroughs and municipalities in Mexico City Metropolitan Area

The Mexico City Metropolitan Area (*Zona Metropolitana del Valle de México*) contains the 16 boroughs of the Federal District and 60 surrounding municipalities, 59 in the State of Mexico and 1 in the State of Hidalgo. Figure A.1 maps the border of the metropolitan area as well as the municipalities and boroughs within it. Table 3.1 provides a key to match the names of boroughs and municipalities to the map, as well as a list of the associated urban rings (See Chapters 2 and 4). Boroughs beginning in "09" are from the Federal District. The code "15" indicates a municipality in the State of Mexico; "13", Hidalgo. For additional documentation, see INEGI (2005).

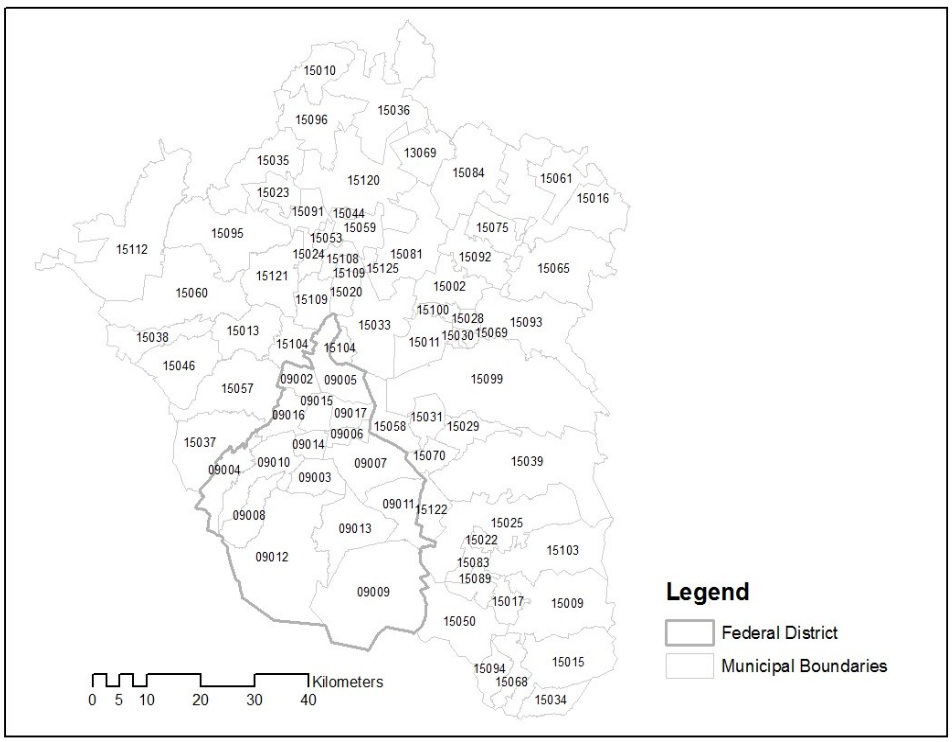

Figure A.1 Map of metropolitan area's boroughs and municipalities

Table A.1 List of metropolitan area's boroughs and municipalities

Borough / Municipality	Code	Urban Ring
Benito Juárez	09014	Center
Cuauhtémoc	09015	Center
Miguel Hidalgo	09016	Center
Venustiano Carranza	09017	Center

Azcapotzalco	09002	First
Coyoacán	09003	First
Gustavo A. Madero	09005	First
Iztacalco	09006	First
Iztapalapa	09007	First
Álvaro Obregón	09010	First
La Magdalena Contreras	09008	Second
Tlalpan	09012	Second
Xochimilco	09013	Second
Ecatepec de Morelos	15033	Second
Naucalpan de Juárez	15057	Second
Nezahualcóyotl	15058	Second
Tlalnepantla de Baz	15104	Second
Cuajimalpa de Morelos	09004	Third
Milpa Alta	09009	Third
Tláhuac	09011	Third
Atizapán de Zaragoza	15013	Third
Coacalco de Berriozábal	15020	Third
Cuautitlán	15024	Third
Chalco	15025	Third
Chicoloapan	15029	Third
Chimalhuacán	15031	Third
Huixquilucan	15037	Third
Ixtapaluca	15039	Third
Nicolás Romero	15060	Third
La Paz	15070	Third
Tecámac	15081	Third
Tultitlán	15109	Third
Cuautitlán Izcalli	15121	Third
Valle de Chalco Solidaridad	15122	Third
Tizayuca	13069	Fourth
Acolman	15002	Fourth
Amecameca	15009	Fourth
Apaxco	15010	Fourth
Atenco	15011	Fourth
Atlautla	15015	Fourth
Axapusco	15016	Fourth
Ayapango	15017	Fourth
Cocotitlán	15022	Fourth
Coyotepec	15023	Fourth
Chiautla	15028	Fourth
Chiconcuac	15030	Fourth
Ecatzingo	15034	Fourth

Huehuetoca	15035	Fourth
Hueypoxtla	15036	Fourth
Isidro Fabela	15038	Fourth
Jaltenco	15044	Fourth
Jilotzingo	15046	Fourth
Juchitepec	15050	Fourth
Melchor Ocampo	15053	Fourth
Nextlalpan	15059	Fourth
Nopaltepec	15061	Fourth
Otumba	15065	Fourth
Ozumba	15068	Fourth
Papalotla	15069	Fourth
San Martín de las Pirámides	15075	Fourth
Temamatla	15083	Fourth
Temascalapa	15084	Fourth
Tenango del Aire	15089	Fourth
Teoloyucan	15091	Fourth
Teotihuacán	15092	Fourth
Tepetlaoxtoc	15093	Fourth
Tepetlixpa	15094	Fourth
Tepotzotlán	15095	Fourth
Tequixquiac	15096	Fourth
Texcoco	15099	Fourth
Tezoyuca	15100	Fourth
Tlalmanalco	15103	Fourth
Tultepec	15108	Fourth
Villa del Carbón	15112	Fourth
Zumpango	15120	Fourth
Tonanitla	15125	Fourth

Urban areas and urban screen

Municipal boundaries do not reflect terrain features, such as lakes or mountains, or urbanized areas of the metropolis. Peripheral municipalities, in particular, are much larger than their currently urbanized or developable areas. As a result, maps based on municipal boundaries tend to produce visually skewed maps of Mexico City's settlement patterns. To produce more accurate visualizations of urban and demographic trends by municipality, I screen portions of boroughs and municipalities that are not urbanized using INEGI's Urban Areas (*Localidades Urbanas*) shapefile in maps that present data by municipality and borough, rather than AGEB. Figure A.2 and Figure A.3 show the average annual population growth by municipality with and without the urban screen. Excluding the screen gives more visual weight to peripheral municipalities that contain significant amounts of non-urbanized areas.

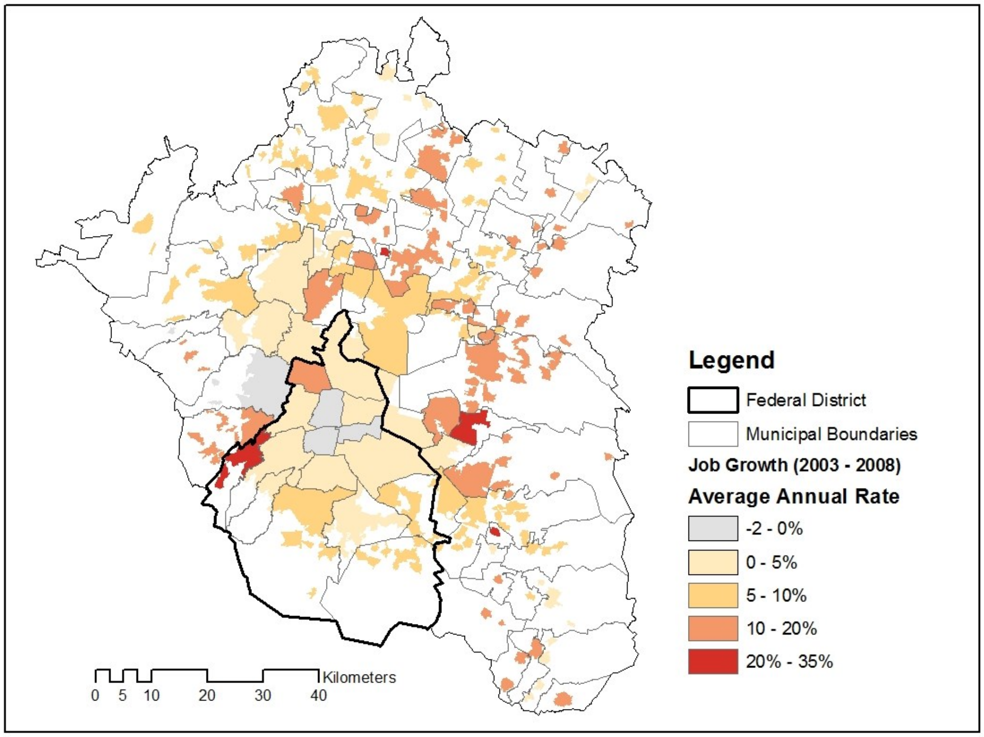

Figure A.2 Job growth by municipality and borough with urban screen

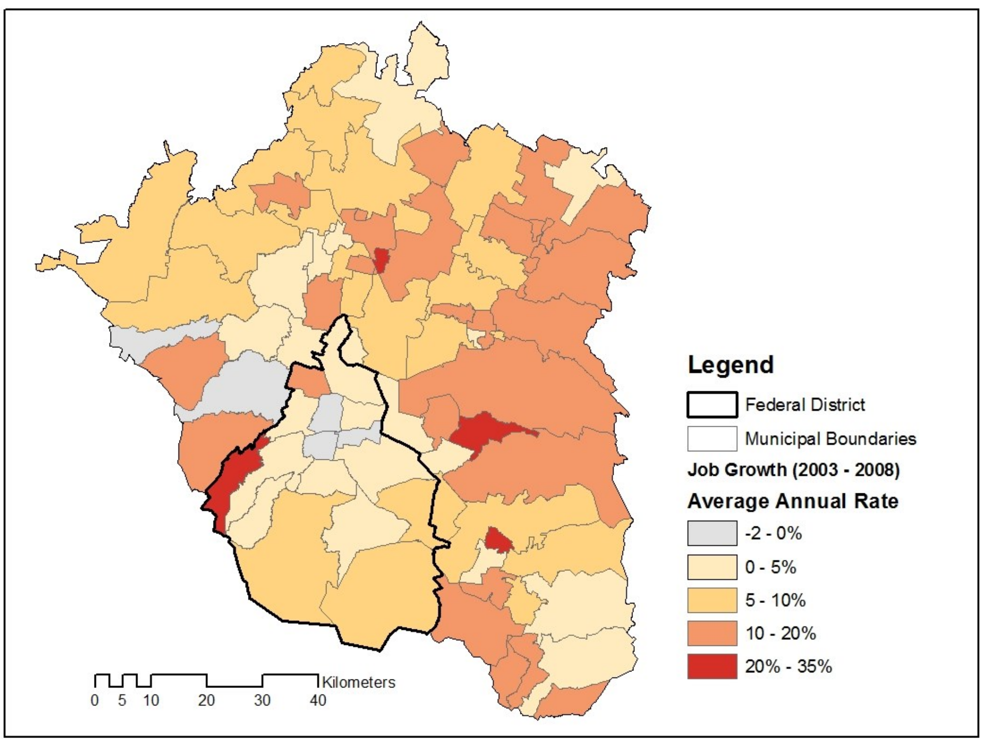

Figure A.3 Job growth by municipality and borough without urban screen

AGEBs

The smallest geographic unit of analysis in this dissertation is the AGEB (*Área Geográfico Estadística Básica*). It is roughly the equivalent size of a US Census Tract. In 2005, the metropolitan area contained approximately 5,000 AGEBs, with an average of 4,000 residents per AGEB. In 1990, AGEBs were slightly larger and there were approximately 3,000 of them in the metropolitan area. Shapefiles from 2005 were directly available from the National Institute of Statistics and Geography (INEGI). In order to generate shapefiles for 1990, I used INEGI's 2000 shapefiles and the 1990 to 2000 national conversion table. After converting 2000 AGEB codes to 1990 ones, I joined shapefiles that had been subdivided between 1990 and 1995 and 1995 and 2000, using ArcGIS 9.3's dissolve tool.

Appendix B: Data

This dissertation relies primarily on two metropolitan household travel surveys conducted in 1994 and 2007. I combine data from these surveys with transportation infrastructure and census shapefiles from the National Statistics and Geography Agency (INEGI) and the Secretary of Transportation and Highways (SETRAVI) and a national municipal database (INEGI, 2012a). The 2007 survey contains information on just over 50,000 households—including income, household size and composition, and geographic location to the AGEB—and 200,000 weekday trips—including the geographic location of origins and destinations, trip purpose, trip duration, trip time, out-of-pocket expenses, and mode of travel. It also includes expansion factors that represent the proportion of total households and trips in the metropolitan area that each surveyed household and trip represent. The 1994 travel survey was smaller and contains data on 126,000 trips. Unfortunately, I did not have access to the full 1994 travel survey and approximated household-level statistics as described in Chapter 3. For additional survey documentation, see INEGI (2007b). The following text describes the sources and calculation of data used in the dissertation's statistical analyses that are not taken directly from the survey.

Vehicle Kilometers Traveled

To calculate vehicle kilometers traveled, I converted AGEB shapefiles to centroid points, using the ArcGIS feature to point tool. I then calculated center to center network distances using the road network and ArcGIS's network analyst extension. I then added a column for distances traveled to the dataset on trips taken during an average weekday in 1994 and 2007. I then created a separate column for the distance of trips made by car, divided by the total number of occupants, and summed this figure by household to arrive at the total amount of vehicle travel each household generated during a day. This may underestimate VKT, when members of different households carpool. However, it prevents double counting the VKT of separate household members on the same car trip. Furthermore, it provides more accurate estimates of total car travel when multiplied by the survey expansion factor.

Distance to transit, distance to major highway, and distance to the Zócalo

I used ArcGIS' network analyst's Closet Facility tool to calculate the network distance from each AGEB's centroid to the closest Metro stations, closest highway, and the central Zócalo. Highway ramp data were not available and so I calculated the distance to the nearest path rather than the nearest entrance. This likely underestimates the actual distance. Although the transit network was accurate across years, the 1994 highway shapefile was far less accurate than currently available networks from ESRI, INEGI, and Open Street Maps. I opted to use the more modern network. This provides longer and likely more accurate network distances than the less complete network since the network analyst applies Euclidean distances to first connect an AGEB centroid to the network.

Average home-based travel times

As a measure of accessibility, I took the average reported travel time of home-based trips by municipality and borough within each trip. I also divided this by total trip distance for an estimate of travel speeds. Trips over three hours long were excluded from the estimates. In addition to travel times by car, I estimated time by other modes as well as the ratio of car travel time to other modes.

Population density

I estimated neighborhood population densities using the 1990 and 2005 census counts by AGEB divided by the total land area of each AGEB. Shapefiles include the road network and local parks and plazas, but exclude non-urbanized land and major parks.

Job Density

I estimated population densities using the total count of jobs in the 1998 and 2008 economic censuses by municipality divided by the sum of land areas in each AGEB within a municipality and borough. Job counts, which I got from INEGI (2012a), were not available at the AGEB. I also produced a measure of job accessibility by summing the number of jobs, as reported by the work destinations in the travel survey, within one-to-five kilometers of the each household's home AGEB. As these did not significantly improve model fits over municipal job, I opted to use the simpler measure.