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The Impact of Energy Prices on Sprawl

Moynihan, Michael

Princeton, NJ : Princeton University

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THE IMPACT OF ENERGY PRICES ON SPRAWL

MICHAEL W. MOYNIHAN, JR.

A DISSERTATION

PRESENTED TO THE FACULTY

OF PRINCETON UNIVERSITY

IN CANDIDACY FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

RECOMMENDED FOR ACCEPTANCE

BY THE WOODROW WILSON SCHOOL OF

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ADVISER: DOUGLAS S. MASSEY

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Abstract

This dissertation uses ordinary least squares regression analysis to measure the impact of gasoline price changes on sprawl defined as land density of population, employment and light visible from space over multiple decades. Using census data compiled and normalized to 2000 boundaries in the Geolytics Neighborhood Change Database (NCDB) for the decennial census years 1970 through 2000 and energy price data published by the Energy Information Agency (EIA), it tests the effect of gasoline prices on eight population density-derived measures of sprawl for 72 Primary Metropolitan Statistical Areas and 48 states. Using data contained in the Zipcode Business Patterns (ZPB) database maintained by the Census Bureau, it tests the impact of gasoline prices published by ACCRA on a variety of employment dispersion measures of sprawl for Metropolitan Statistical Areas (MSAs). And using a dataset created by Burchfield et al of light visible from space, it tests the effect of gasoline prices published by ACCRA on the Burchfield et al sprawl index for 275 MSAs. The regressions control for a variety of socioeconomic, demographic, legal and physical variables and use instrumental variables and other techniques to test for causal relationships.

The dissertation finds robust evidence that gasoline price changes did influence sprawl at the 95% confidence level over the periods studied with higher prices leading to less marginal sprawl and lower prices leading to more marginal sprawl. In turn, it discusses ways that policymakers might intervene using this pathway to influence sprawl, notably through the imposition of gasoline taxes.

Table of Contents

	Abstract	iii
	Acknowledgements	v
	List of Figures and Tables	ix
	List of Appendices	xiii
1.	Motivation and Overview	1
2.	The Evolution and Understanding of Cities	9
3.	Conceptualizing and Measuring Sprawl	47
4.	Methods	98
5.	Results and Discussion	
	a. Sprawl measured as population density	161
	b. Sprawl measured as employment density	215
	c. Sprawl measured as light visible from space	254
6.	Conclusion and Policy Recommendations	275
	Appendices	297
	References	376

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List of Figures and Tables

Figure 4-1	National and City Gas Prices 2000 to 2009	143
Figure 5-1	New York PMSA: Lorenz Curves 1970 to 2000	165
Figure 5-2	Forth Worth-Arlington PMSA: Lorenz Curves 1970 to 2000	166
Figure 5-3	Various PMSAs: Lorenz Curves – 2000	167
Figure 5-4	New York PMSA: Population Density by Rank – 2000	172
Figure 5-5	New York PMSA: Logged Population Density by Rank-2000	174
Figure 5-6	Fort Worth PMSA: Tract Density by Rank 2000	175
Figure 5-7	Various PMSAs: 2000 Logged Tract Density by Rank	176
Figure 5-8	New York PMSA: Tract Density by Distance from Center 2000	180
Figure 5-9	New York PMSA: Logged Tract Density by Distance from Center 2000	181
Figure 5-10	Fort Worth-Arlington PMSA: Log of Tract Density by Distance from Center 1970 to 2000	182
Figure 5-11	Various Cities: Logged Tract Density by Distance from Center 2000	183
Figure 5-12	Fort Worth-Arlington PMSA: Tract Density Near the Center 2000	187
Figure 5-13	New York CBSA: Zip Code Job Density by Rank 2000	223
Figure 5-14	New York CBSA: Zip Code Logged Job Density by Rank 1996 to 2008	224
Figure 5-15	Dallas Forth Worth: Zip Code Logged Job Density by Rank 1996 to 2008	225
Figure 5-16	Various CBSAs: Zip Code Job Density by Rank 2000	226
Figure 5-17	New York CBSA: Zip Code Job Density by Distance from Center 2000	231
Figure 5-18	New York CBSA: Logged Zip Code Job Density by Distance From Center 1996 to 2008	232
Figure 5-19	Various CBSAs: Logged Zip Code Job Density by Distance From Center 1996 to 2008	233
Figure A-1	A Simple Model of the City	304
Figure A-2	A Three Good Model of the City	307
Figure A-3	Formation of a Sub Center	326
Figure A-4	Log-Log Plot of Density vs. Rank	340
Figure A-5	Fort Worth-Arlington: Log-Log Decay of Tract Density by Rank	341

Table 2-1	City Formation in History	16
Table 2-2	Models of Urban and Metropolitan Structure	23
Table 3-1	Definitions of Sprawl	48
Table 3-2	Metrics of Sprawl in the Literature	52
Table 3-3	Key Determinants of Sprawl	59
Table 4-1	Influence of Gasoline Prices on Employment Dispersion:	

	Potential Pathways	139
Table 4-2	Key Variables: Sprawl	157
Table 5-1	Fixed Effects Regression of Gini Measure of Metro Area Tract Density Inequality on Gasoline Prices and Controls 1970 to 2000	169
Table 5-2	Fixed Effects Regression of City Dispersion on Gasoline Prices and Controls 1970 to 2000	178
Table 5-3	Log of Population Density Regressed on Distance from Center by City Type—2000	187
Table 5-4	Fixed Effects Regression of City Dispersion on Gasoline Prices and Controls 1970 to 2000	188
Table 5-5	Fixed Effects Regression of Urban Intensity on Log of Gasoline Prices and Controls 1970 to 2000	190
Table 5-6	Fixed Effects Regression of Sprawl Intensity on Log of Gasoline Prices and Controls 1970 to 2000	192
Table 5-7	Fixed Effects Regression of Urban Index on Log of Gasoline Prices and Controls 1970 to 2000	193
Table 5-8	Fixed Effects Regression of Land Conversion on Gasoline Prices 1970 to 1990	195
Table 5-9	Fixed Effects Regression of Standard Deviation of PMSA Tract Density on Energy Prices 1970 to 2000	197
Table 5-10	Fixed Effects Regression of City Dispersion by Rank on Mileage Normalized Gasoline Prices and Controls	202
Table 5-11	Fixed Effects Regression of City Dispersion by Distance on Mileage Normalized Gasoline Prices and Controls	203
Table 5-12	Cross Sectional Regression of Density Decay by Distance on 2-Year Lagged Gasoline Prices and Control Variables – 2000	205
Table 5-13	Cross Sectional Regression of Density Decay by Rank on 2-Year Lagged Gasoline Prices and Control Variables – 2000	206
Table 5-14	Cross State Regression of Sprawl Intensity on Gasoline Prices and Control Variables - 2000	208
Table 5-15	Cross State Regression of Urban Intensity on Gasoline Prices and Control Variables - 2000	209
Table 5-16	Cross State TSLS IV Regression of Gasoline Prices on Excise Taxes – First Stage (2000)	211
Table 5-17	Cross State TSLS IV Regression of Urban to Sprawl Ratio on Gasoline Prices and Control Variables Using IVREG Command - 2000	212
Table 5-18	Cross State TSLS IV Regression of Urban Intensity on Gasoline Prices and Control Variables Using IVREG Command – 2000	213
Table 5-19	Cross State TSLS IV Regression of Sprawl Intensity on Gasoline Prices and Control Variables Using IVREG Command – 2000	214

Table 5-20	Fixed Effects Regression of Rank Density Gradient of Jobs by Zipcode on Gasoline Prices and Controls 1999 to 2008	227
Table 5-21	Fixed Effects Regression of Distance Density Gradient of Jobs by Zipcode on Gasoline Prices and Controls 1998 to 2008	235
Table 5-22	Fixed Effects Regression of Rank Density Gradient of Jobs by Zipcode on National Gasoline Prices and Controls 1999 to 2008	249
Table 5-23	Fixed Effects Regression of Distance Density Gradient of Jobs by Zipcode on National Gasoline Prices and Controls 1998 to 2008	241
Table 5-24	Fixed Effects Regression of Rank Density Gradient of Jobs by Zipcode on Gasoline Prices and Controls 1999 to 2008	246
Table 5-25	Measures of Central Tendency of Burchfield et al Indices of Sprawl	257
Table 5-26	Correlation of Burchfield et al Index and Moynihan Dissertation Measures of Sprawl	261
Table 5-27	Fixed Effects Regression of Burchfield et al Sprawl Index on Lagged Gasoline Prices and Controls, 1976 to 1992	264
Table 5-28	Fixed Effects Regression of Burchfield et al Sprawl Index on Lagged Gasoline Prices and Controls, 1976 to 1992	268
Table 6-1	Key Measures of the Impact of Gasoline Prices on Sprawl	275
Table 6-2	Effect of Selected Policy Measures on the Environment, Efficiency and Equity	286
Table A-1	Fixed Effects Regression of Log-Log Density to Rank Decay on Gasoline Prices and Controls 1970 to 2000	342
Table A-2	Tract Population Density: Measures of Central Tendency 1970 to 2000 for Selected Areas	344
Table A-3	Gini, βz and βc Coefficients for Top 10 PMSAs by Size – 2000	345
Table A-4	Historically Monocentric Cities as Measured by Population in 1900	347
Table A-5	Coefficient and T-Statistic of Fixed Effects Regression of Sprawl Metrics on Gasoline Prices, Various Lags	349
Table A-6	Cross State Regression of Sprawl on Gasoline Prices and Control Variables – 2000	356
Table A-7	Cross State Regression of Urban Intensity on Gasoline Prices and Control Variables – 2000	357
Table A-8	Cross State TSLS IV Regression of Gasoline Prices on Excise Taxes – First Stage – 2000	361
Table A-9	Cross State TSLS IV Regression of Gasoline Prices on Excise Taxes – First Stage – 2000	362
Table A-10	Cross State TSLS IV Regression of Urban to Sprawl Ratio on Gasoline Prices and Controls – Second Stage – 2000	363
Table A-11	Cross State TSLS IV Regression of Sprawl Intensity on Gasoline	

	Prices and Controls – Second Stage – 2000	364
Table A-12	Cross State TSLS IV Regression of Urban Intensity on Gasoline Prices and Controls – Second Stage – 2000	365
Table A-13	Cross State TSLS IV Regression of Urban to Sprawl Ratio on Gasoline Prices and Control Variables Using IVREG Command – 2000	366
Table A-14	Cross State TSLS IV Regression of Urban Intensity on Gasoline Prices and Control Variables Using IVREG Command - 2000	366
Table A-15	Cross State TSLS IV Regression of Sprawl Intensity on Gasoline Prices and Control Variables Using IVREG Command - 2000	367

List of Appendices

Appendix A	A Theoretical Model of the City
Appendix B	Zipf's Law and the Population Density of Urban Tracts
Appendix C	Tract Population Density: Measures of Central Tendency, 1970 to 2000 for Selected Areas
Appendix D	Gini, βz and βc Coefficients for Top 10 PMSAs by Size – 2000
Appendix E	Mono and Polycentric Cities: Historical Division
Appendix F	Sensitivity of Gasoline Price Effect on Sprawl to Time Lag
Appendix G	Demonstrating Causality

To my wife, Jane and children,
Michael, Katherine and Johnny

"There is a suburb outside each of the gates, which are 12 in number, and these suburbs are so great that they contain more people than in the city itself--for the suburb of one gate spreads in width til it meets the suburb of the next…. And thus there are as many good houses outside the city as inside[1]."

Marco Polo, c 1299

[1]Polo, Marco, *The Book of Ser Marco Polo, the Venetian: Concerning the Kingdoms and Marvels of the East", trans. Henry Yule, New York: Cambridge University Press, 1871, reprinted 2010, p. 367, describing Cambaluc, China at the site of modern day Beijing.*

Chapter 1: Motivation and Overview

This dissertation explores how changes in energy prices affect urban structural development and particularly assesses whether energy price changes influence that pattern of development known as sprawl. Sprawl—characterized by the dispersion of settlement, employment and commerce in space—is a relatively recent phenomenon in the history of urban settlement dating from the proliferation of the automobile in the 20th Century. It extends an older phenomenon, however, suburbanization. While definitions of sprawl vary greatly (Galster, 2001), most scholars include as a critical element the liberal supply of land as an input in growth and link sprawl to reliance on automobile transportation. Glaeser and Kahn go as far as to state: "the root cause of U.S sprawl is….the technological superiority of the automobile" (2004, p. 4). Transportation mode and cost, moreover, undergird many models of urban growth and structure (Jackson, 1985, Mills, 1967).

Transportation involves physical work and work requires energy. Since energy costs are central to transportation cost and, more fundamentally, because energy is central to the sustainability of all biological systems including human societies (Diamond, 2005), one might expect scholars to have studied the role of energy in urban structure. Yet despite the well established role of transportation cost in urbanization, the obvious link between energy and transportations costs, the availability of detailed data on US energy costs from the US Energy Information Agency, and the periodic elevation of energy concerns to the forefront of national discourse, scholars have

paid scant attention to the impact of energy prices on urbanization and sprawl to date[2]. No one has rigorously studied whether and how changing energy prices may promote, restrict or reverse sprawl. This dissertation is designed to address this gap in the literature.

Most existing studies of sprawl take advantage of available cross sectional data to explain sprawl at a given point in time using variables that differ by region. In so doing, they have neglected variables that change over time—such as energy prices, and failed to take advantage of the explanatory power provided by a panel data approach to understanding sprawl. My dissertation remedies this gap in the literature as well. I test the impact of energy costs on urban development *over time* and, in particular, the promotion, restraint or reversal of sprawl in urban areas in the United States.

The question of whether energy prices affect sprawl is of theoretical importance because if such a link exists, it would enrich understanding of urban growth and structure and link economic research on energy price behavior with theories of urban structure. But it is also of vital practical importance to the conduct of policy across a spectrum of issues. Any sensitivity of sprawl to energy prices would suggest that policy interventions designed to impact final energy prices (such as energy taxes, a cap and trade regime to lower green house gas emissions or regulation of energy futures markets) could influence subsequent urban development. If so, energy policy could be used proactively as a policy tool to shape regional economic development or achieve other policy *desiderata* in the areas of health, society and economic

[2] A rare exception is Glaeser, Kolko and Saiz, 2001 where, in a paper that explores the role of consumption in urban density, the authors briefly discuss the correlation of gasoline prices with population density of the capital city in 35 countries in 1990.

welfare. Sprawl has a bearing on many current policy questions because—relative to traditional urban and rural modes of settlement that have existed for centuries—it has a distinct profile with respect to ethnic and racial stratification, economic welfare, public health and public finance.

In addition, energy policy intervention undertaken without concern for the impact on sprawl could have unintended consequences with respect to economic efficiency, health, racial stratification, poverty and other issues.

Second, sensitivity of sprawl to energy prices, if present, raises issues regarding the sustainability of urban development premised on a given level of prices if those prices later change abruptly. Of particular concern is the long term sustainability of sprawling development given its high level of dependency—relative to earlier forms of settlement—on one form of technology, the automobile that requires energy. As pointed out by Fujita and Thisse, urbanization has a "putty clay" element. While exhibiting great flexibility in how it occurs initially—that is to say, great sensitivity to different determinants—once built, it hardens irreversibly so that it cannot easily be modified. If transportation cost is an important determinant in the structure of urbanization—as theory suggests—a subsequent change in transportation cost may render the structure far from efficient. A sudden shock in prices could render the physical form of the urban structure unsustainable. Since in recent years, energy prices have exhibited sharp volatility above an upward secular trend, future price shocks or simply a sustained period of energy price increases could create large policy problems in the future. Vulnerability of sprawling urban development to energy price changes, if it exists,

should inform current planning decision-making *ex ante* lest development later prove inefficient and unsustainable.

In addition to transportation cost, energy prices may also impact the sustainability of urban growth through other pathways. Dissociated single family homes require more power to heat and light than multi-family dwelling units—particularly, insofar as single family homes at the periphery are, on average, larger in size than multifamily dwellings at the urban core.

Sprawl has also figured prominently in normative discussions of urban structure. Its role in the normative debate is complex for the reason that the precursor of sprawl, suburbanization was originally viewed as a positive alternative to urban congestion only to become viewed, as dispersion accelerated, as a negative development by many (though not all) scholars who have studied sprawl (Gans, 1967, Glaeser and Kahn, 2003). Prior to the middle 20th Century, most normative discussion of urban structure, whether examining social metrics such as happiness, public health questions such as disease and poverty or merely the economic question of efficiency focused on problems of congestion, not dispersion. The high densities found in pre-industrial cities and the stratospheric ones that arose in industrial cities as migrants flooded cities in search of work led a variety of reformers and critics of society to describe the ills of the slums and develop proposals to counteract them (Engels, 1892, Rabinowitz, 2002). Even today, the problems of the inner city still continue to loom large in urban studies.

A common element of many urban reform efforts—rivaling moral reform, campaigns against alcohol, efforts to limit birthrates among the poor and public health crusades—was decentralization to combat congestion. The garden city movement in England and the urban planning movements promoted suburban expansion as a solution to congestion ills (Rabinowtiz, Jackson, 1985 Hall, 1988).

However, the rise of the post industrial city and associated sprawl in the 20th Century refocused attention, at least in the developed world on ills stemming not from excessive density, but rather from excessive land consumption and reliance on the automobile. A strain of thought spanning the work of Park, Burgess, Myrdal, Massey, Orfield and Wilson has ascribed problems of the inner city to the exodus of the middle class (Hall, 1988) and, eventually, jobs (WIlson, 1996). Lucas and Rossi-Hansberg (2002) and Brueckner and Helsey (2009) raise the issue of how urban equilbria may differ from optimal spatial structure, leading to inefficient dispersion. Accordingly, the balance between congestion and diffusion since the proliferation of the automobile has loomed large in normative as well as theoretical discussions of city structure. Understanding how energy costs affect dispersion of urban settlement is of vital importance to this normative discussion insofar as policy directed at the cost of energy through sprawl could influence normative outcomes as well.

There is solid evidence to suggest that energy prices might indeed affect sprawl. Kahn (2000) finds that suburban residents drive 31% to 35% more than inner city residents and gasoline contributes significantly to the marginal cost of driving. As discussed at greater length in

Chapter 3, a variety of research supports the idea that suburban living is energy and gasoline intensive. The gasoline intensity of suburban living may reflect longer commuting times for some, but as jobs have followed population to the urban edge, reducing commuting times for others, may also merely reflect the driving intensity of shopping, greater distances and dispersion of homes, schools, malls, churches and places of activity away from the city center.

Accordingly, this dissertation studies the influence of energy prices on sprawl. I operationalize sprawl in three ways that reflect its consumption of land. First, I examine the effect of energy price changes on measures of population density. Second, I examine the influence of energy prices changes on employment dispersion. Third, using data compiled by Burchfield et al in an innovative study of sprawl as revealed by lighting visible from space, l examine the effect energy prices on land consumption.

My first measure of sprawl is a set of population density metrics I develop for large cities derived from population density data. My primary data source for these regressions is the Neighborhood Change Database ("NCDB") developed by Geolytics from decennial Census Data from which I extract a panel dataset of topographical and socioeconomic data that I, in turn, amend with energy price data from the Energy Information Agency.

My second measure of sprawl is employment dispersion (following Glaeser and Kahn 2003) derived from Zipcode Business Patterns data. For this analysis, I create a panel dataset by combining regional employment data from the Census Bureau's Zipcode Business Patterns with

census data from the NCDB with gasoline price data in the ACCRA-COLI (cost of living) index published by the Council for Community and Economic Research (C2ER). [Call C2ER to get what ACCRA stood for]

My third measure of sprawl is a sprawl index derived from GIS measurement of nighttime light photographed from space developed by Burchfield et al (2005). I use the dataset developed by Prof. Burchfield and Prof. Puga et al (available at http://diegopuga.org/data/landpop/) that measures sprawl using pictures from space and amend it with energy price data from the Energy Information Agency. Using these measures, I carry out least squares and probit regression on motor gasoline prices to test whether and to what degree energy prices explain sprawl.

By means of this analysis, I show that energy prices—as predicted by classic models of urbanization-do influence sprawl, and a failure to anticipate future energy prices is likely to lead to sub-optimal choices that diminish future social and economic welfare.

In Chapter 2, I provide an introduction to theories of urban development and structure. In Chapter 3, I discuss efforts to conceptualize, model and measure sprawl and review the literature on the determinants and consequences of sprawl as well as the determinants of energy prices. In Chapter 4, I present and discuss the methodology for the empirical analysis employed including the models to be tested and a discussion of the variables to be used in the regression analysis performed. In Chapter 5, I present the findings of the analysis and discuss

the results. Finally, in Chapter 6, I offer conclusions and draw the policy implications of the findings.

Overall, my dissertation shows that energy prices do impact sprawl and that transportation, housing and energy policy should be mindful of the likely impact of energy prices on sprawl and, wherever possible, anticipate the impact of prices on sprawl *ex ante*, in order to maximize economic efficiency and minimize negative externalities from diffuse, land-intensive development.

Chapter 2: The Evolution and Understanding of Cities

Since cities first appeared on earth during the Neolithic revolution more than 7,000 years ago, they have proven to be robust and adaptive systems for human propagation (Mumford, 1961). At the heart of the city is a spatial relation among its inhabitants that reflects the productive and social advantages derived from close association mediated by physical constraints. Neither concentrating residents and firms at a single point nor allowing free, even, dispersal across available space, the city suspends its agents in a distribution reflecting the benefits of proximity and the costs and limits of congestion (Mill, 1967, Fujita and Thisse, 1996). Urban settlement has shown and continues to show wide diversity, encompassing small villages, fortified settlements, regional market towns, large urban centers and more recently dispersed urban settlement. Accordingly, those seeking to understand the city must examine not only the gravitational and orbital forces that create a city but also how those variables lead to a diversity of urban forms.

While large permanent settlements began historically along alluvial rivers as an aberration on the landscape that reflected the adaptive benefits of cultivating crops, once formed, they quickly projected a field of influence on surrounding territory. The source of this influence, analogous to a gravitation field, was and is the advantages derived from being physically present at the city center (Von Thunen, 1966). City centers, formed due to the efficiencies incumbent upon concentration, were and are often the site of markets, transportation hubs, governmental offices, social gathering places, storehouses and other places housing communal activities in which it is advantageous or even essential for members of a community to participate

(Mumford, 1961, Sjoberg, 1960, Weber, 1958). Given the physical energy requirements of movement of people and goods, to visit the city center from anywhere else literally takes energy. Thus no sooner did cities come into existence than they began to require their residents to expend energy to leave or visit the city center.

Type of Cities

While all cities at all times and places have shared certain characteristics, scholars have distinguished three main periods in the history of urbanization and three main types of cities that correspond, in turn, to three dominant modes of social and economic activity. The first type of city, the pre-industrial one, spans the period from the first cities in Mesopotamia to the onset of the industrial revolution in Europe (Sjoberg, 1960). The second type of city, the industrial city developed in the Europe and then America and elsewhere in the early 19th Century and has evolved over the last two centuries. The third type of city, the post-industrial city first appeared in the United States in the middle of the 20th Century (Harvey, 1990) Most urban growth today is of an industrial or post-industrial character with industrialization predominating in developing countries and post industrial growth prevailing in developed ones.

Pre-Industrial Cities

One of the earliest writers to analyze cities, Aristotle argued in *The Politics* that like all things, cities can neither be too small, lest they not qualify as cities at all, nor too large lest they

collapse unto themselves.(1962) While, following Plato, he argued that 5,000 was the maximum size for an ideal *polis* or city state, 19th Century archeological research suggest that the city of Ur in the south of modern day Iraq surpassed 500,000 in population a millennium before Christ (Clark, 1951) while Rome at the time of Augustus surpassed the million population mark. The pre-industrial city whether modest in size like a Greek *polis* or vast like the Roman metropole, was, bounded in space by a transportation constraint—typically the distance a person could walk in a day imposed by the necessity of returning home at night—often marked physically with the presence of a wall to supply defense (Sjoberg, 1960). Once established, the earliest cities tended to consecrate the central area with essential functions. Anyone required or desiring to participate in these functions could save energy and time by living nearby. Prior to the development of money, allocation of desirable locations within a settlement or city was probably carried out by social leaders using the methods of hierarchy or authority ranking (Fiske, 1992, Massey, 2005). The typical town center was monopolized by religious and civic functions (Sjoberg, 1960). Military provisions were accorded critical importance (Gat, 2002) but at various times under different conditions, military, administrative, religious or commercial uses might claim prime real estate. (Weber, 1958, Pirenne, 1921)

The earliest fixed settlements arose to administer agriculture. But pre-industrial cities also encompass cities focused on trade, defense, religion and even ceremony (as in the case Persepolis, visited by the Persian court once a year (Crone, 1989). Settlements provided security and centralized functions such as storehouses, walls and temples that benefited from economies of scale. Pre-industrial cities and civilizations that flourished from trade such as

Knossos (Minoan), Athens, Bruges, Venice, Hamburg and Boston prospered from economies of scale in transport and featured warehouses, wharves and other functions associated with trade.

Industrial Cities

Industrial cities are characterized by industry as their primary activity. Industrialization led initially to intense crowding at city centers as rural migrants flooded the city in search of jobs (Engels, 1892, Rabinowtiz, 2002). Industry and its enabling transportation infrastructure such as ports and rail transport, due to their capital intensity, tend to exhibit economies of scale. Accordingly, the archetypal industrial city has a single central business district often in the immediate vicinity of a single transportation hub such as the train station or port. In some cases, industrial cities grew outward along the lines originally established by pre-industrial forebears, as in London, Paris or New York. High land values in the center city resulting from rising population favor dense construction as capital in the form of structure is substituted for land. The debut of the passenger elevator in 1857 in New York's Soho district facilitated the construction of ten story buildings and a half century later, an advance in construction technique led to the first skyscraper, Daniel Burnhams's Flatiron building(Jackson, 1985) making possible greater and greater employment density. But as the industrial revolution advanced, the introduction of mechanized *horizontal* transportation permitted a second wave of expansion, subject to land being available at the fringe, that led cities to tear down their walls, incorporate suburbs and expand radially along transportation routes to, in some cases, achieve

hypertrophic size (Jackson, 1985, Berry, 1964). Thus the industrial city is characterized by high density at the core as well as dispersion at the periphery.

In the United States, the availability of land at the perimeter of cities and the phenomenon of annexation facilitated expansion relative to old world cities. Still cities remained bounded in area by a need to commute to the center and in some instances physical barriers imposed by water or other natural boundaries.

Outside of the United States, early industrial cities with their feudal roots often exhibited settlement patterns based on non-monetary factors. With the elevation of the money economy and its extension to land, markets arose to mediate occupancy for non-official uses through a pricing mechanism that by raising or lowering prices in response to bids could make people (cumulatively) indifferent to living at the center or periphery. Because the price of a unit of land at the center could be met by one wealthy person or many poor ones and capital in the form of structure can be substituted for land, potential solutions to the problem of allocation included both a few wealthy people at the center or many poor ones (Berry et al, 1963). Rigid social structures in pre-industrial cities and limited income restricting the mobility of the poor often left the wealthy at the center and the poor at the fringe. In contrast, social and economic mobility in the United States where some cities such as New York were laid out in lots to encourage real estate speculation, rising incomes and immigration often led the wealthy to seek out land at the periphery and the poor to congregate at the center. (Berry, 1964, Jackson 1985).

Post-industrial Cities

Since the middle of the 20th Century, the proliferation of the automobile and creation of the post industrial economy together with normative planning efforts have ushered in a third phase of urbanization (Harvey, 1990, Hall, 1988, Rabinowitz, 2002, Whyte, 1958) characterized by diffuse urban development and decentralized, multinodal economic activity in a pattern of spatial organization commonly known as sprawl.

It is important to note that dispersion predates the post-industrial city. Whereas the pre-industrial city had a "natural" outer limit, the distance someone could walk in order to return home at night to sleep, the industrial city by dint of railroads and mechanized, horizontal transport, could expand considerably further. Industrial cities, scholars have found, expanded in the late 19th and early 20th Century at faster rates than post modern cities sprawl today (Mills and Tan, 1980). The difference is that the older, monocentric industrial cities tended to expand in a more organized fashion along the lines of railroad routes that required a certain measure of planning with most rail lines converging in the center. Freed of the centralizing element of rail, the post-modern city has tended to expand in more places at once, giving rise to multiple nodes of discontinuous development. As land values rise, substitution of capital in the form of structure has led to multiple sub-centers or edge cities dispersing employment as well as homes. Thus one can agree that sprawl is qualitatively different than the urban growth that preceded it while nonetheless recognizing that the dispersive quality of sprawl is very much a continuation of urban dispersion that began in the industrial era.

The post-industrial city is a result of a variety of factors as discussed further on that include, as the name implies, the decline of industry as a central economic activity in favor of services, cheaper costs of transportation and the proliferation of the automobile, reduced returns to agglomeration that may reflect improved communications technologies. Physically, the post-industrial city is characterized by comparatively flat densities, multiple business districts, a large number of highways and roadways and discontinuous development.

Formation of Cities

In an effort to understand cities, scholars have developed a variety of models featuring various causes and consequences. These include qualitative descriptions of variables and quantitative mathematical models that can be subjected to empirical analysis. The same variables often appear in different models making it difficult to prove or disprove a theory on the basis of the significance of a particular variable (Mieszkowski and Mills, 1993). While there are many ways to divide analysis of the city, I find it convenient to divide them into explanations of city *formation* and city *structure.* I begin with models that explain city formation. These may take historical, qualitative or quantitative form.

Historical Explanations of City Formation

Because cities did not exist prior to a point in history and then appeared—and in turn have evolved—the history of cities provides a series of natural experiments in urban formation. A variety of urbanists, historians and scholars have sought to explain cities in history as the human response to temporal changes in technology, climate, trade and social preferences. Developments in technology, trade and so forth in their historical context thus become exogenous variables. This type of analysis is particularly useful in the case of pre-industrial cities where quantitative data is lacking but is applicable, as well, to modern cities. Table 2-1 provides a typology of explanations of city formation.

Table 2-1 City Formation in History

Type of City	**Cause**	**Scholar**	**Examples**
Pre-Industrial	Agricultural/neolithic revolution	Childe (1951), Mumford (1961), Sjoberg(1965)	Ur
	Defense	Gat (2002)	Various (Mesopotamia, archaic Greece, pre-contact Americas)
	Religion	Sjoberg (1965)	Constantinople, Baghdad, Jerusalem
	Administration	Mumford (1961), Kenny (1997)	Roman New Towns, Washington DC, British "hill stations" in India, Brasilia, Persepolis
	Trade	Pirenne (1969)	Knossos (Minoans), Athens, Venice, Hansa towns
Industrial	Factor Endowments: Minerals, Water	Mills (1967)	Manchester, Pittsburgh, San Francisco, Beaumont
	Manufacturing and Exports	Todaro (1969), Berry, (1964) Tiebout (1956)	Various
	Planning	Rabinowitz, Gang and Stuart (1999),	Letchworth, Welwyn Garden Cities, Russian planned cities, Chinese planned cities

Post-Industrial	De-industrialization and growth of services	Harvey (1989)	Los Angeles
	Automobile	Whyte (1958), Glaeser and Kahn (2003)	Houston
	Policy/Planning	Rabinowitz (2004), Wright (1932)	Garden City, Long Island, Reston, Va, Broadacre City (conceptual)
	Population Growth	Hall (1988), Gans (1982)	Levittown

The first cities, writes Mumford (1961), were cities of the dead. For the first 8 million years of their existence, hominids maintained a migratory existence. Over the course of the last 50,000 years prior to settling down (Crone, 1989), *homo sapiens* sometimes buried their dead in fixed locations to which they returned on a recurrent basis. While groups of humans may have engaged in seasonal meetings of tribes where they exchanged goods and widened the genetic pool through mating, permanent settlements awaited the domestication of plants, in particular, wheat, barley and peas (Jacobs, 1969, Massey, 2002).

The City as Agricultural Center

Scholars have thus explained the appearance of cities as a result of agriculture. Cities provided a spatial and social mechanism for efficiently managing agricultural production in and around the city following the technological shock of the domestication of plants. The earliest large-scale agriculture occurred near rivers and required back breaking irrigation. Thus agriculture, cities, kings, priests, and war all appeared at roughly the same time in human history during the Neolithic revolution as the solution to how to motivate and manage a workforce to sow, water

and protect the harvest (Childe, 1936, Mumford, 1961). Due to low levels of agriculture productivity, acquiring the land of others (or alternatively, slaves and tribute) was one of the few ways a community could raise its standard of living and support more people, leading to constant warfare (Sjoberg, 1965, Massey, 2005). In this model, the practice and requirements of agriculture explain the structure and development (and much of the social structure) of the first pre-industrial cities.

The City as Provider of Security

Notwithstanding the role of cities in agricultural production, Gat (2002), studying the pre-industrial city (which was often a city state invested with sovereignty and therefore responsibility for its own defense) and surrounding agriculture areas, finds security to be the key driver of urbanization. At a time when 90% of people lived outside cities, he argues that security explains the paradox of people subjecting themselves to the ills of the city such as disease. At a time when most battles were not elaborate sieges but simple skirmishes, the city dramatically increased security for farmers even in the absence of walls. In this model, the need for security amid competition for resources explains city formation.

The City as Center of Religion

It is not necessary to build temples or buildings to practice religious worship. However, economies of scale in the production of temples and religious institutions may also have contributed to the growth of cities insofar as religious buildings, orders and institutions encouraged worship and, once established, enjoyed a scale advantage. Early religious buildings

often doubled as commercial warehouses and administrative centers. Accordingly, one finds a ziggurat at the center of Mesopotamian cities and large religious buildings at the center of classical and Christian era cities in Europe and pre-contact ones in the Americas. In the high middle ages, there is evidence that cities built religious cathedrals as a way to stimulate pilgrimage, trade and economic development. In this model of urban growth, religion is an important engine of growth as a result of economies of scale. (Mumford, 1961)

The City as Center of Trade

While agriculture and security provided reasons for cities to form, once constituted, cities became natural centers for trade, aggregating demand and production themselves and providing a fixed location for exchange. Settlement in cities combined with the domestication of plants and animals, the fermentation of grapes and grain and the development of technologies to forge implements needed in these activities gave rise to new types of industry, workforce specialization and trade. Long distance trade in items for which a particular city or region might enjoy a comparative advantage, for example in furs, herring or wine, became yet another engine for urban growth. Economies of scale in long distance transportation including those imposed by the scarcity of water transportation favor the development of trading hubs that mediate trade as opposed to point-to-point trade among scattered towns or market participants

Pirenne (1969) views the resurgence of trade in the middle ages as a key driver of the resurgence of cities. He links the accelerated urban growth that occurred during the high

middle ages to the revival of long distance trade in Europe following the First Crusade and reconquest by Christian Europe of the Mediterranean permitting secure transport of goods by water. Herodotus (1942) likewise ascribed the growth of city states in Greece to the suppression of piracy. A related body of research by Pirenne and others has traced the creation of new towns throughout Europe chartered by nobles or kings and often built as speculations on reclaimed wetlands to the opportunity for profit created by trade. Kings and nobles facilitated trade by offering freedom from duties and taxes at trading centers, creating currency through *seigneurage* and providing other market services. In many instances, nobles sponsored fairs such as the celebrated fair at Troyes in Champagne (Gies, 1969) or towns in order to profit from trade. Many cities have arisen and prospered due to trade including Venice, the Hansa cities in Northern Europe and Hong Kong. To promote trade, governments have generally played a key role in providing conditions for markets (Massey, 2005). This model explains city growth as a function of returns to trade which, in turn, depends to a substantial degree on the security of trade.

The City as Product of Factor Endowments

It is evident from a casual survey of cities that some have arisen in response to factor endowments, for example, of a mineral, energy source or location advantageous for trade. San Francisco grew dramatically during the gold rush of 1849, Pittsburgh owes its early growth to the confluence of iron ore, coke and water for transportation and Beaumont, Texas grew rapidly following the discovery of oil at Spindletop in 1901.

More generally, cities are almost always located near water. New York grew up around a harbor and many industrial cities developed on the Great Lakes where they could take advantage of waterborne transportation. Mills (1967) shows that the economic assumption of heterogeneity of land as an input in a general equilibrium economic model is sufficient to give rise to cities as it will cause growth to occur on desirable land in preference to undesirable land.

The City as Manufacturer and Exporter

Industrial cities have grown up around successful industry clusters. And a number of prominent pre-industrial cities such as London, New York and Shanghai subsequently made the transition to industrial centers. Manufacturing is notable for its capital and labor intensity (as opposed to land) and benefits from agglomeration and spillovers (Porter, 1985). It also pays higher wages than agriculture due to greater productivity. As a result, industrialization has generally been accompanied by rural-urban migration, rapid population growth and increasing density. Migrants may flood cities even in the absence of jobs attracted by the *option* or *expected value* of getting a job paying higher wages over the migrant's lifetime (Berry, 1964, Todaro, 1959). In turn, urbanists and those active in practicing urban development often espouse the idea that export industries stimulate the local economy. Economic base theory holds that the net income derived from net exports exerts a multiplier effect when cycled through a local economy. (Leontif, 1986, Tiebout, 1956). These models of the city explain industrial cities as a function of production and exports.

Planned and Administrative Cities

As the earliest city states managed to grow and expand their territory, they founded colonies. Successful civilizations, such as the Roman Empire, created large, administrative centers *de novo* to consolidate power in different areas of their empires. Mumford (1961) describes how the Romans built "new towns" on an identical model across the Roman Empire. The new towns, designed for a population of 50,000 each typically had arenas, baths and shopping streets, some colonnaded, based on the Broad Way or Boulevard of Sumer. At their center, a north south street known as the *cardo* and an east west one known as the *decumannu* intersected above buried religious relics. In the middle ages, as discussed, local landowners often created "new towns" as well using established models as a trade and real estate speculation to increase their liquid income (Lyon, 1957).

Throughout history, planned cities have been common, ranging from the founding of settlements that grow into cities to the "hill stations" built by the British in India (Kenny, 1997) to accommodate British civil servants to the creation of initially small planned cities such as Washington, DC and large planned ones such as Brasilia. The Soviets and Chinese Communists built many large planned cities during the twentieth century. A particular type of planned city is the residential suburb built to provide comparatively low density housing often with the explicit goal of avoiding the congestion of the industrial city as discussed further below. This model interprets the creation and form of planned cities as an outcome of the exogenous decision to build the city.

Models of Cities

In contrast to efforts to explain city formation in the context of history as a result of one or more exogenous variables active at a certain time, another line of analysis has sought to understand the mechanics of city *structure* and growth. These models typically are designed to apply to the full range of cities across time and space, modeling differences in cities as due to differences in a core set of variables Following, Mieszkowsky and Mills (1993), I first divide models of metropolitan structure and development into two categories: 1) "natural evolution models" that describe how cities evolve and suburbanize naturally as a function of prices and technology and 2) more social or political models of city structure that model city structure and expansion as a result of location choice by people across a bundle of services provided by municipalities as a function of social and political variables. I include in this model, variants where choice is de-emphasized relative to the role of larger forces such as capitalism or Darwinian competition. Following Glaeser and Kahn I add a third category, closely linked to the second, models of the city explained by politics or planning where individual choice is constrained by elites, policy, planning or governmental intervention through laws, zoning, subsidies and the planning process. Table 2-2 summarizes these models.

Table 2-2 Models of Urban and Metropolitan Structure

Type	**Name /Scholar(s)**	**Description**	**Dependent Variable**	**Independent Variables**	**Parameters**
Economic "Natural Evolution" Models	Von Thunen	Land use= f(transport cost by sector)	Land use	Transportation cost/sector	

	AMM Model (Alonso, Muth, Mills), also Clark, Berry, Brueckner and others	Ln(POP DENSITY)=a+b *(DISTANCE FROM CENTER) (Mills and Price, 1982)	Pop Density	Distance from center, transport cost, income, agricultural rent	Intercept (a), Rate of Decay (b). Variables influencing b may include transport cost and spillovers
	Lucas, Rossi-Hansberg (2002)	Land Rent = f(commuting cost, distance from center, spillovers)	Land Rent by Use	Distance from center, transportation cost, externalities	Commuting cost (***K***), externalities relative to proximity (δ)
Social and Political Models	Tiebout Model	Max U(public goods, taxes) Sorting = f(town service mix)	Utility Sorting	Goods, taxes	
	Extended Tiebout Model *("Flight from Blight), ie Brueckner and Helsey, 2009*	Max U(public goods, bads, taxes) Min (Crime, Redistributive Taxes, Pollution etc.) Sorting = f(town service mix)	Utility Sorting	Goods, bads, taxes	
Reform	Engels (Communist)	Spatial Separation = f(class)	Spatial separation/slums	class	
	Riis(Reform)	Slums = f(neglect)	Density, slums	Neglect, exposure (information), policy,	
	Jane Addams, Frances Donavan (Progressive)	Slums = f(neglect, moral decay)	Slums	Neglect, Moral decay	
	Sinclair (Progressive)	Slums = f(political corruption)	Slums	Political corruption. exposure (information)	

Sociological	Burgess/Park Ecological Model	Spatial sorting aka "natural areas" = f(ethnicity/race, migration, cbd growth)	Rings or natural areas, spatial sorting	CBD growth, migration, race/ethnicity	
	Myrdal	Slums = f(segregation)	Slums	Segregation (prejudice)	
	Massey Denton,	Spatial Segregation = f(prejudice, law, policy)	Indices of segregation (i.e. D, P, dissimilarity others)	Prejudice, laws/policy	
Politics and Planning	Sjoberg, Haussman,	Land Use = f(societal needs)	Land use	Core needs	
	Howard, Burnham, Wright, Jacobs, Gyourko	Land use = f(planning, architecture)	Land use	Planning, architecture, zoning	
	Molotch, Petersen, Danielson, Henderson and Mitra, 1994	Land use = f(political power)	Land use	Political power	
	Hall and others Car subsidies, housing subsidies and other pro-suburban government policies	Suburbanization = f(government policies and subsidies) of Max U(goods, bads, taxes) s.t. subsidies, laws, rules, zoning etc.	Suburbanization	Subsidies and policies: highway subsidies, FHA, mortgage interest	

Economic "natural evolution" models of the city

Ricardo (1888), working in the tradition of the physiocrats, introduced the idea of land rent to economics, arguing that the fertility of land determines its rent. He made no provision, however, for location value. Observing that identical land may be put to different uses in the context of an urban system, the German landowner and economist, Von Thunen (1966), developed a model to explain the structure of market towns using transportation cost of different products. Studying German market towns in the middle of the 19th Century, Von Thunen found in transportation cost *differentials* a key determinant of differing bid rent curves for alternative uses and resulting sorting of uses around an urban center. Dairy farmers outbid firewood producers, for example, for land at the center of the town due the rapid spoilage of dairy products relative to firewood. He modeled the city as mono-centric around a market center with differing uses taking place in concentric rings around the city in order of descending transportation cost.

Marshall (1920), while not invoking the cost of transportation directly to explain the city, coined the term agglomeration to describe the economic benefits or externalities that firms realize from close proximity to one another when transportation costs are minimized. In an oft quoted passage of his *Principles of Economics*, Marshall (1920, Book IV. Chapter X. § 3) observed: "When an industry has thus chosen a location for itself, it is likely to stay there long: so great are the advantages which people following the same skilled trade get from near neighborhood to one another. The mysteries of the trade become no mysteries; but are as it were in the air, and

children learn many of them unconsciously" (Fujita and Thisse, 2002). These two concepts—transportation cost and agglomerative spillovers—figure prominently in must subsequent economic models of the city. Von Thunen himself (1966) summarized the centrifugal forces that might tend to disperse economic activity and, in turn, the centripetal forces that would therefore be necessary to sustain cities. The former are the economies of scale of large labor saving installations of machinery, proximity to demand, division of labor and the economies of scale in the production of machines. To account for cities, those inward forces must exceed outward ones that Von Thunen identified as the greater expense of raw materials inside a city than outside, the cost of haulage and the price of fuel, rent, food and other "necessities" that are greater in a large city than outside one.

During the interval between Von Thunen's work and its rediscovery in the twentieth century, mainstream classical economics, following Ricardo, evolved in a way that deprecated the role of place due to the assumptions of zero transaction costs and constant returns to scale. Arrow and Debreu in their canonical axiomization of neoclassical economics in the 1950s, following Ricardo, chose to handle the problem of location by indexing commodities by time and place. Thus urban economic theory stands somewhat apart from other branches of economics in viewing location as a critical dimension, allowing increasing returns to scale and assuming transaction costs in the form of transportation costs as essential to urban development (Samuelson, 1983) though this is evolving. (Increasing returns similar to those invoked to explain the city appear in the work of Romer on endogenous growth, Arthur with respect to technology and Krugman with respect to economic geography (Arthur, 1989, Quigley, 1998, Krugman, 1991).

Reinterpreting Von Thunen's work, Alonso (1964) made transportation a key element of his theory of the city. Building on the geographical and demographic analysis of Clark (1951), Alonso, Mills (1967), Muth (1961), Henderson (1974), Fujita and Thisse (1996), Brueckner (1983), Lucas (2001), Rossi-Hansberg (2002) and others have modeled the city as encapsulating a tension between the *centripetal*, gravitational pull of production externalities or spillovers, in essence Marshallian agglomeration, and *centrifugal* congestion costs that include, principally, that of transportation and a preference for space. A related literature has examined the economic efficiency of different urban structures given assumptions about production externalities and transportation costs (Fujita and Thisse, 2002.)

The simplest version of the Alonso-Mills-Muth model constructs the city as a distribution of population in space around a central business district. In Clark's original formulation of a "law" of population density, the distribution is of an exponential form, being highest at the center and decaying exponentially with distance from the center (Clark, 1951).

In the classic version of the AMM model (Mills, 1967), the city is monocentric. Mills assumes a contiguous central business district (CBD) where residents work. Increasing returns in the Cobb Douglas production function follow from the existence of the city. Residents, in turn, choose their location or distance from the center based on the price of land relative to the price of transportation to the center. Land at the periphery will cost less than at the center based on the cost of transportation so that residents remain indifferent to location choice. While Mills found

the mathematics of his theory "inelegant", with certain simplifications identified by Brueckner (1982), as distance from the city increases, density decreases exponentially as predicted according to the formula first identified by Clark (1951):

$$\textit{Pop Density} = ae^{-b(\textit{Distance From Center})}$$

or

$$\textit{Ln(Population Density)} = \ln a - b*(\textit{Distance from Center})$$

The latter linear form is often employed to examine datasets empirically.

Key parameters of the model are ***a***, the predicted value of Population Density at the exact center of the city (rarely observed due to outbidding by commercial uses) and ***b*** the slope or gradient of density decay from the center. Key variables besides population and land area that influence the parameters ***a*** and ***b*** are *transportation cost* that determines the discount at which land on the periphery must rent and income which sets the budget constraint. The *cost of land* outside the city boundary is also a variable. It is readily apparent that cities will sprawl more as transportation grows cheaper and cities with low cost land at their periphery such as Las Vegas will sprawl more than those with expensive land at their edges such as San Francisco.

Since the development of the basic model, it has been extended in many ways. Beckmann (1970) bases an individual's utility on the number of interactions possible—which increases with proximity to a city center—and land. A common change is to make the CBD endogenous. Some

models include a measure of increasing returns or spillovers in the production function of the city either through scale returns to capital or increasing returns to labor through learning or knowledge transfer (Mills and Price, 1984). Lucas (1999) incorporates externalities in the production function and develops a parameter to measure externalities. Lucas (2001) also examines firm competition for land at the center where externalities are greatest while Lucas and Rossi-Hansberg (2002) model a city that includes mixed uses: both residential and commercial uses. Since residents are competing with industry for land, one use will outbid the other at different distances from the city, leading to sorting of uses. Depending on commuting cost and how between-firm externalities vary with distance, the model can produce a Mills (monocentric) city or an entirely mixed one or other variants. In two good versions of the AMM model, the city produces one good and imports another such as food from outside (Krugman, 1991). In this instance, if the gains in the form of production spillovers from the center city location exceed the cost of transporting the goods in and out of the city, industry will concentrate in the center.

Henderson and Mitra (1995) include multiple employment sub-centers. Fujita and Ogawa (1982) develop a model that predicts multiple equilibria. Some authors also model the role of large developers or entrepreneurs in urban growth as in Rauch (1993), Henderson and Slade (1993), and Helsley and Strange (1993). Yiu and Tam (2006) allow for multiple work locations for two earner households.

Developing the implications of the AMM model, it is apparent that technology may lead to sprawl by flattening the rent gradient (both through new transportation technologies and new communications technologies such as the Internet) or, alternatively steepen the gradient if the new technology increases spillovers. For example, a new communications technology could flatten the gradient if it acts as substitute for personal interaction or steepen it if it complements and encourages face-to-face meetings and knowledge transfer. (Gaspar and Glaeser, 1998). Examining international data, Ionnades et al (2008) find robust evidence that more telephones per capita lead to greater levels of population dispersion.

Long term structural changes in the economy may also impact the gradient. De-industrialization has flattened it (Squires, 2002). Examining Von Thunen's conditions for urban concentration, for example, it is clear that the benefits to modern US manufacturers of a downtown location do not overcome the exceptionally high costs of transporting raw materials into a city congested by the automobile nor the exceptionally high land rents that now obtain in cities. Accordingly, manufacturers no longer seek out center city locations but rather seek out locations well outside the city (Wheaton, 1977). Since many (though not all) services enjoy fewer spillovers than manufacturing, conversion of a city from a manufacturing to services economy is likely to reduce the importance of the central business district and therefore residential gradient.

In his classic 1967 paper based on the work of Von Thunen, Clark and others, Mills' equations do not yield Clark's exponential formulation. However, Mills subsequently found Clark's exponential formula as reconciled by Brueckner(1982) under certain assumptions to be a

satisfactory and convenient way to model density decay from the center. A wide body of empirical research supports different variants of the AMM model (Rossi-Hansberg, 2003, Mills and Price, 1982).

For the most part, the AMM model treats employment density as secondary to population density. This may reflect the fact that initially, understanding population was complex enough and cities exhibited concentration of industry at the center. For this reason, early models of the city assumed that job location was determined exogenously (White, 1999). Mills (1972) contemplated the possibility of a polycentric city or one exhibiting employment dispersion when he proposed two possible equilibria, a segregated city with employment at the center and an integrated one with employment mixed with residential use. The deciding factor in which equilibrium results in his model is the cost of transport relative to people (commuting). Because he considered transport of goods more expensive than that of people, he considered the segregated equilibrium to prevail.

Over the intervening years, undoubtedly motivated by the rise of sub-centers of edge cities (Garreau, 1991) and the empirical observation that jobs are dispersing outward, scholars have enriched early models with greater attention to the question of job location. In general, they find that firms select their location based on a different set of variables than households: variables linked to production. These variables may include the transportation cost of goods as in Mills (1972) but also include location-specific productivity linked to distance from other firms (Fujita and Ogawa, 1982), externalities (Lucas and Ross-Hansberg, 2002), land requirements

(DiPasquale and Wheaton, 1996) or sector (Glaeser and Kahn, 2001). Von Thunen, himself, focused primarily on job location, not population location (1966). He found that uses moved away from the center toward cheaper land in inverse proportion with their cost of transportation. Fujita and Ogawa (1982) find multiple equilibria for employment and population density based on their mutual competition for land. Lucas and Rossi Hansberg (2002) find that different externality parameters and costs of transportation can produce a variety of equilbria from a Mills city to one with decentralized employment. While high transport costs at the extreme (by ending travel) would theoretically cause economic production to decentralize into a diffusion of independent autarkies (Fujita and Thisse, 2002), moderate transport price shocks exert a centripetal or centrifugal effect with higher prices encouraging concentration and eventually a smaller city and lower transport prices, dispersion and expansion.

Glaeser and Kahn (2001) find that employment has dispersed over the last half century in a manner analogous to population but that dispersion varies by sector, with knowledge and spillover-intense industries paying for a central location and low skilled industries availing themselves of cheaper land at the periphery. Glaeser and Kahn (2001) examining firm location decisions argue that firms locate workers, as previously discussed, based on four factors with the goal of maximizing profits by minimizing the cost of inputs that include not only land but also labor adjusted for productivity, transportation and materials relative to revenues. They hypothesize that job levels of industry, ***j***, in location, ***i***, are a function of local prices of the final good, transport costs, local productivity differences, local labor supply and the cost of local inputs, notably land. Key variables they find to be significant upon empirically testing their

model are residential dispersion, defined as the residential density gradient away from the center that operates through its influence on labor cost, and the spillover-intensity of sectors and professions. Other scholars including White (1976), Sullivan (1986) and Sivitanidou and Wheaton (1992) have developed models where job location is determined by variables such as wages (White, 1999).

More recently, a number of scholars have explored the tendency of firms to fragment operations so that management and headquarters jobs move to the center while operation jobs move to the periphery creating center city management and administrative "hubs" (Rossi Hansberg et al, 2009). Davis and Henderson (2004), for example, find that firms concentrate management jobs at the center to take advantage of externalities but locate operations elsewhere while Duranton and Puga explore the role of communications technologies in facilitating functional specialization of cities so that firms can locate headquarters in large towns and operations in smaller ones. Rossi-Hansberg et al show that firm separation of management and other functions explains the finding that job levels and rents are rising at the center while share of jobs is actually rising at the periphery in response to growing population.

Social and Political Models of City Structure

The second category of models described by Mieszlowski and Mills, interpret urban structure, in particular, outward expansion through suburbanization as a form of fiscal and social choice within the framework of consumer choice. In Tiebout's model (1956), consumers move to towns that offer the best bundle of services relative to taxes based on their preferences.

Subsequent authors include as well, the avoidance of "bads" in the central city. Mieskowski and Mills (1993) describe these models as a "generalization of the Tiebout model or "flight from blight".

Tiebout Sorting

Tiebout (1956) proposed a solution to the problem identified by Samuelson of discovering voter preferences for public goods in the absence of direct purchase. Since public goods, by their non-exclusive, non-rival nature, tempt voters to free ride, policymakers must "adapt to" or estimate voter preferences. Tiebout proposed a solution based on the insight that people reveal their preferences for social goods relative to taxes at the local level when they choose a community in which to settle.

The Tiebout model and derivatives in the context of metropolitan structure interpret movement from one local jurisdiction to another—including within a metropolitan area—as a quest of people to maximize their utility with respect to public goods such as schools or golf courses relative to bads such as taxes, crime and corruption. Because different people will have different preferences, this leads to sorting. And because Tiebout assumes an optimal size for the delivery of certain services, once cities reach that size they have an incentive to limit population through "zoning" and "implicit agreements among realtors" locking in stratification.

Tiebout himself did not propose a mathematical version of the model but placed it in the context of consumer choice theory whereby consumers maximize their utility over a basket of

goods and services, in this case, public goods, bads and taxes by choosing their community. For the consumer the problem is:

Max U (goods, bads, taxes)

s.t. taxes<I

Aggregated across all actors, Tiebout suggests the solution is analogous to the general welfare solution for a private economy. While Tiebout assumes no externalities to public goods outside the community, relaxing this assumption renders the solution inefficient and other authors have shown the inefficiency of redundant services due to excessive political sub-division (Orfield, 1997).

Empirical analysis of Tiebout sorting suggests that it works best in explaining sorting in regions with multiple jurisdictional choices.

In the extended or "flight from blight" version of the Tiebout model, consumers not only seek out a bundle of services relative to taxes in local jurisdictions but seek to escape particular problems of the inner city that may include crime, slums, decay, pollution and redistributive taxes. In this case as well, it leads to sorting that may actually intensify the problems of slums as wealthier people seek out high levels of services and poor people must content themselves with more bads and lower levels of services. Empirical support for the "flight from blight" model is mixed with Mills and Price (1982), for example, finding that only race has an impact on suburbanization as discussed at greater length in the context of sprawl below. Both the original

Tiebout model and its extensions assume a variety of different municipalities and would not apply in a case where a single city has annexed all surrounding territories.

Social Reform

While Mieskowski and Mills do not trace the roots of the idea of Tiebout sorting, they lie in earlier efforts to expose, understand and modify spatial segregation within cities. Because the greatest disparity and problem in cities has been traditionally been disparity between rich and poor, early efforts to understand sorting focused on documenting, understanding and seeking to mitigate the problems of slums.

Cities have always had problems of congestion, health and poverty. As Rome's social wars between *plebs* and *patricii* (Last, 1945) and medieval struggles between *populares and nobile* in Italian city states (Waley, 1988) readily attest, the poor have long wrestled with the rich for rights and real estates in cities. However, pre-industrial cities by virtue of their small size and the familiarity between rich and poor exhibited comparatively little spatial segregation. True, in Rome, the wealthy controlled the high ground such as the Palatine Hill and the poor lived below. In pre-industrial cities—however, slaves often lived in the same homes as their masters (Park, 1914). In Southern American cities, after emancipation, slaves settled in less desirable locations but remained close enough to the well-to-do to provide services. New Orleans, for example, assumed a patchwork layout with wealth streets alternating with those of servants. However, with the industrial revolution crowding grew so great and conditions among the poor so appalling that they attracted the attention of a new group of social reformers.

Since many employees in industrial cities no longer provided domestic services but rather worked in factories, industry promoted spatial segregation between rich and poor. The invention of mechanized horizontal transport as part of the industrial revolution also encouraged spatial attenuation by income (and in the United States race) as the advantaged obtained a mechanism to separate themselves from the less advantaged (Jackson, 1985). In the United States, immigration from diverse countries—and eventually internal migration of Africans from the South to the North compounded the issue of poverty, slums and spatial and economic separation. Slums which brimmed full with each wave of migration—either internal from the country or external from other lands—drew the attention of the middle class. Initial efforts to help slum dwellers took the form of settlement houses and poor relief. However, both in Europe and the United States, taking advantage of new media including pamphlets, magazines and photography, social reformers believing that exposure was essential to their cause, began to document social ills. In turn, they developed models to explain them and proposed policies to change them.

One of the first to write about the conditions of the working poor was Engels (1844), who documented poverty among the working class in England. Engels applied the Marxist framework to explain spatial separation by class and proposed Communism as a solution to the squalor. As industrialization took hold in America, Jacob Riis (1971) documented the problems of the poor in New York first in penny newspapers and then using new camera technology in photographs. Riis believed that poverty flourished in obscurity. He strove to publicize the conditions of the poor, demolish slums and create small parks to provide light and air in slum

neighborhoods. Sinclair (1906) and other progressives exposed conditions in the cities but attributed them to a different cause—municipal corruption. Progressives proposed a suite of reforms that included hiring professionals to run cities and enacting food safety, labor and child protection laws. Jane Addams in Chicago and Frances Donovan in New York worked to enact laws to limit the workday and prohibit child labor. While social reformers were primarily activist, in their writings, they offered early theories of slum formation as well as slum mitigation.

Sociological Models

Contemporary with reformers like Addams and Donavan, professors in the emerging field of sociology, began to study the city and slums more rigorously. Weber (1958) had studied the city in history, though he considered the city state to be the only true representation of the city. He saw the city as community—rather than just physical structure or place—and viewed its physical layout as an extension of its communal function. Burghers, for example, placed their central meeting places in the center. As cities grew, community changed. Durkheim (1984) developed the concept of anomie. In America, sociologists associated with the University of Chicago, using Chicago as their laboratory, applied the scientific method to study of the city. While devoting much of their work to the social consequences of city existence, members of the Chicago school also studied urban structure.

Wirth (1938) defined the city as, in part, exhibiting a population gradient. Park (1926, 1952) developed a theory of urban ecology informed by Darwin and the study of plants to explain the

formation of communities and "natural areas" within cities. Burgess (1928) developed a rich theory of the city based on "mobility", quantity of interactions among people and succession of groups and spatial organization that included a central business district and rings around the city. The Chicago race riot of 1919 gave impetus to studies of the Chicago "Black Belt" that abutted the central business district CBD and exhibited some of the worst slum conditions in Chicago. Drawing elaborate maps of Chicago, Burgess explained the Black Belt as the result of the movement of the wealthy outward as the expanding CBD encroached on their neighborhoods. During the transition from residential to commercial use, homeowners divided their houses into rooms prior to demolition that accommodated the in-migration of rural blacks. Borrowing terms from botany, Burgess detailed the processes by which competing ethnic groups "invaded" surrounding areas and, in effect, competed for real estate in the city.

In the middle of the 20th Century, Mrydal (1944) found segregation to be a defining part of what he called the American dilemma. More recently, Massey and Denton (1993) have found segregation along multiple dimensions to be a unique and persistent element of American urban spatial structure. Massey and Denton (1993) found that whites commonly move when the black population approaches 5% in a community and then employ techniques such as exclusionary zoning and realtor steering to preserve separation. In addition exiting neighborhoods when blacks arrive, whites also avoid entering black neighborhoods (Ellen, 2000). Racially motivated migration to the periphery combined with exclusionary low density zoning therefore contributes to population dispersion.

Planning and Politics

In the late 19th Century, an alternative strain of reform with long term significance for urban development examined the physical structure of cities as a variable that influences inhabitants. As an antidote to the ills of congestion, a group of reformers proposed aggressive civic intervention to change the form of the city or simply encourage people to leave it behind for new living forms at the periphery (Jackson, 1985). Implicit in their work was a belief that poverty might be a result initially of natural forces but was susceptible to intervention.

Utopians including Geddes, Stein, Beecher and Stowe in the United States and Howard in England envisioned Garden cities or single family homes as facilitating idealized domestic living. To popularize healthy suburban living, Edward Bok, editor of the Ladies Home Journal, published plans for the bungalow, a type of house derived from India (Jackson, 1985, Rabinowitz, 2002). A new school of planners emerged who modeled social conditions as the outcome of living conditions and living conditions as the work of planning and architecture. To change social outcomes, they proposed new methods of planning and building. Contemporary with the progressive movement in the United States, emerged two related efforts, the City Beautiful and Planning movements.

The City Beautiful and Planning movements began as architectural movements. The White City at the 1892 Columbian Exhibition in Chicago was essentially a private endeavor of leading American citizens working in conjunction with city authorities (Larsen, 2003). However, as these movements progressed, their interaction with government intensified. Governments proved patrons of City Beautiful projects. Coincident with the proliferation of zoning in the Untied

States, the planning movement recognized the role government might play in directing private development.

The City Beautiful movement launched by Burnham after the success of the White City at the Columbian exhibition that he oversaw as America's most celebrated architect, sought to lift the moral and social character of the city by beautifying it according to European standards. Large public works projects such as New York's Municipal Building and the US Post Office in Washington DC, though beautifying the downtown of many cities failed, ultimately, to make a major dent in urban slums. Accordingly, urban planners turned their sights to the ideas of Le Corbusier and others who sought more radical change in the design of cities.

Urban design by decree precedes the market development of cities. From ancient times to today, city rulers and elders have shaped the layout of cities. Emperors such as Augustus who "inherited a city of brick and left one of marble" (Suetonius, 1913, p 119), royal architects such as Haussman who redid Paris and today, coalitions of developers and politicians (Logan and Molotch, 2007), have altered the appearance of cities through large public works projects, slum clearance, urban renewal and ordinances. Decisions by planning boards, zoning authorities, the city council, elders or aldermen and others on the questions of land use, zoning, density, transportation can literally dictate development of a city. Public expenditure allocations—whether to schools, roads, parks, buildings, welfare, hospitals, jobs or other potential uses of money—are typically made politically. The decision to annex an adjacent territory or town can entirely reshape the map of a city.

In early 20th Century America, reformers invoked the power of leading citizens and the government in efforts to eradicate the tenement districts and replace them with taller buildings surrounded by green. "Housers" as they became known advocated for new higher quality housing in the city. This strain of planning would give rise to the larger urban renewal projects of the 1950s that razed whole sections of cities, replacing them with public housing or other buildings. Le Corbusier's superblock was simplified on the way to construction but became the staple of many postwar public housing developments (Jacobs, 1961). A new profession of planning was born, led by prominent urbanists such as Lewis Mumford who helped found the Regional Planning Association. To combat the corruption of machine-ruled cities, progressives advanced the idea of authorities run by professional managers to solve regional problems (Doig, 2001).

A related movement sought relief from congestion, at least for the affluent, outside the city. Planners advocated on behalf of suburban expansion well before the advent of the automobile. The first railroad suburbs as they came to be known, developed with large houses for the upper middle class, surrounded by green in scaled down imitation of the houses of the rich, could be reached only by comparatively expensive horsecars, streetcars and then rail. However, as the price fell, through the process of filtering, the suburbs opened up to the middle and then working class (Jackson, 1985).

Implicit in the activity of these reformers was a model of the city that includes politics, planning and architecture as key independent variables. In addition to local and regional planning, in the United States (and, indeed throughout the world as city states have become submerged in larger national political entities), large scale federal policy has also impacted housing and urban development, notably large scale federal expenditure on roadways beginning with the creation of the Interstate Highway System and Highway Trust Fund (undertaken for security reasons, not to promote suburbanization) and housing policy designed to promote the ownership of single family homes as the FHA program and tax deductibility of mortgage interest (Hall, 1988). Those who believe that federal policy impacts cities thus model the American city as a function, in part, of federal policy, intentional or inadvertent.

With the proliferation of sprawl and in response to crime and other problems in the inner city, particular, in the vicinity of project housing, a number of authors have, sought to reverse policy that they deemed inimical to inner city life in order to return to an older, walkable model of urban life. Jane Jacobs (1961) argued against the “superblock”, a legacy of LeCorbusier, popular in project housing and urban redevelopment in the 1950s and 1960s which disrupted the inner city “street ballet”. While these authors have questioned federal and local planning policies that, they argue, have done more harm than good, they too implicitly model the city as in large degree, a creation of planning and policy.

Over the last 40 years, scholars have also modeled the modern American city as the result of growth efforts by elites variously described as members of a “Growth machine” or regime.

Molotch, for example, observes that greater land use intensity, evident in population growth, benefits landowners, giving them a strong incentive to pursue growth. While sub-groups may compete with one another on some questions—where to locate a convention center, for example—whenever they collude as it is often in their interest to do, they form community. United in their pursuit of growth, newspapers, corporations, landowners, other members of the elite and the politicians they support thus constitute a growth machines. (Molotch, 1976). Peterson, similarly, observes that with many of the old functions of the city state performed, since the New Deal, by other levels of government, cities have little left to do beyond the pursuit of growth (Peterson, 1981). Urban blight that appeared in the 1950s offered urban elites a particular target for growth efforts that they addressed with varying success using a combination of federal money, rezoning and urban renewal initiatives. Stone (1989), studying Atlanta, found that middle class black politicians and the white economic elite formed a durable regime for their mutual benefit, able to survive occasional protests and regular elections.

All of these models explain cities as a function, in part, of social and political choice—socially by people or groups acting directly—or politically by people or groups acting in some measure collectively through political mechanisms. Comparing the three types of models, the first category of "natural evolution" models and the second two categories of social and political choice models, it is apparent that they suggest very different explanations of sprawl that can nonetheless be reconciled. The first set, the "natural evolution" models see sprawl as what happens if development is left to occur unhindered, ie, without planning or supervision. The second set sees spatial settlement as, in part, the result of policy and social choice—initially in response to the problems of congestion such as slums—and with the recognition that sprawl

may present problems equal to congestion—as susceptible to intervention. The two approaches can be reconciled by allowing that economic forces in the industrial city encouraged congestion and in the post-industrial context encourage dispersion—but in both instances are susceptible to intervention.

Chapter 3: Conceptualizing and Measuring Sprawl

While cities have expanded since their emergence, the nature of expansion has changed with the proliferation of the automobile. City planner, Earle Draper coined the term sprawl in 1937 to describe development in the Southeast and in 1946, British planner E.J Osborne lamented the long commutes, economic waste and social decay wrought by the automobile (Nechyba and Walsh, 2004). In 1958, two years after passage of the Federal Highway Act of 1956 created the US interstate system of highways, *Fortune* editor William Whyte (who had criticized suburbia in his book *The Organization Man (1956)* popularized the concept of sprawl, decrying the early consequences of the bill: "Already huge patches of once green countryside have been turned into vast, smog-filled deserts that are neither city, suburb nor country" (Whyte, 1958, p. 102). He wrote that developments were appearing randomly in no-man's lands near the interchanges and exits of the growing highway network with development "being left almost entirely in the hands of the speculative builder." From its genesis, therefore, the term sprawl has been associated with highways and planning. This is in contrast to earlier expansion that occurred along mass transit corridors (Jackson, 1985).

Defining Sprawl

Today, while most people would probably say that they can recognize sprawl, quantifying it and rigorously defining it have proved far more difficult. Sprawl may be a pattern, process, cause or consequence of land use (Galster et al, 2001). It may be a form of urbanization or the lack of urbanization. To some it is a continuation of traditional development dating back to the

beginning of cities and extension of suburbanization—while to others, it is *de novo*. It is closely related to the post-industrial city, appearing in the United States at a point contemporary with the beginning of de-industrialization and the growth of services. But it is not identical to post-industrialization since some cities such as Los Angeles began to sprawl well before de-industrialization commenced and industrializing cities outside the US today may sprawl at their periphery. Table 3-1 lists some definitions of sprawl.

Table 3-1 Definitions of Sprawl

Definition	**Scholar**
Aesthetic	Blake (1964), Kunstler (1996), Keats (1957)
Types of Development: Discontinuous, ribbon, low density, leapfrog	Clawson (1962), Harvey and Clark (1965)
Population Density gradients	AMM (Alonso, 1964, Muth, 1969, Mills, 1972, Brueckner 1982)
Employment Density gradients	Glaeser and Kahn (2003)
Political fragmentation	Carruthers (2002) Orfield (1997)
Multivariate definitions	Downs (1998), Galster et al (2001), Ewing et all (2008)

Some definitions of sprawl focus on its aesthetic qualities. The architect and scholar Peter Blake, found sprawl above all ugly. In his 1964 book, "God's Own Junkyard: The Planned Deterioration of America's Landscape", he collected images of the aesthetic cost of sprawl. Kunstler (1996) finds the absence of a common aesthetic disconcerting. Others found the jarring lack of an

aesthetic less problematic than the conformity of tract home communities as epitomized by Levittown. (Keats, 1957)

More rigorous qualitative definitions of sprawl began to appear in the decade after Whyte's article. Clawson (1962) focused on the discontinuous nature of sprawling development. Harvey and Clark (1965), surveying definitions of sprawl, found them lacking and defined three types of sprawl, low density continuous development, ribbon development, and leapfrog development. Abrams (1971) described sprawl qualitatively as the awkward result of bad planning.

Other scholars developed quantitative definitions of sprawl measuring population density and other measurable variables, many focused on land use. For example, Malpezzi (1999) developed measures of density and lack of continuity while Torrens and Alberti (2000) developed measures of density, leapfrogging, interspersion and accessibility. As catalogued by Galster et al (2001), definitions of sprawl include "low density (Lockwood, 1999), random (GAO, 1999), large-lot single-family residential (Popenoe, 1979), radial discontinuity (Mills, 1980), single land use or physical separation of land uses (Burchell et al, 1998; Cervero, 1991), widespread commercial development (Downs, 1998), strip commercial (Black, 1996; Burchell and others, 1998), and non-compact (Gordon and Richardson, 1997)".

Despite a half century of experience with sprawl, the term continues to lack an agreed on definition (Burchell et al, 1998). Cutsinger and Galster (2005) point out that many definitions of sprawl—particularly those quantitative ones that fix relationships among variables—implicitly

envision it as one singular phenomenon. This leads to single but complex indices of sprawl, consistent with the idea that all sprawl is the same when in fact, they argue, different communities can vary along different axes of sprawl and the broad phenomenon of sprawl is inherently multi-faceted, proceeding along a vector of dimensions.

Variables associated with sprawl include low density, rigid separation between residential and commercial zoning, lack of connectivity of streets and presence of strip malls. Some associate sprawl with racial separation but others find sprawl to reduce racial segregation (Kahn, 2001). Others define sprawl as employment dispersion (Glaeser and Kahn, 2003) and political fragmentation (Carruthers, 2002). However, it can be empirically difficult to distinguish sprawl from urban or "smart" development that mix high and low densities and even from rural patterns of settlement characterized by low density. For example, do 20 people moving onto 1000 acres of farmland constitute sprawl? While they might meet a mathematical definition of sprawl by virtue of consuming an inordinate amount of land, the resulting change to the rural landscape might be virtually invisible to observers. Finally, it can be difficult to distinguish evidence of sprawl from its causes or consequences.

While sprawl is difficult to define, a central element of most definitions is its liberal use of land as an input in regional economic development. Since population density was cited by Wirth (1938) in his classic article as a key element of city character and is the dependent variable in the classic Alonso Muth Mills model of the city, definitions of sprawl as low density development are compatible with the classic theory of urban growth applicable to earlier eras.

However, low density development is, itself, a complex term. If an area develops in a sprawling fashion, for example, scaled to the automobile featuring strict separation of use, as more people move into the area and density increases to traditionally urban levels, one may legitimately ask whether this constitutes less sprawl or more. Increasing density in a region that appears to sprawl represents no new consumption of land and therefore, no new sprawl on a land-weighted basis, but places more people in a "sprawling environment", intensifying sprawl on a population-weighted basis.

Measuring Sprawl

Accordingly, the devil in assessing and measuring sprawl is in the details. Qualitative definitions of sprawl as discontinuous, unplanned ribbon development featuring tract housing separated from commercial malls,—while perhaps the most satisfying intuitively—pose problems for conducting tractable quantitative analysis. Quantitative studies of sprawl, meanwhile, do not always comport with intuition. For example, the well known index of sprawl compiled by *USA Today* finds notoriously anti-growth Portland more sprawling than Los Angeles. In two thorough literature surveys of measures of sprawl, researchers found no agreement and no basis for useful comparisons of measures (Burchell et al, 2001 and Galster et al, 2001).

Apart even from the question of definition, a lack of abundant and consistent data at the metropolitan level has further hampered efforts to develop a commonly accepted measure of sprawl. Even when commentators agree on a variable as influencing sprawl, for example,

population density, they often classify different states of those variables differently. The US Census Bureau, for example, classifies counties with density of greater than 1,000 per square mile as urban, while many researchers place the threshold for urban density at 3,000 per square mile or above. (The precise threshold value of urbanization is less significant if examining change over time as change of state can still be indicative of change.) Due to changing boundaries, definitions and jurisdictions, there is a particular dearth of consistent data over time.

Efforts to measure sprawl have generally adopted one of two broad approaches, complex or simple. Complex measures strive to capture sprawl in all its dimensions, often in the form of an index, while simple measures zero in on one critical indicator of sprawl. Table 3-2 summarizes key approaches to measuring sprawl.

Table 3-2 Metrics of Sprawl in the Literature

	Variables	**Authors**
Complex Measures of Sprawl	22 variables in 4 categories	Ewing et al (2008)
	Multivariate	Downs (1999)
	8 dimensions of sprawl	Galster et al (2001)
Simple Measures of Sprawl	Population density, density gradient or related measures	AMM Model, Pendall (1999), Fulton et al (2001)
	Employment density, density gradient or related measures	Glaeser and Kahn (2001, 2003)
	Central city share of housing starts	Thomas (2010)

	Multifamily housing as % of total	
	Nighttime light visible from space	Burchfield et al (2005)
	Sprawl index (derived from population density)	Hynes et al (2003)

At one extreme, scholars trying to understand the entirety of sprawl in all its dimensions have developed multivariate indices of sprawl. In one of the most thorough examinations of sprawl, Ewing et al (2008) measure sprawl in 83 metropolitan areas encompassing about half the nation's population using 22 variables grouped into four categories. Their highly nuanced study—one of the most exhaustive to date—provides a snapshot and index of sprawl but, insofar as it focuses on a single point in time, does not allow for analysis of reasons for *change* in sprawl over time. Moreover, the multiple variables collapse causes, indicators and consequences of sprawl, complicating causal analysis. Also adopting a multivariate approach, Downs defines sprawl in terms of indicators, causes and consequences of land use and is particularly interested in potential ties between sprawl and the decay of city centers (1999). He finds, however, no statistically significant link between sprawl and urban decline.

However, complex, multivariate measures of sprawl, if the intent is to model the causes and consequences of sprawl may create endogeneity issues if used as dependent variables in models with multiple controls. Thus another challenge to measuring sprawl if the intent is to understand its causes and consequences is the difficulty of separating indicators of sprawl from

causes and consequences. (Galster et al, 2001) For example, is commuting by auto an indicator of sprawl, a cause or a consequence?

One approach to the endogenity issue is to carefully exclude from the measure of sprawl, variables that are potentially causes or consequences. Galster et al (2001) undertake such an effort. Examining eight dimensions of sprawl in 13 metropolitan areas, the authors purposely exclude variables that might contribute to sprawl or result from it, in order to arrive at stable, disciplined measure of sprawl in different dimensions. Their approach is cross sectional, however, and suffers from the limitation of not addressing temporal change. An alternative approach to the endogenity issue is to minimize the complexity of the measure of sprawl by, for example, examining just one variable for sprawl in a model with a single dependent variable. A number of scholars, drawing from the work of Clark (1951), Berry (1964), Mills (1972) Brueckner (1982) and the AMM model for urban growth designed to measure growth of traditional cities, as described earlier, have used population density as a measure of urban dispersion or sprawl. As discussed, in a commonly used expression of the AMM model:

$$ln(POPULATION\ DENSITY) = ln\ a - b*DISTANCE\ FROM\ CENTER$$

The variable ***a*** denotes the intercept of the equation or the density when distance is zero at the center of the city. The variable, ***b*** measures the slope or gradient of density decay from the center and is therefore a measure of sprawl as discussed further below (Clark, 1951).

Glaeser and Kahn (2003) zero in on one composite variable, employment density (constructed from jobs and zipcode data), and study sprawl as changes in that variable with respect to distance from the center. They model sprawl based on concentration of jobs within concentric rings around city centers. Using data from the Department of Commerce, Zip Code Business Patterns for 1996 for 100 metropolitan areas as further discussed below, the authors divide cities into four rings based on the distribution of jobs about the city center and assay the level of job dispersion. Their employment dispersion model follows classic analysis of the shape of the city using the AMM model of sprawl and they perform an analogous regression of population density on distance from the center. One expression of their model is strictly analogous to the population density approach:

$$\ln(\text{EMPLOYMENT DENSITY}) = \ln a - b*\text{DISTANCE FROM CENTER}$$

Once again, the parameter, ***b*** provides a measure of sprawl although their actual methodology is more complex as discussed further below. Their study does not, however, examine temporal change in sprawl. This underscores the fact that much analysis of sprawl in the United States has focused on differences in levels of sprawl between cities as opposed to changes in sprawl over time.

Fulton et al (2001) adopt a highly focused definition of sprawl that they operationalize as population density. They compare rates of population growth from the census to land consumption from the Department of Agriculture's Natural Resources Inventory to draw conclusions about rates of sprawl. Because population is growing in the West and South and

shrinking in the Northeast and Midwest, their methodology leads to the conclusion—contrary to that of others—that sprawl is increasing fastest in areas of population loss such as the Midwest and Northeast.

In one of the few temporal studies of sprawl, Lopez and Hynes (2003) use population data combined with estimates of land area from the census to construct a density-based index of sprawl, rank metropolitan areas according to the index and calculate change in sprawl in the 1990s. To construct their index, they divide density into three ranges, urban, sprawl and rural and then chart the changes in the index over time to determine which areas of the country are sprawling. They do not, however, include control or independent variables to study the *determinants* of sprawl.

In a study published by the Environmental Protection Agency, Thomas (2010) focused on new construction and models sprawl as exurban share housing starts (relative to inner city share). Examining this data, Thomas found a trend toward infill development in the 1990s.

Burchfield et al use nighttime light visible from space captured by aerial photographs in 1976 and satellite imagery in 1992 to track change in sprawl over time. Their innovative study uses highly granular 30x30 meter resolution to discern undeveloped land between buildings. They interpret nighttime light as a proxy for development and construct an index for sprawl using their findings. The two-period approach enables them to examine causes of sprawl over time. Consistent with their real world dataset, they include many geographic variables as controls.

However, many of the control variables they use—such as groundwater availability, temperate climate, rugged terrain, and early transportation infrastructure are not indexed in time, meaning much of the explanatory power is cross sectional.

A number of popular studies have adopted simple measures of density as markers of sprawl. *USA Today* (2001) has developed a simple index of sprawl based on percentage of people living in urbanized areas and the change in that percentage between 1990 and 2000. The dummy variable at the root of the *USA Today* calculation of sprawl, the Census Bureau's definition of urbanization, density of more than 1000 people per square mile, does not distinguish between high and low density urbanization. Thus a region can appear low density even when it has crossed the threshold of being urbanized and, for this reason, the Census Bureau's definition of urbanization may not be an ideal one to use when ranking one area against another. The Sierra Club (1999) has developed an ordinal ranking of the sprawl level of cities according to density, land consumption relative to population growth, time spent in traffic and development of open space.

While these studies shed light on the scope and nature of sprawl and provide insight into its causes and consequences, their surprisingly different conclusions testify to the difficulty of quantifying what at first glance might seem an obvious, self evident phenomenon Moreover, their varying conclusions reflect the lack of consistent data at the granular level about patterns of metropolitan development traceable, in part, to the differing data needs of the federal

government which collects most national data and cities and states, themselves, which have responsibility for managing regional growth.

In light of the lack of a commonly accepted definition of sprawl, I adopt metrics that are both information-efficient and tractable. As discussed further in Chapter II, I choose measures that reflect the central role of land intensity in sprawl and are compatible with earlier measures of urban growth. My first set of metrics, following Clark, Mills and the AMM model measure population density variants; my second metric, following Glaeser and Kahn is employment density; my third metric is the Burchfield Puga measure of sprawl derived from light visible from space.

Determinants of Sprawl

Just as the models and measures of sprawl adopted by scholars vary, so do hypothesized determinants. Different models of sprawl, like the models of cities described above, employ different sets of dependent and independent variables. As with models of cities, determinants or explanatory variables can therefore be conveniently divided into two main categories that roughly correspond to disciplines, economic determinants within "natural evolution" models of sprawl and social and political determinants within a policy, choice or "flight from blight" theory. Some determinants are, however, compatible with both model groups, for example, household incomes (Mieskowski and Mills, 1993). Table 3-3, though not exhaustive, lists the principal determinants of sprawl found in the literature.

Table 3-3 Key Determinants of Sprawl		
Model	**Variable**	**Scholar**
"Natural Evolution"	Spillovers/Increasing Returns/Agglomeration	AMM model
	Population	AMM model
	Transportation cost	AMM model
	Income	AMM model, Margo (1992)
	Cost of peripheral land	AMM model
	Natural endowments: water or "rugged" boundaries	Burchfield et al(2005)
	Market failures ie. congesting pricing, amenities and infrastructure cost	Brueckner and Helsey, 2009
	Spillovers and other industry sector specific qualities; labor cost	Glaeser and Kahn, 2001
Social and Political Choice	Bads: Crime, Schools, Environment, Taxes, Slums	Tiebout (theoretical 1956) Berry-Cullen and Levitt (crime 1999), Jackson (1985)
	Political Fragmentation	Tiebout (theoretical), Jackson 1985), Orfield(1997)
	Zoning	Glaeser and Gyourko (2002)
	Transportation subsidies	Hart and Spiva (1993), Gutfreund(2004)
	FHA subsidy	Jackson (1985)
	Home mortgage interest deduction	Voith (1999), Glaeser and Shapiro (2002)

	Racial heterogeneity	Massey and Denton (1993), Mills and Price (1982)
	Immigrants/ethnic heterogeneity	Jackson (1985), Fulton et al(2001)

Economic Determinants

In contrast to non-economic definitions of sprawl or those that strive to distinguish sprawl from earlier forms of suburbanization (Downs, 1998), most economic analysis of sprawl utilizes some version of the AMM model for growth of cities. Sprawl, after all, is a form of urban growth at the edge of a city. In the words of Brueckner and Fansler (1983, p. 479):

> The economist's view of urban expansion stands in stark contrast to this emotionally-charged indictment of sprawl. …The model underlying this view, which was originally developed by Muth (1969) and Mills (1972)… suggests that urban spatial size is determined in a straightforward way by a number of exogenous variables.

While there are many variants of the AMM model, most include as variables population, land, transportation cost, increasing returns to scale in production and income. In a common version of the model, ***ln(Population density) = lna-b(Distance from Center)***, the parameter, ***b*** describes the population density gradient and it, in turn, can be explained by a series of determinants:

$$b = f(T, S, I, P, N, L,)$$

where ***T*** is transportation, ***S*** is spillovers, ***I*** is income, ***P*** is price of neighboring land , ***N*** is population and ***L*** is land. The first key determinant, ***T*** is transportation. If transportation is free

or cheap, then population will disperse outward from the city while if transport is costly, then dispersion will be constrained, *ceteris paribus*. A decline in transportation cost is therefore associated with expansion and an increase in transportation cost with contraction. A second key element in some models is ***S***, spillovers or scale economies in the production function of the city. If the city's main industry (or industry on average) has a high degree of increasing returns to scale, then industry will concentrate in the center. A concentrated central business district will, in turn, advantage living near the center, leading to a steeper residential population gradient (though commercial uses will outbid residential use at the center). Another important independent variable that may impact the rate of decay is ***I***, family or household income which impacts the budget constraint of housing consumers. When income is high, people can more readily afford to commute and consume more space. Cheap, available land at the periphery, ***P*** also promotes sprawl relative to constraints such as water or expensive land. Finally, changes in population, ***N*** may impact the population density gradient depending on what happens to land, ***L***. If land remains the same, the gradient is likely to steepen *ceteris paribus*; if the radius of the city increases at the same rate as population, the gradient will remain unchanged; and if the radius of the city increases faster than population, the gradient is likely to flatten.

It bears mention that the AMM model is primarily concerned with population density, where people sleep, not where they work. There is no equally canonical model focused on employment density—where people work. Rather, (other than von Thunen's original model of sorting of uses) early versions of the AMM model assume that employment is concentrated in a central business district—or find like Mills(1972) that the high transport costs of goods drive concentration. Later ones explain concentration of employment at the center primarily through

production function externalities. Another group of models explain dispersion as a result of wage differentials that impact land costs. As discussed above, only a few recent models are rich enough to explain decentralization of employment though employment has been decentralizing in the United States for half a century along with population. Lucas and Ross-Hansberg (2002) find different equilibria for business and residential uses based on an externalities parameter and cost of transportation. Di Pasquale and Wheaton (1996) find that certain commercial uses such as manufacturing have dispersed from cities while other uses such as office space have concentrated in them. A separate line of inquiry studies whether jobs have followed people out of cities or vica versa and generally finds in favor of the former (White, 1999, Boarnet, 1994). However, the theory is comparatively undeveloped relative to the theory of residential dispersion. The Glaeser and Kahn (2001) measures of employment dispersion are based on the assumption that firms maximize a Cobb-Davis production function over a set of inputs. They hypothesize that job levels of industry j in location i are a function of local prices of the final good and transport costs, local productivity differences, local labor supply and the cost of local inputs, notably land. Key variables they find to be significant in testing their model are residential dispersion, defined as the residential density gradient away from the center that operates through its influence on labor cost, and the spillover-intensity of sectors and professions.

The second category of models of sprawl, based on social or political models of the city is less standardized than the AMM model. In studying cities, sociologists and political scientists have examined the structure of the city beginning with Park and Burgess in the early 20th Century. However, a difference between predominantly economic and social/political models is that the

latter tend to view the distribution as a multidimensional vector that includes race, ethnicity, income and other variables. In other words, they find the ethnic and racial composition of neighborhoods as important as their density or location. Both approaches to understanding sprawl help to illuminate the phenomenon.

Social and political models may include race or ethnicity as an explanatory variable of sprawl. Models may also include as explanatory variables policies imposed by the government—economic as well as social—such as exclusionary zoning, FHA rules, housing subsidies, the federal mortgage interest deduction and highway subsidies (Glaeser and Kahn, 2003).

Many scholars, to be sure, have ascribed sprawl to variables belonging to multiple categories. Hall, for example, ascribes sprawl in the United States to five developments after World War II, the development of the Interstate Highway System, zoning practice, mass federal support of housing through the FHA, the return of the GIs and baby boom and the celebration by architects of "what was" instead of "what should be". The latter refers to a celebration of the architecture and culture that grew up unplanned along the American road—rather than new ideals in the European tradition of Le Corbusier. It is readily apparent that three of these factors are policy-related, i.e. the Interestate Highway System, zoning practice and federal support of housing, however, one is demographic, the return of the GIs and baby boom which created demand for housing. A fifth, a change in architectural preferences is presumably exogenous and cannot readily be ascribed to economic or social change.

Similarly, proponents of one model may test other models or include a diverse set of variables in their primary model as controls. For example, in their "natural evolution" model of sprawl, Mieszkowski and Mills include race and other variables. Similarly, Glaeser and Kahn test the impact of a wide range of race and policy variables using their dataset of job dispersion derived from employment by zipcode data. With these groupings in mind, I now turn to the literature on specific determinants of sprawl.

Transportation

The first major determinant of the gradient of dispersion and a staple of models of urban agglomeration is transportation cost. Insofar as empirical evidence has borne out many variants of the AMM model of city structure, there is strong empirical evidence, as well, of the role of transportation cost in city spatial structure. Glaeser and Kahn (2003 and 2008) find that transportation cost influences population and employment density. A rich literature has documented the role of transportation cost in increasing central densities while reducing peripheral ones. While the role of transportation cost as a key determinant of population gradients flows naturally out of monocentric models of the cities, it figures prominently in multicentric models as well (Henderson and Mitra (1995). Transportation cost also influences economic efficiency. Rossi-Hansberg has shown that lower commuting costs lower the difference between optimal and equilibrium spatial allocations (2004).

Transportation cost also enters into many qualitative and planning models of sprawl. Perhaps the simplest description of the role of transportation in urban development is Le Corbusier's oft quoted maxim that "The city that achieves speed achieves success" (1987). Speed of transportation allows a city to avail itself not only of the economic and social benefits of agglomeration, .but also of inexpensive open land at the periphery and all that comes with it. Accordingly, as transportation technologies have improved, cities have expanded. Jackson (1985) describes how successive modes of transportation including the horsecar, the street car, the train and the automobile extended the size of the city by allowing people to commute from greater and greater distances at a lower and lower cost.

Hall (1988) relates how H.G. Wells anticipated the growth of automobiles and roads and in the 1920s. As more and more Americans purchase autos, a debate ensured over whether to subsidize mass transit or invest in freeways. The automobile led to enthusiasm among some planners for radical decentralization around a new, auto-centric mode of living. In the Soviet Union, Moisei Ginsburg and Moisei Okhitovich argued that the car would spell the end of the concentrated city and usher in a new mode of decentralized living. In the United States, Frank Lloyd Wright published a plan for what he called Broadacre city, a highly decentralized city built designed around the automobile.

Glaeser and Khan go so far as to attribute sprawl to the automobile and praise its benefits as a way of providing people with more living space relative to city dwelling. Using cross sectional analysis for the United States of income and sprawl levels by MSA that shows a geographic

correlation between driving and density and amplifying this with international data on gas taxes and sprawl, they conclude "as long as the car remains the dominant transport mode, sprawl is likely to remain the dominant urban form." They further argue that the car is a necessary condition for growth that may reflect other causes as well. For example, while Margo (1992) attributes half of sprawl to rising incomes, Glaeser and Khan argue that rising incomes alone would not have led to sprawl without the technological invention of the automobile.

The variable of interest in the AMM model of the city is not mode of transportation but its cost. The cost of transportation, however, varies by mode and different people will choose different modes based on their preferences and costs. Glaeser and Kahn note that the costs of purchasing and operating a car are such that it costs considerably more to commute by car than public transportation. For this reason, they theorize that the rich tend to drive cars and the poor to use public transportation, leading to stratification.

In addition to a strict income effect, because the rich earn more than the poor per unit of time, quicker commuting times justify spending more on commuting. And autos offer additional utility relative to public transportation in the form of shorter commuting times, avoidance of walking, the luxury of driving by car, the ability to talk on the phone and privacy. Ingram and Liu (1999) and Glaeser, Kolko and Saiz (2001) examine the impact of gas taxes on car ownership in Europe and population density in 35 capital cities, respectively, and find a statistically significant negative effect. Glaeser et al qualify their finding of elasticity of density of capital cities to

gasoline prices of 1.1, however, by noting the small sample size (N=35) and single control (GNP per capita).

While there is wide agreement on the role of the car in promoting sprawl, there is less consensus on whether this reflects merely the natural superiority of the automobile or political intervention and even collusion. Jackson (1985) describes the process by which the oil companies bought up and demolished old trolley lines in cities. Gutfreund (2004) links the growth of sprawl to creation of the Interstate Highway system and the system of subsidies in the form of the gas tax and Highway Trust Fund on which it rests. Glaeser and Kahn while acknowledging subsidies to road transportation do not consider them to be of key importance.

Despite the obvious role of gasoline cost in auto transportation, there is a noticeable gap in the literature in assessing the impact of fuel cost—in the form of gasoline cost—on transportation which my dissertation is designed to address.

Spillovers and Increasing Returns

Absent agglomeration or returns to scale, in the words of Mills, "each acre of land would contain the same number of people and the same mix of productive activities…all land is equally productive… and the demands of consumers can be located in a small area near where consumers live" (Mills, 1972, p.4). While this world does not exist insofar as economic activity

does concentrate geographically, giving rise to cities, sprawl arguably represents a step in the direction of this hypothetical, evenly dispersed, non agglomerative alternative reality. Agglomeration—despite its absence from most economic theory—is necessary to explain cities.

In the last two decades, a growing literature has arisen around increasing returns, agglomeration, spillovers and clustering, not only in an urban context but in regional economic analysis and even in the north south, developed and developing world debate (Fujita and Thisse, 1996). In one- or two-good models of the city in the AMM tradition, they show up in the production function of the city and can occur with respect to capital or labor. In complex analysis of the city, they may take the form of localization or agglomeration economies created by shared inputs, demand aggregation and externalities of one type or another. They may accrue within one firm as scale economies or to firms in a single sector that share inputs, knowledge and markets or across an entire urban economy and be technological or pecuniary (Scitovsky, 1954).

Saxenian (1994) has studied spillovers in Silicon Valley and the Boston area, finding face to face communication critical to economic advantage. Porter (1985) studied clustering at the national and sub-national level. Others have studied clusters in Europe such as those in Italy (clothing, furniture and shoes), France and elsewhere (Fujita and Thisse, 1996, Pyke et al 1990, Becattini 1990). Krugman (1991) has modeled core and peripheral growth based on increasing returns. Rossi Hansberg and Wright (2007) have reconciled increasing returns at the city level with constant returns across the broad economy through city rise and fall in a model that yields a Zipf

distribution of cities and other observed regularities. Empirical studies of cities and regions have generally found strong growth advantages to agglomeration.

Changes in the structure of the economy in the late 20th Century have led, according to some scholars to a natural trend of reduced gains to agglomeration and the decentralization of cities. Services may be less agglomerative than traditional manufacturing insofar as most, though not all, are less capital intensive and may exhibit fewer spillovers or increasing returns to human capital. Wheaton and Lewis (2000) and Borchert (1967) have separately studied changes in the returns to agglomeration as the American economy has shifted from manufacturing to services and linked these to decentralization in living arrangements as well as industry which today prefers road access at the periphery to rail access at the core. It bears mention, however, that Silicon Valley—a decentralized region—is often presented as a textbook example of clustering and spillovers and that New York's Wall Street area is highly concentrated, suggesting a high level of increasing returns to financial services.

While spillovers or agglomeration would appear to be a central element in determining urban compactness or sprawl and therefore of value in an empirical assessment of determinants of sprawl, unfortunately, there is no easy way to observe returns to scale at the city level. In models, scholars have envisioned increasing returns in a single production function for the city as accruing to capital through improved technology or labor through sharing of specialized knowledge. Empirically, however, measuring those returns woud require searching for these effects across multiple firms and industries. True, one could compare urban output by

population across cities or a range of time; however one would have to account for a huge range of other variables before isolating returns to scale. Lucas (2001) suggests a way to use observed *within*-city rent gradients to estimate human capital externalities and Rauch (1993) suggests a way to arrive at externalities from cross city wage data. Agglomerative benefits should appear, as well, in transportation savings at the center (DiPasquale and Wheaton, 1996) that show up in rents. However, the data needed to perform any of these calculations for multiple cities is not readily available and would have to be painstakingly assembled. Notably, most general equilibrium economic analysis assumes constant returns. To date, no one has estimated increasing returns coefficients for all US metropolitan statistical areas.

Income

An interesting income effect emerges from the AMM model. Reinforcing Jackson's historical observation (1985) that the first American suburbs were accessible only to the well to do due to the high cost of transportation but that subsequent lowering of commuting costs and rising incomes opened up the suburbs to the middle class after World War II, the AMM model suggests that rising incomes will lead to suburbanization. As the budget constraint is relaxed, assuming that per mile transportation costs remain constant or decline, residents have more money to spend on housing, land and transportation. Housing and land being normal goods, they will consume more of them, shifting the city boundary outwards (Fujita and Thisse, 1996, Bairoch, 1985). Margo (1992) finds that as much of 50% of sprawl is attributable to income growth although Glaeser and Kahn (2003) argue this amount is too high. Brueckner (2000)

calculates the elasticity of city size with respect to income to equal 1.5, meaning a 1% change in income leads to a 1.5% change in city size. My model in Appendix A suggests that housing consumption rises with income.

The income elasticity of sprawl can also be used to explain the observation in the United States that the poor often live in the inner city (with high densities making up for higher land rents) while the wealthy tend to live in suburbs (Fujita and Thisse, Wheaton, 1977). However, individuals that place a high value on time such as finance professionals may prefer proximity to the city center (Fujita, 1989) and the wealthy can outbid the poor for center city land if enticed to do so by the presence of cultural or aesthetic amenities (Brueckner, Thisse and Zenous, 1999.)

In Europe and older cities in Asia, it is more common for the poor to live in suburbs. In developing countries this may be due to a lower budget constraint even for the wealthy who collectively lack the means to exit cities. Or it may reflect the high cost and poor quality of transportation to and from the center that makes suburban living unattractive to those with means. In developed countries other than the US, it may reflect inner city amenities, lack of cheap land available outside cities for expansive suburbs (due to agricultural subsidies that raise the reservation price of land) and in formerly pre-industrial cities, the long linkage between city residence and economic and political status dating to the era of free towns and city states (Berry, 1964, Delvano, 1998).

Population Growth

The impact of population growth on city expansion and sprawl flows directly out of the AMM model. Brueckner (2000) finds that the elasticity of city size relative to population is 1.1. Thus, a 1% change in population corresponds to a 1.1% change in city size. Expanding on the AMM model, Rossi Hansberg et al (2009) find that population growth is, in fact, able to account for a variety of changes in urban structure that include firm fragmentation, declining firm size, concentration of managers at the centers and non managers at the fringe and rising employment at the center and periphery but rising share at the periphery.

The intuition for population growth causing sprawl is that more people require more units of housing, roads, stores, schools, plumbing and other elements of growth. If technology (such as the automobile) favors growth scaled to the automobile, then population growth can be expected to lead to sprawl. On the other hand, in principle, rising population could be accommodated through high density or infill development scaled to the pedestrian or situated around rail transport

Using the AMM framework, it is apparent that what happens to the population density gradient as population increases will depend on whether city boundaries are allowed to expand. If city boundaries do not expand, population growth will lead to a steeper gradient. If the city boundary is unconstrained by natural or political boundaries, the gradient is likely to flatten as population increases and the city radius increases.

Accordingly, one might expect population growth to interact with other variables such as geographic ones—whether a city is surrounded by open land or water and mountains, economic ones such as income and the price of land outside cities and technological ones such as the presence of automobiles. In poor countries, the high cost of auto transportation relative to incomes, may explain why high rates of population growth have led to urban overcrowding rather than sprawl. On the other hand, population growth in the US given the ubiquity of the automobile may translate almost directly into sprawl. In making the argument for the central role of automobile transportation in sprawl, Glaeser and Kahn (2003) cite the work of Ingram and Liu on the impact of gas taxes in Europe and sprawl as supporting the argument that making cars easier to own and operate is conducive to sprawl in the presence of population growth. The US-based Sierra Club has periodically focused attention on population growth as an indicator of sprawl (http://www.sierraclub/sprawl/population.asp"). And others have linked sprawl in the US to population growth as a result of migration. Immigrants initially tend to concentrate in high density, inner city locations as discussed below (Bae, 2004) but by the second generation begin to lose their affinity for the urban center.

Extending the analysis of population growth to systems of cities, Chaterjee and Carlino (2001) find that smaller cities absorb more of rising population so that rising population ultimately leads to greater dispersion of employment away from large city centers.

Price of Surrounding Land

The AMM model suggests that the price of land at the periphery may impact sprawl between cities. For example, Las Vegas may sprawl more than New York because it is surrounded by worthless desert rather than water or land that could be used for industry or storage. During the 2005-2008 housing bubble, Wall Street analysts used the term "sand cities" to refer to cities undergoing the fastest development and later greatest distress such as Las Vegas. Empirical studies of the impact of peripheral land price on sprawl or city size are ambiguous though Brueckner and Fansler (1983) find the expected statistically significant *negative* impact with cheaper land at the periphery leading to more expansion. They find the elasticity of urban land area with respect to price of agricultural land to be -0.23, meaning a 1% increase in land price at the periphery corresponds to just under a quarter percent decrease in city area. Delvana (1998) suggests that agricultural subsidies in Europe by raising the price of farmland outside cities, making farming more attractive and real estate development more expensive, may limit sprawl

Market Failures

Yet another approach to understanding sprawl as an economic phenomenon models excessive consumption of land *as well as* blight in cities as a result of market failures with respect to pricing. Market failures that may encourage sprawl are lack of congestion pricing, not accounting for the value of open space and not charging for new infrastructure required by development (Brueckner and Helsey, 2009).

Industry Sectors, Functions and Labor Cost

When analyzing firm location choice or employment, as opposed to population dispersion, key determinants are likely to be factors that influence the profit function of firms rather than the location decisions of households (Rossi Hansberg et al, 2009). Glaeser and Kahn (2001) find industry sectors to be statistically significant determinants of firm location choice insofar as spillover-intensive sectors benefit more from centralization and low human capital sectors benefit more from cheaper land at the periphery. Certain job functions may also follow people out of the city to lower wage costs, providing they can find amply qualified employees at the periphery (Boarnet, 1994). Rossi Hansberg et al (2009), for example, find that city centers are becoming management and administrative hubs but the peripheral share of employment is rising as firms separate management from operational functions. Data on job function is generally available at the county level only, however, limiting microlevel analysis.

Bads

In contrast to formal economic models of sprawl, social and political models including Tiebout models of location choice have a heterogeneous character. They may include some of the same variable as the AMM model including changes in transportation cost and household income. They add, however, variables such as race, ethnicity, age profile and a host of policy and policy variables. Just as many economists include variables such as race and policy in their analysis, sociologists, political scientists and planners include variables such as income in their analysis so the two approaches overlap considerably.

In the expanded Tiebout model of "flight from blight", bads in the inner city may theoretically induce movement to homogenous, more affluent communities in the suburbs through "flight from blight". Bad schools, crime, a bad environment and redistributive taxes are theorized to induce movement out of the city by those with the means to do so. For example, Bradford and Kelejian (1973) argue that bads explain a significant share of suburbanization. They do not use a gradient dependent variable for suburbanization in the tradition of the AMM model but rather employ a measure of the ratio of center city to citywide population density.

A key problem in studying the impact of bads on sprawl is the difficulty in establishing causality. The relevant question is: do bads drive people out of the inner city or does middle class flight make the city bad? In some real world cases, causality would appear to run in both directions, creating a vicious cycle. For example, middle class flight may reduce the tax base, leading to higher tax rates, making the city even less attractive to the middle class. Or election of a leader deemed to be anti-middle class such as Coleman Young in Detroit or Marion Barry in Washington, may induce middle class flight, reducing the tax base, making the fear a self fulfilling prophecy. Such sorting is consistent with the Tiebout framework but does not support the conclusion that the bad *caused* sprawl or, for that matter, that sprawl caused the urban bad.

It may also be the case that urban bads and suburban sprawl are not related. Disputing the methodology of Bradford and Kelejian (1973), Mills and Price (1982) find limited support

for a causal impact of bads on suburbanization. Mieskowski and Mills (1993) find limited support for the flight from blight thesis, generally, while Downs (1999) has found no causal link running from sprawl to urban problems. Indeed, scholars have hypothesized causality between bads and flight to run in different directions depending on the bad in question. One hypothesized determinant of sprawl is crime. In this model, sprawl in the form of flight to suburbs is a middle class response, in part, to crime. However, there is anecdotal reason to suspect that the effect is ambiguous. Both the US and Europe, for example, experienced post war sprawl but Europe did not experience US-style crime. Crime also began to skyrocket in US inner cities in the late 1960s, long after sprawl was well underway (Mieskowski and Mills, 1993). Both sprawl and crime might be due to a third variable, such as de-industrialization or the coming of age of second generation migrants in ghettos or changes in the age distribution. Brueckner and Helsey (2009) hypothesize that both sprawl and urban decline are due to an identical set of market failures that have nothing to do with bads: lack of congestion pricing, failure to price the benefits of open space and failure to charge developers the marginal price of new infrastructure necessitated by development

In the case of education, a similar common conception often advanced by politicians is that poor inner city schools encourage flight. Upon election in 2001, New York Mayor Michael Bloomberg undertook an effort to improve school quality, in part, to keep the middle class from leaving the city. In the case of schools, as opposed to crime, however, rather than studying the impact of school quality on flight, most scholarly research has focused on the role of socioeconomic status and property tax funding in school quality.

Additional bads (or in their absence goods) that might drive suburbanization are poor environmental quality due to pollution, slums and taxes that in a jurisdiction with a wide range in incomes may be redistributive relative to a jurisdiction with homogenous income. In all of these cases, there is solid evidence of a movement by the affluent away from inner city bads, however, the direction of causality—whether the affluent are fleeing bads, or their flight leads to bads in the neighborhoods they leave behind—or, indeed, whether causality runs in both directions—is hard to determine. Counter examples abound as well. For example, many southwestern cities with limited industry at their center and, presumably, less pollution than industrial cities, exhibit substantial sprawl. (In this case manufacturing production externalities in old cities could simply be outweighing any environmental impact.) New York with high taxes has many affluent residents at its core. Disentangling causality is clearly complex. While robust evidence of causality running from urban bads to suburban flight is lacking, some scholars find a linkage. Berry-Cullen and Levitt (1999), for example, find support for a causal impact of crime on sprawl with each reported crime leading to the departure of one person.

Political Fragmentation

Related to the idea that bads may lead to sprawl is a slightly different hypothesis, namely that differing preferences for bundles of city services relative to taxes may lead to the proliferation of new communities. Because new communities cannot be formed in the existing city but must be formed outside it, the *desire* to self sort may lead to sprawl. Orfield, Downs(1998) and other commentators find a principle cause of sprawl (but also a definition of the phenomenon) in

fragmented political authority (Black, 1996, Burchell et al, 1998, Moskowitz and Lindbloom, 1993).

Tiebout (1956) again provides context to the role of political fragmentation in sprawl by modeling how households self sort to seek out communities that deliver the most value for taxes, based on their privately held preferences that their choice of communities then reveals. Working in the same vein, Berglass and Pines (1981), Hochmann (1981), Henderson (1977) and others, incorporating the idea of city as developer, address how land prices, in effect, capitalize the value of services relative to taxes and, in effect, place a price on each city's tax-services value proposition. A principal driver of new town and city formation and political fragmentation has been the desire of groups of people to escape simultaneously the political authority of city governments and their taxes—which they often linked to political machines—and more recent immigrant groups

The political economy of suburbanization creates a strong incentive both for cities to annex surrounding territory and for areas around cities to form competing political authorities to resist annexation. When a city is able to annex an adjoining area, it gains the ability to tax those residents who may, indeed, use its services. In contrast, the community able to escape annexation and form an independent community can free ride on many city services that assume the form of (non rivalrous and non exclusive) public goods such as libraries, parks and subsidized transit systems as well as the spillovers provided by the city. The cost of forming separate communities, however, is inefficient duplication of services (Orfield, 1997).

Demographic and Cultural Factors

In addition to income, the desire to self sort may also have an ethnic, demographic or racial component. Insofar as sprawl seems to have proceeded fastest and furthest in the United States and achieve its apotheosis here, one school of analysis has sought the causes of sprawl in features unique to the United States. For example, von Hoffman and Felkner (2006), reviewing the extensive literature on American urbanization, find causes for sprawl in the unique demographic and cultural history of the United States. Steady immigration through 1925 and after 1965, the authors argue, provided a stream of new people who could best be accommodated at the urban periphery. Internal migration from the South to the North and the Baby Boom added to population pressures that promoted sprawl. In addition, they argue, a longstanding American ideal of "taming the prairie", owning a single family home, enjoying the moral and health benefits of single family home ownership in a healthy suburban environment and, finally, escaping new groups of immigrants and African Americans, fueled suburbanization and with it sprawl.

Beckmann (1973) has found that larger families—such as those that appeared in the United States following World War II during the baby boom—promote suburban development due to their preference for space. Jackson (1985) describes patterns of out migration of ethnic groups to suburbs. Clearly some suburbs like neighborhoods have higher concentrations of certain

ethnic groups. While different European ethnic groups may once have self sorted depending on country of ancestry or religion, ethnic identity and spatial separation have faded over time.

In contrast to ethnicity, however, immigrant or foreign born status does correlate strongly, though *negatively* with sprawl (Fulton et al, 2001). This is consistent with the hypothesis of Jackson (1985) as well as earlier social scientists of the Chicago school that immigrants tend to settle in cities but that as each new wave of immigrants moves into central cities, native born Americans (or simply the previous wave of immigrants) move outwards. There is evidence that foreign born population follow native born population in moving out of the central city as incomes rise, leaving behind, however, residual ethnic enclaves in central cities as with Koreans in Los Angeles or Cubans in Miami (Myers and Lee, 1996, Bae, 2004, Portes, 1987) with some groups persisting in the inner city longer than others.

Indeed, the US has a longstanding pattern of immigration into central cities where work opportunities have generally been greatest followed by migration out of cities as incomes rise. When combined with in-group cohesion and income stratification by ethnicity, this has led certain ethnic groups to settle in different communities. Ethnic stratification among whites is much weaker, however, than racial stratification with Hispanic dissimilarity falling somewhere in between (Massey and Denton, 1993)

Race

The one demographic variable that scholars have found to correlate most strongly *and persistently* with American spatial urban structure is race. While whites and blacks lived in close proximity during the pre-industrial era, the emergence of blacks as economic competitors to whites in the north in the 1920s sparked a major round of segregationist activity and racial sorting that persists today. Massey and Denton (1993) have shown that white Americans typically remain in neighborhoods until the neighborhood reaches a threshold of 5% African American at which point they leave. Creating a new political entity that they control enables whites to impose exclusionary zoning and otherwise impose policies to maintain spatial and political separation from blacks. A variety of other authors have found confirming evidence of an impact of race on sprawl including Mills and Price (1982) and Glaeser and Kahn (2003). (There is some disagreement on the normative impact of sprawl on racial equality with Kahn (2001) arguing that sprawl, though driven in part by race, lessens racial separation.) (A separate literature on the "spatial mismatch" between jobs and people (Kain, 1968, Wilson, 1987) that gives rise to slums is addressed less to the question of how slums might give rise to sprawl than how sprawl—particularly the dispersion of jobs—might give rise to slums and is discussed later.)

Policy and Planning

Jackson (1985) links the development of the suburb and, by extension, sprawl to the garden city movement in Europe, the planning movement in the United States and, in turn, exclusionary association of escape from the city and single family home ownership in the suburbs with the

American Dream. The planning movement while striving to improve the character of cities, sanctioned, as well, flight from the traditional city and creation of suburban forms of living on the urban periphery. Jackson (1985) explores how the steady expansion of cities and development of suburbs flowed naturally out of American moral ideals superimposed on improvements in transportation technology, new construction techniques such as balloon construction and population growth. From a luxury for the rich and well to do, suburban living became gradually more accessible to the poor. His analysis, however, is largely qualitative. Hall describes how such celebrated architects as Frank Lloyd Wright celebrated the automobile city in his 1932 design for Broadacre City and, indeed, argued for the end of the city (1988) in celebrating a new architecture of "what was". Indeed from the 1930s onward, architecture increasingly looked to the automobile and new suburban living as the wave of the future; only in recent years, has a counter-movement celebrated urbanism.

A number of scholars have studied pre-automobile suburbanization using quantitative data and found that suburbanization did occur rapidly prior to 1950, however, policy and planning initiatives in the late 19th and early 20th Century or the type Jackson (1985) describes are difficult to isolate and quantify as explanatory variables. (Mieskowski and Mills, 1993). More recently, as government intervention in the housing market has grown in a number of dimensions, locally through zoning and political fragmentation and at the federal level in the US through intervention in the transportation and housing sectors, a number of scholars have studied particular government policies. They have found qualified evidence for a statistically significant impact of policy and planning on sprawl.

Local Planning, Policies and Politics

Pendall (1999) searches for the causes of sprawl in political organization, land use policies, and municipal spending in addition to land values and levels of traffic. He finds that different regulatory practices, political structure and prices of land and housing are associated with higher or lower degrees of sprawl. Zoning policy clearly impacts and, in the United States, encourages sprawl. Gyourko et al (2008) examine the impact of zoning policy on sprawl and find that techniques such as exclusionary zoning by lowering density and spreading out development, contribute to sprawl. Morrill and Levinson examine the role of restrictive zoning in older suburbs in driving development in exurbs further out from cities. Garreau (1991) has similarly studied the phenomenon of Edge Cities that have developed outside strict areas of zoning. Kirby and Lynch (1987) examine the role of pro business, pro growth policies in fostering booms and development in the sunbelt in contrast to more restrictive policies in older cities. Insofar as political fragmentation may reflect a desire of groups to separate themselves from others by race, ethnicity or income, the latter variables may indirectly impact sprawl.

Federal Policy and Sprawl

According to Howard (1998), federal transportation policy, in particular, support for the Interstate Highway system through the federal gas tax and the Highway Trust Fund helped create and may encourage sprawl. Gutfreund (2004) finds that the creation of the Interstate Highway system and the system of subsidies in the form of the gas tax and Highway Trust Fund

on which it rests helps explain sprawl. Supporting the bias toward suburbanization implicit in Federal support of highways, the US government has also, arguably, provided support for suburban- and exurbanization through housing policies that strongly support home ownership. For example, Voith (1990) argues that the home interest tax deduction has contributed to sprawl. Since single family homes are far more concentrated outside cities than inside them and programs for co-ops and condos remain less developed, this has stimulated exurban development.

In addition to the mortgage interest deduction and favorable tax treatment of capital gains from owning a home, the FHA system of loan guarantees have driven home ownership upward in the United States. From the creation of the Federal Home Owners Loan Corporation to the FHA and today's Fannie Mae and Freddie Mac programs, federal support for housing has become one of the largest government interventions in the economy. While a number of authors draw a connection between mortgage subsidies and sprawl (Jackson, 1985), proof of this pathway awaits further research.

Herbers and Power examine the role of retirees who draw their income from federal transfer payments such as social security or draw other portable investment income and those with portable job skills in driving growth in the sunbelt. Sheehan (2001), however, has found sprawl to be an international phenomenon. Notwithstanding the limits on physical expansion of cities in Europe, neatly surrounded by farmland as discussed above, Sheehan finds sprawl to be endemic to modern society.

Studying Europe, Delvana (1998) has implicated agricultural subsidies that make land outside cities economical to farm and expensive to develop, high taxes on car purchase that make driving expensive, mass transit subsidies that lower the cost of urban living and rules favoring small shops over large ones that promote short, frequent shopping trips as opposed to time-consuming, infrequent shopping at larger markets, as limiting sprawl.

Energy Prices and Sprawl

Despite the primacy of transportation cost in models of city structure and growth and the well known role of energy prices in shocking the economy at large, notably with the 1970s oil shocks, precious little research has examined the link, if any, between energy prices and sprawl. Ingram and Liu (1999) Glaeser, Kolko and Saiz (2001) and Glaeser and Kahn (2003), employing a comparative approach across countries find that gas taxes by driving up the cost of car ownership have a statistically significant impact on lowering sprawl. Though gas taxes are a smaller element of driving cost than fuel costs, they do not examine the impact of fuel costs. Romanos (1978) proposes a model in which higher energy prices inspire energy conservation through the formation of multiple urban employment centers serving a region. In this sense, he argues that gas prices lead to concentration in the form of suburban sub-centers. He stops short, however, of examining the general impact of energy prices on sprawl.

Wassmer (2008) finds that household car ownership exerts a modest impact on urban size and density. He estimates that a 10% reduction in households owning cars, on average, would reduce city size by only .5%. However, he does not analyze the impact of gasoline prices on city size or density.

Surprisingly, no one has conducted direct studies on the impact of energy costs on suburbanization or sprawl. In contrast, a rich body of literature studies the functioning of energy markets in general. In particular, in the wake of the 1970s oil shocks on the economy and in the context of electricity deregulation and market design, a number of scholars have studied elasticity in energy markets and the relation of prices to supply and demand. In this context, most scholars distinguish between short- and long term price elasticity of demand due to the role that time and capital goods play in mediating levels of energy consumption. Higher energy prices do not immediately transfer to less consumption at equilibrium because of the difficulty most users face in reducing their level of energy consumption. Nor do lower energy prices instantly raise consumption. Using a Slutsky framework, energy in the short term demonstrates low price elasticity because, as an essential good, consumers cannot readily adjust consumption and have few short term substitutes. Only when users are able to purchase new higher efficiency appliances—or purchase appliances that use an alternate fuel—for example, a new gas heating system to replace an electric one—do they significantly change their level of household energy consumption in response to prices.

In the case of transportation fuel, to use less fuel, they must change their commuting pattern or purchase a different car. Nor so long as they live in the same place and drive the same car are they likely to consume much more fuel if prices drop. Low price elasticity in the short term is compounded in electricity and home heating fuel markets by the consumer's incomplete information insofar as billing occurs *ex post* after the decision to consume and consumers have no *ex ante* knowledge of prices. But even in gasoline price markets, fluctuating prices and the time delay between fill up and consumption, pose a barrier to calibrating consumption to price. In short, due to a limited ability to do without and "lock in" through capital goods, exacerbated by poor consumer information about prices, energy demand is likely to demonstrate, in the short term, a very limited substitution effect and a modest price effect in response to changes in price. In the long run, however, price elasticity is considerably higher.

Surveying 97 studies of price and income elasticity for gasoline, Dahl and Sterner (1991) find an average price elasticity for gasoline in the short term of -.26 and in the long term of -.86. Espey (1998) subjecting studies to rigorous analysis, found a median short term elasticity of -.23 and long term price elasticity of -.43 but nonetheless robust support for an elastic response.

Income elasticity of fuel prices is also of interest insofar as the AMM model and the qualitative models of authors such as Jackson (1985) suggest the affluent are more likely to exit the city due to their greater capacity to bear transportation charges and rising affluence may thus drive sprawl. In the Dahl and Sterner survey, income elasticity averaged .48 in the short term and 1.21 in the long term. The positive sign in the case of income confirms the ability of the affluent

to afford more gasoline and the difference between the short and long term figures, that time is needed to substitute goods or change behavior. Thus the Dahl and Sterner (and Espey) findings are consistent with the Jackson and AMM hypothesis that affluence helps to explain suburbanization. While Hughes et al (2006) find that short term price elasticity has declined in the last decade due to increasing dependence on the automobile, they find income elasticity has remained largely constant.

To summarize for transport fuel, in the short term, consumers face a significant barrier to consuming less fuel insofar as their daily commute may be fixed, their shopping choices constrained, their car difficult to exchange and their knowledge of the cost of transport incomplete. Over the long term, however, these barriers decline. Consumers may replace capital goods or effect significant change in behavior, for example by moving. And when price changes are sustained, consumers are more likely to take note of this information and act upon it.

A cautionary note is that rising dependence on the automobile may be limiting short term ability to respond to prices (Hughes et al, 2006). Mass transit miles as a share of the total have declined steadily over the last three decades (Polzin and Chu, 2005). Substituting walking or rail transport for driving—after moving to a higher density area—is more readily accomplished in metropolitan areas where public transportation alternatives exist and where *employment* is concentrated—notably in monocentric cities. In America's growing post modern cities and sprawling regions that lack major nodes of agglomeration or where nodes are widely distributed

and lack public transportation, consumers have fewer options to reduce gasoline consumption by changing behavior or moving. They may have to exit the metropolitan area entirely. In short, *sprawl* may lock in *sprawl* in a given area at least in the short term if there is no meaningful substitute present to lower fuel consumption if it rises in price.

In short, the difference in short- and long term price elasticity of demand implies that *short term variance* may not have an impact on behavior insofar as consumers may lack time to change their capital goods (or location) before the price reverts to its previous level. In contrast, a sustained, *permanent change* would appear more likely to impact consumption. Invoking expected utility theory, one can hypothesize that consumers may react to the *expected value* of prices based on past history computed over a period of time rather than continually responding to price changes.

For the purposes of my dissertation, the short- and long-term elasticity differential suggests it is reasonable to expect a lag between energy price changes and the impact, if any, on sprawl. Thus, I intend to search for an impact of *lagged* gasoline prices on current indices of sprawl to account for the time required for consumers to change behavior and builders and the economy more broadly to adjust to changes in energy prices. As discussed at greater length in Chapter II, after experimenting with different lagged periods and moving averages, I focus on two year lagged gasoline prices.

Consequences of Sprawl

My dissertation is mainly concerned with the role of energy prices in determining sprawl, however, the consequences of sprawl are nonetheless relevant because they determine whether it is desirable to promote, constrain or ignore sprawl. While some authors view sprawl favorably and others argue it is a natural outgrowth of our current economy that cannot readily be altered, most scholars *investigating its consequences* have focused on its costs. Sprawl affects society in a number of ways that require different measures and analytic tools and raise different theoretical issues. To understand its overall impact, therefore, it is useful to examine its impact in each specific sphere:

Cultural and Aesthetic Impact

Sprawl has changed the physical appearance of the United States (and, indeed, the entire world) and many consider that change to be for the worse. In some cases the elements of sprawl that have drawn the ire of critics relate to its haphazard quality and the lack of a common aesthetic theme (Blake, 1964, Kunstler, 1996). In other cases, critics have disparaged dreary conformity notably in tract housing and retail malls. The variety of criticism suggests that what may seem easy to criticize anecdotally is difficult to standardize or quantify. Thus cultural and aesthetic critiques of sprawl have been qualitative in nature. The lack of a quantitative way to measures aesthetics makes this a difficult outcome to incorporate in normative rigorous assessments of the impact of sprawl.

Economic Impact

The construction of sprawling development insofar as it represents new investment exerts a positive impact on local economy activity. But to truly assess whether the impact is positive or negative one must perform general welfare analysis to determine whether the impact is Pareto positive relative to alternative forms of development and, moreover, who wins and who loses from sprawl (Mills and Price, 1972). To date, no one has undertaken this substantial project. Many authors have, however, studied the efficiency of sprawl and found it wanting.

The principle economic argument against sprawl is that it is inefficient (Peiser, 1989). Relative to more compact development, it may require excess roads, plumbing and other services due to its discontinuous nature and greater consumption of land compared with older, more parsimonious forms of development. It may also reduce positive externalities that accrue to proximity and therefore reduce the efficiency of production.

Indeed, due to the very externalities that give birth to cities, as Lucas and Rossi-Hansberg (2002, p. 1445) observe, "there is no reason to believe that market prices—land rates and location specific wage rates—give firms and households the right incentives for making land use decisions." The very agglomerative externalities that give rise to the city suggest that prices do not reflect externalities and therefore provide the wrong signals to economic actors (Rossi-Hansberg, 2003). Zoning and other interventions are designed, in part, to address these pricing failures. A key problem is that private actors participating in an urban economy in the absence

of countervailing policies may not arrive at a Pareto optimal equilibrium through maximizing their own utility. Highlighting the question of market failures, Rossi-Hansberg (2003) observes that the privately optimal decisions by actors in the city at equilibrium do not take into account the impact of these same decisions, and therefore yield sub-optimal allocations.

Brueckner and Helsey (2009) argue that sprawl is inefficient in three principal ways that reflect market failures. First, the market fails to price congestion properly; second, it fails to price open space properly and third, it fails to charge developers for the new infrastructure needed to support development. By this, they mean that free vehicular access to the center that does not reflect the true cost of congestion encourages dispersion, open space destroyed by development is not fully valued and developers rarely pay for infrastructure needed to support development such as roads, schools and hospitals surrounding their projects. While they argue that these market failures can be addressed prospectively through taxes and fees they do not offer a solution to the problem of inefficient sprawl that is already in place nor suggest a mechanism to mitigate the impact through *ex post* interventions.

A related literature argues that decentralization may reduce the productive benefits of agglomeration. Lucas and Rossi Hansberg (2002) develop a model that supports the conclusions of Rossi Hansberg (2001) that the equilibrium land use in the presence of high commuting costs whereby productive and residential uses are mixed differs from optimal land use. In general, dispersion of businesses reduces agglomerative benefits and is likely to be inefficient. However, some scholars believe that sprawl is largely positive (Glaeser and Kahn, 2003). While

acknowledging that market failures might lower efficiency, Glaeser and Kahn believe the benefits of sprawl far outweigh its costs. Indeed, they argue that the major problem with sprawl is that not everyone can afford it.

Orfield (1997) examines the economic inefficiency of the proliferation of municipalities due to large scale duplications of services. When combined with the economic sorting of residents, the latter advantages only a handful of wealthy communities while impoverishing the remainder. Sprawl may also contribute to "spatial mismatch". Wilson argues that the flight of jobs out of the inner cities exacerbates the problems of those left behind, principally African Americans so that while suburbs may benefit from sprawl, residents of the inner city pay the price. Downs (1999), however, argues that exurbanization does not negatively impact the inner city. Brueckner, Thisse and Zenou (2000) model the impact of commuting costs on ghettoization of the unemployed. An additional economic argument against sprawl is that it locks in dependence on automobile transportation that may grow more expensive in the future (Fujita and Thisse, 2002). However, the precise degree to which sprawling development may impact efficiency based on the cost of auto transportation awaits further research.

Environmental Impact

In addition to and apart from its economic impact, sprawl has environmental effects. Here, most scholars believe that sprawl has negative environmental consequences relative to denser development. First by consuming more land than alternative methods of development, sprawl

runs directly counter to the principal of conservation that underlies many environmental goals. In addition to land, sprawl consumes rivers, streams, ponds and other water resources. For this reason, its environmental impact is likely to be greater than equivalent levels of development that consume less land. Second, insofar as sprawl promotes auto travel and the production of greenhouse gases, it may be deleterious for the environment. A variety of studies have shown that sprawl produces more greenhouse gases than higher density living due to its correlation with auto usage (Kahn, 2000), the lower efficiency of single home heating relative to heating multifamily properties and the larger quotient of transportation implicit in low density living and resulting higher levels of fuel consumption. While there is general agreement that sprawl is environmentally problematic, precise quantification of the impact awaits further research, in part, due to the absence of a counterfactual example of a world without sprawl.

Health Impact

Sprawling areas also has a different health profile than more urban ones. Whereas suburban living was originally heralded as healthier than the urban variety, cities today no longer have dramatically higher incidence of disease than suburbs or exurbs. Nor are cities as polluted as they were a generation ago. Meanwhile, after adjusting for age and income, people living in suburbs appear to have a higher incidence of obesity and heart disease. Apart from areas of poverty in inner cities, city dwellers are healthier than their suburban and exurban counterparts. The precise causality of this effect may relate to greater time spent in cars, higher levels of

sedentary activity, less walking, greater consumption of fatty, fast and prepare foods and lower attention to health.

Frumkin (2002) surveying the public health impact of sprawl in eight dimensions, air condition, heat, physical activity patterns, motor vehicle crashes, pedestrian injuries and fatalities, water quality and quantity, mental health and social capital and finds that sprawl has both positive and negative impacts on health with the negatives ones falling more severely on the less advantaged. Less walking and bicycling in sprawling regions may worsen health. On the other hand, suburban areas do not exhibit the heat effects found in some cities.

A number of authors have studied the connection between Inactivity from greater use of the automobile in lieu of walking and obesity. McCann (2003) finds that a substantial portion of the increase in obesity and hypertension in the United States and developed countries in recent years is due to sprawl after controlling for other factors. The prevalence of fast food restaurants in exurbs may also encourage obesity. Lopez (2004) finds a positive correlation between sprawl and obesity. Sprawl may, however, provide health benefits relative to urban environments by offering fresher air, separation of use between residential and commercial or industrial sections, and greater recreational opportunities due to proximity to undeveloped land and lower cost land for recreational facilities (Sturm and Cohen, 2004)

Social Impact

Sprawl, in contrast to its image as providing a healthy, idyllic environment for the rearing of children, may create obstacles to effective parenting. Long commutes, long distances between homes and shopping and reliance on the automobile are associated with the enervation of street life. The absence of "adult eyes" on the street due to time spent in cars and the increased incidence of mothers working only increases the need to drive to find social stimulation, further increasing time spent in car. Even the characteristic curved nature of suburban streets (designed to maximize prices by maximizing green horizons) makes them, ironically, less safe for children since neighbors cannot see one another's yards, reducing neighborhood social interaction.

Baumetier and Leary (1995) surveying the literature of the psychology of cities observe a human requirement for interaction with others and interaction in a stable enduring framework that may be attenuated by sprawl. Putnam (1999) has suggested that excessive dispersion reduces social capital and social interaction and therefore is socially harmful by virtue of lowering levels of social interaction. There is evidence that distance lowers levels of interaction. Renters interact more than owners of detached homes. (Glaeser and Sacerdote, 1999) Brueckner and Largey (2008), however, challenge Putnam's finding using survey data from the Social Capital Benchmark Survey conducted in 2000. They conclude that the impact of low density living on social interaction is small and, indeed, negative suggesting that the poor quality of interactions in cities more than compensates for the larger number of nearby people.

Chapter 4: Methods

My dissertation topic is the impact of energy prices on sprawl defined as land intensity of population, employment and light visible in space. Accordingly, I test the marginal impact of energy price changes on measures of sprawl empirically for a group of urban areas in the Untied States over multiple time periods using multivariate regression analysis and controlling for other variables.

My empirical model is derived from a mathematical model of the city I construct that draws on a long tradition in the urban economics literature, discussed in Chapter 3 of interpreting the city as a tradeoff between the centripetal, agglomerative forces that give rise to cities and the centrifugal costs of congestion that constrain their density and size. Drawing on the work of von Thunen, Clark, Berry, Alonso, Muth, Mills, Wheaton, Brueckner, Malpezzi, Rossi-Hansberg and others I construct a simple model of the city using the variables of housing and land consumption, transport consumption, energy cost, population, production externalities and wages. In particular, my model follows derivations by Brueckner (1987) and Bertaud and Malpezzi (2003). The model adds to the existing literature in that I include explicit variables to absorb the effects of social, demographic and topographic factors that, in the real world, clearly shape the structure of the city. Continuing a long line of inquiry, I model density and land price changes moving out from the city center as the result of the rise of commuting costs. In particular, I assume constant utility across a locational indifference curve where agents through the mechanism of prices are indifferent to alternative bundles of housing, transport and other goods. I attribute the desirability of the center to spillovers and increasing returns that attract

firms to a central business district. Following Rossi-Hansberg et al (2009), I allow firms to locate outside the center where they may avail themselves of lower land and labor costs at the cost of reduced agglomerative benefits. The model suggests that sprawl should be elastic to gasoline prices, wages, city size as measured by population, labor participation, demographic variables of the population, topographic features of the city, and an agglomeration parameter that may vary by industry or job occupation. A detailed description and derivation of the model is provided in Appendix A.

Having constructed a model of the city that predicts how key variables may influence sprawl, I then specify a series of empirical models suggested by that model and the literature, using different datasets to test the model's predictions. To take advantage of available panel data, I perform ordinary least squares regression using fixed effects on multiple urban areas over periods of time in addition to cross sectional regression analysis. To verify causality, I employ techniques to rule out endogeneity and omitted variable bias or measurement error that include instrumental variables, time sequence analysis, analysis of determinants and fixed effects.

The basic empirical model that I test is:

$$S = \alpha + \beta E + \gamma C$$

where S is an index of sprawl, α is a constant, E is an index of energy prices, β is the coefficient describing the marginal impact of energy prices on sprawl, C is a vector of control variables and γ is the vector of coefficients describing the marginal impact of the control variables. In certain

variants of the model, I also log ***S*** so that the coefficients for explanatory variables will have the characteristic of describing the marginal effect of each variable on sprawl.

In turn, it is convenient to divide the control variables into three categories, those that remain fixed for a given city over time, ***F,*** those that change in time but are fixed across cities, ***T*** and those that change over time and city, ***C***. Examples of ***F*** are year of city incorporation, state and presence of physical barrier such as the ocean, an example of ***T*** is national GDP growth while an example of ***C*** is local average household income.

I separate them because the former cannot explain sprawl over time but may help explain differences between areas at one point in time, the second group can explain sprawl over time within area, but not between them, while the third group may impact sprawl in time and by area. The distinction is helpful for performing fixed effects regression on the panel data to exclude bias from unobserved variables of type ***F*** or ***T.*** Excluding bias from unobserved variables improves estimates of the effects of observed variables. In the case of "before and after", two period, panel data such as that from Burchfield et al, variables of type ***F*** that do not change in time cannot impact the dependent variable, sprawl unless combined into interactive variables. Because I believe that correlation between residuals of the regression and variables may exist, I employ a fixed rather than random effects approach.

In the empirical version of the model, I index the variables by urban area, ***u***, and time, ***t*** reflecting the panel format of the data. Finally, I hypothesize that energy prices may not impact

sprawl immediately but rather impact it in the future, so I include a time lag variable $l \geq 0$ reflecting the lag in periods so that energy prices at time t is associated with sprawl at period $t+l$ or alternatively, sprawl at time t is associated with energy prices at time $t-1$. This leads to the least squares problem:

$$\min \Sigma_i^N \ (S_{ut+l} - (\alpha \hat{} + \beta \hat{} E_{ut} + \gamma \hat{} F_u + \delta \hat{} T_t + \varepsilon \hat{} C_{ut}))^2$$

and the empirical model:

$$S_{ut+l} = \alpha + \beta E_{ut} + \gamma F_u + \delta T_t + \varepsilon C_{ut} + \mu_{ut}$$

Where the expected value of the error term for all observations, $E(\mu) = 0$. The error term absorbs variance from sources that cannot be measured. However, so long as its expected value is 0 and it is uncorrelated with other variables, the coefficients will be unbiased, consistent estimators of the true effects. My hypothesis is that energy prices do affect sprawl and my null hypothesis is that energy prices do not affect sprawl.

A Panel Data Approach

Much of the empirical literature on sprawl, with a few important exceptions, has used cross sectional data to compare regions at a single point in time. The reason for this approach, apart from its lower data requirements, appears to be that researchers have sought to understand why some regions sprawl more than others and what *primarily local* policy levers might be moved to impact sprawl (Galster et al, 2001 Burchfield et al, 2005). Because many potential causes do not change over time, a cross sectional approach can show how unchanging factors

such as year of incorporation and largely fixed factors that might be altered such as zoning explain sprawl. Cross sectional analysis is often used to rank sprawl across urban areas in order to identify most sprawling or least sprawling urban areas (Galster et al, 2001).

A purely cross sectional approach, however, suffers from the serious limitations that it does not directly address causes of sprawl over time and provides little insight into factors, especially national or global ones, that might cause *all* cities to sprawl. Nor does it suggest what policy levers might be employed nationally to impact sprawl. Because I am interested in the impact of changes in energy prices on sprawl, the national as well as local dimensions of sprawl and national policy levers on sprawl, I examine changes in sprawl over time. This requires using time indexed data for sprawl and energy prices, yielding T observations for each urban area as shown above. To draw robust conclusions from the data, it is desirable to examine multiple urban areas, U. Therefore, it is desirable to use balanced panel data for sprawl and energy prices containing UT observations.

The use of panel data imposes some methodological constraints. Time series data can be subject to drift or serial correlation due to a unit root. Thus different variables may appear to be correlated when they are not. For example population could appear to correlate with gasoline prices merely because both are rising over time for unrelated reasons. When regressing sprawl on other variables I need to ensure that drift or trending in the data—due to unobserved variables—does not lead to a spurious finding of correlation. Tools available to the researcher to detect and filter out drift or autocorrelation include performing the Wald-

Wolfowitz, Durbin-Watson or Dickey Fuller tests, differencing the data, examining changes in proportions as opposed to absolute numbers, adding control variables, or if necessary performing a Prais-Winsten regression with a Cochrane-Orcutt correction. I test for serial correlation, include control variables that might contribute to drift, use proportions that normalize the data, and difference the data as needed as checks on the primary regressions using OLS.

While my primary focus is on sprawl over time I also perform cross sectional analysis and incorporate some interactive variables in regressions of gasoline prices and variables that vary in space but not time to test how sprawl may change in response to energy prices given differences between areas.

Measures of Sprawl

There is no universal definition of sprawl, an imprecise term that has been applied to such diverse phenomena as ribbon development, discontinuous development, segregated uses and merely development scaled to the automobile. Different measures of sprawl often show limited correlation with one another suggesting that sprawl takes place in multiple dimensions (Galster et al, 2001).

Moreover, insofar, as I seek not only to define sprawl but also to explain it, it is immediately apparent that I should exclude from my metrics of sprawl all variables that are more properly causes. Population growth, for example, can cause sprawl. However, it is unequivocally not a *measure* of sprawl since population can grow in densely urban regions. Nor is it advisable to include consequences of sprawl. Obesity though correlating with sprawl is clearly not a good metric for sprawl since it can occur in the inner city as well as at the periphery.

I distinguish between sprawl, its causes and its consequences to avoid endogeneity problems that would result from regressing a variable—or component of a variable—on itself. Insofar as I intend to regress the measure of sprawl on energy prices and a set of control variables, it is desirable to exclude from my measures of sprawl any variables that are more properly explanatory. A sprawl index that included gasoline prices would obviously correlate with gasoline prices and one that included population growth, for example, would show correlation with population growth if the latter was included as a control variable.

The desire to exclude variables from my index of sprawl that might interact with explanatory variables argues for a simple index of sprawl—following Mills and Price (1972) or Glaeser and Kahn (2001)—as opposed to a highly complex model of sprawl such as those developed by Ewing et al (2008) or Galster et al (2001). A critical question in a temporal analysis of sprawl is finding adequate comparable data available at multiple points in time. This argues in favor of using standardized measures such as those collected by the Bureau of the Census and government agencies. While definitions of sprawl in the literature vary, most scholars agree

that a key element of sprawl is the liberal use of land as a factor in urban development (Clark, 1951, Berry, 1963, Glaeser and Kahn, 2001, Lopez and Hynes, 2003.) Consumption of land is of interest in and of itself because of the environmental impact of land use and the transportation implications of low density settlement. Accordingly, I choose to operationalize sprawl through variables that capture this critical element in three distinct ways, people relative to land, employees relative to land and nighttime lighting as a proxy for altered land use.

A common measure of people relative to land is population density. I construct multiple metrics of population density. My second set of metrics, following Glaeser and Kahn (2003), measure employment dispersion or jobs relative to land. The third measure, drawn from Burchfield and et al (2005), uses changes in light visible from space as a measure of land consumption.

Population Density Measures

Population density is perhaps the oldest measure of urban concentration, predating the concept of sprawl. In a seminal article, Clark (1951) drawing on earlier work by Jefferson (1909) and Meuriot (1898) developed a formula and coefficients to describe the decay in density from the center, $d_x = d_0 e^{-bx}$ where d_x, is population density at distance x from the city center, d_o is derived central density, and b is the density gradient. Berry (1963), in turn, provides a theory to explain Clark's findings and test them empirically. As previously discussed, Alonso (1967) provides a broader theory to explain decaying densities while Muth (1969) and Mills further develop what

is known as the AMM model. Mieszkowski and Mills (1993) and Jordan, Ross, and Usowski (1998) measure the density gradient from the city center as an indicator of sprawl.

While these authors and, indeed, most scholars who have studied urban growth primarily compare cities at fixed points in time, population density change is also well suited to evaluating ongoing or temporal sprawl. It is not clear, however, that the concept of population decay away from the center, while well suited to analyzing pre-industrial and industrial cities with a single center, is equally well suited to studying the multi-centric, post-industrial cities that have appeared over the last half century and, indeed, most typify the effects of sprawl precisely due to their lack of a center. The concentration of sprawl in post-modern cities with multiple nodes of concentration motivates a search for another measure of density compatible with a multi-nucleated city (Lopez and Hynes, 2003). Accordingly, I undertake a review of potential measures prior to selecting one principal metric and multiple variants.

The simplest measure of population density is simply density itself or population divided by land area for the area in question. The intuition for using some measure of population density change as an indicator of sprawl is as follows. Imagine a city where population remains constant. Most people would agree that if the city expands outward in space incorporating additional land, transferring people from high density dwellings at the core to low density dwellings at the expanded periphery, then this would constitute sprawl. The density *ex post* would be lower than the density *ex ante* as new land is captured. If on the other hand, people move from the periphery to the core, abandoning and depopulating a ring at the edge of the

city, causing the city to shrink, this would constitute the opposite of sprawl. (A movement of people to or away from the city's core without changing the outer boundary, however, would be ambiguous.)

Relaxing the constraint on population to allow it to grow, one would expect to see more people living in the core as well as new development at the periphery. Population growth is likely to lead to more sprawl in absolute terms. One can then test whether sprawl is increasing or decreasing in relative terms by measuring whether the accumulation is occurring in sprawling or densely urbanized tracts.

Simple measurements of population density, however, constitute a poor metric for sprawl for several reasons. First, they fail to differentiate between cities with extremely high density in some places but low density in others and cities with a uniform density. Second, the presence of a desert, park, lake, industrial area or other uninhabited tract of land area can throw off density measurements (Fulton et al, 2001). A special problem at the MSA level is that since MSAs consist of counties, when an MSA expands into an adjacent country, the Bureau of the Census makes the entire county part of the MSA. Often, much of the newly incorporated county remains rural (Lopez and Hynes, 2003). Counties may also consist largely of desert, as in the case of the Mohave desert in the Riverside-San Bernardino MSA. Simple density reveals nothing about the variance of density and degree of concentration at the center. Indeed, Clark (1951, p. 490) dismissed simple measures almost sixty years ago:

> The figures of density of population of cities sometimes published in reference books are practically meaningless. Arbitrary administrative decisions as to how much rural or

> semi-rural land is to be included within the city boundaries may completely alter the results. Fruitful study of urban population densities can only be made by drawing a map of the city and plotting, either by stippling or shading, the densities of population by the smallest component areas (Census Tracts or administrative sub-divisions) for which data are available.

Using data at the census tract level, as Clark suggests, makes it possible to trim back the edges of the MSA to exclude land that has not yet been developed. (It is not possible to screen out unpopulated areas within the MSA entirely since the Census Bureau includes most of the central ones within tract boundaries.) His methodology is also well suited to studying the variance and gradient of population in monocentric cities. However, it is readily apparent that the approach of Clark, Mills and followers of tracking density decay by distance is less well suited to the study of variance and density gradients in the polycentric cities that have emerged during the automobile age that have no obvious center. A further complicating factor in working with densities is how to handle cities topologically constrained by boundaries on one or more sides such as an ocean, lake or mountains. To best capture population density—or its inverse land per person—and understand how it varies within a city, I use a set of density measures.

While population density data is available directly from the Bureau of the Census, I use the census bureau data included in the Geolytics Neighborhood Change Database (NCDB) that provides data for each of the decennial census years, 1970, 1980, 1990 and 2000, normalized to year 2000 boundaries. The chief advantage of using the NCDB data—derived from census bureau data—is that it makes adjustments for changes in census tract and metropolitan area boundaries that occurred over the period in question, normalizing all of variables in the database to 2000 boundaries to facilitate comparisons.

As my definition of urban area, I choose the Primary Metropolitan Statistical Area (PMSA). Although the Census Bureau has deprecated the PMSA as a unit of statistical measurement in favor of the Metropolitan Area and Core Base Statistical Area, it was the designation in use at the time of the last fully published census. Compared with the larger MSA designation it is more granular and corresponds better with intuitive notions of the city. For example, Baltimore, MD is its own PMSA but at the MSA level is combined with Washington DC into a single MSA encompassing both Washington DC and Baltimore. Using the PMSA designation—particularly in studying urban areas going back to 1970—makes it possible to study traditional cities such as Baltimore.

I employ the following population density-derived metrics as measures of sprawl.

Gini Coefficient of Density

The Gini coefficient is often used to measure inequality within a distribution of income. It can be applied to any distribution and has the advantage that it is independent of the form of the distribution and can be calculated without making any assumptions about the distribution type. As my first measure of sprawl, I calculate the Gini coefficient for population (normalized for land) within each urban area defined graphically as the ratio of the area between the Lorenz curve of the distribution and a hypothetical Lorenz curve for a uniform distribution and the area

below the curve for a uniform distribution. Since the latter area, normalized, is equal to ½, the Gini coefficient is also equal to twice the area between the Lorenz curve and that of a uniform distribution. The Lorenz curve is defined as:

$$L(y) = \frac{\int_{0 \text{ to } y} x \, d\, F(x)}{\mu}$$

where $F(x)$ is the cumulative density function and μ is the mean.

When the distribution is uniform—the equivalent of every tract having an identical density—the Gini coefficient is 0. This represents total equality. In contrast when one tract accounts for all the population and all other tracts have zero density, then the Gini coefficient is 1. This represents total inequality. The Gini coefficient also equals the relative mean difference or mean of the differences between the size of the observations and the mean of the observations, μ:

$$G = \frac{\sum_{i = 1 \text{ to } n} \sum_{j = 1 \text{ to } n} |x_i - x_j|}{2 n^2 \mu}$$

The Gini coefficient, while generally considered a robust statistic, exhibits greater sensitivity to outliers above the mean than some other measures of central tendency. This quality enhances its ability to assess concentration of wealth. An increase in the highest value will translate to a higher Gini coefficient. This is because the Gini coefficient is calculated by first ordering the observations from lowest to highest. If the last, highest observation accounts for a large share of the total, the area between the Lorenz curve of the distribution and the Lorenz curve of a uniform distribution will approach ½. For example, if nine census tracts have a density of 10

people per square mile but one has a density of 100 per square mile, the Gini coefficient is .43. However, if the latter has a density of only 50 per square mile, then the Gini coefficient will only equal .26. In contrast, providing the order of observation values does not change, higher values of intermediate observations will lower the Gini coefficient as the area below the Lorenz curve will increase.

However, in the case of population density, the sensitivity of the Gini coefficient to the highest value is not a major concern as census tracts are designed by the Bureau of the Census to be bounded in order to facilitate efficient data collection and tract comparisons.

Slope of Decay in Tract Density by Rank

As my second measure of urban intensity, I construct a coefficient that describes the distribution of densities of populated tracts for each MSA for each year. Following Clark and Mills, I examine density relative to a hypothesized city core. However, because many sprawling centers lack a traditional city center or are polycentric, exhibiting growth around multiple nodes, rather than using distance from a theorized single city center, my first measure examines density relative to a *proxy* for physical location. Following Zipf (1949) who introduced the concept of relating frequency to rank, I examine the linkage between density and density rank. Zipf's law in urban studies explains city size as a function of rank (Dittmar, 2008.). Building on this construct but applying it to density of tracts *within* metropolitan areas, I rank *tracts* by population density and then regress population density on rank.

Specifically, I sort tracts by density for each year. In turn, following Clark and Mills, I fit a line to the distribution of log of densities relative to rank by performing ordinary least squares regression that is robust to heteroskedasticity of the log of density on the rank of tract density to yield a coefficient equal to the slope of the fitted line as follows:

$$\boldsymbol{Ln(Pop\ Density) = lnA - B(Rank)}$$

For a ranked distribution, $\boldsymbol{D}$ of n densities, $\boldsymbol{d}$, of rank $\boldsymbol{\rho}$, measured on the log scale, at time **t**, I identify the coefficients, $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ that solves the following:

$$\min \Sigma_1^N \ (\ln \boldsymbol{d_{pt}} - (\boldsymbol{\alpha_t + \beta_t \rho}))^2$$

The coefficient$\boldsymbol{, \beta,}$ provides a measure of the decay in log of density by rank. A steeper density gradient represented by a more negative $\boldsymbol{\beta}$ (larger absolute value) slope corresponds to a more urbanized environment while shallower gradients correspond to a more sprawling environment. (Note in assuming an exponential distribution, I follow Clark and Mills rather than Zipf who employs a Pareto distribution of degree 1 to analyze problems in human ecology. To understand the implications of this choice, in Appendix A, I repeat the calculations employing a Pareto distribution and find that the results are not appreciably different.) This measure is robust to multicentric and unevenly dense cities insofar as it ranks density ordinally without regard to physical location.

Slope of Decay in Tract Density by Distance from City Center

While sprawling and polycentric cities may not have a traditional central business district at their center and may have multiple density nodes, they do have a geographic center. As an alternate model of density decay, following Clark, Mills and others but modifying their methodology to take advantage of tract centroid data, I construct a coefficient of density decay from the center based on distance from the geographic center.

To construct this measure, I first calculate the geographic center of each PMSA by taking the mean of tract centroid data for longitude and latitude as obtained from the NCDB. In turn, I calculate the distance of each tract to that center. Finally, I perform heteroskedastically robust OLS regression of the log of tract density on distance to obtain a coefficient for rate of decay for each PMSA. As with the rank measure constructed above, the coefficient is negative, reflecting declining densities from the core. Accordingly, lower or more negative coefficients represent a steeper rate of decline consistent with a concentrated core while higher or less negative coefficients represent a shallower rate of decline consistent with sprawl.

Urban and Sprawl Intensity

For another look at sprawl, I divide census tracts into categories by density: urban, sprawling, rural and other which includes water and other empty spaces. Informed by the literature on urbanization, I define urban tracts as those with a population density of over 3500, sprawling

tracts as those with a population density of less than 3500 per square mile but greater than 200, rural tracts as those with a population density below 200 but greater than 20 and other as any tracts with less than 5 people per square mile (including deserts, water bodies and other depopulated regions.). Excluding the rural and other categories I calculate the ratio of urban population to total population to obtain an index of urban intensity. I then calculate the ratio of sprawling population to total population to obtain an index of sprawl intensity. (These two indices do not sum to 1 because of the other category.)

Thus:

$$\textbf{Urban intensity, } U_{it} = Pu_{it}/(Pu_{it} + Ps_{it} + Po_{it})$$

and

$$\textbf{Sprawl Intensity, } S_{it} = Ps_{it}/(Pu_{it} + Ps_{it} + Po_{it})$$

where Pu_{it} = the population in tracts with urban density and Ps_{it} = the population in tracts with sprawling density and Po_{it} is tracts with other density for a given MSA***, i,*** at time***, t.***

These measures, by excluding rural and "other" census tracts, are largely robust to bias from unbuildable land whether due to natural or man made causes *i.e.* rivers or deserts. As measures of density, they are independent of either the size of the region or the population making it possible to compare large cities (both in population and area) to small ones. Independent of the

distance of tracts to business districts or a hypothesized city center, it is robust to physical constraints such as a mountain or ocean that might complicate distance calculations, and, it can be used for polycentric cities. Comparing densities of census tracts rather than geographic units like acres, i.e. constraining population rather than area, it allows for community diversity. By charting this measure over time, it is possible to track changes in the degree of sprawl.

Index of Urbanization

As a variant of the urban intensity measure, I calculate tract density and assign a categorical, ordinal index variable to each tract that can assume the values 1 to 14 where 1 equals density below 200, 14 equals densities above 3500 and the values 2 through 13 equal intermediate values. A higher index value reflects higher average density and a lower index value lower average density. Change over time from a higher to lower value is consistent with sprawl and change from a lower to higher value with urbanization.

Standard Deviation of Tract Density

As yet another measure of sprawl, I examine the standard deviation of tract density since a higher standard deviation of tract densities suggests a long tailed distribution of high and low density tracts consistent with an urbanized core while a lower standard deviation suggests uniformity in tract density consistent with sprawl.

Tracting as a Measure of Sprawl

The first US census as required by the Constitution, was taken in 1790, however, the concept of census tracts did not appear until 1910. Thereafter, tract advocates such as Howard Whipple Green encouraged tracting of major cities which required local support. Tracting prior to 1990 occurred in two dimensions, first through the addition of new tracted counties and cities and, secondly, in tracted metropolitan areas, outward from populated centers as they grew. (Census Bureau Website: http://www.census.gov/history/www/programs/geography/tracts_and_block_numbering_areas.html.) Around tracted metro areas the second pathway, therefore, the creation of new tracts followed outward development.

By 1990, the Bureau had defined either tracts or their equivalent, Block Numbering Areas for the entire country. Thus, from 1970 to 1980 while first time tracting was still underway, a new tract *within* a defined PMSA (as later normalized to 2000 boundaries) is most likely due to conversion of land from rural to developed status. From 1980 to 2000, within a defined PMSA (as normalized to 2000 boundaries), it is most likely due to rising population in the metro area which led the Census Bureau to divide an older track into two or more parts and is therefore still likely to correlate with development. While new tracting is not a perfect marker of sprawl, I include it as a supplemental measure of sprawl. To measure it, I create a dummy variable equal

to 1 for tracts which appear for the first time in a given census and limit observations to the time periods 1970 through 1990.

The Population Density Metric Model

Having constructed the foregoing population density-derived metrics of sprawl, ultimately I regress them using fixed effects OLS regression on energy prices and control variables as discussed further in Chapter 5.

Employment Density Measures

The second group of metrics of sprawl I employ, following Glaeser and Kahn (2001) are metrics of employment dispersion. Employment dispersion exhibits strong correlation with population dispersion (Rossi-Hansberg et al, 2009) with Glaeser and Kahn (2001) estimating correlation to be .79. Both population and employment density exhibit decay, on average, moving away from the traditional city center or, in the case of polycentric cities, from sub-centers. Glaeser and Kahn show that if one follows Mills (1967) in assuming a Cobb Douglas production function with land as an input, one observes the same exponential decay in employment density as that observed for population density by Clark, Mills and others, a relation frequently confirmed in empirical analysis. One can say, therefore, that employment density dispersion resembles

population density dispersion in important respects. Insofar as both liberally consume land as an input, they are indicative of sprawl.

Despite their similarities, however, employment and population density are not identical. Job and dwelling location play distinct roles in most theories of the city. Early models of the city place employment at the city center and dwellings at the periphery. Population dispersion flows naturally out of the AMM model, however, employment dispersion contradicts the assumption of a CBD at the center. As previously discussed, early models of the city simply assumed an exogenous CBD at the city center (Mills, 1967). In a subsequent paper, Mills (1972) attributes the existence of the CBD to the higher cost of transport of goods relative to people, leading firms to outbid dwellers for land at the center. Later models of the city explain firm concentration in the CBD as a function of endogenous benefits derived from externalities at the city center such as knowledge spillovers or proximity to central markets through an externalities parameter. Other authors extend the basic AMM model to incorporate sub-centers. Rossi-Hansberg (2004) models firm location choice as a result of externalities and transport costs with higher externalities driving concentration and higher transport costs driving dispersion of business. Rossi-Hansberg et al (2009) explain the finding of job growth at both the center and periphery with a model that distinguishes between types of employment. In their model, firms locate management jobs that benefit from externalities at the center while locating non-management jobs at the periphery. Wheaton and DiPasquale (1996) qualitatively describe structural changes that have influenced location decisions by sector. Manufacturers have followed transportation hubs out of cities while retail businesses have followed customers; in contrast, offices still value the agglomerative benefits at the center.

It is also readily apparent that the decision-making agent is different in employment as opposed to residential location choice and that the agents make decisions based on different factors. Whereas people choose where to live, firms choose where to locate jobs. Theory suggests that people seek to maximize welfare based on a set of preferences that may include non monetary social benefits while firms seek to maximize profits. Thus while employment and population may both be dispersing from the center, they are doing so from different starting points and for potentially different reasons. People disperse from the center when the *costs* of central living and *benefits* of dispersion outweigh their opposites. In contrast, employers, assumed in early models to concentrate in the CBD, to disperse, must leave their assumed location of choice, presumably to achiever higher profits. Many models of the city include a production function that constrains the output of firms based on the prices of inputs and outputs at different locations that include transport costs and agglomeration benefits. Transportation cost which plays such a key role in most models of the city influences residence choice directly; it influences firm location choice indirectly through the price of inputs (such as labor, capital, knowledge and land) at different locations.

Job location also differs from dwelling location insofar as jobs appear to have a stronger tendency to agglomerate—even away from the center—than places of residence as evidenced by the rise of suburban sub-centers or Edge Cities that concentrate jobs more than dwellings. In recent decades, virtually all cities in the United States have developed sub-centers outside the core and are no longer, strictly speaking, monocentric. The role of sub-centers has become more salient empirically—when using government collected data—by the decision of the

Bureau of the Census to redefine urban statistical areas to include multiple sub-centers as well as older towns within urban areas. The decision of the Bureau of the Census to deprecate the primary metropolitan statistical area (PMSA) in favor of the Core Based Statistical Area (CBSA) in 2000 marks a significant shift away from the conception of the city as an area consisting of one primary city center surrounded by dependent surburbs—the idea at the root of the AMM model of the city—towards the definition of an urban area as a collection of job centers.

Notwithstanding the complexities attendant on explaining employment dispersion, there is strong precedent in the literature to study measures of employment dispersion as markers of sprawl. Glaeser and Kahn (2001), as noted, show that employment density, if one assumes a Cobb-Douglas production function with land as an input, decays exponentially in a manner analogous to population density. In their study of job dispersion (2004), they study change in logged employment density relative to distance from the center. They also measure job density in concentric rings around the city center at distances within 3 miles, from 3 to 10 miles and, from 10 and 35 miles and then construct an index of sprawl based on the percentage of jobs located within each ring. As the central point for each city they use the spot suggested by local leaders in the 1982 Special Census Survey. These measures are purposely designed *not* to be independent of multi-nodalism or city size.

Following their example, I also regress log of employment density on distance from the center and examine change in density in rings. However, because I am interested in understanding the polycentric cities that have become ubiquitous in the United States in recent years and in small

and large cities alike and, moreover, because I use more recent data, I use a different measure of the centerpoint of the city and also develop an alternative measure of density relative to *rank*, following Zipf. This measure of decay in density by rank is analogous to the one I develop for population density. In addition, I study the Gini coefficient for employment density.

My primary source of data is the Zipcode Business Patterns (ZPB) series (part of the County Business Patterns series) compiled by the Census Bureau from a variety of sources including the Business Register, the Annual Survey of Manufactures and Current Business Surveys. It contains data on jobs by zipcode. I use the ZBP data for jobs and link it to control variables at the MSA level collected as part of the decennial census and included in the NCDB. I connect zipcode data to MSA data through a cross walk file that I obtain from the Census Bureau available at http://www.census.gov/population/www/metroareas/metroarea.html

Since the literature suggests that firms make decisions based on sector, I include sectoral jobs figures though these are available only at the metropolitan area level, not at the individual zipcode level. Ultimately, I create a dataset that combines jobs by zipcode, area of the zipcode, the center of each zip code area relative to the city center (and therefore the distance of jobs from the center), control variables for the city, gasoline prices by city and jobs by industry sector and a measure of population decay for 362 CBSAs. I supplement this data set with various statistical measures calculated from the basic data.

Several caveats are in order.

First, zip codes are a considerably less precise geographic unit for statistical analysis than census tracts. Whereas census tracts were developed for the express purpose of statistical analysis, zip codes were developed and are today maintained and utilized by the US Postal Service for the sole purpose of delivering mail. *No* effort is made to keep them consistent over time (Census Geography and Map FAQs, http://www.census.gov/geo/www/tiger/tigermap.html#ZIP). Because of public interest in data at the zip code level, in 1999, the Census bureau made an effort to create standardized zip code-like areas that link zip codes to tracts called Zip Code Tract Areas (ZCTAs.) I use the 1999 ZCTAs to link census variables to the ZBP jobs data compiled by zip code.

Second, the Census Bureau censors jobs data supplied by employers in published reports for reasons of confidentiality. When considering whether to report number of workers at an establishment within a zip code, in cases where disclosing the information would reveal information about a specific firm, the Census Bureau reports the number zero. Censorship is extensive[3]. Because this introduces error in the results that may or may not be randomly distributed, as a check on findings, I conduct a separate set of regressions using *number of establishments* which is not censored. While not entirely addressing the problem of censorship this increases confidence in results.

[3] Conversation between author and official of Census Bureau.

Third the zip codes tracked in the Zip Code Business Patterns series vary by year so that not all years have all zip codes. Similarly, because submitting price data to ACCRA is voluntary, the gasoline price data collected by ACCRA varies by year so that not all years have data for all cities. As a check on the ACCRA data I also use national gas prices from the EIA as urban area gasoline prices exhibit a high degree of correlation over time.

Fourth, for both energy prices and control variables, I need to use different sources and geographies and then link these to the zip code data. The jobs data comes from a survey of employers, not households; because few job holders live where they work, it is not possible to link jobs by location to the demographic characteristics of specific job holders at the zip code level. However, if one assumes that job holders live in the same metropolitan area in which they work (an underlying assumption of the Metropolitan Area concept), one can link jobs by location to census variables at the city level. For household control variables, I estimate intra-decade values from the 1990 and 2000 figures in the NCDB using straight-line estimation. I also create interactive variables combining 2000 figures with gasoline prices that do not require intra-year estimation.

Fifth, while I collect jobs data by zip code, to aggregate this data by city, I need to use one of the definitions of urban area maintained by the Bureau of the Census so as to relate it to gasoline prices. Since I rely on gasoline prices provided at the level of the CBSA and, moreover, because it has become the standard definition of an urban area, I use the CBSA designation. This is, indeed, the new preferred urban definition of the Bureau of the Census having replaced the

Primary Metropolitan Statistical Area. CBSAs can either be Metropolitan or Micropolitan in size; I restrict my analysis to metropolitan CBSAs. Relative to PMSA, however, CBSAs do not look like traditional cities. Many like the Allentown-Bethlehem-Easton, Pennsylvania CBSA do not have a single city at their core; others while they may have a single city at their core like the Boston or Chicago CBSA extend over multiple states to such a degree that they no longer resemble traditional cities. For example, the Chicago CBSA encompasses substantial portions of Wisconsin and Indiana while the Boston CBSA encompasses southern New Hampshire. Use of the CBSA designation clearly makes it more difficult to apply the AMM model to the study of the city. However, ultimately I use the CBSA boundaries because the CBSA designation has become the preferred designation of the Census Bureau and because it is the designation for which granular gasoline price data is available.

Finally, the literature suggests that the key variables affecting firm location decisions relate to firms, not their workers. Gasoline prices may affect firm location choice decisions through multiple pathways, as discussed, that vary based on the sector of the employer and the job level in question.

Sectoral job data is not available at the zip code level, primarily due to confidentiality issues[4]. It is, however, available at the level of metropolitan areas. Using this data, I calculate the percentage of total employment by two digit NAICS sector, notably for manufacturing, finance and real estate, management, professional and technical, information technology and health. I perform these calculations based on number of employees and on number of establishments.

[4] Email correspondence between author and Census Bureau official.

Thus, while I do not have running counts on jobs in a given sector in a given zip code, I do have figures tracking sectoral change within metropolitan areas. I include these figures as controls in certain regressions.

To link up these diverse data sources, I merge the various tables in Stata using geographic identifiers, principally zip code and CBSA or MSA fields to link up the records within the tables) and to create a dataset that integrates multiple fields from the various tables. This process creates a final dataset that includes 363 core based statistical areas over the period 1994 to 2008 and incorporates data from over 40,000 zip codes.

The resulting dataset contains jobs data from 1994 to 2008 by zip codes, the location of the zip codes, control variables for 1994 to 2000 and gasoline prices from 1992 to 2008. Because more data is missing in the earlier years, I focus on the ten year time period 1999 to 2008

I also construct new variables including an estimate of the MSA center from NCDB data (equal to the mean of tract centroids weighted by employment density as described above) and the distance from the zip code centroid to the MSA center to place the zip codes within the MSA. Using this dataset, I construct several measures of sprawl.

Slope of Decay in Job Density Relative to Rank

Following Zipf's use of rank as an independent variable explaining frequency or size and replicating the procedure for population density described above, I estimate a coefficient that describes the distribution of employment for each CBSA by rank. In particular, I rank zip codes by employment density and regress the log of employment density per zip code on the rank of that zip code to obtain a coefficient describing the linear rate of decay. This yields a model of the following form:

$$\textit{Ln(Employment Density)} = \ln A - B(\textit{Rank})$$

For a ranked distribution, ***D*** of n densities, ***d,*** of rank ***ρ,*** measured on the log scale, at time **t**, I identify the coefficients, ***α*** and ***β*** that solves the following:

$$\min \Sigma_1^N \left(\ln d_{\rho t} - (\alpha_t + \beta_t \rho)\right)^2$$

As with population density described above, the coefficient**, *β*,** provides a measure of the decay in log of density by rank. A steeper density gradient represented by a more negative ***β*** (larger absolute value) slope corresponds to a more urbanized environment while shallower gradients correspond to a more sprawling environment. (To provide assurance that the zip code densities follow an exponential distribution by rank as opposed to a Pareto distribution, I also calculate the coefficients of the log of density regressed on the log of rank, and compare the results. I find that the exponential distribution fits the data better than a power law distribution.) A decrease in the Zipf coefficient signifies steeper decay consistent with a more urbanized core while an increase in the coefficient signifies a shallower slope consistent with greater sprawl.

The Zipf measure is particularly appealing in the case of employment density because it is robust to the presence of Edge Cities and Census definitions of urban areas designed to include multiple sub-centers or small cities within one urban area.

Slope of Decay in Employment Density Gradient by Distance from City Center

As with population density above and following Glaeser and Kahn (2001), I also examine the dispersion of employment relative to the urban center. I do so mindful that the changing form of metropolitan areas and, in particular, the rise of sub-centers has reduced the salience of the CBD. Glaeser and Kahn calculated distance from the city center as distance from the CBD as identified by local leaders in the 1982 Special Census Survey. That survey, however, is now almost 30 years old. They, themselves concluded in 2004 that the American monocentric city of the mid-20th Century is virtually extinct. I use the more objective method of calculating the geographic center of each CBSA. Unlike the old PMSA designation, however, CBSAs often encompass multiple small city centers and, therefore, the geographic center of the CBSA may not lie within a high job density area at all. As an example, in New York City, the center of the CBSA is near Manhattan's Park Avenue in the 40s, reflecting the comparative absence of sub-centers in the New York MSA. However, examining Boston, the center of the CBSA lies 57 miles northwest of Boston's City Hall, near Manchester, New Hampshire (in contrast to the center of the old Boston PMSA located 4 miles west of City Hall, in Brookline.)

In view of the distance of the unweighted geographic center in CBSAs such as Boston and Chicago that include smaller cities from the CBD of the core city (and similar problems in CBSAs lacking a single core city such as the Allentown-Bethlehem-Easton CBSA in Pennsylvania), I choose to weight the geographic center by employment density. Specifically, I calculate the job density-weighted geographic center of each MSA. This yields centers that are more satisfying intuitively though I continue to calculate them according to a standard, objective formula. For example, the job density-weighted geographic center of Boston lies near City Hall. Given the ubiquity of multi-centrism today, I consider the job-weighted geographic center to be a more objective measure than the 1982 center as determined by local leaders.

Replicating the procedure used for population density above, I then regress employment density on the log of distance to obtain a coefficient that describes the rate of decay in jobs from the center. My model is

$$\textit{Ln(Employment Density)} = \ln A - B(\textit{Job Weighed Distance from Urban Center})$$

For a ranked distribution, $\boldsymbol{D}$ of n densities, $\boldsymbol{d}$, of rank $\boldsymbol{\rho}$, measured on the log scale, at time **t**, I identify the coefficients, $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ that solves the following:

$$\min \Sigma_1^N \left(\ln \boldsymbol{d}_{\rho t} - (\boldsymbol{\alpha}_t + \boldsymbol{\beta}_t \boldsymbol{\rho})\right)^2$$

As with population density described above, the coefficient***, β,*** provides a measure of the decay in log of density by distance. A steeper density gradient represented by a more negative ***β*** (larger absolute value) slope corresponds to a more urbanized environment while shallower gradients correspond to a more sprawling environment. A decrease in the Clark-Mills coefficient signifies steeper decay consistent with a more urbanized core while an increase in the coefficient signifies a shallower slope consistent with sprawl.

Because, as discussed, the rise of Edge Cities has diminished the importance of the CBD—even in smaller geographic regions—as the chief locus of employment and under the CBSA designation adopted by the Census Bureau, many urban areas no longer have single centers, I do not expect this measure to provide an exceptionally high goodness of fit. Nonetheless, a statistically significant relationship exists between job density and distance from the weighted center across the 363 CBSAs surveyed.

In some variations of the model, I condition the regression on measures of mono and polycentrism. One test is the correlation between the distance gradient and the rank gradient. Another is the t-statistic of the distance gradient coefficient. I calculate these measures to distinguish between urban areas that bear a resemblance to the traditional Mills city and those that exhibit little correlation between density and central location. However, I find that even polycentric cities exhibit a strong correlation between job density and proximity to the job-weighted center.

The Clark Mills measure of employment density decay is my second metric of job density-derived sprawl.

Measures Not Used

In contrast to population density, employment density is lumpy, reflecting the presence of sub-centers or Edge Cities and other large concentrations of jobs. Jobs concentrate to a greater degree than dwellings due to the lower space requirements of working and agglomerative benefits, both within and between firms of proximity. For this reason, metrics that reliably quantify sprawl measured as population density dispersion do not reliably quantify sprawl interpreted as employment density dispersion. Edge cities confuse the meaning of dispersion of jobs and buffer the impact of exogenous variables on dispersion. Neither the Gini coefficient of employment density nor the standard deviation of employment density reliably measure sprawl because job fluctuation in sub-centers countermands job fluctuation in the CBD.

In the case of the Gini coefficient of population density, I interpreted a higher Gini coefficient (greater inequality) as concentration at the center or in high density tracts and a lower Gini coefficient (greater equality) as population dispersion or sprawl. This approach was supported by the comparatively monotonic decay of population density relative to distance from the center (and strict monotonicity with respect to rank) over the period 1970 to 2000. With the assumption of monotonicity, a higher Gini must indicate either concentration at the center or in high density tracts.

This methodology is not supported for employment density over the period 1998 to 2008, however, because the presence of Edge Cities—as a middle tier of employment density between central and peripheral zip code densities—lowers the Gini coefficient and buffers the impact of exogenous variables on the Gini coefficient. Consider a hypothetical city with a CBD, several sub-centers and a periphery. Growth of jobs in sub-centers, leaving the CBD and periphery unchanged will lower the Gini coefficient but cannot be interpreted as sprawl ie greater consumption of land per job.

Similarly, in the case of standard deviation of population density, with the lower bound approaching zero, I interpreted greater standard deviation as greater density in the CBD or high density tracts and lower standard deviation as dispersion or sprawl. However, in the case of employment density, employment concentration in sub-centers whether of new jobs or jobs leaving the CBD by amplifying values or increasing the number of observations closer to the mean will *lower* the standard deviation, but cannot be interpreted as sprawl, i.e. land intensity. Instead, higher density in Edge Cities meets the definition of greater job concentration, the reverse of sprawl.

If anything, therefore, I would expect higher gasoline prices to lower the Gini coefficient and standard deviation by increasing densities in sub-centers, as a "middle class" of densities between the extremes at the center and fringe. Due to the ambiguous role played by sub-centers relative to the CBD, however, I choose not to rely on these metrics for job dispersion.

The Employment Dispersion Model

Having constructed the foregoing employment dispersion-derived metrics of sprawl, ultimately I regress them, using fixed effects OLS regression, on gasoline prices and control variables. For gasoline prices, I use both city prices obtained from the ACCRA cost of living series and national prices from the EIA. As previously discussed, controls, as suggested by the literature, include different combinations of city employment, sector variables, demographic variables for the CBSA in question and the gradient of population density.

Dispersion of Light Visible from Space

The third measure of sprawl I use, drawn from the dataset compiled by Burchfield et al (2005).uses a unique methodology of measuring light visible from space and cross referencing it with geospatial data and political boundaries to compare land consumption between 1976 and 1992. The Burchfield et al model measures the urbanization of 30x30 cells based on light emitted at night and, using this geographic data, estimates the change in this light and then through the presence or absence of light, density of settlement. Resolution is precise, enabling the authors to discern open space and settled space at a resolution of from 30 to 60 meters. Their measures of sprawl for each MSA at the two points in time reveal the amount of open space surrounding settlement. Specifically they measures sprawl as: "the percentage of

undeveloped land in the square kilometer surrounding an average residential development". Using this methodology, the authors find comparatively little change in sprawl by MSA over the sixteen year period they examine.

Where large changes in sprawl do emerge from the data, for example, in Las Vegas, the change may not correspond with intuition about sprawl. Indeed, their data show that Las Vegas showed a decrease in sprawl of about 33% over the period 1976 to 1992, the largest decline of any MSA in the country while Sharon, Pennsylvania recorded the largest increase in sprawl of any MSA of 24%. These changes reflect the starting points of the sprawl index in both cases. Las Vegas started with a high index and Sharon with a low one. Las Vegas experienced so much population growth over this period that the MSA grew denser although an observer might describe the growth as intensification of sprawl rather than its elimination. Sharon experienced so much population *loss* that the region grew less dense, however, an observer might not view the result as physically resembling sprawl.

I regress their measures of sprawl for 1976, 1992 and the interval between on energy prices, performing cross sectional analysis for 1976 and 1992 to test how gasoline prices might explain differences in sprawl by region and two period fixed effects time series analysis for the period between 1976 and 1992 to test the impact of gasoline prices on sprawl, generally, over time.

The Light Visible from Space Model

Using the Burchfield et al index, I perform OLS regression on energy price data and controls for the years around 1976 and 1992 and perform two period fixed effects OLS regression on energy prices and control variables over the interval 1976 to 1992 as discussed further in Chapter 5. Because the two period fixed effects model causes the fixed Burchfield et al variables such as ruggedness of terrain to drop out, I experiment with interactive variables composed of the fixed variable times gasoline prices.

Measures of population density, employment density and light visible from space relative to land, constitute my dependent variables. I now turn to my independent and control variables.

Independent and Control Variables

Energy Price Data

The Energy Information Agency (EIA) within the US Department of Energy collects and maintains data on energy prices. Because of the strong role afforded transportation modes and prices in the social and economic literature on urbanization and the well documented role of the automobile in sprawling development, my measure of energy prices is that of gasoline prices, gasoline being the primary fuel used by cars.

Effect of Gasoline Prices on Residential Sprawl

The literature suggests that sprawl *is* driving-intense. Kahn (2000) finds that suburban residents drive 31% to 35% more than urban ones. Burchfield et al observe a correlation of .27 between their measure of sprawl and average miles driven per day (Burchfield et al, 2005). Microdata on energy spending available from the 2000 Individual Public Use Microsample (IPUMS) analyzed by Glaeser and Kahn indicates that suburban household spend far more on gasoline (and other forms of energy) than urban households. Similarly, they find from the National Household Travel Survey (NHTS) for 2001 that distance from the city center correlates with higher gasoline usage (Glaeser and Kahn, 2008). One can say generally that it costs energy to live further from the city center.

However, it is important to understand why sprawling living is car- and hence gasoline-intensive relative to urban living as the reasons are not necessarily precisely those one might first suppose. Sprawl, rather than increasing commuting times relative to urban living, reduces commuting times according to data from the National Personal Transportation Survey (cited in Glaeser and Kahn, 2004 and Rossi-Hansberg, 2009) with the log of commute times showing strong correlation with population density. The reason is that sprawl besides dispersing people also disperses jobs. While those who work in the city must commute longer if they move out, others who find jobs outside the center may shorten their commutes by moving away with the latter effect prevailing. Thus, change in commuting time is *not* the only or even primary pathway by which I hypothesize that energy prices impact sprawl.

Several possible pathways by which energy prices might impact sprawl, thus, present themselves. First, exurban commuting is far more likely to involve a car than traditional urban commuting because exurbs are built for car transportation (and lack public alternatives as lower densities at the urban fringe make public transportation less viable). (This effect is less pronounced in newer parts of the country lacking mass transit systems.). Even if commuting time declines with sprawl, time commuting by auto or auto-conditioned commuting may increase. Accordingly, the first pathway by which I hypothesize changing fuel prices might impact sprawl is by substitution between modes of transit. A gas price rise would make it more attractive to live close to the center and commute by public transportation while a gas price decline would make it more attractive to live further out and commute by car.

Second, exurban living is associated with much more intense use of a car for other daily tasks including shopping, ferrying children to school, recreation and social activities. Accordingly, a rise in gas prices might also incent households to move closer to the city where distances are shorter (requiring less driving) or into the city where they can accomplish tasks by foot. Alternatively, a gas price decline might incent them to perform those activities by car, making exurban living more attractive. Thus, movement toward or away from the center provides a mechanism to improve welfare in response to changes in gasoline prices.

Broadening the question to examine overall energy consumption of transportation and non transport-consumption of energy, sprawl also correlates with energy consumption. For example, larger self standing houses of the type found at the fringe of cities require more

energy to heat or cool than smaller, on average, multifamily housing units closer to the center where families share walls, conserving energy. In this case, the energy variable is not gasoline but rather natural gas, heating oil or electricity. Overall energy prices might impact urbanization through their impact on non transportation consumption of energy.

Finally, because of the positive income elasticity of sprawl suggested by my model in Appendix A and also the literature (Margot, 1992, Fujita and Thisse, 1996, Bairoch, 1985) and related positive income elasticity of housing, it is reasonable to hypothesize that changing energy prices—by impacting the budget constraint of actors in the urban economy—might select *for* sprawl or *against*. Lower energy prices might free up income for actors to spend on larger housing in the exurbs while higher energy prices by reducing income, might force them to consume less housing.

Effect of Gasoline Prices on Employment Dispersion

In the case of employment dispersion, the comparative paucity of theoretical attention to the determinants of firm job location choice motivates development of a hypothesis of how gasoline prices affect the firm. As discussed, Mills attributed employer concentration at the core of the monocentric city to the higher cost of transporting goods relative to people to a transport hub. When commute costs surpass those of transporting goods or, indeed, grow excessively high, however, commuting may no longer be viable. At the limit, business and residential might even fully converge in the form of "backyard capitalism" (Fujita and Thisse, 2002, p. 27). Short of the

limit, higher commuting cost, some models suggest, may encourage not only residential movement to the center but employer diffusion to the edge leading to mixed use districts or alternating bands of use (Lucas and Rossi-Hansberg, 2002). These models underscore the complexity of the effect of transport and fuel costs on employer location choice. Unlike people, firms do not, themselves, commute or drive to work so (except in industries that consume gasoline directly such as transport or certain industrial processes), gasoline is not a direct input in production. Rather, higher gas prices are likely to influence firms through the price of production factors such as labor, land and goods. Gas prices affect the transportation costs of workers, cost of transporting production inputs from suppliers and outputs to customers, business activities such as meetings with suppliers and clients and land rent. Mediating the effect on profits of cheaper land or lower cost workers, however, are likely to be variables such as the availability of sufficiently skilled workers at the fringe or the value of spillovers to a particular business or business function. Similarly, higher gas prices could drive high skilled businesses to move toward hubs but push low skill businesses to seek out cheap land. Classically, as in von Thunen, firms locate near the central market to minimize costs of transport with the center corresponding to a transport hub. In those few American cities that still have ports or *entrepots* near the center, manufacturers might move closer to the center. But where *entrepots* are located at the periphery as they normally are today, higher gas prices could prompt a move of manufacturers to the fringe. (Modern container ports require a great deal more land than pre-container ports. For this reason, most water ports have long since moved out of center cities.) In short, gasoline prices could cause employers to concentrate or disperse depending on the relative weig ht of a variety of pathways summarized in Table 4-1.

Table 4-1 Influence of Gasoline Prices on Employment Dispersion: Potential Pathways					
Price shock	**Production Input**	**Pathway**	**Result**	**Varies by**	**Impact on Sprawl: i.e. Dispersion vs. Concentration**
Higher gas prices	Labor cost	Higher Cost of Worker Commute	Move toward transport hubs	Face-to-face need/ sector/ occupation	Concentration (high skilled)
			Move toward labor		Dispersion (low skilled)
		Higher Living Cost of Labor	Move toward walking areas		Concentration at hubs
	Energy cost	Higher Direct Input Cost in Production	Substitution if possible/Move to low gas price state		None (unless low gas price state correlates with sprawl)
	Doing business cost i.e. meetings w clients/ suppliers	Higher Transportation Cost	Move toward transport hubs/ telephone	Face-to-face need/ sector/ occupation	Concentration at hubs (high skilled)
					None
	Cost of Supplies	Higher Transportation Cost	Move toward suppliers or transport hub	Location of suppliers	Depends on supplier location
	Cost of Delivered Goods	Higher Transportation Cost	Move toward transport hub or market	Sector i.e. retail or manufacturing and, if manufacturing, location of hubs i.e. central port or rail terminus or fringe	Concentration at hubs (if customers or transport terminals at center)
					Dispersion (if customers or transport terminals at periphery)

	Land cost	Higher Residential Bid Price	Move to cheaper land	Sector, function i.e. ability to move	Dispersion
					None

The model of Rossi-Hansberg et al (2009) provides guidance as to which pathways dominate. In knowledge-intensive sectors where externalities are critical, the benefits of cheaper land at the periphery are unlikely to outweigh loss of externalities. Similarly, *within* firms certain, knowledge-intense functions require spillovers and benefit from concentration. Other land-intense functions may not benefit from spillovers or face to face contact. For these functions, cheaper labor and land costs at the periphery may drive dispersion. Thus industries may separate along sectoral lines and firms may fragment along functional lines. Glaeser and Kahn (2004) also distinguish between high skilled and low skilled sectors. Analyzing Table 4-1 it is clear that higher gasoline prices should drive high skilled workers and highly agglomerative sectors to concentrate—either at the city center or in sub-centers, but drive low skilled workers and non agglomerative sectors and functions to disperse toward cheaper land and workers. I therefore hypothesize that higher gas prices will lead to concentration of workers—particularly of high skilled ones and those in agglomerative industries—but dispersion of low skilled workers and those in non-agglomerative sectors. Retail use, will, however, follow people. To distinguish between these pathways, it is advisable to include sector controls. I do not expect the effect of gasoline prices on employment density to be as simple as that on population density due to multiple pathways described above and the role of sub-centers in employment location. Nonetheless, I hypothesize that higher gasoline prices will lead to firm concentration at the center *or* sub-centers (as captured by the Zipf coefficient) and that the dominant effect of higher real gas prices after controlling for sector will be to concentrate employment spatially as firms follow employees inwards (as captured by the Clark-Mills coefficient).

Effect of Gasoline Prices on Light Visible from Space

In the case of the Burchfield et al index of sprawl, the role of gasoline prices is similar to that for residential location described above. The Burchfield et al index measures the amount of open space around residential housing. More space, or sprawl, is associated with greater driving distances. Accordingly, as with the residential measures described above, higher gas prices will make living in sprawling areas more expensive through commuting and daily living and therefore incent people to demand housing that entails less driving. Accordingly, I hypothesize that higher gas prices will lower the lagged Burchfield et al index and lower gas prices will encourage sprawl as measured by the index.

Energy Indices

To test the potential impact of energy prices on sprawl, I regress sprawl on several energy indices, gasoline prices, lagged and averaged in several ways, to capture the impact through the transportation and driving pathways. I experiment with a national series, state series and city series.

Thus, my energy variables are:

$\boldsymbol{E_1}$ = National Gasoline Prices

E_2 = State Gasoline Prices

E_3 = City Gasoline Prices

The EIA maintains time series data on national oil prices going back to 1851 and national gasoline prices since 1949. More granular geographic data and data for newer fuel types such as electricity, however, are less available. Annual state data on prices and consumption of gasoline and many other energy products is available as part of the SEDS series maintained by EIA since 1970. Monthly data at some levels is available since 1973. Weekly city and regional data is available from the EIA since 2000 or 2003. There is a high degree of correlation between national and state and local prices which do not vary by that much and tend to move in lockstep with one another.

Figure 4-1 illustrating weekly retail gasoline prices since the year 2000 shows the relationship between gas prices at the national and city level graphically and suggests a high degree of correlation in their movements even though prices in some cities are habitually different from those in others.

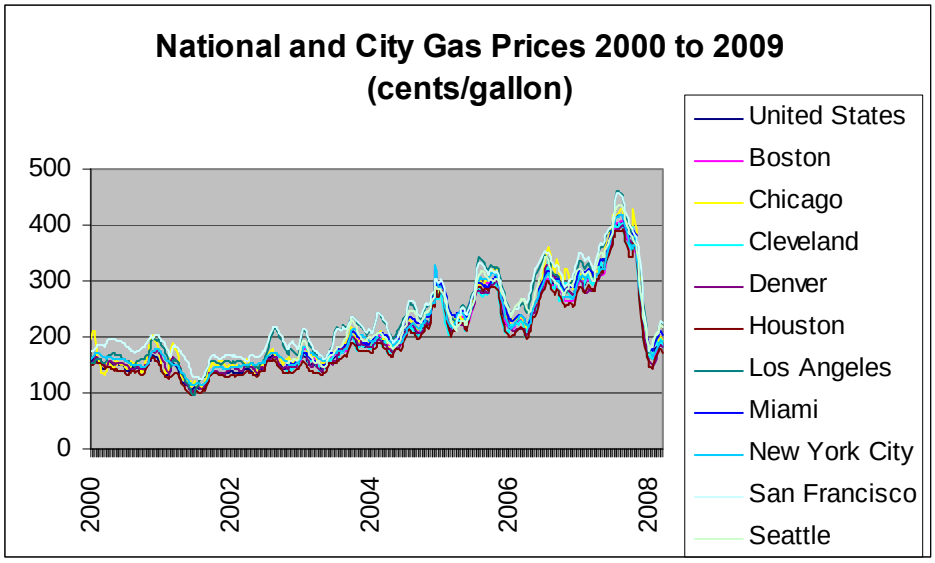


Figure 4-1 Source: Energy Information Agency

In fact, the T-statistics for OLS regression of national prices on city prices range from a low of 102 for Seattle to a high of 259 for Houston while the R^2 ranges from .9746 to .9933. Standard errors of less than .01 in all cases suggest a high level of temporal stability in regional price variation.

Confident in the close tracking of national and regional gasoline prices over time, I use the state annual series of data available since 1970 through the State Energy Data System (SEDS) and impute state values for 1965 through 1969 based on the correlation between national prices and those for states for the population density analysis. For urban areas in one state, I use the prices for that state and for urban areas in multiple states I average the state values together. I adjust figures as necessary for inflation using cost of living data available from the Bureau of Labor Statistics . The SEDS tables report prices in dollars per million BTUS across all energy types

to facilitate comparisons. I convert the prices into $/gallon, the common metric for gasoline, using a conversion factor of 8.049067111 millions BTUs/gallon.

For regression of employment dispersion numbers at the zip code level on gasoline prices, I experiment with different data sources. One source of gasoline price data is simply national data. These lack specificity by city but due to the high level of correlation between local and national figures represent a useful series for temporal analysis.

For gasoline prices by city, there are two data sources available at the city level, figures from the Energy Information Agency and figures collected by the Council for Community and Economic Research's (formerly known as ACCRA) cost of living index (COLI). This data has the advantage of being available for many if not all metropolitan areas since the early 1990s. (In contrast, the Energy Information Agency provides city level data for only 10 cities, and for those ten cities, only since 2003 or in some cases 2000). The COLI figures are provided by government participants in the COLI project at different levels of government that include towns, cities and counties. These data are therefore not standardized for MSAs let alone zip codes; however, the COLI dataset does provide a core-based statistical area (CBSA) field to link prices to urban areas. While not perfectly granular, this is the best available data on gas prices at the city level.

For the cross sectional regressions for 1977 and 1992 of the Burchfield et al measure of sprawl on gasoline prices, I first use the SEDS state energy prices, using the prices for one state or averaging the group of states in which the MSA is located and, as a variant, use the ACCRA COLI

prices which are available for metro areas. ACCRA COLI prices are not available for all MSAS, particularly, in 1976, however. In all time series price analysis, I use inflation adjusted prices, deflating as necessary, and, also deflate dollar denominated variables for sprawl, using the gasoline price deflator provided by EIA or CPI for income. For non gasoline prices, I follow the same procedure as for gasoline prices, using state data from the SEDS system available since 1970 and imputing prices for 1965 to 1969.

My primary series for purposes of regression analysis are 2-year lagged prices which show the greatest correlation with measures of sprawl. (This choice is the result of more extensive analysis that suggests that correlation fades moving from lagged two years to the present and moving from lagged two years backwards.) In a few cases, I look at the mean of three or five years worth of gasoline prices.

Control Variables

As previously mentioned, my choice of control variables includes standard socioeconomic variables, lagged dependent variables and those motivated by the literature on sprawl. It is useful to divide potential variables into three groups, those that vary by place but not time, those that vary by time but not place and those that may vary by either time or place.

Variables that Vary by Place but Not Time

Although most of my analysis is of panel data where variables that vary by place but not time are accounted for through fixed effects regression, these variable are of interest for the cross sectional analysis I perform on Burchfield et al's definition of sprawl. Moreover, by multiplying unchanging fixed variables by a changing independent variable such as gasoline prices, it is possible to create an interactive variable that reveals information about the impact of a fixed variable on change in sprawl. My choice of these variables is motivated by the literature. Burchfield et al have found "Ground water availability, temperate climate, rugged terrain, decentralized employment, early public transport infrastructure, uncertainty about metropolitan growth, and unincorporated land in the urban fringe to increase sprawl" (Burchfield et al, 2005). Glaeser and Gyourko (2002) have found zoning to increase sprawl and Glaeser (2000) has found coastal proximity to decrease sprawl. The AMM model includes a measure of land which in the presence of rugged terrain, for example, constrains expansion. Unincorporated land at the fringe may correlate with lower cost of land at the periphery, a common variable in the AMM model. I also control for region and state in order to account for local and regional differences in sprawl.

Variables that Vary by Time but Not Place

Gasoline fleet mileage standards are set at the federal level and therefore vary over time but not by place. Similarly, national GDP growth changes temporarily but not geographically within the United States. National gas prices also vary over time but not by place. These variables that

vary in time but not place will not have an impact on cross sectional analysis of sprawl by region as they affect all regions equally. While they can however exert a temporal effect on regions, they have less explanatory power than variables that vary by both time and place. Where possible, therefore, I employ the latter though I do use national gasoline prices, compiled by the Energy Information Agency, for example, as a check on the ACCRA-COLI city gasoline prices to increase confidence in the quality of the ACCRA-COLI data.

Variables that Vary by Time and Place

Variables that vary by both place and time are the most relevant ones for the fixed effects regression of panel data that I perform using population and employment dispersion data over the period 1970 to 2000. These include standard socioeconomic ones such as income, race, age, commuting patterns and percent foreign born population. For both cross sectional and fixed effects analysis, these variables may be statistically significant.

Population is a key variable in the AMM model of urbanization. It may contribute to sprawl because more people will require more housing units. This is my first control variable.

Second, since land is a normal good, it is income elastic. Wealthier people—at least in the United States where social rigidity does not constrain mobility—tend to consume more space (Fujita and Thisse, 1996). (Berry (1964) explains why in other nations, they may nonetheless,

congregate at the city center. Margo (1992) finds that income explains for up to half of suburbanization. Greater wealth also increases income available to spend on transportation. Finally, a lengthy history in the United States of exclusionary zoning designed to limit density based on income could impact settlement patterns based on income. Accordingly, one might expect to observe negative correlation between tract income and population density as well as sprawl.

Third, a long history in the United States of racial barriers to mobility expressed through exclusionary zoning, loan and title covenants and other formal and informal discriminatory measures suggests the likelihood of negative correlation between population density and race (Massey and Denton, 1993 and 1998, Jackson, 1987). A number of authors have found face to impact suburbanization (Mills and Price, 1982). Due to different patterns of employment by race and ethnicity, one might also expect to see negative correlation between employment density and race. However, one might also expect to see positive correlation between race and sprawl as white seek to separate themselves from Blacks.

Young and older people, people of working age and families with children may have different preferences for space (Beckmann, 1973) and proximity to other people and these preferences could express themselves as higher or lower population density. Finally, foreign born population may tend to congregate either in city centers or outside of them. (Fulton et al, 2001)

I experiment with different combinations of control variables including lagged dependent variables to test for autocorrelation. Thus my control variables include different combinations of the following variables summarized in the table below: Average household income, family Income, white, black and hispanic population, foreign born population and working age population. In some cases, I multiply these values for one year by gasoline prices to create an interactive variable for all years. I do not include some variables that authors have found to be significant, notably crime, because evidence for its impact is ambiguous. Nor do I include variables that do not vary by urban area such as national economic growth or fleet mileage. I do, however, normalize gasoline prices by the latter in some models of the variant to test for any fleet mileage effect.

In analyzing employment density as a measure of sprawl, I follow the literature suggesting that industry sector and population dispersion constitute key variables. I do not include occupational data because data are not available at a granular level. I also create interactive variables that measure socioeconomic characteristics for the MSA in question by multiplying gas prices times socioeconomic variables from the 2000 Census contained in the NCDB. I also construct certain control variables from the dataset. These include the correlation of the rank and distance gradients and the t-statistics of coefficients of the rank and distance gradients obtained in the first stage regressions of log of employment density on rank and distance respectively. T-statistics exceeding 1.96 or 2.56 (representing the 95% and 99% levels of confidence, respectively) increase confidence that the original size-rank and size-distance distributions are, in fact, of exponential form and can be validly modeled once the dependent variables are logged by a linear equation amenable to linear regression analysis.

Working with the Burchfield et al measures of sprawl I use control variables compiled by Burchfield et al and in some variants multiply these by gasoline prices to create interactive variables suitable for longitudinal analysis. I also introduce new socioeconomic control variables to the dataset drawn from Neighborhood Change Database as described above. Because Burchfield et al use 1999 boundaries for MSAs, I use these as well in calculating control variables for the years 1976 and 1992. I use Census data normalized to 1999 (or by convention 2000) boundaries by Geolytics in the NCDB. Beginning with values for the decennial census years, 1970, 1980, 1990 and 2000, normalized to 2000 boundaries, I interpolate 1976 data using straight-line estimation between 1970 and 1980 data and perform similar straight-line estimation of 1992 figures from 1990 and 2000 Census data.

Of note, of the 277 MSAs defined in 1999, 52 were not defined in 1970. Because Burchfield et al measure light using a fixed geography and their control variables do not come from the census, the lack of a definition for some MSAs in 1970 does not affect their calculations. It does, however, mean that no census control data can be interpolated for 1976 insofar as these MSAs did not exist in 1970, the previous Census year. Accordingly, in my regressions employing MSA-derived controls, I drop these observations from the dataset.

The NCDB does not include New Haven and surrounding areas as an MSA but does include a smaller area as a PMSA. For controls for the New Haven-Bridgeport-Stamford-Waterbury-Danbury, CT NECMA included in the Burchfield et al dataset, I substitute values derived from

data for the smaller New Haven-Meriden PMSA. Finally, because the NCDB does not have data for the Yuma, Arizona MSA, I drop this observation in regressions with controls though not in regressions without controls.

Data Considerations

Perhaps the central challenge of studying the linkage between sprawl and energy prices is finding compatible matching data by geographic unit and point in time. As discussed, for my population density models, I use the Geolytics Neighborhood Change Database (NCDB) that provides data for each of the decennial census years, 1970, 1980, 1990 and 2000 normalized to year 2000 geographic boundaries. The chief advantage of the NCDB data is that the complex issues surrounding normalizing data across census years have already been addressed. .

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For my employment density models, there is no equivalent to the NCDB and, accordingly, I must construct my own dataset using data, as previously discussed, from the Zipcode Business Patterns series maintained by the Bureau of the Census. I then add a variety of controls as discussed. While constructing a dataset from multiple sources is not ideal, there is no alternative way to study employment at an equally granular level.

For energy prices, where I rely on EIA data and ACCRA data as described, in the case of time series analysis going back to 1970, I solve the problem of data matching for energy prices, as

described above, by first establishing the exceptionally strong correlation across time if not cross-sectionally between national, regional, state and city energy prices and then regressing measures of sprawl on state energy prices. (The absence of micro level city and tract energy price data during the 1970s and 1980s is a shortcoming of my methodology imposed by available data but a manageable one. I do use city level gasoline prices obtained from ACCRA in the regressions on employment dispersion.)

For non census control variables compiled by scholars, most of which are fixed in time (such as region of country, year of incorporation, etc.), I include these as controls that lack indexing for time. Since most do not change often in time and therefore do not require time indexing for cross sectional analysis, nor show significance in fixed effects regressions on panel data, this lack of indexing is not a serious shortfall. In some instances, however, I multiply fixed variables times a time-indexed variable such as gasoline prices to construct interactive variables that survive in longitudinal analysis.

Endogeneity issues

Any econometric study that studies historical data and cannot employ the experimental method must contend with the risks of spurious correlation, reverse or simultaneous causality and endogeneity whereby correlation does not imply causality. This concern is most pressing in my dissertation with respect to interpreting correlation between sprawl and energy prices. The central role of gasoline in transportation cost that most models of the city suggest is critical to

urban formation strongly suggests that correlation between sprawl and energy costs is unlikely to be merely spurious.

A more serious concern, however, is that reverse or simultaneous causality or endogeneity may exist whereby sprawl might influence energy prices. There are, of course, strong reasons to believe that causality runs from energy prices to sprawl and not the other way around. Individual energy consumers, especially households are price takers in energy markets due to the huge size of those markets and the international nature of trade in petroleum. This suggests that many energy prices *are* likely to be truly exogenous to consumer behavior. However, it is important to understand the limits to this assumption and express several caveats that motivate testing for endogeneity.

While individual households are almost certainly price takers in energy markets, consumer demand in aggregate is sufficiently large that it might influence energy prices. Sprawling development by raising gasoline usage, for example, might raise prices. One cannot entirely rule out a reverse effect whereby changed energy demand from a change in sprawl affects prices. Following best practices to address this problem, I employ techniques to demonstrate causality that include instrumental variables and qualitative analysis. I further employ fixed effects methodology to raise confidence in the consistency of observed effects by screening out cross city differences.

Instrumental variables

One way to demonstrate causality is to use the technique of instrumental variables. With Two Stage Least Squares (TSLS) regression analysis using instrumental variables, one first identifies a variable that *is* correlated with the explanatory variable but clearly is free of influence from the explained variable. The variable must satisfy the two conditions that **corr (E, I) ≠ 0** and **corr (I, μ) = 0** where ***E*** is the explanatory variable, ***I*** is the instrument and ***μ*** is the error term. Unfortunately, the literature suggests that finding an instrument for gasoline prices is difficult. Hughes et al (2006) reviewing the work of Ramsey et al (1975) and Dahl (1979) who use other petroleum byproducts such as kerosene as instruments, find that petroleum byproducts could be influenced by oil price shocks. They suggest two alternative instruments for gasoline prices, crude oil input quality and crude oil production disruptions but find these to be weak instruments. The literature on instruments for gasoline prices is not that promising.

However, tax rates or taxes are often used as instruments for the commodities taxed because tax rates are generally set exogenously through a political process with causality running from tax rates to the price of the commodity rather than the other way around. Cigarette taxes, for example, have been used as an instrument for cigarette prices (Becker et al, 1994). In the case of gasoline, taxes are set infrequently and, therefore, in all likelihood, without reference to ongoing changes in demand. Gasoline taxes have not yet been used in the United States for land use purposes. States derive revenue from multiple sources: higher gasoline taxes may mean lower taxes on income, for example. (In Europe where taxes are used to lower carbon

emissions, Glaeser and Kahn (2004, pp25-26) find *gas* taxes to be independent of car ownership.) Because excise taxes change very infrequently they are not well suited to panel data analysis. They are, however, suited to cross sectional analysis. Federal taxes affect all states equally. Not all cities impose municipal taxes and many metropolitan areas straddle multiple cities and states. Most *states*, however, levy taxes and these taxes are sufficiently varied as to alter the local price of gasoline state by state. Accordingly, I test and ultimately choose state taxes on gasoline as my instrument for gasoline prices. I use 2000 state excise tax data from the Federal Highway Administration (FHA) and for gasoline prices, 2000 data published by the FHA that adjusts figures supplied by the Energy Information Agency to include taxes.

Employing TSLS, in the first stage regression, I regress gasoline prices on state taxes (and other control variables) to obtain a predicted value for gasoline prices in terms of other variables. In the second stage regression, I regress measures of sprawl on the predicted value. The resulting coefficient is equal to the effect of gasoline prices on sprawl. Because any correlation between the explanatory variable and the error term is isolated and excluded during the first stage regression, the coefficient in the second stage regression is a consistent indicator of the true effect of gasoline prices on sprawl that is free of reverse causality.

The choice of state gasoline prices motivates use of state level geography. Accordingly, I use state gasoline prices, metrics of sprawl calculated at the state level and state level controls. Because state taxes on gasoline affect consumers most directly, I use household, tract level data

from the NCDB. I aggregate the tract level data at the state level to be compatible with other state level data. Finally, the choice of state level data motivates the choice of metrics of sprawl that are meaningful at the state level. I do not use gradient measures such as the Zipf metric or Clark-Mils metric that are defined for a metropolitan area. Nor do I use the Gini coefficient due to the ambiguous role of sub-centers in influencing values. I select three simple metrics of sprawl that are meaningful at the state level, ratio of urban to sprawling tracts as measured by density, proportion of total tracts with sprawling density and proportion of total tracts with urban density. These metrics provides simple, consistent measures of sprawl that are meaningful across states.

In addition to employing instrumental variables, I also perform some qualitative analysis with respect to causality. One way to demonstrate a causal effect is to utilize the vector of time. It is generally held to be the case that while the past can influence the future, the future, being uncertain, cannot influence the past. If energy prices correlate with sprawl at a ***future*** point in time, it is more likely that energy prices are causing sprawl than that the future sprawl is retroactively changing energy prices. Thus, if I find that the strongest impact of energy prices on sprawl occurs when lagging energy prices by two to three years, the existence of a lag in the effect provides support for causality running from prices to sprawl.

An important qualifier is that serial autocorrelation in time on the part of either the independent or dependent variables would negate the significance of the lag in effect. If either variable is highly correlated with itself one, two, or more years forward or backwards, the time

indexing loses significance with respect to causality. Moreover, due to the influence of energy price futures on current prices and extensive efforts by energy producers to predict future demand in order to plan current production, while the time lag provides qualified support for causality, one cannot entirely rule out a time-backwards causal effect. For this reason, the instrumental variable approach provides the greatest certainty that the effects observed are causal as well as correlative.

Table 4-2 Key Variables: Sprawl		
Population Density		
Gini Measure of Population Density Inequality	Coefficient obtained from calculating twice area under normalized Lorenz curve of distribution	Continuous, bounded by 0 and 1
Zipf Measure of Rate of Decay of Population Density by Rank (constructed)	Coefficient obtained from sorting tracts by density and regressing density on log of rank of tract.	Continuous
Clark-Mills Measure of Rate of Decay of Population Density by Distance from Center (constructed)	Coefficient obtained from regressing population density of tracts on log of distance from center	Continuous
Urban Intensity (constructed)	Urban population density or not (> 3500 people/sq. mile) at tract level aggregated for PMSA; urban population/total population at PMSA level for 1970, 1980, 1990 and 2000 normalized to 2000 boundaries using NDCB data	Binary at tract level; continuous at city level, bounded by 0 and 1
Sprawl Intensity (constructed)	Sprawling or not at tract level aggregated for PMSA; Sprawl population/total population for 1970, 1980, 1990 and 2000 normalized to 2000 boundaries calculated at MSA level using NCDB	Binary at tract level; continuous at city level, bounded by 0 and 1

	data	
Ratio of Urban to Sprawl Intensity (constructed)	Ratio of urban to sprawl intensity aggregated for PMSAs as above.	Continuous
Standard Deviation of Population Density	Standard deviation of tract density	Continuous
Newly Tracted	Newly tracted at tract level or not; mean of binary variable at PMSA level	Binary at tract level; Continuous at city level
Employment Density		
Rate of Decay of Employment by Rank	Coefficient of regression of employment by zip code (obtained from County/Zipcode Business Patterns) on log of rank	Continuous
Rate of Decay of Employment by Distance from Center	Coefficient of regression of employment data available from County/Zipcode Business Patterns) on log of distance from geographic city center	Continuous
Burchfield et al		
Sprawl Index (Burchfield et al)	Described in Burchfield et al, 2005 and available online in sprawl_msa.dta at http://diegopuga.org/data/sprawl/	Continuous

Energy Cost Variables

Gasoline Prices	National level annual data available since 1949 from the Energy Information Agency (DOE EIA AER) National monthly data available since 1973 (MER) State level data available through SEDS since 1970; weekly data available since 1990 for ten states Weekly city level data available since 2000 or 2003 for ten	Continuous; note I substitute the unleaded for leaded series beginning in 1980

	states Weekly regional level data available since 1992 City level data since 1992 obtained from ACCRA. (Note: Considerably older data is available but for fewer areas. I requested data since 1992 to match jobs data from ZBP.) State data for year 2000 from the Federal Highway Administration (based on EIA data)	
State Excise Taxes	State level data for the year 2000 from the Federal Highway Administration	Continuous
Overall Energy Prices	State data available online since 1970 from the Energy Information Agency (DOE EIA)	Continuous
Change in Energy Prices	Calculated from above series	Continuous

Other Cause of Sprawl Variables

Zoning	Presence of MLS Rules from Gyourko et al	Binary
Streetcars, restaurants and bars etc. aquifer, ruggedness of terrain, elevation at fringe, road density, cooling days, heating days	Burchfield et al. See http://diegopuga.org/data/sprawl/	Binary and continuous

Control Variables

Population	NCDB/Census	Continuous
Avg. Household Income	NCDB/Census	Continuous
Family Income	NCDB/Census	Continuous
Proportion Black	NCDB/Census	Continuous

Proportion White	NCDB/Census	Continuous
Proportion Hispanic	NCDB/Census	Continuous
Proportion Foreign Born	NCDB/Census	Continuous
Proportion Working Age (18-64)	Constructed from NCDB/Census	Continuous
Average Real Household Income-2000 times Gasoline Prices	Constructed from NCDB/Census and EIA data	Continuous
Proportion White-2000 times Gasoline Price	Constructed from NCDB/Census and EIA data	Continuous
Proportion Black-2000 times Gasoline Price	Constructed from NCDB/Census and EIA data	Continuous
Proportion Hispanic-200 times Gasoline Price	Constructed from NCDB/Census and EIA data	Continuous
Proportion Working Age (18-64) times Gasoline Price	Constructed from NCDB/Census and EIA data	Continuous
2-digit NAICS Sector Variables (Proportion of total)	County Business Patterns, Bureau of the Census	Continuous
Cross Industry Occupational Levels (% of total)	Bureau of Labor Statistics	Continuous
Population by Rank Gradient	Constructed from dataset	Continuous

Chapter 5: Results and Discussion

To test the impact of gasoline prices on sprawl, as discussed, I employ three distinct models encompassing three datasets, three different time periods and three sets of measures of sprawl. The metrics of sprawl are based on population density, employment dispersion and light visible from space. In turn, I regress the sprawl metrics on gasoline prices and controls. All three models yield statistically significant evidence that gasoline prices influence sprawl over time. State gas prices also influence state sprawl. The evidence that local gasoline prices influence metropolitan sprawl, however, is ambiguous.

The Impact of Gasoline Prices on Sprawl Measured as Population Density

The first model that I employ explains sprawl defined through metrics of population density as a function of gasoline prices and other variables. My choice of metrics base on population density is motivated by the extensive literature on urban structure that views population density as a critical element and artifact of urbanization as discussed in Chapter 1.

Along with the location of public buildings and business establishments, the density (which is to say the location) of dwellings—where people spend their nights and a good part of their days—is a defining element of urban structure. In the United States, the Census Bureau measures population by sending census forms to dwellings. It measures population relative to the place

where people sleep, not where they work. This is important because daytime and nighttime population can vary significantly as people move in and around a city (Wirth, 1938). Population and population density thus implicitly refer to a category of structure, housing, and are intimately connected to the physical built environment—consisting of single family homes and apartment buildings or complexes—that provide nighttime shelter for residents. While density of dwelling units is also linked to density of jobs within commuting distance (as shown by significant positive correlation), in this model I restrict my analysis to population or dwelling density.

Definitions of urban, sprawling and rural densities vary. The Census Bureau defines urban density to be 1,000 people per mile or above; most scholarship however employs a higher boundary. Lopez and Hynes (2003) surveying the literature of sprawl definitions define urban density as 3,500 people per square mile or above, rural density as 20 people or below and sprawling density as from 20 to 3500 people. (2003). 3500 is far lower than the central density of pre-industrial and industrial cities: the City of Ur may have had a density of 125,000 per square mile in 2000 BC, Paris had a density of 160,000 in its four central *arrondissements* in 1860 and New York had a density of 300,000 per square mile on the Lower East Side in 1900 (Clark, 1951).

Yet while citywide measures and even tract level density measures are a starting point to understanding sprawl or the structure of a city, because they are silent on the critical dimensions of balance between densities, location of density and changes in density, they are

deficient as metrics of sprawl. To fully understand urban structure, it is advisable to know the variance of densities, the shape of their distribution—whether skewed, long tailed, or condensed—and where, within a metropolitan area, the densities are greatest. Yet, for a model to remain tractable, it is also desirable to choose metrics that are efficient in their use of data and adaptable to a wide variety of urban types. I measure sprawl as a function of population density in eight distinct ways designed to balance these objectives.

A Gini Measure of Sprawl

My first measure of population density-denominated sprawl is a constructed measure of the variation between high and low density tracts within a city modeled on the Gini coefficient commonly applied to income distributions.

As discussed in Chapter 4, Gini developed his coefficient as a simple way to describe the shape of the variance of a distribution. The measure has gained wide acceptance in measuring inequality of income but has been applied to other distributions as well. The Gini measure of a distribution which can range from 0 to 1 is equal to the *ratio* of A) the area *between* the Lorenz curve of a distribution and the cumulative density function (CDF) of a uniform distribution, to B) the area below the CDF of a uniform distribution. Equivalently, it is equal to twice the area between a normalized uniform CDF curve and normalized Lorenz curve. Perfectly equal distributions have a Gini coefficient of 0 (following a uniform distribution) whereas perfectly unequal ones have a coefficient of 1. An advantage of the Gini coefficient is that it requires no

assumptions about the shape of the distribution. The chief disadvantages of the Gini coefficient, as discussed in Chapter 4 are its sensitivity to outliers and spikes in the distribution. However, I do not expect population density of census tracts—engineered by the Bureau of the Census for the collection of data—to have many outliers or spikes. I hypothesize that higher gas prices will lead to greater compactness in city structure and inequality in density figures, reflected in a higher Gini coefficient whereas lower gas prices will lead to a more uniform distribution of densities characterized by a lower coefficient.

Figure 5-1 shows a Lorenz curve for the New York PMSA relative to a cumulative density function for a uniform distribution. It is evident that there exists a fair degree of "inequality" or variance in tract densities in the New York PMSA. The inequality changed only slightly over the period 1970 to 2000.

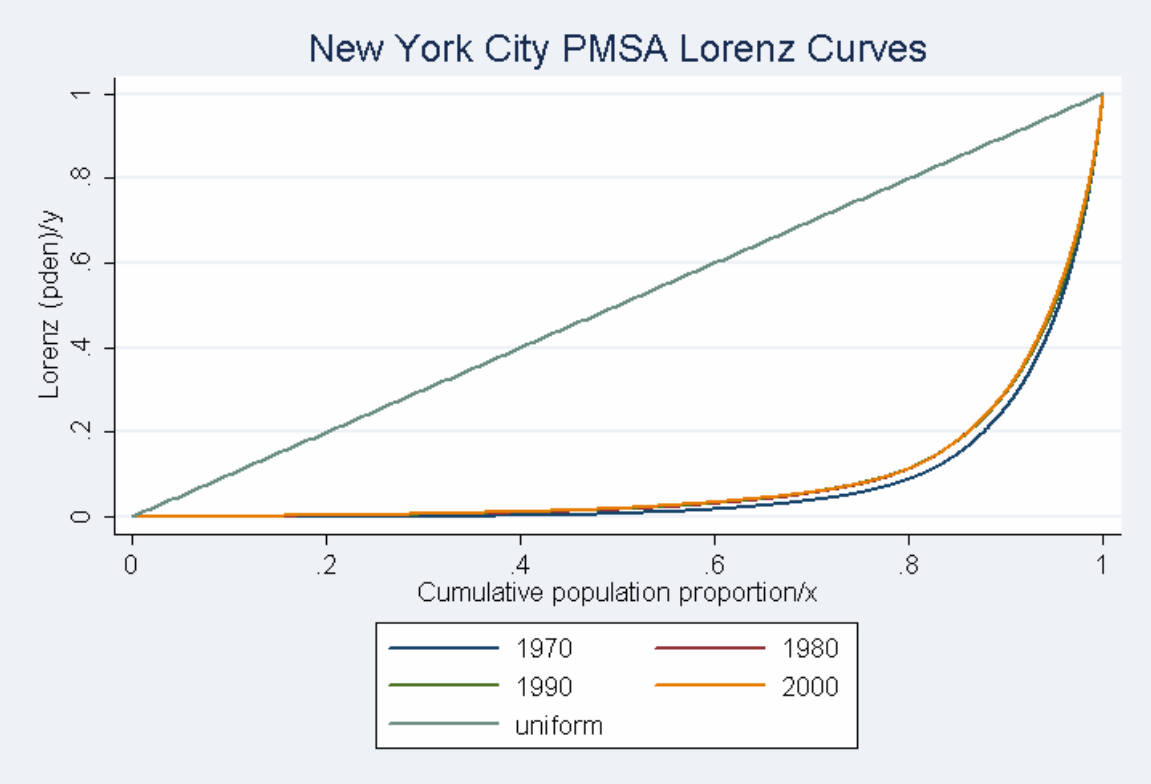


Figure 5-1

By contrast, Figure 5-2 shows a similar graph for the Forth Worth-Arlington PMSA. There is less inequality in population density, reflecting its flatter distribution of population and considerably greater change in equality over the period 1970 to 2000. The distribution grew flatter over this period as well.

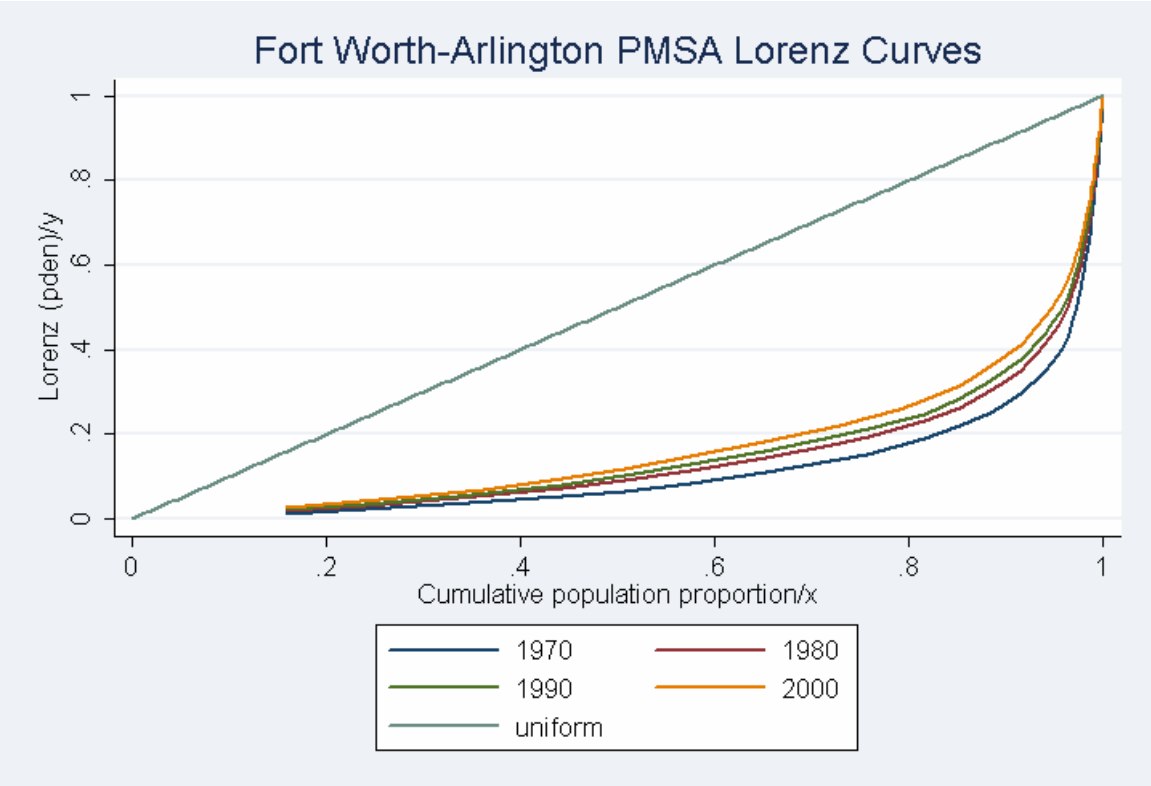


Figure 5-2

Figure 5-3 shows a variety of PMSAs as of the year 2000 and illustrates a wide range of curves.

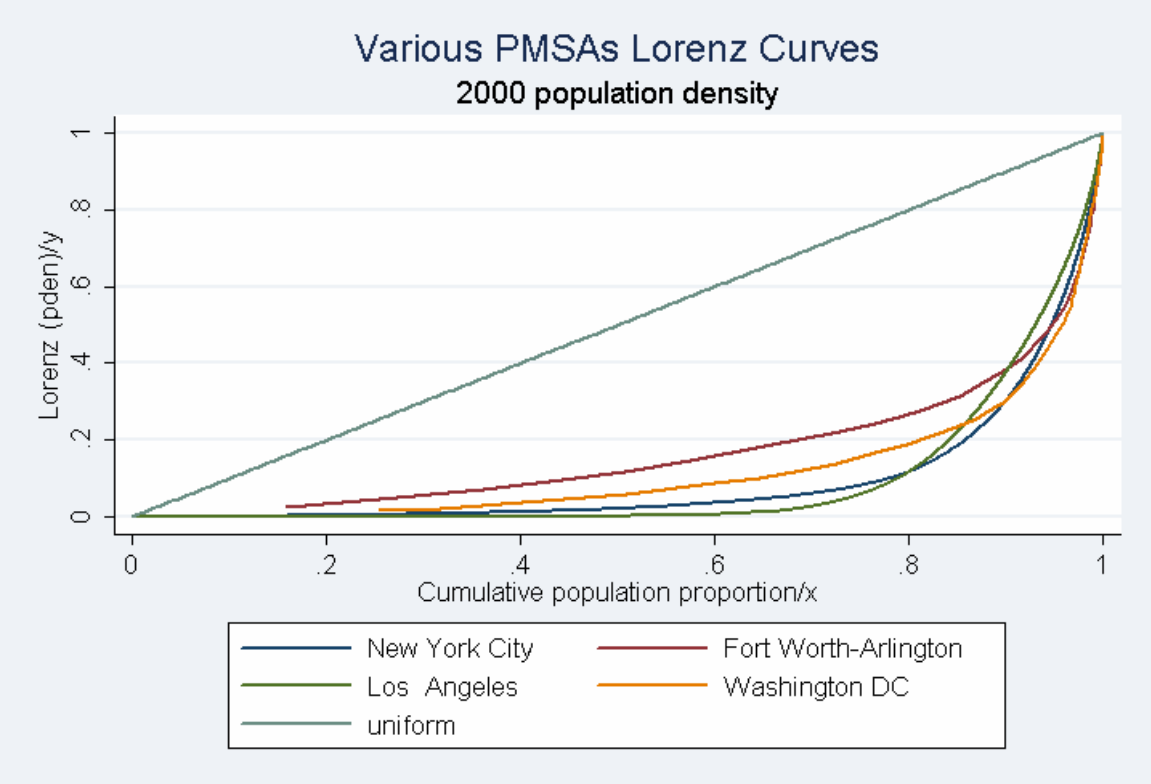


Figure 5-3

The less area between the uniform distribution and the Lorenz curve, the lower the Gini and the less inequality. Fort-Worth Arlington had a lower Gini and less inequality than New York with Washington DC and Los Angeles falling in the middle.

To test the impact of gasoline prices on the GIni measure of sprawl, I first calculate the Gini coefficients for each PMSA by year. In turn, I regress the Gini measure for 72 PMSAs on state gasoline prices and various controls, aggregated from the tract level to that of the PMSA over the period 1970 to 2000 using fixed effects OLS regression.

This period, as previously noted, saw a great deal of history. Notable events include major oil shocks in 1973 and 1979, four economic recessions in 1973-1974, 1980, 1981-1982, and 1990-91 and four economic expansions from 1970 to 1973, 1974 to 1979, 1982 to 1990 and 1992 to 2000 (Temin, 1998). In the United States it also saw the expansion of the population from 203,392,031 in 1970 to 281,421,906 in 2000, driven by rising immigration that led to a dramatic change in the race, ethnicity and national origins of US residents including a rise in the self-identified Hispanic share of the population from 4.5% to 12.5%[5] It corresponded with changes in average age and working age population which declined and then rose. The period also exhibited changes in patterns of urban segregation by race, the deindustrialization of older industrial centers, government led urban renewal, "gentrification" and the repurposing of downtown areas, as well as the neo-industrialization of areas in the south and Midwest, together with a secular regional shift in share of population from the North and East to the South and West.

While it is not possible to control for every development during this period, I control for hose that are the most likely to impact sprawl according to my model (Appendix A) and the literature. . Certain variables such as national economic growth and oil price shocks impacted the entire country. I capture the local impact of national growth at the tract level via family and household income figures and the impact of oil price shocks at the state level through gasoline price changes. I capture population change at the tract level. I capture demographic changes, notably changes in age distribution and immigration, through age structure and foreign born

[5] http://www.census.gov/population/www/documentation/twps0029/tab08.html

status at the tract level. I also control for race and Hispanic origin at the tract level. I also experiment with some other variables such as movement of population between regions but do not include regional variables in the final regressions because they drop out of the model using the fixed effects methodology. Finally, I adjust figures in US dollars for inflation and make other adjustments to facilitate comparisons. Gasoline prices are adjusted to $2000 US$/gallon. Income figures are deflated using BLS income deflators to 1970 US$ and given in thousands. City population figures are given in millions or at the state level tens of millions. The Gini coefficient is multiplied by 100 in the table that follows to increase the number of significant digits in the regression coefficients reported by the Stata software.

The results, shown in Table 5-1 show that gasoline prices have a statistically significant impact on sprawl measured using the GIni metric with and without controls. Higher gas prices lead to a higher Gini coefficient or greater inequality in population density across the metropolitan area. Lower gas prices lead to a lower Gini coefficient or less inequality in population density.

Table 5-1			
Fixed Effects Regression of Gini Measure of Metro Area Tract Density Inequality on Gasoline Prices and Controls 1970 to 2000			
Dependent Variable: Gini Coefficient of PMSA Tract Densities*100			
	(1)	(2)	(3)
	Gasoline prices	With controls	With Extended controls
Two-year lagged gasoline prices (2000 US$/gallon)	15.824 (12.30)**	15.728 (7.19)**	10.021 (4.22)**
Population (millions)		-3.411 (4.24)**	-4.492 (5.10)**
Average Household Income (000)		0.560 (3.99)**	0.965 (1.89)
Proportion White		8.090 (1.43)	-16.875 (1.88)
Family Income (000)			-0.593 (1.23)

Proportion Foreign Born			-19.968 (1.70)
Proportion Black			-46.650 (2.85)**
Proportion Hispanic			15.405 (1.65)
Proportion Working age (18-64)			-45.513 (4.56)**
Constant	32.540	23.376	89.145
	(19.12)**	(3.92)**	(6.33)**
Observations	288	288	288
Number of PMSAs	72	72	72
R-squared	0.41	0.51	0.60
Absolute value of t statistics in parentheses. Gini unweighted.			
* significant at 5%; ** significant at 1%			

The above results are based on an unweighted Gini coefficient that weights tracts equally (so that tracts sum to their total). Weighting tracts by land area, however, (so that population sums to its total) and regressing the weighted Gini coefficient on gasoline prices and identical controls, yields similar, statistically significant results.

A Zipf Measure of Sprawl

My next measure of density-denominated sprawl is a constructed measure of the variation between high and low density tracts within a city that measures change in tract density change by rank.

Zipf pioneered the pairing of variables and their rank in the field of linguistics and explored similar relationships across a wide range of human activities. His second example in his 1949

book, *Human behaviour and the principle of least effort: An introduction to human ecology,* after the frequency of words varying inversely with rank, was that the population of cities varied inversely with rank so that a population multiplied by its size should equal a constant (Zipf, 1949). Applying his pairing of population and rank to the question of sprawl, I construct a measure of sprawl derived from the relation of population *density* and rank *within* cities.

Until now Zipf's law has not been explicitly applied to the ranking of tracts by size within cities. However it has been applied to similar topics. Zipf's key insight was that the mathematical relation between size and rank of a variable conveys information about the variable beyond the size alone. The set of ordered pairs, size and rank, forms a distribution. I exploit the information contained in the density by rank distribution to construct a measure of the population density gradient. As discussed in Chapter 3, the population density gradient as a function of distance is a venerable measure of suburbanization in urban literature. Beginning with Clark (1951), population density has been used by Berry, Mills and many others as a measure of decentralization. In lieu of measuring the gradient by distance (which I will return to in a moment), for my first metric of sprawl, I measure the gradient of density of census tracts by rank. I then study how explanatory variables including gasoline prices impact this measure over time.

As illustrated in Figure 5-4 graphing population density as a function of rank for the New York PMSA, as an example, reveals a concave curve. It has the familiar exponential form:

$$\textbf{POPULATION DENSITY} = \alpha e^{-\beta p}$$

where **p** = **RANK** and **α** and ***β*** are parameters describing the intercept and rate of decay.

While the exponential function is that used by Clark, Mills and others to model density decay (though with respect to distance), one could also, following Zipf, explicitly, model this distribution using a Pareto or power law expression as the following can also produce a concave graph with appropriate values of ***a*** and ***b***:

POPULATION DENSITY = aRANK^{-b}

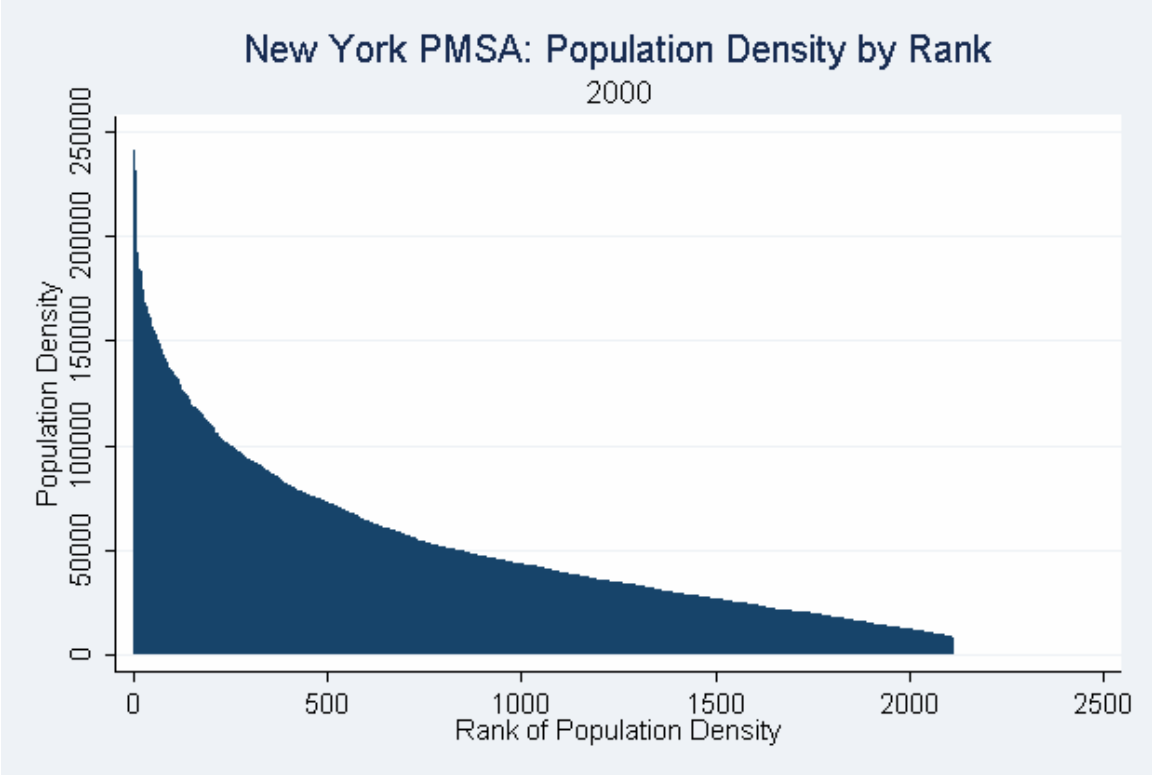


Figure 5-4

To convert these equations into linear ones better suited to linear regression analysis, it is advantageous to log both sides, yielding the following two formulas.

The exponential version is:

$$\mathbf{LN(POPULATION\ DENSITY) = LN(\alpha) - \beta RANK \qquad (1)}$$

In which logged population density is linear in rank. The analogous Pareto formulation is:

$$\mathbf{LN(POPULATION\ DENSITY) = LN(}a\mathbf{) - }b\mathbf{LN(RANK) \quad (2)}$$

In which logged population density is linear in logged rank. The former linear equation follows Clark (1951), Berry et al (1963), Mills (1972) and others. The latter equation in the case where b=1 is analogous to Zipf's law. The difference is that population density is substituted for population and tract rank *within* cities for rank *of* cities. Since these two expressions have a similar form, differing only in logging the independent variable, rank, henceforth, I focus on (1), following Clark, Berry and Mills. (I reserve (2) and a deeper discussion of the applicability of Zipf's law to population *density within* cities for Appendix B.) Figure 5-5 illustrates the more linear curve obtained from graphing the log of population density and rank. (The conditioning of the graph on log of population density > 9 reflects the paucity of observations at the fringe.)

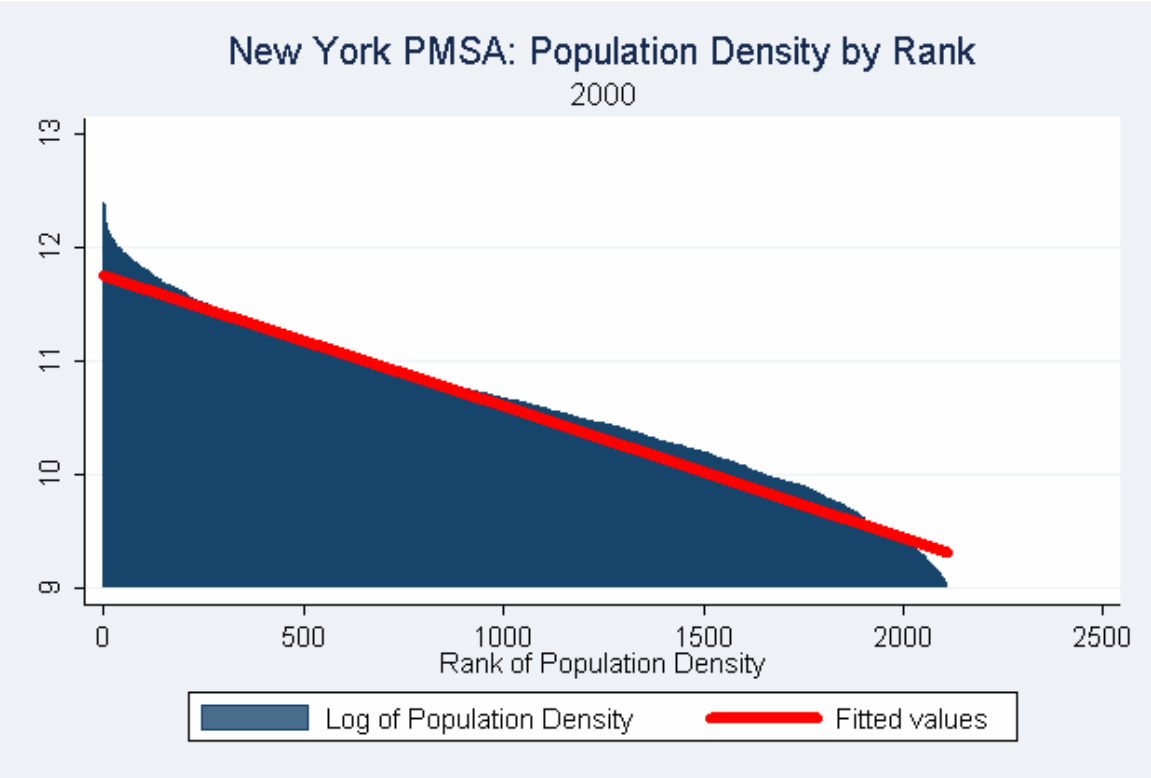


Figure 5-5

Expressed this way, the coefficient ***β*** is equal to the rate of change of logged density with respect to rank and measures the compactness or dispersion of density in the city. A more negative coefficient or *steeper* slope denotes a more rapid decline in density relative to rank (greater compactness). In contrast, a less negative (or more positive) coefficient or *shallower* slope denotes a more gradual decline in density relative to rank, (greater dispersion or land intensity).

As another example, Figure 5-6 shows the change in this relation over time for the fast growing Forth Worth-Arlington, Texas PMSA.

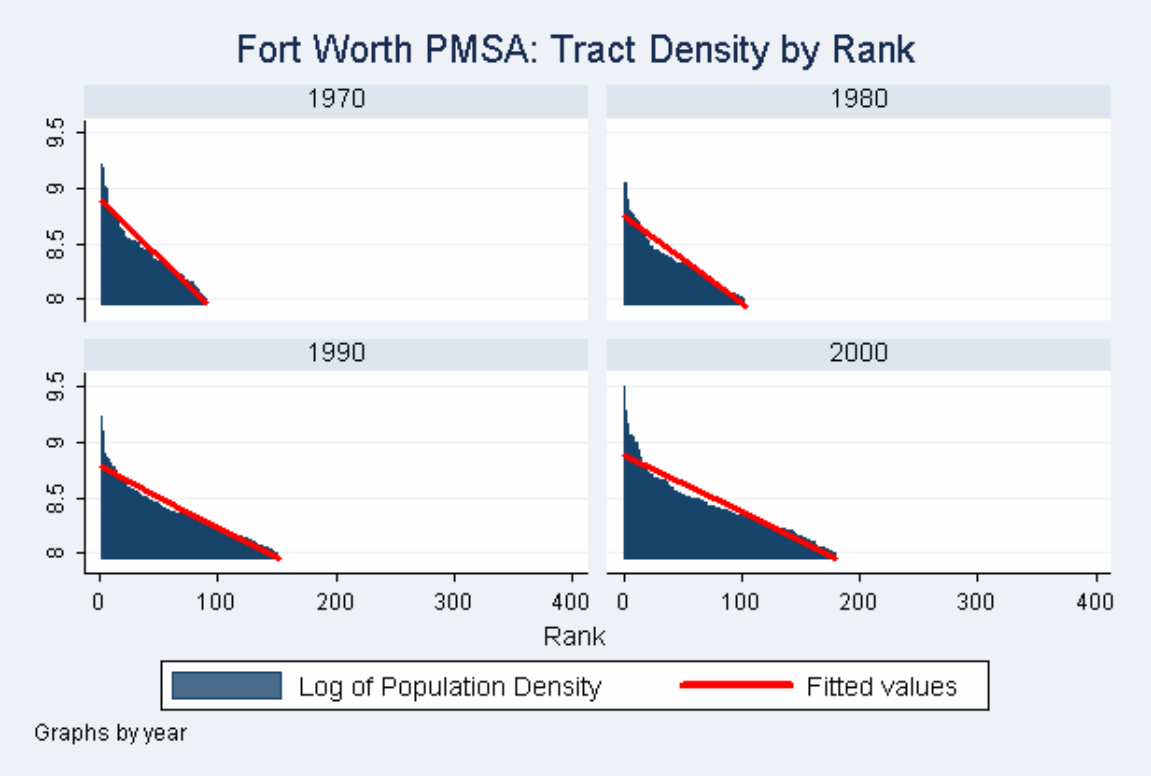


Figure 5-6

It is apparent that the Fort Worth-Arlington MSA grew more dispersed over this period. Indeed, ***β*** went from -.0170645 in 1970 to -.014777 in 1980 to -.0117392 in 1990 to -.0105198 in 2000.

To provide a sense of the variation in these curves by city, Figure 5-7 depicts the decay in log of density by rank for five cities, Chicago, Houston, Los Angeles, New York and San Francisco and all other cities.

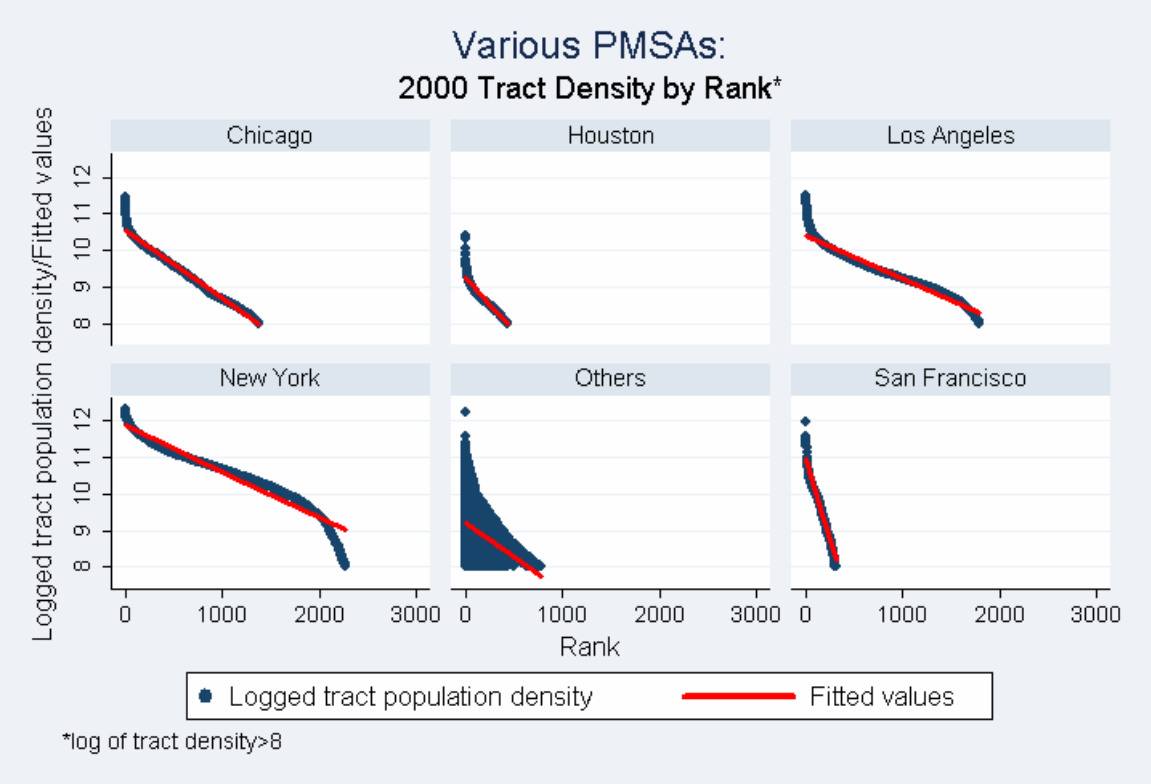


Figure 5-7

The ***β*** values for the five cities above (in 2000) using OLS regression that is robust for heteroskedasticity are: Chicago(-.0022723), Houston(-.0053961), Los Angeles(-.0017181), New York(-.0016594), San Francisco(-.0125135). Of these San Francisco is the most condensed followed by Houston, Chicago, Los Angeles and New York. (Note that these coefficients reflect PMSA definitions.

I designate the coefficient ***βz***—which reflects the rate of density decay with respect to rank—the Zipf measure of sprawl.

Aggregating this measure over years and PMSAs, I find that it ranges from a minimum of -.2386992 to a maximum of -.0016294 with a mean of -.0530229. Insofar as the Zipf metric equals the coefficient of a regression in which the dependent variable, tract density has been log transformed but the independent variable, rank has not, it can be interpreted as the percent change in tract density corresponding to a one unit change in rank. For all 72 PMSAs over the time period in question, therefore, a one unit decline in rank is associated with a -.163 percent change in tract density.

To test the impact of gasoline prices on the Zipf measure of sprawl, in a two stage regression process, I first regress the natural log of tract density on rank using OLS regression that is robust to heteroskedasticicty to obtain βz for each PMSA. In turn, I regress the Zipf measure for 72 PMSAs on gasoline prices by the relevant state and various controls, aggregated from the tract level to that of the PMSA over the period 1970 to 2000 using fixed effects OLS regression. (The Zipf metric is multiplied by 100 to raise the number of significant digits in regression coefficients reported by the software.)

Table 5-2 shows the results of Ordinary Least Squares Regression using Fixed Effects of the Zipf measure of sprawl on two year lagged state gasoline prices for the period 1970 to 2000. The results with and without controls motivated by the literature and changes noted above show a statistically significant impact of gasoline prices on the Zipf measure of sprawl.

Table 5-2			
Fixed Effects Regression of City Dispersion on Gasoline Prices and Controls 1970 to 2000			
Dependent variable: Coefficient, ***θz***, of Regression of Log of Tract Density on Tract Rank (Zipf Metric)*100			
	(1)	(2)	(3)
	Gasoline prices	With Controls	With Extended Controls
Two-year lagged gasoline prices (2000 US $/gallon)	-1.915 (10.06)**	-2.226 (6.33)**	-1.237 (3.45)**
Population (millions)		-0.211 (1.63)	-0.126 (0.94)
Average Household Income (000)		-0.013 (0.57)	-0.054 (0.69)
Proportion White		-0.082 (0.09)	-1.086 (0.80)
Family Income (000)			0.072 (0.99)
Proportion Foreign Born			-7.531 (4.24)**
Proportion Black			-7.133 (2.88)**
Proportion Hispanic			4.543 (3.21)**
Proportion Working age (18-64)			7.923 (5.25)**
Constant	-2.785 (11.06)**	-1.869 (1.95)	-6.767 (3.17)**
Observations	288	288	288
Number of PMSAs	72	72	72
R-squared	0.32	0.33	0.52
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

With or without controls, higher gas prices are associated with more negative values of ***θz***, a steeper slope and, therefore, less city dispersion or sprawl. This measure is robust to numerous city characteristics including size and sub-centers. It does, however, correlate with population (corr = .53) as larger metropolitan areas with more tracts have shallower gradients as predicted for distance gradients by my version of the AMM model. (See Appendix A.)

Density Gradient by Distance Metric of Sprawl,

My third density-derived measure of sprawl, following Clark (1951), Mills (1972) and others, directly measures sprawl as a function of population density with respect to distance from a city center. It is not clear *a priori* that this metric, well suited to studying the monocentric structure that typified preindustrial and industrial cities is equally well suited to polycentric, post industrial cities. However, by using the geographic center of the city as opposed to a single central business district, it is possible to analyze density relative to distance from the center. This method is precisely analogous to the methodology used above for my first, Zipf measure of sprawl, except that distance is substituted for rank.

To calculate distance, I first calculate the geographic mean of the city by taking the mean of the latitudes and longitudes of the centroids of the census tracts. I then calculate the distance of each tract centroid in miles from the center city point using standard triangulation methodology to obtain a distance from the center of the tract to the center of the city in miles. I judge this quantitative approach to measuring distances simpler and less subjective than the method used by Glaeser and Kahn (2003), of relying on the spot named by local leaders in the 1982 Special Census Survey to determine a center.

Figure 5-8 illustrates the decay in density by distance from the city center for the New York PMSA. The curve has the same concave outline as the Zipf measure shown above, except for a convex shape near the origin indicative of low density at the city center (consistent with displacement of dwellings by industrial or commercial uses as observed by Clark, Mills and others) and the fact that it does not decrease monotonically with respect to distance. The spikes evident at various points indicate the presence of high density tracts or sub-centers at various distances from the center of the PMSA. The discontinuity indicates the lack of monotonicity in density by distance.

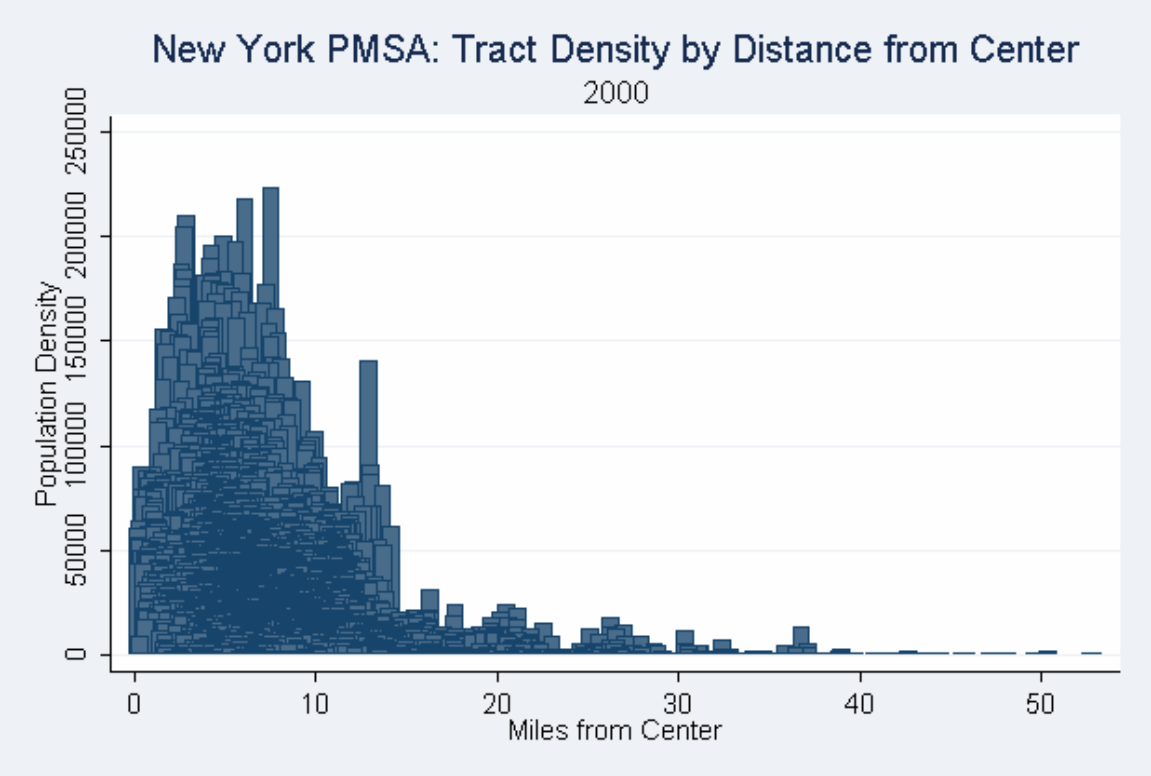


Figure 5-8

Again to convert the curve into a linear relation amenable to linear regression analysis, following Clark and Berry, I take the log of each side. This yields the equation:

LN(TRACT DENSITY) = α – β(DISTANCE FROM CENTER)

Figure 5-9 illustrates the decay in *log* of density as one moves away from the geographic center of the New York PMSA.

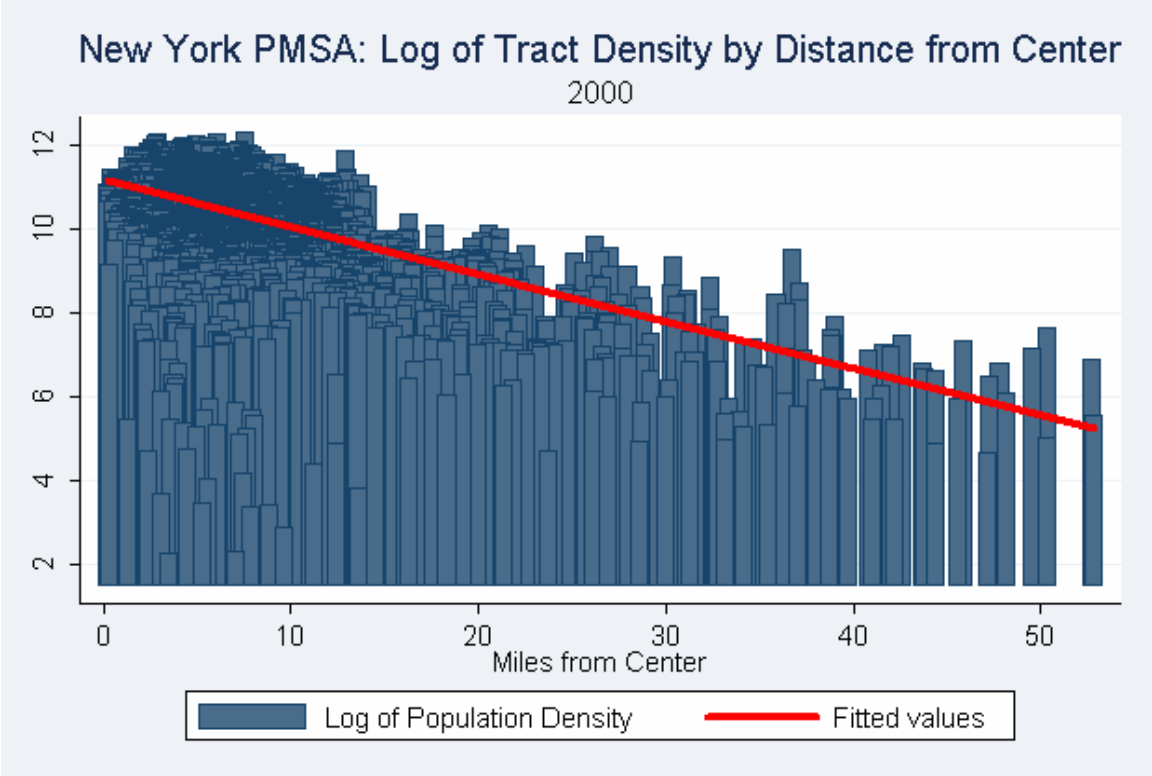


Figure 5-9

This graph, also conditioned at the extremes, shows a steady, reasonably linear decay in density by distance from the center. As with the Zipf metric above, it is interesting to compare graphs of log of tract density relative to distance from the center for a given city region at different points in time.

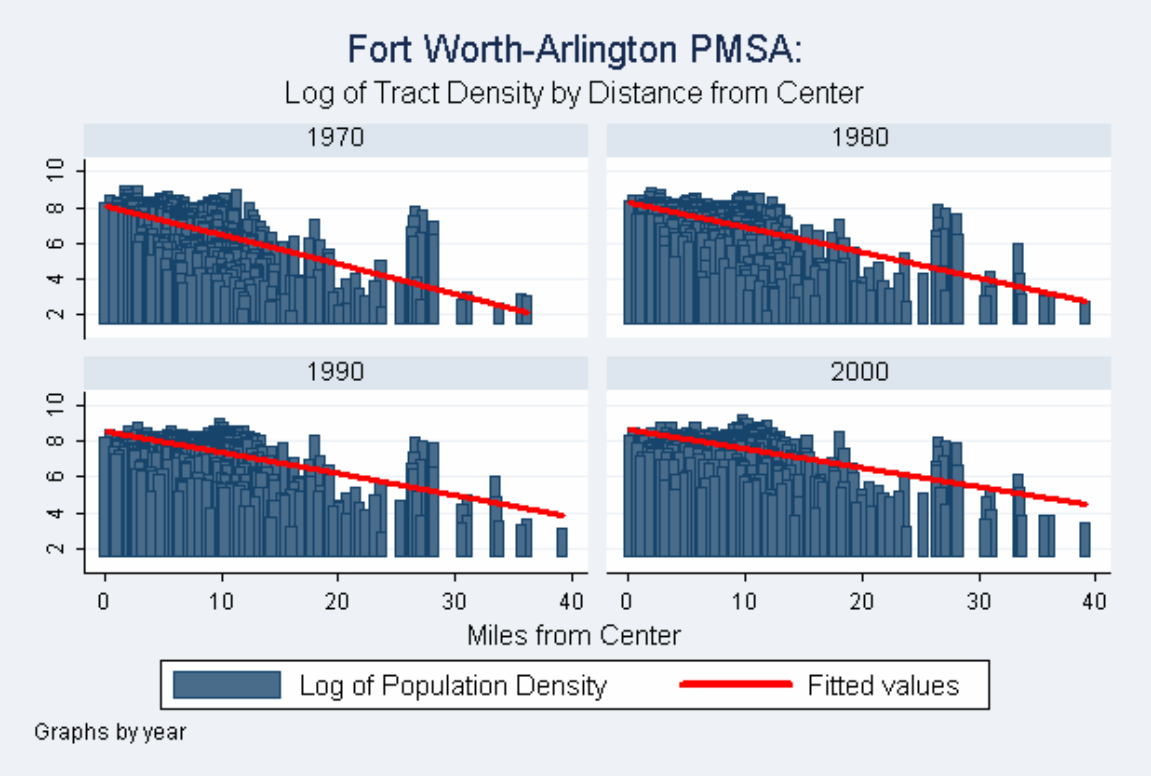


Figure 5-10

Figure 5-10 shows the change in decay for the Fort Worth-Arlington MSA. The slopes of the line are as follows: 1970(-.1652083), 1980(-.1428464), 1990(-.119402) and 2000(-.105943). They are steepest in 1970 and shallowest in 2000. The graphs also indicate filling in over this period. In turn, different cities reveal different patterns as illustrated by Figure 5-11.

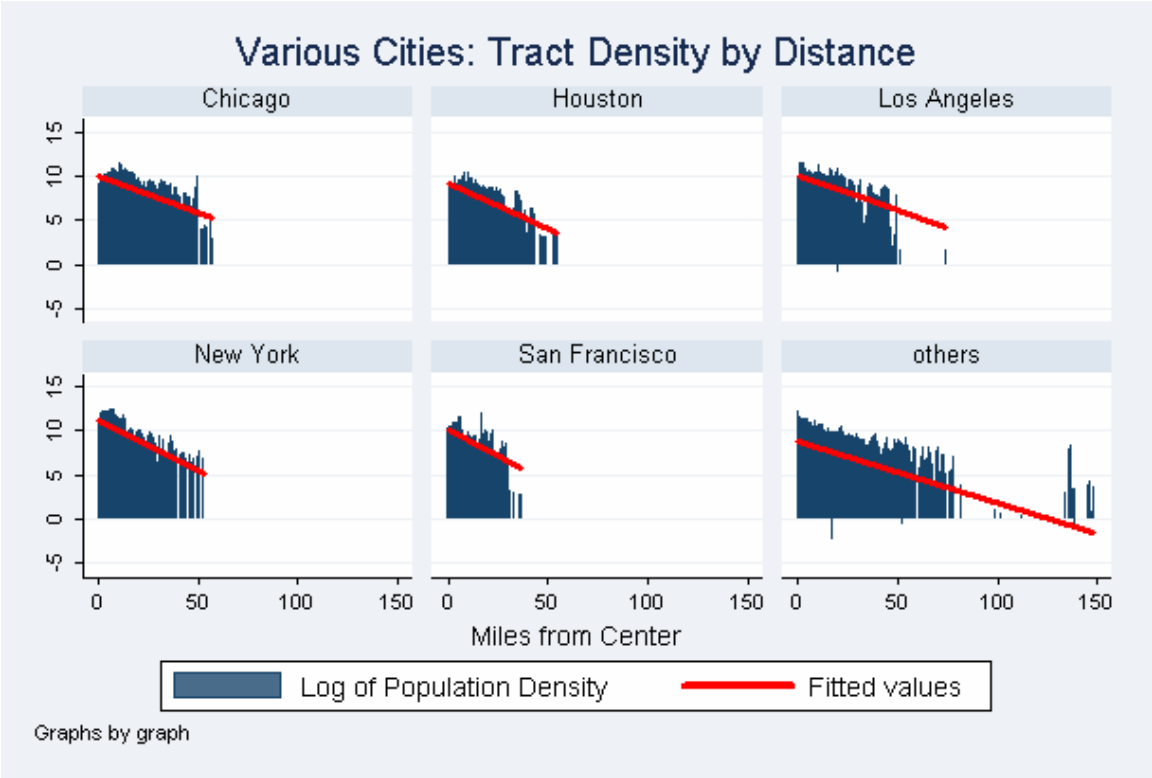


Figure 5-11

As with the Zipf measure above, a more negative or steeper slope, ***β,*** denotes a more compact city while a less negative, shallower (or even positive) one is consistent with dispersion. I designate this coefficient, ***βc.*** (Appendix B provides measures of central tendency for the ***βc*** values for selected PMSAS.) The Clark-Mills metric like the Zipf metric tested above thus provides a measure of the distribution of density within the city. It provides my second measure of sprawl.

While the Clark-Mills metrics vary over time and place, pooling cities and years, they range from a minimum of -.8191177 to a maximum of .0556679 and have a mean of -.1562097. (This is

shallower than the gradients found by Clark (1951), probably due to his confining observations to what are now considered center cities. Examining New York in 1900, for example, he goes out only 7 ½ miles and finds a slope of -.55.) Insofar as the Clark-Mills metric equals the coefficient from a regression in which the dependent variable, tract density, has been log transformed but the independent variable, distance from the center, has not, it can be interpreted as the percent change in tract density corresponding to a 1 mile change in distance from the center. (In other words, tract density will change by 100 *(Clark-Mills metric) percent per one mile change.) For all 72 PMSAs over the time period in question, therefore, each mile away from the city center is associated with 15.6% decrease in density.

Like the Zipf measure described above, the Clark-Mills measure provides a measure of sprawl regardless of city size. (It can be problematic to compare cities, however, as larger cities, in general, have many more tracts and, therefore, shallower gradients as discussed. The correlation of city population to $\boldsymbol{\beta_C}$ is .31.) Compared with the Zipf measure, it has the advantage of conveying information about actual physical distribution. It points out concentrations of density away from the center, for example. It has the disadvantages of requiring more data—namely latitudinal and longitudinal centroid data for tracts compared with the Zipf measure where rank can be deduced trivially from size by mapping the data to the natural numbers. It is therefore more data intensive and less efficient in use of data. It has the additional disadvantage, noted by Clark, of not holding at the center of the city. It also may not be as well suited to polycentric cities as the Zipf metric.

To quantify the differences between the Zipf and Clark-Mills measures, for the New York PMSA, for example, ***βz*** has a t-statistic of -193.30 or -565.12 if one restricts observations to the more populated areas of the city with log of population density greater than 9. ***βc*** has a t-statistic of -75.78. Both measures are therefore highly significant but the ***βz*** measure is more so.

The ***βz*** statistic is significant near the origin while the ***βc*** metric is not. Within one mile of the geographic center of the New York PMSA (distance < 1 mile) ***βc*** is not statistically significant (t=0.19), for example, and within one mile of the geographic centers of all 72 PMSAs, the predicted value of ***βc*** is similarly not statistically significant This probably reflects lower population densities due to competing uses near the center (as observed by Clark.)

Related to the above findings, insofar as the t-statistic is related to variance (t=datamean*sqrt(N)/σ or var=(datamean*sqrt(N))^2/t^2), the ***βc*** metric exhibits greater variance than the ***βz*** metric, This additional variance is greatest near the center. Once outside the center, it is not as large as one might expect, suggesting the distance measure is adequate for studying even polycentric cities.

As an illustration, figure 5-12 shows that in Forth Worth-Arlington Texas, density from the center outward to a distance of 10 miles actually increases. This is in contrast to figure 5-10 above showing its decrease over the full 40 mile radius of the metropolitan area and figure 5-6 showing its monotonic decrease with respect to rank. The variance between the actual data and predicted values shows up in a t-statistic for the ***βc*** metric of -14.22 for Forth-Worth Arlington,

still highly significant but lower in absolute terms than that for the ***βz*** metric of -38.90 obtained by regressing density on rank.

To test further how ***βc*** performs as a measure for polycentric as opposed to monocentric cities, I divide the PMSAs into two groups, those centered on historically dominant CBDs such as Boston, Baltimore and New York and others. As a proxy for historically monocentric cities with traditional centers, I use those that were among the top 20 in population in 1900. In 1900 after the advent of industrialization but before the proliferation of the automobile, the largest 20 cities all had prominent centers that persist today. Other urban areas were either smaller or did not exist in 1900 and are therefore, less likely to have a large, prominent center and more likely to have arisen in the age of the automobile. The division of cities is provided in Appendix D. (Repeating the analysis using largest cities in 1920 does not appreciably change results.)

The data show that the standard error of ***βc*** for "polycentric" cities is larger than that for historically "monocentric" ones as defined (and the t-statistic less than half that for historically "monocentric" cities, however, ***βc*** is still highly significant for both. In sum while ***βc*** is not as well suited as ***βz*** for the analysis of polycentric cities—operationalized as those not among the largest twenty in 1900, it is still a highly statistically significant measure of their density distribution.

Table 5-3			
Log of Population Density Regressed on Distance from Center by City Type– 2000*			
	Standard Error**	T-Statistic	Coefficient
Monocentric Cities (In Top 20 in 1900)	.0014153	-70.63	-.0999681
Polycentric Cities (Other)	.0021625	-28.10	-.0607653
*weighted by tracts **heteroskedastically robust			

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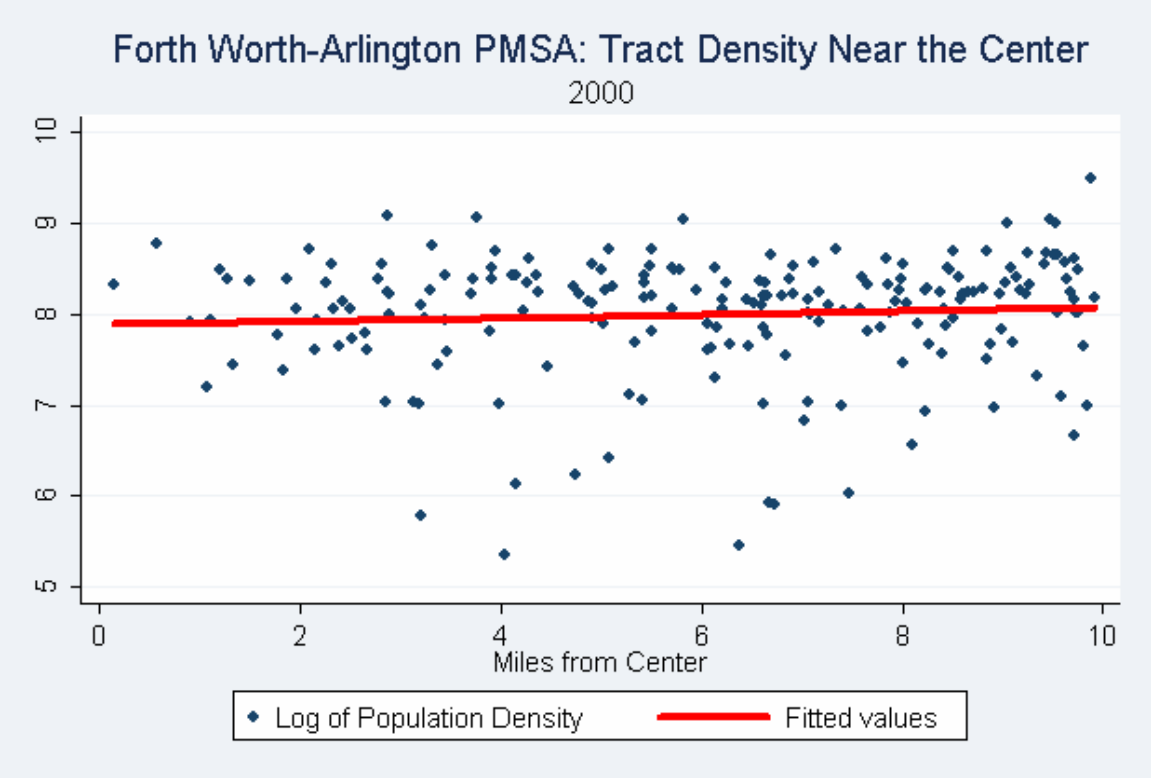


Figure 5-12

Thus, constructing a distance based measure of density decay following Clark and Mills provides an important complement to the Zipf measure and is my third measure of sprawl. In the table that follows, the Clark-Mills metric is multiplied by 100 to raise the number of significant digits in regression coefficients reported by the software.

Table 5-4 shows the results of Ordinary Least Squares Regression using Fixed Effects of the Clark-Mills metric of sprawl on two-year lagged state gasoline prices for the period 1970 to 2000. The results with and without controls motivated by the literature and changes noted above show a statistically significant impact of gasoline prices on sprawl.

Table 5-4			
Fixed Effects Regression of City Dispersion on Gasoline Prices and Controls 1970 to 2000			
Dependent Variable: Coefficient, ***Bc***, of Regression of Log of Tract Density on Distance from Center (Clark-Mills Metric)*100			
	(1)	(2)	(4)
	Gasoline prices	With Controls	With Extended Controls
Two-year Lagged Gasoline Prices (2000 US$/gal)	-8.040 (5.75)**	-8.537 (3.29)**	-8.458 (2.70)**
Population (millions)		0.886 (0.93)	1.779 (1.58)
Average Household Income (000)		-0.102 (0.61)	-1.374 (2.29)*
Proportion White		1.084 (0.16)	-14.737 (1.35)
Family Income (000)			1.312 (2.29)*
Proportion Foreign Born			-32.902 (2.22)*
Proportion Black			-23.305 (1.11)
Proportion Hispanic			2.414 (0.20)
Proportion 65+			-27.665 (1.17)

Constant	-5.050 (2.73)**	-5.208 (0.74)	12.619 (0.89)
Observations	288	288	288
Number of PMSAs	72	72	72
R-squared	0.13	0.14	0.18
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Higher gasoline prices are associated with a lower value of βc, a steeper slope and therefore, less city dispersion.

Other Metrics of Sprawl

To further increase confidence that the impact of gasoline prices on population density is statistically significant, I test five other measures of population density.

Urban Tracts as a % of Total

Urban density tracts are urban by definition. Over time, more urban tracts as a percentage of total tracts in a metropolitan area, implies that more of the city is urban. New urban tracts can arise from rural or sprawling tracts becoming urban or the census bureau dividing urban tracts into two. Either method is indicative of a greater concentration of urban density dwellings. More generally, when the number of urban tracts in a metropolitan area grows more rapidly than the number of sprawling or rural tracts, a metropolitan area becomes more urban.

To assess the urban status of tracts, I create a dummy variable equal to one for urban density tracts (tract density>3500 people/sq. mile as suggested by the literature (Lopez and Hynes, 2003)) and zero for non-urban density tracts (tract density<3500 people/sq. mile). I then take the mean of this tract level variable for each PMSA to construct a measure of urban intensity by PMSA. Urban intensity of metropolitan areas is my fourth variable for sprawl.

Table 5-5 shows the results of performing OLS regression using fixed effects of Urban Intensity on gasoline prices and controls, logged to improve fit. (Regressing urban intensity on un-logged gasoline prices also yields significant results with the sign for gasoline prices in the same direction.) It shows that gasoline prices have a statistically significant positive impact on the urban intensity of PMSAs consistent with higher gasoline prices increasing the urban intensity or reducing relative sprawl.

Table 5-5			
Fixed Effects Regression of Urban Intensity on Log of Gasoline Prices and Controls 1970 to 2000			
Dependent Variable: % Tracts with Urban Density			
	(1)	(2)	(3)
	Log Gasoline Prices	Log Gasoline Prices with Controls	Log Gasoline Prices with Extended Controls
Log of 2-Year Lagged Gasoline Prices	0.143 (5.38)**	0.409 (8.34)**	0.209 (4.55)**
Log of City Population		0.086 (3.66)**	0.126 (4.96)**
Log of City Average Household Income		0.085 (2.69)**	0.240 (3.35)**

Log of Proportion White		-0.168 (2.69)**	-0.235 (3.76)**
Log of Family Income			-0.234 (2.85)**
Log of Proportion Foreign Born			0.019 (1.41)
Log of Proportion Black			0.036 (2.86)**
Log of Proportion Hispanic			-0.046 (4.23)**
Log of Proportion Working Age			-0.465 (5.36)**
Constant	0.122 (1.95)	-2.478 (5.15)**	-1.998 (3.75)**
Observations	288	288	288
Number of PMSAs	72	72	72
R-squared	0.12	0.27	0.51
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Sprawling Tracts as a % of Total

Population density of from 20 to 3500 people per square mile is consistent with sprawl (Lopez and Hynes, 2003). As with the urban intensity measure above, sprawling tracts as a percentage of the total is indicative of the level of sprawl in an urban area. A tract can become sprawling either through the development of previously rural land, the division of sprawling tracts in two or, rarely, the depopulation of a formerly urban tract. The most likely pathway for exit from sprawling status is through conversion to urban status. When sprawling tracts as a percentage of the total rise faster in percentage terms than either rural or urban tracts, the city becomes more sprawling.

To gauge the sprawling character of tracts, I create a dummy variable equal to one for sprawling density tracts (20<tract density<3500 people/sq. mile) and zero for non-sprawling density tracts. I then take the mean of this variable for each PMSA to construct a metric of sprawl intensity. This measure (strongly negatively correlated with urban intensity) is my fifth variable for sprawl.

As shown by Table 5-6, this model provides statistically significant evidence that higher gas prices reduce levels of sprawl intensity.

Table 5-6			
Fixed Effects Regression of Sprawl Intensity on Log of Gasoline Prices and Controls 1970 to 2000			
Dependent Variable: % Tracts with Sprawling Density			
	(1)	(2)	(3)
	Log of Gasoline Prices	Log of Gasoline Prices with Controls	Log of Gasoline Prices with Extended Controls
Log of 2-Year Lagged Gasoline Prices	-0.151 (5.79)**	-0.403 (8.30)**	-0.244 (5.08)**
Log of City Population		-0.074 (3.18)**	-0.083 (3.19)**
Log of City Average Household Income		-0.088 (2.82)**	-0.417 (6.18)**
Log of Proportion White		0.160 (2.60)*	0.176 (2.70)**
Log of Family Income			0.398 (4.91)**
Log of Proportion Foreign Born			-0.023 (1.59)
Log of Proportion Black			-0.021 (1.60)
Log of Proportion Hispanic			0.052 (4.55)**
Constant	0.893	3.325	2.430
	(14.49)**	(6.99)**	(4.37)**
Observations	288	288	288

Number of PMSAs	72	72	72
R-squared	0.13	0.27	0.44
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Index of Urbanization

As my sixth measure of sprawl, I construct an index of tract density that is monotonically increasing with respect to density. The scale ranges from 0 to 14. I then take the mean of this index for each PMSA and examine how the values of the index change over the entire population of PMSAs with respect to gasoline prices and controls.

As shown in Table 5-7, higher gas prices are associated with a higher index of urbanization, consistent with my thesis.

Table 5-7			
Fixed Effects Regression of Urban Index on Log of Gasoline Prices and Controls 1970 to 2000			
Dependent Variable: Logged Index of Tract Density			
	(1)	(2)	(3)
	Log Gasoline Prices	Log Gasoline Prices with Controls	Log Gasoline Prices with Extended Controls
Log of 2-Year Lagged Gasoline Prices	1.124 (4.50)**	3.897 (8.74)**	2.307 (5.29)**
Log of City Population		0.967 (4.53)**	0.839 (3.55)**
Log of City Average Household Income		0.860 (3.01)**	3.497 (5.70)**
Log of Proportion White		-1.649 (2.90)**	-1.285 (2.17)*
Log of Family Income			-3.161 (4.30)**
Log of Proportion Foreign Born			0.403 (3.04)**

Log of Proportion Black			0.292 (2.46)*
Log of Proportion Hispanic			-0.562 (5.41)**
Constant	5.709 (9.71)**	-22.141 (5.06)**	-11.164 (2.21)*
Observations	288	288	288
Number of PMSAs	72	72	72
R-squared	0.09	0.28	0.46
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

New Tracting.

In 1990, the US Bureau of the Census completed tracting the entire country. This represented the culmination of a long history of efforts by tract advocates and statisticians like Walter Laidlaw and the Cleveland health researcher, Howard Whipple Green to induce local authorities to enumerate tracts (Krieger, 2007). After first appearing in 1906 in Baltimore, Boston, Chicago, Cleveland, New York, Philadelphia and St. Louis, tracting spread gradually. Eventually the Census bureau began to create the equivalent of tracts for areas that local officials had not yet tracted, finishing this effort in 1990. (Formal census tracting was completed in 2000.) Prior to 1990, tracting of metropolitan areas often proceeded outward from central cities as population expanded. The other source of new tracts was likely to be entirely untracted areas being tracted. Thus new tracts contiguous with urban areas tended to reflect outward growth. Between 1980 and 1990, within an urban area as subsequently defined, the addition of new tracts while part of an effort to finish tracting the country, was likely to occur in areas that transitioned from non-metropolitan (whereby they were not tracted in 1980) to metropolitan status (as reflected in their subsequent inclusion in a metropolitan area.). Accordingly, tracting represents yet another interesting if non-dispositive, measure of sprawl.

For the decennial time points 1980 and 1990, I create a dummy variable equal to one for tracts not tracted in the previous census but tracted in the current one. I take the mean of this dummy variable by PMSA and then examine how means change over the 72 PMSAs in my dataset with respect to gasoline prices and controls from 1970 to 1990. This is my seventh variable for sprawl.

As shown in Table 5-8, tracting as an indicator of sprawl correlates with lower gasoline prices after controlling for other variables.

Table 5-8			
Fixed Effects Regression of Land Conversion on Gasoline Prices 1970 to 1990			
Dependent Variable: Binary Conversion from Non-Tracted Status or Zero Density to Tracted Status or Non-Zero Density*100			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
2-Year Lagged Real State Gasoline Prices	6.998 (12.19)**	-20.989 (14.61)**	-18.502 (13.39)**
Tract Population (millions)		846.063 (6.69)**	-796.040 (6.38)**
Change in Fleet Miles Per Gallon		-50.355 (13.22)**	-61.688 (15.91)**
Average Real Household Income (000)		-0.094 (3.01)**	-0.242 (4.90)**
Proportion White		46.700 (49.33)**	60.346 (48.98)**
Real Family Income (000)			0.291 (6.09)**
Proportion Black			64.095 (33.52)**
Proportion Hispanic			16.433 (7.51)**

Proportion Foreign			52.198 (22.46)**
Working Age Population (18-64)			-37.892 (13.63)**
Proportion <18			18.483 (5.74)**
Constant	-6.948	4.087	-1.073
	(9.11)**	(1.48)	(0.28)
Observations	49536	49536	49536
Number of id	24768	24768	24768
R-squared	0.01	0.11	0.22
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Higher gas prices lead to less new tracting or sprawl, consistent with my thesis.

Finally, I examine the change in standard deviation of tract densities by PMSA over time relative to gasoline prices and controls. Non-sprawling cities have high densities at the center that decline sharply to rural densities at the periphery. In contrast, sprawling cities exhibit more uniform densities. Accordingly, non sprawling cities should exhibit a higher standard deviation than sprawling ones. And an increase in standard deviation is consistent with a decrease in sprawl while a decrease in standard deviation is consistent with greater dispersion of population and, therefore, an increase in sprawl. This is my eighth and final measure of sprawl.

As Table 5-9 indicates, higher gas prices over time correlate with higher standard deviation of density, consistent with greater urbanization.

Table 5-9			
Fixed Effects Regression of Standard Deviation of Tract Population Density on Gasoline Prices and Controls 1970 to 2000			
Dependent variable: Standard Deviation of Tract Density			
	(1)	(2)	(3)
	Gasoline prices	With Controls	With Extended Controls
Two-year lagged gasoline prices (2000 US$/gal)	745.620 (2.28)*	3,660.429 (6.89)**	2,131.400 (3.63)**
Population (millions)		947.888 (4.85)**	402.269 (1.85)
Average Household Income (000)		190.415 (5.59)**	234.336 (1.85)
Proportion White		-166.252 (0.12)	-2,046.216 (0.92)
Family Income (000)			-99.448 (0.83)
Proportion Foreign Born			3,595.474 (1.24)
Proportion Black			-14,425.865 (3.56)**
Proportion Hispanic			1,723.357 (0.74)
Proportion Working age (18-64)			-6,212.425 (2.52)*
Constant	4,463.659 (10.30)**	-2,847.498 (1.97)	6,940.850 (1.99)*
Observations	288	288	288
Number of PMSAs	72	72	72
R-squared	0.02	0.26	0.38
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Discussion

Gasoline Prices and Sprawl

Tables 5-1 though 5-9 show the results of Ordinary Least Squares Regression using fixed effects of eight indicators of sprawl on gasoline prices and controls over the period in question. Taken together, they demonstrate a consistent, statistically significant impact of energy prices on sprawl.

Of note, the Gini metric provides a goodness of fit (R-squared) of .60 with controls. The Zipf metric provides a goodness of fit (R squared) when including controls of .52 which exceeds that of the Clark Mills measure of .18. The goodness of fit for the Gini and Zipf measure exceeds those of the Urban Intensity (.45), Sprawl Intensity (.44) and Urban Index (.46) measures of sprawl and that of the Standard Deviation (.36) and Land Conversion (.20) metrics. Insofar as a number of researchers have questioned the continuing viability of the simple distance gradient as cities grow increasingly multicentric (Mieskowski and Mills, 1993), the superior goodness of fit of the Gini and Zipf measures suggests that they offer viable alternative measures with which to study the multicentric city.

All eight measures show a significant effect of 2-year lagged energy prices on sprawl. (Appendix F shows how this effect varies with the lag or different averages of energy prices across different years.) Because the measures vary in their units it is not possible to average their impacts. However, the different measures do permit different interpretations that, taken together, shed additional light on the nature of the effect.

The Gini metric of sprawl incurs a .10021 change for unit change in the price of gasoline. This is quite significant insofar as the Gini is bounded by zero and one. It suggests that a ten dollar increase in gasoline prices would literally transform a hypothetical metropolitan area of uniform density into one dominated by a single CBD. While $10 may be unlikely, a $ 1 change which is not at all rare can induce a .1 change in the Gini equivalent to the difference in population density distributions between the 2000 New York (0.649859) and Boston (0.540243) PMSAs.

The Zipf and Clark-Mills coefficients can be interpreted in similar ways insofar as both represent population gradients from the hypothesized point of greatest density. For both measures, I log the dependent but not the independent variables. The coefficients can be interpreted as the change in density gradient per one unit change in 2000 US$ gasoline prices. For the Zipf measure, the gradient will grow steeper by -.01237 for every unit change in gasoline prices and for the Clark-Mills measure, it will grow steeper by -.08458 per unit change in gasoline prices. (The change in *non logged* population density per unit change in gasoline prices is non-linear so the rate of change is not constant.)

My fourth and fifth metrics of sprawl, urban and sprawl intensity provide perhaps the most intuitive measure of how gasoline price changes impact sprawl. Urban and sprawl intensity, expressed as a decimal, or when multiplied by 100 as a percentage, can be easily imagined as the percent of tracts that are urban or sprawling out of the total. The coefficients for the impact of gasoline prices on urban intensity and sprawl intensity are 0.209 and -0.244 respectively.

In these models, I log the independent variables, including gasoline prices, but not the dependent variables, urban or sprawl intensity. (I do this to make the relationships better fit the linear regression model.) The urban intensity model can therefore be interpreted as follows: A 1% increase in gasoline prices corresponds to a .209/100 increase in percentage of tracts that are urban. Since .209 is actually 20.9%, this means a 1% increase in gasoline prices is associated with a 20.9% increase in urban density tracts.

In contrast, the sprawl intensity model shows that a 1% increase in gasoline prices corresponds to a -.244/100 change in percent of tracts that are sprawling. Since -.244 means -24.4%, a 1% increase in gasoline prices leads to a .244% decrease in sprawling density tracts.

The three other measures of sprawl, the urban index, standard deviation of tract density and new tracting also reveal a statistically significant impact of gasoline prices on sprawl. However, their interpretation does not add anything to the intuitive understanding beyond saying the following: a one unit change in log of gasoline prices is associated with a 2.307 increase in the urban index (which is to say a 1% change in gasoline prices leads to a .023 change in the urban index); a one unit increase in gasoline prices causes a 2131.4 increase in standard deviation of tract densities; and a one unit change in gasoline prices leads to a -18.5% decrease in the likelihood that a tract is new.

Fleet Economy

One potential criticism of these findings is they do not reflect improvements in fleet mileage over the 30 year period under study. Beginning in 1975, the Federal government mandated that carmakers increase corporate average fuel economy (CAFÉ) standards in new vehicles and the Department of Transportation publishes historical figures on average fleet mileage per gallon for cars and vehicles. While the1908 Ford Model T is estimated to have gotten about 25 miles per gallon, over the period 1970 to 2000, fleet mileage improved. The pathway through which I hypothesize that gasoline prices influence sprawl is by changing the cost of driving—whether through raising commuting costs in the hypothetical monocentric city (as discussed in Appendix A) or merely living costs from required daily driving—in areas of high driving intensity, i.e. the suburbs vs. low driving intensity, i.e. the urban core, changing the respective cost profile of living in each. (The greater driving intensity of peripheral relative to core living is well documented (Kahn, 2000, Glaeser, Kahn and Rappaport, 2007)). While changing national fleet mileage would have no effect on within-group comparisons at a single point in time, it could amplify or cancel out the temporal impact of changing gasoline prices by allowing residents to drive more or fewer miles at a given cost. In particular, rising fleet mileage since 1970 could mitigate the impact of higher gasoline prices over time.

To verify that fleet mileage improvements will not change results, I perform a separate set of regressions in which I normalize gasoline prices for mileage, dividing them by fleet miles per gallon figures, to obtain a figure for gasoline cost per mile driven. I then regress my metrics of sprawl on this new variable. As illustrated by Tables 5-10 and 5-11, converting gas prices from cost per unit of gasoline to cost per mile which takes account of fleet mileage changes does not alter the finding that gasoline cost impacts sprawl at the 95% confidence level.

Table 5-10			
Fixed Effects Regression of Density Dispersion by Rank on Mileage Normalized Gasoline Prices and Controls			
Dependent Variable: Regression Coefficient of Log of Tract Density on Rank (Zipf metric) β_z			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
2-Year Lagged Gasoline Prices Normalized by Fleet Miles per Gallon (2000 US$/gal/mile)	-13.941 (12.11)**	-21.721 (9.91)**	-18.428 (4.56)**
Population (millions)		-0.186 (1.60)	-0.202 (1.52)
Average Household Income (000)		-0.026 (1.33)	-0.081 (1.05)
Proportion White		2.367 (2.66)**	-0.643 (0.47)
Family Income (000)			0.077 (1.06)
Proportion Foreign Born			-6.178 (3.40)**
Proportion Black			-7.839 (3.22)**
Proportion Hispanic			2.855 (1.91)
Proportion Working age (18-64)			12.008 (3.60)**
Proportion <18			7.732 (2.47)*
Constant	-4.227	-5.052	-11.555
	(45.64)**	(5.93)**	(3.81)**
Observations	288	288	288
Number of PMSAs	72	72	72
R-squared	0.41	0.46	0.54
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Table 5-11			
Fixed Effects Regression of City Dispersion by Distance on Mileage Normalized Gasoline Prices and Controls			
Dependent Variable: Coefficient of Regression of Log of Tract Density on Distance from Center (Clark-Mills Metric) β_C			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
2-Year Lagged Gasoline Prices Normalized by Fleet Miles per Gallon (2000 US$/gal/mile)	-60.899 (6.94)**	-93.946 (5.45)**	-99.994 (3.01)**
Population (millions)		0.974 (1.06)	0.908 (0.83)
Average Household Income (000)		-0.193 (1.25)	-0.408 (0.64)
Proportion White		13.026 (1.86)	4.843 (0.43)
Family Income (000)			0.295 (0.49)
Proportion Foreign Born			-10.050 (0.67)
Proportion Black			-23.192 (1.16)
Proportion Hispanic			-7.788 (0.63)
Proportion Working age (18-64)			96.262 (3.51)**
Proportion <18			69.809 (2.71)**
Constant	-10.923	-18.231	-86.712
	(15.47)**	(2.72)**	(3.48)**
Observations	288	288	288
Number of PMSAs	72	72	72
R-squared	0.18	0.21	0.26
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Other Variables

In addition to the impact of gasoline prices on sprawl, the regressions also reveal a statistically

significant impact of several other variables. Confirming the prediction of the AMM model as discussed in Appendix A, the results of Margo (1992) and hypothesis of Jackson (1985), the data support a statistically significant impact of income—both of the average household and family—on sprawl using the Zipf and Clark-Mills measures. The impact disappears, however, when normalizing for gasoline mileage. Confirming the results of Fulton et al (2001), the data generally support a statistically significant *negative* impact of foreign born population on sprawl, suggesting that the foreign born initially move into cities. This is consistent with the literature on enclaves and immigration (Portes, 1986).

The impact of black and hispanic population on sprawl is not consistent between models. In the Zipf model, both proportion black and proportion hispanic have a statistically significant positive impact on sprawl consistent with the idea that white flight from blacks and hispanics increases sprawl. However, in the Clark-Mills model, the impact of proportion black and proportion hispanic on sprawl is not significant at the 95% confidence level.

Cross Sectional Analysis

My primary goal in this dissertation is to test the impact of gasoline prices on sprawl over time. However, if gasoline prices do impact sprawl one might expect to see variations in patterns of local sprawl based on variations in local gasoline prices.

Movements in local gasoline prices tend to exhibit high correlation with movements in national gas prices. Accordingly, differences by region are stable over time. Complicating cross sectional analysis at the PMSA level is the lack of good PMSA level data for the time period 1970 to 2000. While state data is adequate for time series analysis using fixed effects since local differences are stable over time and to a large degree are fixed effects that drop out of a fixed effect regression, they are not ideal for local comparisons at one point in time as they lack true granularity. Lacking city level data from the Energy Information Agency, I choose to use the same state data used for the panel data analysis. (Later in this dissertation, I test the impact of city gasoline price data collected by ACCRA on employment density.) Regressing population density-based measures of sprawl on gasoline prices and controls yields mixed results.

Regressing the Clark-Mills metric of density decay by distance, βc on gasoline prices and controls at a fixed point in time, (2000) yields statistically significant coefficients for gasoline prices as a determinant of sprawl. Tables 5-12 shows that the coefficient is statistically significant at the 5% level with and without controls.

Table 5-12			
Cross Sectional Regression of Density Decay by Distance on 2-Year Lagged Gasoline Prices and Control Variables – 2000			
Dependent Variable: Clark-Mills Coefficient of Log of Tract Density Regressed on Distance from Center			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
2-Year Lagged Gasoline Prices (2000 US$/gallon)	-42.279 (3.28)**	-38.986 (2.73)**	-41.303 (2.71)**
Population (millions)		0.912	1.089

		(1.82)	(1.81)
Average Household Income (000)		0.518 (1.90)	-0.358 (0.10)
Proportion White		-16.495 (1.44)	-17.293 (1.02)
Family Income (000)			1.246 (0.37)
Proportion Foreign Born			-50.845 (1.84)
Proportion Black			1.257 (0.08)
Proportion Hispanic			40.096 (1.94)
Proportion Working age (18-64)			17.794 (0.33)
Constant	33.386	33.494	19.176
	(2.31)*	(2.04)*	(0.41)
Observations	74	74	74
R-squared	0.11	0.28	0.35
Robust t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Higher gas prices correspond to a steeper slope and less dispersion, consistent with my thesis.

Table 5-13			
Cross Sectional Regression of Density Decay by Rank on 2-Year Lagged Gasoline Prices and Control Variables – 2000			
Dependent Variable: Zipf Coefficient of Regression of Log of Tract Density on Rank			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
2-Year Lagged Gasoline Prices (2000 US$/gallon)	-12.252 (1.84)	-12.120 (1.96)	-9.179 (1.36)
Population (millions)		1.112 (3.27)**	1.017 (3.03)**
Average Household Income (000)		0.546 (2.89)**	1.018 (0.59)
Proportion White		-7.107 (1.27)	-4.103 (0.49)

Family Income (000)			-0.577 (0.37)
Proportion Foreign Born			17.950 (1.49)
Proportion Black			7.613 (0.89)
Proportion Hispanic			-14.253 (1.38)
Proportion Working age (18-64)			-1.608 (0.06)
Constant	8.765	4.413	1.079
	(1.16)	(0.50)	(0.04)
Observations	74	74	74
R-squared	0.03	0.41	0.44
Robust t statistics in parentheses			
* significant at 5%; ** significant at 1%			

However, regressing the Zipf measure, ***θz*** of density decay by rank on gasoline prices and controls does not provide statistically significant results in the model variant that includes extended controls. While a regression performed without a full set of controls does provide a statistically significant coefficient and the signs are all in the right direction, the results fall short of demonstrating a statistically significant effect at the 5% level. One factor clearly complicating results is the pairing of metropolitan level measures of sprawl with state gasoline prices. However, not enough cities publish gasoline prices to use local prices and metropolitan areas often encompass multiple cities. State gasoline price data, therefore, is preferred.

Cross-State Analysis

A solution to this problem of data mismatch is to compare state sprawl with state prices. Sprawl at the state level has a somewhat different meaning than sprawl at the city level. I cannot use

gradients that measure the decline of density from the center. I can, however, use simple measures of urban and sprawling density to assess relative cross state sprawl. I uses the measures of sprawl intensity and urban intensity described above, defining these as proportion of tracts within a state that are either of sprawling (20<density<3500) or urban (3500<density) density. I further revise the dataset drawn from the NCDB to calculate not only density but control variables at the state level. I use 2000 density and gas price data to match control data from the 2000 decennial census contained in the NCDB. Gasoline price data is that published by the Federal Highway Administration (based on EIA data) in 2000 US$.

Tables 5-14 and 5-15 give the results of cross-state regression of urban intensity and sprawl on state gasoline prices and controls as of the year 2000:

Table 5-14			
Cross State Regression of Sprawl on Gasoline Prices and Control Variables - 2000			
Dependent variable: Proportion Tracts Sprawling by State			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
State retail gasoline prices (2000 US$)	-0.840 (2.95)**	-0.741 (2.02)*	-0.519 (2.80)**
State population (10,000,000)	-17.364 (6.96)**	-11.319 (4.20)**	1.118 (0.27)
Average household income (000)		-0.833 (2.82)**	-0.278 (0.19)
Proportion white		21.351 (0.77)	28.065 (0.45)
Family income (000)			0.111 (0.08)
Proportion black			35.401 (0.59)
Proportion Hispanic			23.955

			(0.68)
Proportion foreign born			-249.489 (3.37)**
Working age population			335.550 (1.92)
Proportion 65+			205.358 (1.50)
Constant	198.537 (4.84)**	209.375 (5.17)**	-93.248 (0.68)
Observations	48	48	48
R-squared	0.39	0.52	0.78
Robust t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Table 5-15			
Cross State Regression of Urban Intensity on Gasoline Prices and Control Variables - 2000			
Dependent variable: Proportion State Tracts with Urban Density			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
State Retail Prices (2000 US$)	0.846 (2.96)**	0.748 (2.03)*	0.526 (2.83)**
State Population (millions)	17.436 (6.94)**	11.346 (4.19)**	-1.103 (0.26)
Average household income (000)		0.835 (2.83)**	0.282 (0.19)
Proportion white		-21.797 (0.79)	-29.555 (0.47)
Family income (000)			-0.108 (0.08)
Proportion black			-36.375 (0.60)
Proportion hispanic			-24.077 (0.68)
Proportion foreign born			248.562 (3.34)**
Working age population			-341.038 (1.94)
Proportion 65+			-204.463 (1.49)
Constant	-99.411 (2.42)*	-110.217 (2.71)**	196.571 (1.43)
Observations	48	48	48

R-squared	0.39	0.52	0.78
Robust t statistics in parentheses			
* significant at 5%; ** significant at 1%			

The regressions show a statistically significant effect of state gasoline prices on state metrics of sprawl. This regional, cross sectional effect of gasoline prices on sprawl provides additional support for my thesis.

The model variant with full controls can be interpreted to mean that a $.10 difference in gasoline prices between two states in the year 2000, holding all other variables constant, equates to a 4% difference in the percentage of tracts that are sprawling or urban. Other variables that the model indicates have a statistically significant impact on regional sprawl are proportion foreign born and proportion 65+, with the latter reducing sprawl and the former encouraging it.

The cross state, cross regional effect at one point in time is especially significant because it suggests that states with low gasoline prices such as Georgia, Texas and New Jersey are likely to have more sprawl while states with high gasoline prices such as Oregon, Massachusetts and Minnesota are likely to have less. It also suggests that states have the ability to influence sprawl through changes in state gasoline taxes as discussed further in Chapter 8.

Demonstrating Causality

While the evidence presented so far demonstrates consistent, significant correlation between gasoline prices and sprawl, to prove causality in the absence of a controlled experiment, I employ several additional techniques beginning with instrumental variables.

As discussed in greater depth in Chapter 4 and Appendix F, instrumental variables provide a method to isolate and remove correlation between the explanatory variable and the error term due to reverse causality. By substituting an appropriate instrumental variable that is entirely free of influence from the dependent variable, in this case sprawl but that is correlated with the explanatory variable, gasoline prices, it is possible to remove any reverse causality from the model and thereby increase confidence that a relationship is causal. As discussed in Chapter 4 and Appendix F, I choose state excise taxes on gasoline as my instrument. The latter are set for political reasons to raise revenues and are clearly not caused by or responsive to sprawl. Regressing gasoline prices on state excise taxes reveals strong, statistically significant correlation as shown in Table 5-16:

Table 5-16	
Cross State TSLS IV Regression of Gasoline Prices on Excise Taxes – First Stage (2000)	
Dependent Variable: State Retail Gasoline Prices Including Taxes	
State excise taxes	1.173371 (7.01)**
Constant	118.5744 (34.10)**
Number of observations	48

R-squared	0.4486
F-statistic	49.11
Robust t statistics in parentheses. Excludes Alaska, District of Columbia and Hawaii	
* significant at 5%; ** significant at 1%	

The F-statistic of 49.11 is well above the threshold of 10 commonly used to separate strong from weak instruments, establishing the validity of state excise taxes as an instrument for gasoline prices.

As shown by Tables 5-17, 5-18 and 5-19, performing TSLS regression using instrumental variables of the ratio of urban intensity to sprawl intensity as well as sprawl and urban intensity, separately, on gasoline prices, instrumented as excise taxes, and controls, reveals a statistically significant effect at the 5% level. Accordingly, using instrumental variable to eliminate the possibility of reverse causality strongly suggests that the relationship observed between sprawl and urban intensity at the state level is causal.

Table 5-17			
Cross State TSLS IV Regression of Urban to Sprawl Ratio on Gasoline Prices and Control Variables Using IVREG Command – 2000			
Dependent variable: Ratio of Proportion Tracts Urban to Proportion Tracts Sprawling * 10			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
State Retail Gasoline Prices	0.256 (2.17)*	0.307 (2.41)*	0.233 (2.73)**
State Population (10,000,000)	5.974 (6.99)**	4.424 (4.27)**	0.606 (0.65)
Average household income (000)		0.146 (1.91)	0.607 (1.53)

Proportion white		-11.681 (1.62)	-17.724 (0.94)
Average household income (000)			-0.673 (1.86)
Proportion black			-16.428 (0.88)
Proportion Hispanic			-18.612 (1.60)
Proportion foreign born			87.205 (4.52)**
Proportion working age			-50.496 (1.09)
Proportion 65+			-48.731 (1.24)
Constant	-34.025	-38.999	29.409
	(2.04)*	(2.70)**	(0.75)
Observations	48	48	48
R-squared	0.48	0.56	0.86
Robust t statistics in parentheses. Excludes Alaska, District of Columbia, Hawaii			
* significant at 5%; ** significant at 1%			

Table 5-18			
Cross State TSLS IV Regression of Urban Intensity on Gasoline Prices and Control Variables Using IVREG Command-2000			
Dependent variable: Percentage tracts with urban density			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
State Retail Gasoline Prices	0.977 (2.24)*	1.109 (2.53)*	0.884 (2.48)*
State population (10,000,000)	17.765 (7.14)**	11.674 (4.05)**	0.009 (0.00)
Average household income (000)		0.743 (2.48)*	0.883 (0.58)
Proportion white		-34.003 (1.24)	-6.391 (0.08)
Average family income (000)			-0.733 (0.55)
Proportion black			-3.085 (0.04)
Proportion hispanic			-14.312 (0.34)

Proportion foreign born			247.739 (3.41)**
Proportion working age			-353.460 (1.91)
Proportion 65+			-220.581 (1.55)
Constant	-118.288 (1.91)	-146.921 (2.81)**	137.119 (0.83)
Observations	48	48	48
R-squared	0.39	0.51	0.76
Robust t statistics in parentheses. Excludes Alaska, District of Columbia, Hawaii			
* significant at 5%; ** significant at 1%			

Table 5-19			
Cross State TSLS IV Regression of Sprawl Intensity on Gasoline Prices and Control Variables Using IVREG Command(2000)			
Dependent variable: Percentage tracts with sprawling density 2000			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
State Retail Gasoline Prices (10,000,000)	-0.967 (2.23)*	-1.096 (2.51)*	-0.873 (2.45)*
State population	-17.682 (7.18)**	-11.641 (4.06)**	0.024 (0.01)
Average household income (000)		-0.743 (2.48)*	-0.869 (0.58)
Proportion white		33.346 (1.22)	5.275 (0.07)
Average family income (0000			0.726 (0.55)
Proportion black			2.648 (0.03)
Proportion hispanic			14.347 (0.34)
Proportion foreign born			-248.679 (3.44)**
Proportion working age			347.772 (1.89)
Proportion 65+			221.216 (1.56)
Constant	216.766	245.444	-34.753

	(3.51)**	(4.72)**	(0.21)
Observations	48	48	48
R-squared	0.39	0.51	0.77
Robust t statistics in parentheses. Excludes Alaska, District of Columbia, Hawaii			
* significant at 5%; ** significant at 1%			

Other evidence for causality as discussed further in Appendix F emerges from the observation that sprawl is correlated with *lagged* prices. The one way direction of time supports the view that prices influence sprawl rather than the other way around. While not demonstrating causality per se, fixed effects techniques, by accounting for between metropolitan area differences increase confidence that estimators are consistent. A more detailed discussion of causality that, in sum, makes a powerful case for a causal effect of gasoline prices on sprawl is provided in Appendix F.

The Impact of Gasoline Prices on Sprawl Measured as Employment Dispersion

The second model that I employ explains sprawl—defined as employment dispersion—as a function of gasoline prices and other variables. My choice of employment dispersion as an indicator of sprawl is motivated by the literature on sprawl that finds job dispersion to be a central element of post industrial urbanization (Glaeser and Kahn 2001, 2004, Garreau, 1991, Wheaton, 2004). As with the population density-derived metrics of sprawl previously explored, I construct metrics that describe the distribution of jobs in space and regress them on gasoline prices and controls. However, I use different controls and refine my choice of metrics to reflect fundamental differences in population and employment density.

Employment Density in Models of the City

As previously discussed, the literature suggests a strong correlation between job dispersion and population dispersion in the post industrial city (.79 according to Glaeser and Kahn, 2001). Both population and employment density distributions across space provide a measure of land consumed in the course of growth. However, while superficially similar, firm location choice differs from residential location choice in fundamental ways.

First, while people and jobs have dispersed from cities in recent years, they have done so from diametrically opposed starting points and for different reasons that make their patterns of change distinct. In the classic AMM model of the city, people disperse outwards but businesses remain concentrated at the center. This mono-centric model of the city that has its roots in studies of pre-industrial market towns by von Thunen aptly described American cities through the 1950s (Glaeser and Kahn, 2001). The modern empirical finding that both people and jobs are dispersing, while not at odds with the classic model's prediction for population density, is at odds with the location choice predicted for firms. (See Muth, 1969, however, for a variant of the AMM model that does allow for employment dispersion.) In post-industrial cities, population has continued to disperse but employment density has dispersed so rapidly that it has almost caught up with population dispersion. For this reason, the classic AMM model clearly no longer accurately describes employment location (Glaeser and Kahn, 2001).

As previously discussed, Henderson and Mitra (1996) extend the AMM model to include suburban sub-centers. In their model, employment remains concentrated but distributed across multiple centers that develop outside the center. Garreau (1992) qualitatively documents peripheral business districts analogous to old ones that he calls "Edge Cities" developing at the intersection of major roads (such as Route 7, Route 66 and Route 495 at Virginia's Tyson's Corner.). These new edge cities minimize road transportation costs in a manner analogous to how rail- or port—centered cities once minimized rail or ship transport costs. In turn, Lucas (2001), Lucas and Rossi-Hansberg (2002) enrich the model of the city with externality and transportation cost parameters that allow for multiple equilibria of business and residential dominance ranging from the classic, monocentric Mills city to a diffuse city with homes adjacent to businesses. In their model, an empirical finding of job dispersion suggests a lower externalities parameter. Rossi-Hansberg (2004) derives a model where firms and people allocate land based on a proximity externality for firms and commuting cost. Notably, higher commuting cost encourages firm outward movement toward cheaper land and workers. Glaeser and Kahn (2001) derive an employment gradient that exhibits an exponential decline moving away from the center, analogous to that observed for population density, from a Cobb Douglas production function Observing the simultaneous finding of higher rents at the center *and* employment dispersion at the periphery Rossi-Hansberg et al (2009) develop a model by which some corporate functions concentrate in the center to take advantage of knowledge externalities while others--where spillovers are less important--move to the periphery to lower costs. Their model also explains the empirical finding of declining establishment size. My model of the city in Appendix A allows for dispersion of lower paying jobs. Clearly, changes in transportation—such as the shift from rail to road, communications (Ioannides et al, 2005) and

firm structure have reshaped patterns of firm location in ways not contemplated in the original AMM model.

The second fundamental way that employment dispersion differs from population dispersion is that firms, not people, make the location decisions. Whereas people choose location as a function of preferences over a bundle of goods and services (private and public, pecuniary and social) relative to commuting cost (subject to constraints such as racial barriers), economic theory suggests that firms choose location to maximize profits across a vector of inputs and outputs that include among the former labor adjusted for productivity, land and commodities or parts and among the latter, finished, delivered goods (subject to constraints such as zoning). Gasoline prices and other exogenous variables, as previously discussed, can influence the prices and quantities of this vector of inputs and outputs in multiple ways. The literature suggests that population dispersion itself, firm sector and the occupational level of jobs can all play a role in the firm's job location decisions. Following the literature, I therefore include firm sector data as controls.

The third and critical way that employment differs from population dispersion is with respect to the mediating role of sub-centers or edge cities in urban growth. Agglomerative forces explain job concentration in most models of the city, originally in the CBD. However, the proliferation of the automobile has made possible sub-centers—still governed by agglomerative forces—but now located at diverse points around the city that often correspond with automobile hubs where roads intersect. These sub-centers may also mediate the influence of external shocks on

job dispersion. Whereas in the classic Mills city, jobs only concentrate in the central business district (as the cost of transporting goods exceeds that of people) and can only accumulate there or disappear from there in response to exogenous forces, in the polycentric city, the CBD has been replaced by multiple job nodes that can react to shocks. Sub-centers concentrate jobs to a greater degree than dwellings because jobs require less space and because firms benefit from spillovers to a greater degree than people choosing living arrangements. Accordingly, sub-centers play a greater role in shaping the distribution of jobs than in shaping the distribution of dwellings. As discussed, therefore, in studying the effect of gasoline prices on sprawl, I restrict my choice of job-density derived metrics of sprawl to metrics that are robust to the complicating role of sub-centers.

A Zipf Measure of Job Dispersion

My first measure of sprawl, following Zipf, exploits the information contained in the relationship between size and rank of variables to analyze employment density. Specifically, to obtain a standard gradient measure, as with the rank gradient constructed for population density above, I regress the log of employment density on rank of zipcode to obtain a measure of density decay by rank. Zipf, as previously discussed modeled the rank-size relationship as a Pareto one of the form

$$\mathbf{SIZE} = \alpha \mathbf{RANK}^{-b}.$$

where b=1.

However, to make this relationship analogous to the classic density-distance gradient used in urban studies (Clark, 1951) and having established in the context of intra-urban population density that an exponential distribution fits the rank-size data, I hypothesize that the distribution is exponential and confirm that hypothesis, through empirical testing.

I begin with an exponential equation of the form:

$$\textbf{EMPLOYMENT DENSITY} = \alpha\, e^{-\beta\, \textbf{RANK}}$$

To convert the equation into a linear one better suited to linear regression analysis, it is advantageous to log both sides, yielding the formula:

$$\textbf{LN(POPULATION DENSITY)} = \textbf{LN}(\alpha) - \beta\textbf{RANK}$$

Expressed this way, the coefficient $\boldsymbol{\beta}$ is equal to the rate of change of logged density with respect to rank and measures the compactness or dispersion of job density in the city, with a more negative or *steeper* slope or coefficient denoting a more rapid decline in density relative to rank *i.e.* greater compactness and a less negative (or more positive), *shallower* slope denoting a more gradual decline in density relative to rank, i.e. greater dispersion or sprawl.

To test whether the rank-size distribution for employment density follows an exponential distribution within a reasonable degree of confidence, after examining the distributions graphically, I regress the log of density on rank for each urban area. I find that for all 360 CBSAs in the dataset, the graph of employment density by zipcode relative to rank appears linear in form and the coefficient $\boldsymbol{\beta}$ is statistically significant at the 99% level. Specifically, T-statistics range from -204.0889 to -3.515827 and have a mean of -49.35982. (Performing a similar regression for the coefficient, $\boldsymbol{b}$ of the regression of logged density on *logged* rank assuming a Pareto distribution, I find that the coefficient is also significant in all cases with the t-statistic ranging from -73.11365 to -2.196903 and the mean equal to -25.04676. This confirms that the concave distribution can be modeled as either an exponential or Pareto distribution although the exponential distribution provides the marginally better fit.)

I call this coefficient, $\boldsymbol{\beta z}$—representing the rate of employment density decay with respect to rank—the Zipf measure of job density-defined sprawl. In my second stage regression, to assess the effect of gasoline prices on sprawl, I regress $\boldsymbol{B_z}$, on gasoline prices and controls.

The Zipf measure of employment dispersion is robust to the hypothetical choice of a city center as it is concerned only with rank of geographic units, in this case, zip codes, as opposed to their real world locations. It also has the advantage that it is robust to whether high density job zip codes are located in a central business district or in "Edge Cities" or sub-centers. In either case, the gradient of job density by rank provides an indicator of the benefits of proximity to other firms—or power of agglomeration--relative to the cost of congestion. A steep gradient, indicative of urbanization suggests that the benefits of density significantly outweigh the costs. A shallower gradient, indicative of sprawl, suggests that, relatively speaking, the cost benefit ratio favors dispersion or sprawl Changes in the gradient over time are indicative of the changing benefits of high density relative to costs. Most importantly, a shallow gradient indicates more consumption of land. I therefore interpret the gradient as an index of sprawl.

Figure 5-13 shows the relation between zip code job density and rank over time for the New York CBSA. It is evidently of an exponential form with some zip codes having very high densities and others very low ones as they asymptotically approach the axes.

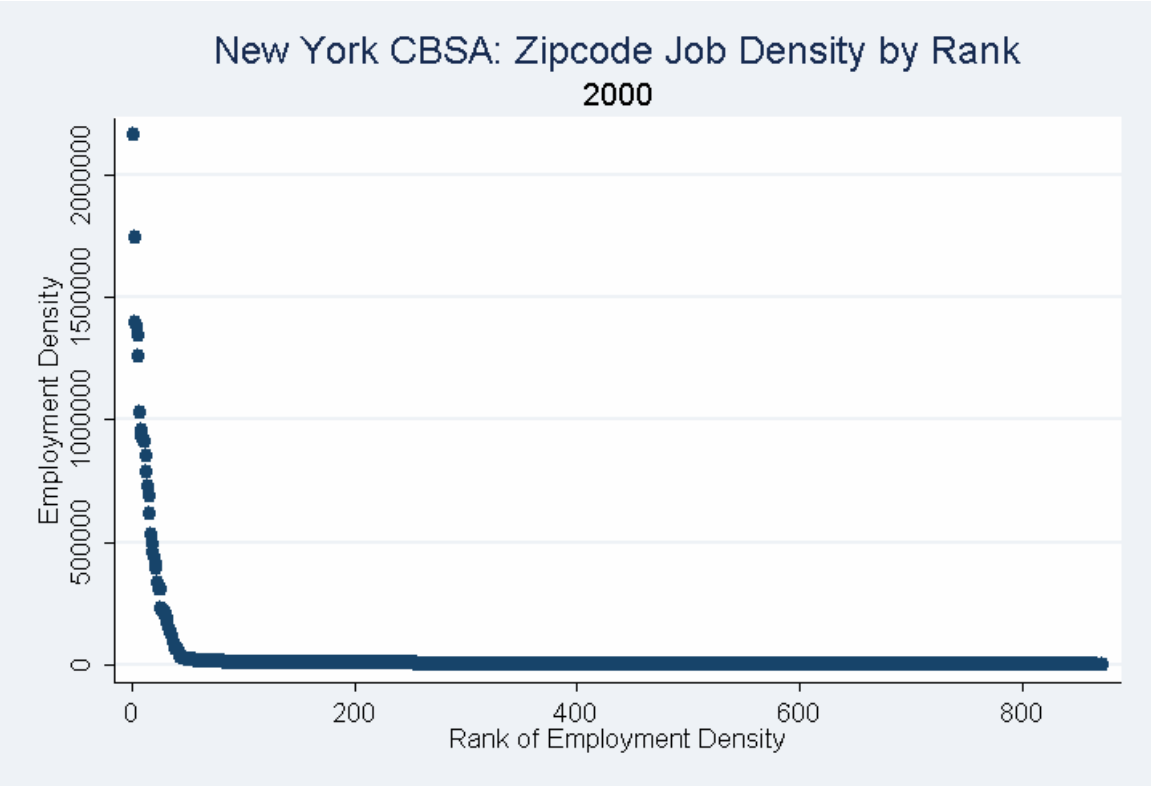


Figure 5-13

Logging density as in Figure 5-14 converts the exponential curve into one of a more linear form. It is evident that, as with population, a fitted line relating the log of job density to rank provides a reasonably good fit except at the extremes.

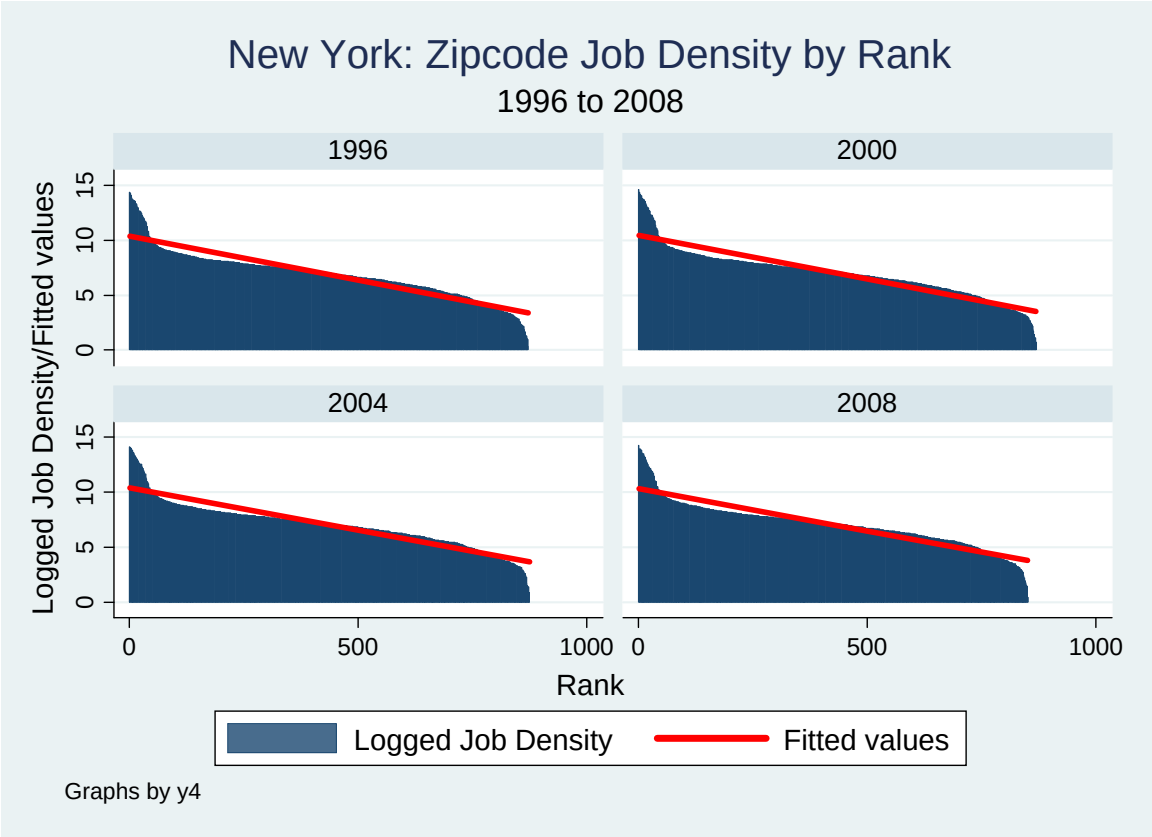


Figure 5-14

It is also evident that the gradient has flattened slightly over the period in question. Indeed, the slopes of the gradient for the four years are in order, -.0080625 (1996), -.0079614 (2000) -.0077113 (2004) and -.0077182.

Figure 5-15 similarly shows the relationship between log of density and rank for the Dallas Fort Worth CBSA over time.

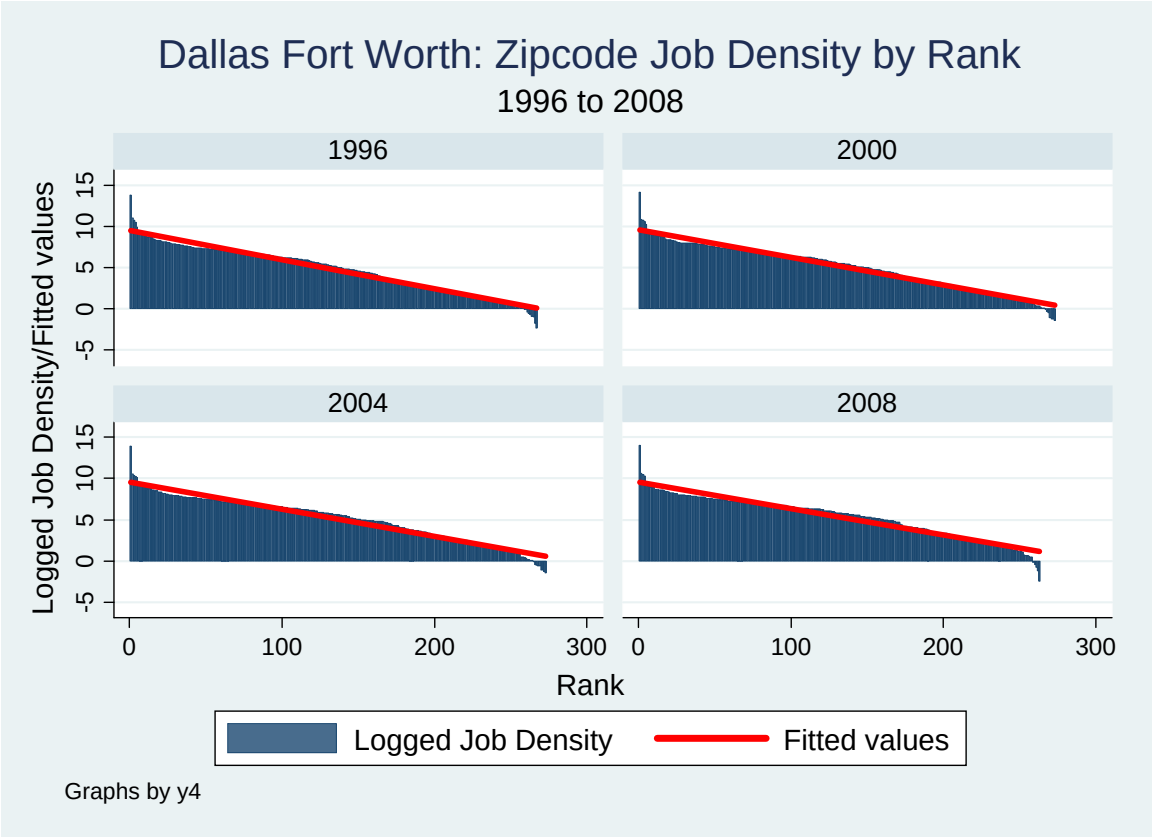


Figure 5-15

In the case of the Dallas Fort Worth CBSA, a line fitted to the data provides a very good fit, supporting the hypothesis that the original distribution is of exponential form. (The coefficients are all statistically significant at the 99% level). It also appears that the gradients are flattening subtly over time. In fact, the slopes of the above lines are: -.0353436 (1996), -.0337036 (2000), -.033076 (2004), -0319019 (2008).

To provide a sense of the variation in these curves by city, Figure 5-16 depicts the decay in log of density by rank for eight urban areas, Allentown-Bethlehem-Easton, Boston, Chicago, Houston,

Dallas Fort Worth Los Angeles, New York and San Francisco, Washington, DC and all other cities. It is clear that an important factor in the slope of decay is number of zipcodes. This is why the huge New York CBSA has a shallower slope than Allentown-Bethlehem-Easton. This suggests that for all its strengths for within group comparisons, the rank gradient is *not* likely to be an ideal indicator for cross city comparisons as it is sensitive to number of zipcodes. This difference being largely fixed drops out of fixed effects regressions but can complicate between group comparisons.

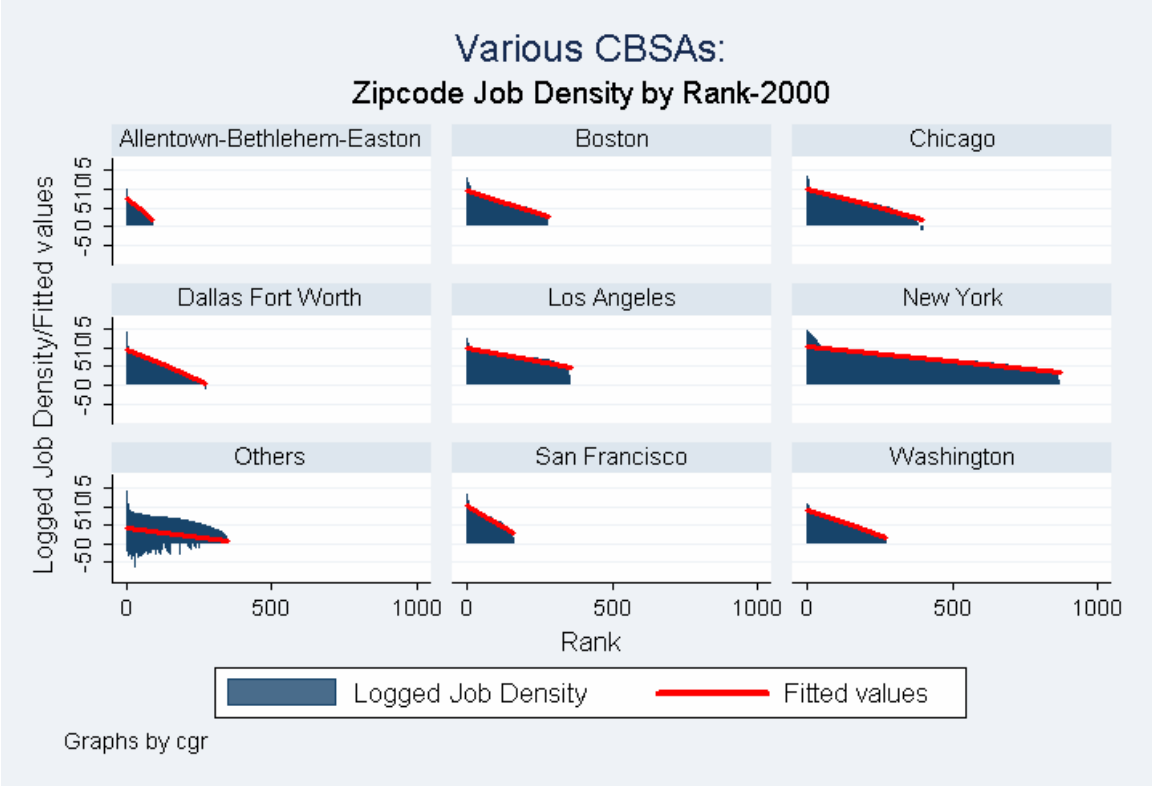


Figure 5-16

Table 5-20 summarizes a variety of regressions performed using Ordinary Least Squares Regression with Fixed Effects of the Zipf measure of job-density defined sprawl on two year lagged local gasoline prices for the period 1998 to 2008. The results with and without controls motivated by the literature and my model (Appendix A) show a statistically significant impact of gasoline prices on sprawl measured as the gradient of job density relative to rank with higher gasoline prices lowering or steepening the negatively sloped gradient and lower gasoline prices raising or flattening it.

Table 5-20					
Fixed Effects Regression of Rank Density Gradient of Jobs by Zip code on Local Gasoline Prices and Controls 1999 to 2008					
Dependent Variable: Urban Job Density-Rank Gradient (Coefficient, B_Z, of Regression of Log of Zip Code Job Density on Rank)*100					
	(1)	(2)	(3)	(4)	(5)
	Gas Prices	With Sector Controls	With Sector and Household Controls	With Sector by Establishment controls	With Extended Controls
Two-year lagged local gasoline prices (2005 US$)	-1.090 (5.85)**	-0.875 (2.89)**	-1.986 (2.23)*	-1.336 (5.22)**	-1.986 (2.17)*
One-year lagged job density-rank gradient *100		0.250 (7.80)**	0.232 (7.15)**	0.251 (10.49)**	0.234 (7.17)**
Total city jobs (000)		6.531 (1.95)	0.117 (0.03)	5.799 (2.16)*	0.341 (0.07)
One-year lagged population density-rank gradient * 100		9.610 (0.75)	1.913 (0.15)	73.635 (6.25)**	3.730 (0.27)
Percent manufacturing		8.179 (1.05)	7.175 (0.91)		12.480 (1.37)
Percent finance, insurance, real estate		14.148 (0.73)	14.984 (0.77)		18.668 (0.91)
Percent management		-23.029 (1.24)	-25.635 (1.36)		-22.672 (1.17)

Percent information technology		23.060 (1.05)	16.176 (0.73)		1.961 (0.08)
Percent retail		-2.886 (0.18)	-9.880 (0.60)		-6.154 (0.34)
Percent health		6.243 (0.73)	6.889 (0.80)		10.810 (0.96)
Gas prices *2000 population (millions)			0.646 (1.63)		0.725 (1.81)
Gas prices *2000 income (millions)			69.050 (1.36)		50.203 (0.95)
Gas prices *2000 proportion white			4.180 (1.24)		4.339 (1.28)
Gas prices *2000 proportion black			7.254 (1.69)		7.082 (1.64)
Gas prices *2000 proportion hispanic			5.567 (2.06)*		5.304 (1.91)
Gas prices *2000 proportion working age			-8.997 (1.47)		-8.321 (1.35)
Gas prices *2000 proportion < 18			-9.870 (0.86)		-8.252 (0.70)
Gas prices *2000 population density gradient			-3.344 (1.71)		-3.677 (1.85)
Percent establishments manufacturing				-70.789 (2.39)*	-30.602 (0.64)
Percent establishments finance, insurance, real estate				-20.998 (0.77)	-43.413 (1.11)
Percent establishments management				-4.884 (0.10)	-55.559 (0.66)
Percent establishments information technology				101.688 (1.80)	170.648 (2.08)*
Percent establishments professional				-20.258 (1.12)	-5.227 (0.20)
Percent establishments				-8.398 (0.51)	-14.765 (0.59)

retail					
Percent establishments health				2.209 (0.18)	-4.168 (0.16)
Constant	-26.792 (84.21)**	-23.950 (5.05)**	-23.499 (4.76)**	-0.715 (0.12)	-19.958 (2.29)*
Observations	2240	1076	1076	1955	1076
Number of CBSAs	286	252	252	280	252
R-squared	0.02	0.09	0.11	0.11	0.12
Absolute value of t statistics in parentheses					
* significant at 5%; ** significant at 1%					

A Clark Mills Measure of Job Dispersion

My second metric of employment density-derived sprawl measures the decay in employment density relative to distance from a city center. As discussed, there is a long tradition dating from the work of Clark (1951) and Mills (1972) of analyzing the gradient of population decay with respect to distance from the city center. Assuming a Cobb Douglas production function, it is possible to derive a similar exponential relation between job density and distance from the center (Mills, 1972, Glaeser and Kahn, 2001). Glaeser and Kahn (2001), testing the relationship empirically, find this gradient to obtain with respect to *job* as well as population density. As discussed in the context of population density, it is not clear that the *distance* gradient metric based on distance from the CBD, well suited as it might be to studying the mono-centric structure that typified pre-industrial and industrial towns, is equally well suited to polycentric, post industrial cities as the "city center" has become harder to define. However, by using the geographic center of the city as opposed to a single central business district, it is possible to

analyze density relative to distance from an objective, *geographic* center. This method is analogous to the methodology used above for my first, Zipf measure of sprawl, except that distance is substituted for rank. I further refine this technique by weighting the geographic center by density of employment.

To calculate distance, I first calculate the geographic mean of the city by taking the mean of the latitudes and longitudes of the centroids of the census tracts. In turn, as previously discussed in the chapter on methods, in light of polycentrism and the large size of some CBSAs as defined by the Bureau of the Census, I find it advantageous to weight the centroids by employment density to obtain job-weighted geographic centers that lie closer to traditional downtowns. I then calculate the distance of each zipcode centroid in miles from the central city point using standard triangulation methodology to obtain a distance from the centroid of the zipcode to the job weighted center of the city in miles. I judge this quantitative approach to measuring distances less subjective than the method used by Glaeser and Kahn (2003) of relying on the spot named by local leaders in the 1982 Special Census Survey to determine a center. My reasons for choosing this methodology over that of Glaeser and Kahn are that the 1982 survey is now 30 years old, polycentric cities do not have a clear center in the conventional sense but only a geographic center and using a formal rule as opposed to subjective estimates avoids subjectivity. I use the latitude and longitude information for each zipcode maintained by the Census Bureau for mapping purposes and published for the year 1999 in their Gazeteer file. While these coordinates may not be exact, particularly given the limitations of zipcode level data as previously discussed, the weighted center derived this way is an objective measures that conforms to intuition about city centers.

Theory and the literature as previously discussed suggest that the employment density gradient follows an exponential distribution of the form:

$$\text{EMPLOYMENT DENSITY} = \alpha e^{-\beta \text{ DISTANCE FROM CENTER}}$$

Where α and β are parameters describing the intercept and rate of decay.

Figure 5.17 shows the relationship for the New York CBSA. It exhibits the expected exponential relationship with values concentrated near the axes.

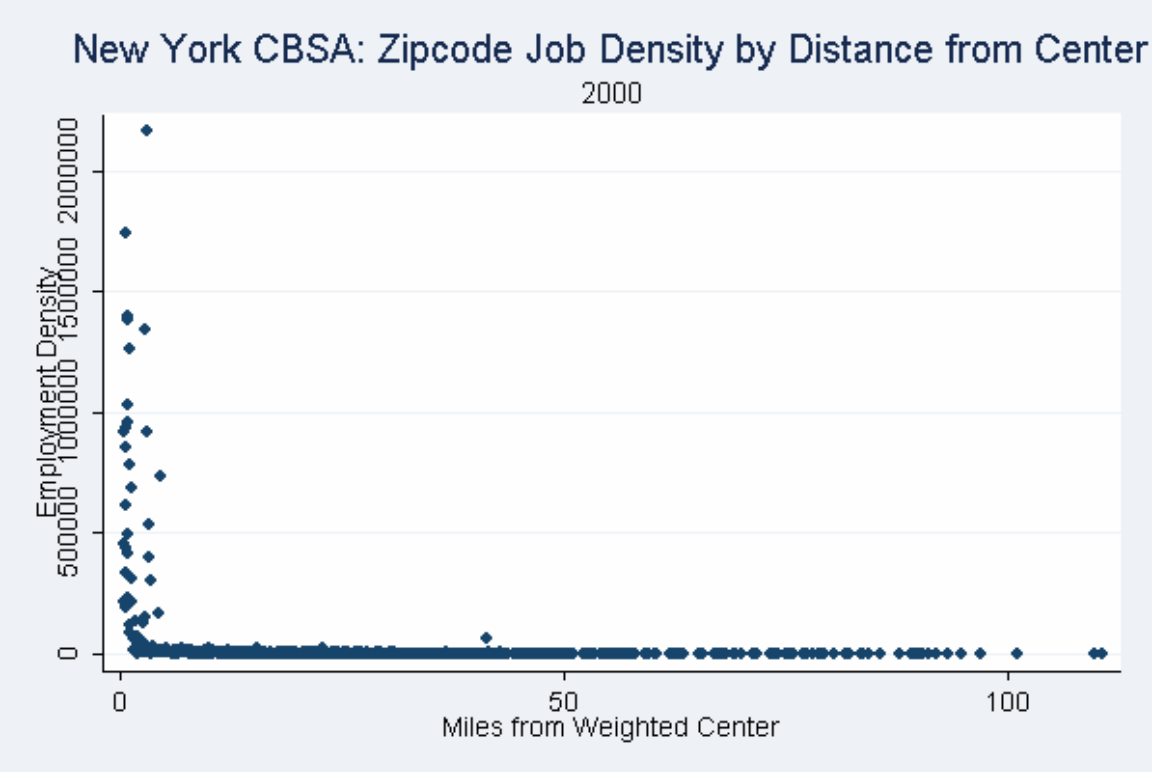


Figure 5-17

To convert the curve into a linear relation amenable to linear regression analysis, I take the log of each side, yielding the equation:

LN(EMPLOYMENT DENSITY) = LNα – β(DISTANCE FROM CENTER)

where **LNα** is the intercept and the coefficient **β** describes the slope or gradient of logged employment density relative to distance to the job weighted city center. Figure 5-18 illustrates the decay in logged density as one moves away from the geographic, job weighted center of the New York PMSA and shows that in the case of New York, the relation is relatively linear.

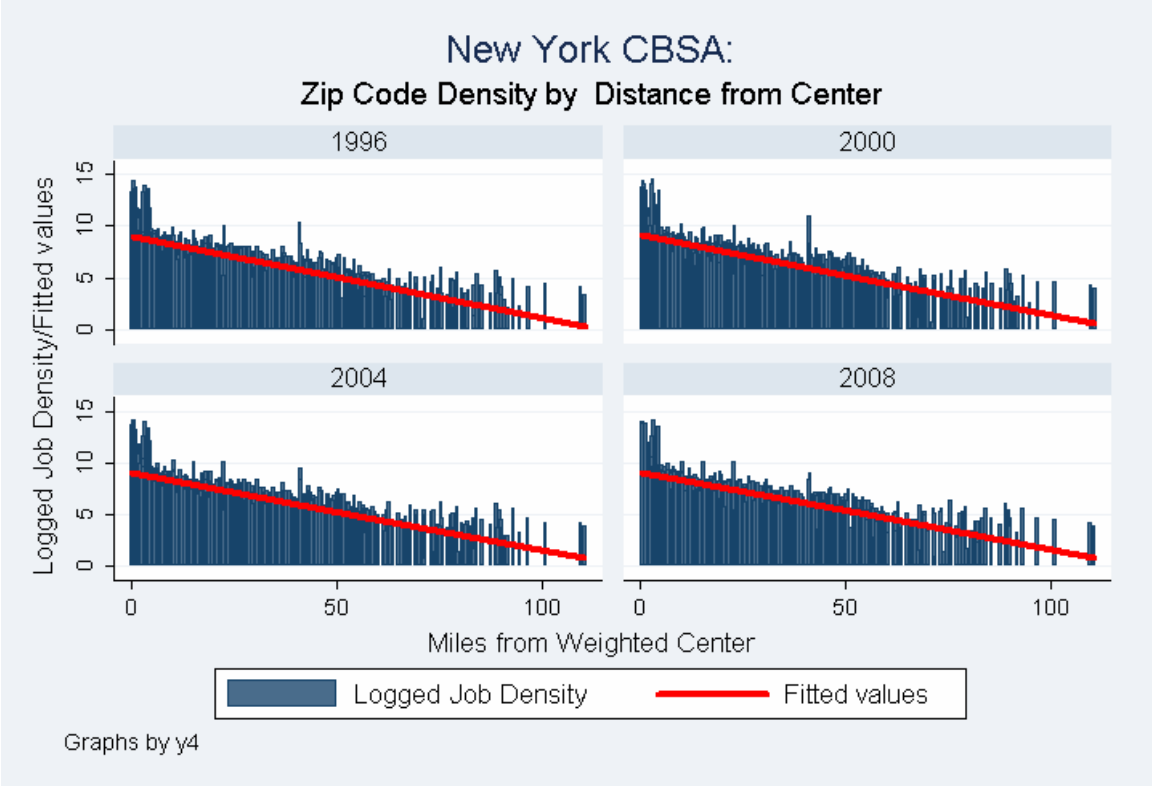


Figure 5-18

I designate the Clark Mills coefficient ***βc*** my second employment density-derived metric of sprawl. I regress it, as well, on gasoline prices and controls.

As with the Zipf metric above, it is interesting to compare graphs of log of tract density relative to distance from the center for a given urban area over time. In the case of New York, the gradients flatten slightly. The slopes of the above lines are: -.0795507 (1996), -.0774935 (2000), -.0750323 (2004), -.0741909 (2008).

Different cities also vary in their distribution. Figure 5-19 shows the distribution of logged employment density relative to distance for a variety of cities.

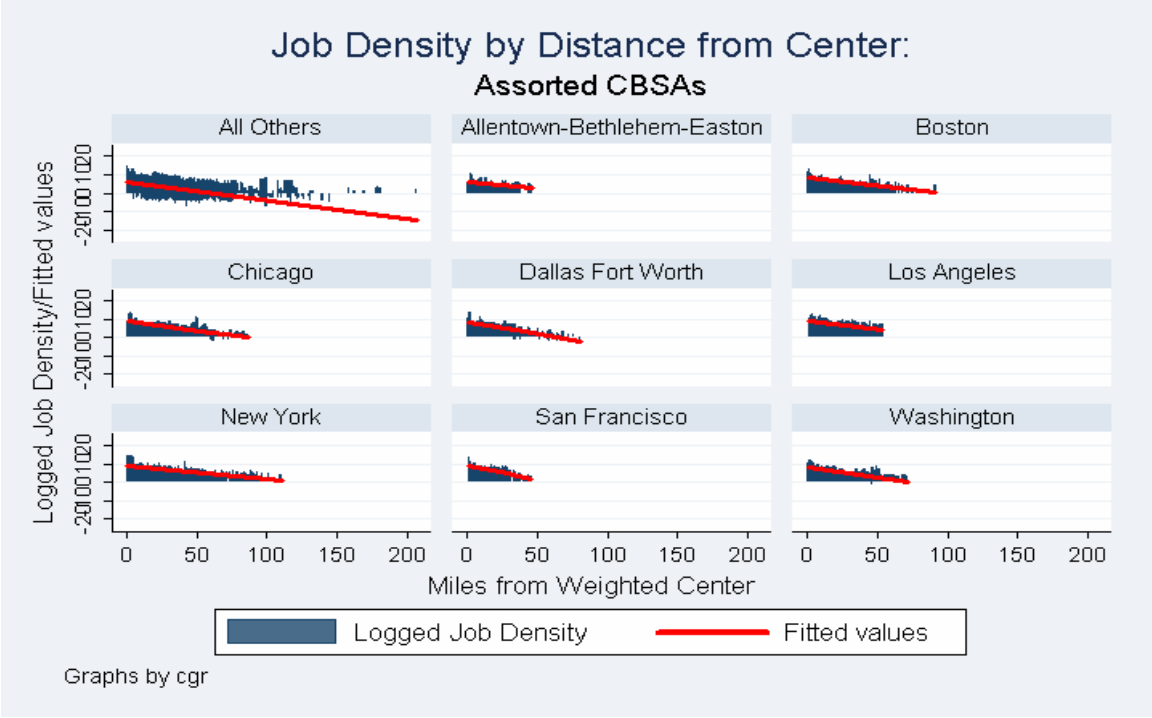


Figure 5-19

All of the cities show decay in density from the weighted center but most also reveal the presence of spikes away from the weighted center, reflecting the presence of sub-centers. Taken as a whole, the spikes are not sufficiently large as to diminish the statistically significant linear relationship between logged job density and distance from the weighted center in the vast majority of cases. The t-statistics for the coefficient, β_c range from -33.47168 to 1.001418 and have a mean of -5.772455 . Of the 360 urban areas, all but 52 have a statistically significant coefficient at the 95% confidence level. This reveals a poorer fit than the Zipf coefficients above but nonetheless, a high level of statistical significance. (Conditioning the second stage regressions on the coefficient being statistically significant does not materially change results.) The graphs also reveal artifacts of the CBSA definitions such as the large size of the Boston CBSA—actually a NECMSA, the presence of a large spike 50 miles from the Chicago city center, corresponding to Gary, Indiana-- and the truncation of the Los Angeles CBSA at the 53.7 mile limit. As with the Zipf measure above, the differences in urban areas including their size and particularities of the CBSA definitions are largely fixed. They constitute unobserved variables that drop out of the fixed effects regressions. However, their presence complicates their use in cross sectional analysis.

Table 5-21 summarizes a variety of regressions performed using Ordinary Least Squares Regression with Fixed Effects of the Clark Mills job density derived measure of sprawl on two year lagged local gasoline prices for the period 1998 to 2008. The results with and without controls motivated by the literature show a statistically significant effect of gasoline prices on sprawl measured as the gradient of jobs density relative to distance from the city center with

higher gasoline prices lowering or steepening the negatively sloped gradient and lower gasoline prices raising or flattening it.

Table 5-21					
Fixed Effects Regression of Distance Density Gradient of Jobs by Zip code on Gasoline Prices and Controls 1998 to 2008					
Dependent Variable: Job Density-Distance Gradient (Coefficient, B_C, of Regression of Log of Zip code Job Density on Distance from Weighted Center*100					
	(1)	(2)	(3)	(4)	(5)
	Gas Prices	With Sector Controls	With Sector and Household Controls	With Sector by Establishment Controls	With Extended Controls
Two-year lagged local gasoline prices (2005 US$)	-0.276 (4.20)**	-0.315 (2.80)**	-0.764 (2.30)*	-0.127 (1.41)	-0.781 (2.29)*
One year lagged job density-distance gradient*100		0.271 (7.77)**	0.262 (7.48)**	0.328 (13.90)**	0.257 (7.29)**
Total city jobs (000)		0.229 (0.19)	-3.377 (2.00)*	0.159 (0.17)	-3.591 (2.05)*
One-year lagged population density rank gradient * 100		3.417 (0.73)	2.681 (0.56)	8.810 (2.11)*	0.580 (0.11)
Percent manufacturing		-3.917 (1.36)	-4.495 (1.54)		-5.182 (1.53)
Percent finance, insurance, real estate		-4.813 (0.67)	-3.726 (0.51)		-1.702 (0.22)
Percent management		-5.752 (0.84)	-8.004 (1.15)		-6.296 (0.87)
Percent information technology		-3.100 (0.38)	-4.605 (0.56)		-8.956 (0.98)
Percent retail		3.751 (0.63)	2.033 (0.33)		5.637 (0.84)
Percent health		-0.895 (0.28)	-0.980 (0.31)		1.244 (0.30)
Gas prices*2000			0.364		0.365

population (millions)			(2.46)*		(2.45)*
Gas prices*2000 income (millions)			-2.832 (0.15)		-0.060 (0.00)
Gas prices*2000 proportion white			-1.289 (1.03)		-1.288 (1.03)
Gas prices*2000 proportion black			-0.281 (0.18)		-0.230 (0.14)
Gas prices*2000 proportion Hispanic			1.050 (1.05)		1.210 (1.18)
Gas prices*2000 proportion working age			2.947 (1.30)		2.661 (1.16)
Gas prices*2000 proportion < 18			-1.711 (0.40)		-1.711 (0.39)
Gas prices*2000 population (millions) density gradient			0.008 (0.01)		-0.055 (0.07)
Percent establishments manufacturing				2.861 (0.27)	23.737 (1.35)
Percent establishments finance, insurance, real estate				-1.196 (0.12)	3.127 (0.22)
Percent establishments management				-12.954 (0.72)	-20.187 (0.65)
Percent establishments information technology				9.258 (0.46)	56.049 (1.84)
Percent establishments professional				5.185 (0.81)	-0.436 (0.04)
Percent establishments retail				6.553 (1.11)	-9.069 (0.97)
Percent establishments health				-1.425 (0.32)	-5.767 (0.61)
Constant	-13.191 (117.60)**	-8.652 (4.75)**	-7.719 (4.08)**	-8.962 (4.22)**	-8.923 (2.75)**
Observations	2240	1076	1076	1955	1076

Number of CBSAs	286	252	252	280	252
R-squared	0.01	0.08	0.10	0.11	0.11
Absolute value of t statistics in parentheses					
* significant at 5%; ** significant at 1%					

Discussion

Gasoline Prices and Sprawl

Tables 5-20 and 5-21 show the results of Ordinary Least Squares Regression using fixed effects of two indicators of job-density defined sprawl on gasoline prices and controls over the period in question. Both sets of regressions demonstrate a consistent, statistically significant impact of energy prices on sprawl with higher prices steepening the gradient and lower prices flattening it.

While the finding of a significant effect when including a large number of controls provides robust evidence of a causal effect of gasoline prices on sprawl, goodness of fit is not as high with this model as with the population density model tested earlier. One potential reason for the lower goodness of fit may be the limits of the dataset that, as previously discussed, required assembly from multiple sources. As discussed, the Zip Code designations are not designed as statistical units and have the numerous shortcomings previously described, however, zip codes are the only granular unit for which jobs data are available. In addition, censoring of data by the Bureau of the Census for confidentiality reasons, as discussed, may also have introduced error into the dataset. However, the fact that the relationship holds even when using uncensored

establishment density as the dependent variable suggests that censoring risk does not invalidate the findings.

The Zipf measure provides a goodness of fit (R squared) when including controls of .12 which exceeds that of the Clark Mills measure of .11 but the R squared for the two models are of a similar order of magnitude. Interestingly, while one-year lagged job density is a statistically significant predictor of job density one year later, it does not raise the goodness of fit of the model including the lagged auto-regressed variable beyond .12 in either the Zipf or Clark-Mills models.

Care must be taken in interpreting the results from the Zipf and Clark-Mills regressions in light of the role of sub-centers. The Zipf metric, in effect, counts rising density in sub-centers as concentration. At most if growth of the sub-center comes at expense of the CBD, it may register a very slight flattening. That is the intent of the metric as it provides a distance-robust metric of land intensity of employment. The Clark-Mills metric is, by contrast, ambiguous in its treatment of sub-centers. If the sub-centers lie well outside the center, rising relative density there will flatten the gradient. If rising density occurs in sub-centers near the core, it will steepen the gradient. More complex, granular analysis of *why* the gradients are changing in each city is prevented by the scale dependence of sub-centers and CBDs that have different densities in large and small metropolitan areas. The literature on using statistical techniques to identify sub-centers describes challenges that make identifying sub-centers in even *one* metropolitan area

difficult, let alone identifying them across metropolitan areas[6].) As a summary measure, the Clark-Mills metric tells us that, overall, job density gradients are elastic to gasoline prices over time but the role of sub-centers is ambiguous.

As illustrated by Tables 5-22 and 5-23, substituting national gas prices from the EIA for local ones from ACCRA COLI does not substantially change results. Gas prices, measured this way, continue to show a consistently significant influence on sprawl. This suggests that the regional or between-group differences in gasoline prices do not have a great deal of explanatory power relative to temporal or within-group changes for these indicators of sprawl.

Table 5-22					
Fixed Effects Regression of Rank Density Gradient of Jobs by Zip Code on National Gasoline Prices and Controls 1999 to 2008					
Dependent Variable: Job Density-Rank Gradient (Coefficient, B_Z, of Regression of Log of Zip Code Job Density on Distance from Weighted Center) * 100					
	(1)	(2)	(3)	(4)	(5)
	Gas Prices	With controls	With controls	With controls	With extended controls

[6] While there is not yet a commonly accepted definition of sub-center job density, approaching the phenomenon of sub-centers from a theoretical and empirical point of view, a variety of scholars have proposed methods to identity sub-centers statistically without recourse to subjective or ad-hoc identification (McMillen and Lester, 2003). These efforts have been complicated by the tendency of variables that might identify sub-centers such as employment density and distance from the CBD to vary both temporally and by urban area. Nonetheless, methods have been proposed by McDonald (1987), Guiliano and Small (1991), McMillen (2001) and Craig and Ng (2001) among others. Identification of sub-centers is highly sensitive to cutoff points that may very locally. While deserving praise for ingenuity, collectively, these efforts reveal the challenges of establishing a single density-based definition of sub-centers that can be applied even to one urban area over time, let alone to panel data as extensive as mine.

Two-year lagged *national* gas prices	-1.003 (6.31)**	-1.231 (6.04)**	-1.626 (2.29)*	-1.368 (7.68)**	-1.666 (2.23)*
One-year lagged distance gradient		0.319 (13.79)**	0.235 (7.26)**	0.314 (20.36)**	0.237 (7.27)**
Total city jobs (000)		7.378 (2.83)**	1.176 (0.26)	5.812 (2.69)**	1.083 (0.23)
One year lagged population gradient		22.698 (2.75)**	3.255 (0.25)	51.067 (6.46)**	5.692 (0.41)
Percent manufacturing		2.522 (0.53)	5.955 (0.75)		11.880 (1.30)
Percent finance, insurance, real estate		-14.813 (1.28)	13.669 (0.70)		17.331 (0.84)
Percent management		-16.902 (1.44)	-24.702 (1.32)		-21.164 (1.09)
Percent information technology		2.833 (0.19)	14.930 (0.67)		1.004 (0.04)
Percent retail		1.408 (0.15)	-9.327 (0.57)		-5.305 (0.29)
Percent health		9.080 (1.59)	6.295 (0.73)		10.401 (0.92)
Gas prices *2000 population (millions)			0.449 (1.31)		0.534 (1.53)
Gasprices* 2000 income (millions)			78.394 (1.57)		57.901 (1.11)
Gas prices*2000 proportion white			3.794 (1.13)		3.911 (1.16)
Gas prices * 2000 proportion black			6.675 (1.56)		6.428 (1.49)
Gas prices * 2000 proportion hispanic			5.706 (2.12)*		5.365 (1.93)
Gas prices * 2000 proportion working age			-9.626 (1.59)		-8.943 (1.46)
Gas prices * 2000 proportion <18			-9.862 (0.86)		-7.723 (0.66)

Gas prices * 2000 population density gradient			-2.842 -2.842		-3.098 0.000
Percentage establishments manufacturing			(1.54) (1.54)		(1.66) (.)
Percentage establishments finance, insurance, real estate				1.537 (0.09)	-34.567 (0.72)
Percentage establishments management				-16.440 (0.99)	-40.268 (1.03)
Percentage establishments information technology				-29.489 (0.75)	-67.959 (0.81)
Percentage establishments professional				35.027 (0.95)	160.971 (1.96)*
Percentage establishments retail				17.320 (1.66)	-4.154 (0.16)
Percentage establishments health				2.607 (0.23)	-17.742 (0.70)
Two-year lagged *national* gas prices				19.314 (2.29)*	-4.431 (0.17)
Constant	-28.383 (102.27)**	-17.193 (5.57)**	-22.953 (4.64)**	-12.723 (3.34)**	-18.669 (2.13)*
Observations	4059	2027	1076	3472	1076
Number of New CBSAs	360	348	252	360	252
R-squared	0.01	0.14	0.11	0.16	0.12
Absolute value of t statistics in parentheses					
* significant at 5%; ** significant at 1%					

Table 5-23
Fixed Effects Regression of Distance Density Gradient of Jobs by Zip Code on National Gasoline Prices and Controls 1998 to 2008
Dependent Variable: Job Density-Distance Gradient (Coefficient, $\boldsymbol{B_{C,}}$ of Regression of Log of Zip Code Job Density on Distance from Weighted Center) *100

	(1)	(2)	(3)	(4)	(5)
	Gas Prices	With controls	With controls	With controls	With extended controls
Two-year lagged *national* gas prices	-0.254 (3.25)**	-0.399 (4.38)**	-0.613 (2.96)**	-0.270 (2.93)**	-0.622 (2.82)**
One-year lagged Distance Gradient		0.332 (16.51)**	0.321 (11.04)**	0.361 (20.86)**	0.319 (10.95)**
Total city jobs (000)		0.127 (0.10)	-2.174 (1.53)	0.074 (0.07)	-1.946 (1.32)
One year lagged population gradient		1.363 (0.31)	2.322 (0.50)	5.554 (1.36)	1.749 (0.36)
Percent manufacturing		-4.448 (2.28)*	-3.674 (1.63)		-3.108 (1.18)
Percent finance, insurance, real estate		-10.255 (1.88)	-7.591 (1.21)		-8.928 (1.37)
Percent information technology		-2.103 (0.30)	-9.619 (1.33)		-13.007 (1.68)
Percent retail		6.598 (1.70)	5.899 (1.25)		6.292 (1.21)
Percent health		-0.005 (0.00)	-0.321 (0.12)		4.060 (1.18)
Gas prices *population			0.267 (2.52)*		0.261 (2.42)*
Gasprices*income			12.488 (0.85)		9.897 (0.65)
Gas prices*percent white			-0.432 (0.38)		-0.443 (0.39)
Gas prices * percent black			0.340 (0.25)		0.224 (0.16)
Gas prices * percent hispanic			0.772 (0.91)		0.706 (0.81)
Gas prices * percent working age population			-0.975 (0.51)		-0.830 (0.43)

Gas prices times percent children			1.299 (0.39)		1.760 (0.51)
Percentage establishments manufacturing				-13.381 (1.55)	5.700 (0.38)
Percentage establishments finance, insurance, real estate				1.745 (0.20)	4.511 (0.37)
Percentage establishments management				10.537 (0.52)	-12.547 (0.59)
Percentage establishments information technology				28.534 (1.49)	32.637 (1.31)
Percentage establishments professional				-1.473 (0.27)	2.931 (0.35)
Percentage establishments retail				6.398 (1.10)	-0.504 (0.07)
Percentage establishments health				5.897 (1.35)	-14.512 (1.94)
Constant	-12.915 (94.53)**	-7.943 (5.74)**	-7.708 (4.92)**	-8.571 (4.33)**	-8.332 (2.95)**
Observations	4059	2744	1494	3472	1494
Number of CBSAs	360	359	272	360	272
R-squared	0.00	0.12	0.13	0.13	0.13
Absolute value of t statistics in parentheses					
* significant at 5%; ** significant at 1%					

Appendix E shows how the impact of gasoline prices varies with the lag or different averages of energy prices across different years. It is clear that the impact is greatest after two years and fades as one examines either earlier gasoline prices or ones closer to the year in which employment density is measured.

The finding that lower gasoline prices encourage job dispersion in distance (lowering of the Clark-Mills metric) is notable because it suggests that firms did not respond over the period studied to lower transport costs for workers by seeking out spillovers at the center. Nor when gasoline prices rose, did they move out from the center closer to workers at the fringe. Rather, higher transport costs, on the whole, drive consolidation at the center (and in sub-centers). This is consistent with my thesis that higher gasoline prices promote a shift to concentrated working and living. In the case of firm location choice, it suggests firms, on average, benefit from concentration when transport costs are high, perhaps due to hub and spoke transport whereby the center minimizes transport costs of goods and labor. However, the coefficient of effect of gasoline prices on sprawl doubles when including sector controls. This may reflect the offset of some lower skilled jobs moving to the fringe as firms respond differently to the price shock depending on the sector and skill level of jobs, keeping knowledge intense jobs at the center but moving low skilled jobs and functions that do not benefit from agglomeration to the fringe. (Glaeser and Kahn, 2004, Rossi-Hansberg et al, 2009).

The Zipf and Clark-Mills coefficients can be interpreted in similar ways insofar as both represent employment density gradients from the point of greatest density regressed on gasoline prices. For both measures, the coefficients can be interpreted as the change in density gradient per one unit change in 2005 gasoline prices gallon. Using the fully loaded models, for the Zipf measure, the gradient will grow steeper by -.01986 for every unit change in two-year lagged gasoline prices and for the Clark-Mills measure, it will grow steeper by --0.00781 per unit price change.

Fleet Economy

As with the population density-defined models of sprawl, a potential criticism of my employment density model is that it does not take into account fleet fuel economy. As previously noted, fleet economy has not changed drastically since the invention of the automobile. The 1908 Ford Model T is estimated to have gotten about 25 miles per gallon, better mileage than many vehicles receive today. Over the period 1998 to 2008, government standards remained constant for cars while fleet mileage improved slightly. In the case of employment density, the impact of fleet economy on my model is ambiguous because I hypothesize that gasoline prices influence job density through multiple pathways that affect the profitability of the firm. Whereas in the case of population density, the key question was the cost of transporting people, in the case of employment density, gasoline cost could affect firm location choice through the pathway of the cost of transporting people ***and*** goods, the first through labor cost and cost of interaction among people and the second through cost of inputs and outputs. The government does not impose fleet economy standards on heavy trucks and fleet mileage for heavy and light trucks combined is very different than that of cars. With trucks, other variables such as their size and type—as well as the type of goods being transported--may influence the unit fuel cost of transport. This problem is mitigated by the fact that fleet mileage standards for autos and light trucks did not change appreciably over the period 1998 to 2008—cars stayed constant at 27.5 and light trucks edged up slightly (20.7 to 22.5). Mileage of heavy trucks fluctuated only modestly.

The US Department of Energy publishes data for mileage (Davis et al, 2011) If one makes the assumption that car mileage is an unbiased estimator of mileage affecting firms overall—through the pathway of labor and goods over the period in question, it is possible to normalize gasoline prices to account for vehicle mileage. Table 5-24 resembles Table 5-20 except that gasoline prices are adjusted for miles per gallon The adjustment to gasoline prices does not appreciably change the results and the regressions show a similarly statistically significant impact of gasoline prices on job density-defined sprawl.

Table 5-24					
Fixed Effects Regression of Rank Density Gradient of Jobs by Zip Code on National Gasoline Prices and Controls 1999 to 2008					
Dependent Variable: Urban Job Density-Rank Gradient (Coefficient, $B_{Z,}$ of Regression of Log of Zip Code Job Density on Rank) *100					
	(1)	(2)	(3)	(4)	(5)
	Gas Prices	With Sector Controls	With Sector and Household Controls	With Sector by Establishment Controls	With Extended Controls
Two year lagged gasoline prices normalized by mileage per gallon	-23.976 (5.85)**	-19.251 (2.89)**	-43.701 (2.23)*	-29.399 (5.22)**	-43.684 (2.17)*
One year lagged rank gradient * 100		0.250 (7.80)**	0.232 (7.15)**	0.251 (10.49)**	0.234 (7.17)**
Total city jobs (000)		6.531 (1.95)	0.117 (0.03)	5.799 (2.16)*	0.341 (0.07)
One year lagged population density rank gradient * 100		9.610 (0.75)	1.913 (0.15)	73.635 (6.25)**	3.730 (0.27)
Percent jobs manufacturing		8.179 (1.05)	7.175 (0.91)		12.480 (1.37)
Percent jobs finance, insurance, real estate		14.148 (0.73)	14.984 (0.77)		18.668 (0.91)
Percent jobs management		-23.029 (1.24)	-25.635 (1.36)		-22.672 (1.17)

Percent jobs information technology		23.060 (1.05)	16.176 (0.73)		1.961 (0.08)
Percent jobs retail		-2.886 (0.18)	-9.880 (0.60)		-6.154 (0.34)
Percent jobs health		6.243 (0.73)	6.889 (0.80)		10.810 (0.96)
Gasprices*2000 population (millions)			0.646 (1.63)		0.725 (1.81)
Gasprices*2000 income (millions)			69.050 (1.36)		50.203 (0.95)
Gasprices*2000 proportion white			4.180 (1.24)		4.339 (1.28)
Gasprices*2000 proportion black			7.254 (1.69)		7.082 (1.64)
Gasprices*2000 proportion hispanic			5.567 (2.06)*		5.304 (1.91)
Gasprices*2000 proportion working age			-8.997 (1.47)		-8.321 (1.35)
Gasprices*2000 proportion <65			-9.870 (0.86)		-8.252 (0.70)
Gasprices*2000 population density gradient			-3.344 (1.71)		-3.677 (1.85)
Percentage establishments manufacturing				-70.789 (2.39)*	-30.602 (0.64)
Percentage establishments finance, insurance, real estate				-20.998 (0.77)	-43.413 (1.11)
Percentage establishments management				-4.884 (0.10)	-55.559 (0.66)
Percentage establishments information technology				101.688 (1.80)	170.648 (2.08)*
Percentage establishments professional				-20.258 (1.12)	-5.227 (0.20)
Percentage establishments retail				-8.398 (0.51)	-14.765 (0.59)

Percentage establishments health				2.209 (0.18)	-4.168 (0.16)
Constant	-26.792 (84.21) **	-23.950 (5.05)**	-23.499 (4.76)**	-0.715 (0.12)	-19.958 (2.29)*
Observations	2240	1076	1076	1955	1076
Number of CBSAs	286	252	252	280	252
R-squared	0.02	0.09	0.11	0.11	0.12
Absolute value of t statistics in parentheses					
* significant at 5%; ** significant at 1%					

Other Variables

In addition to the impact of gasoline prices on sprawl, the regressions also provided some limited evidence of a statistically significant effect by other variables on job density-defined sprawl.

The chief variables that the literature suggests may influence the distribution of jobs are the dispersion of people—jobs may follow people out of the city, and the relative intensity of industry sectors and occupations within cites. Other potential explanatory variables include auto-regressors and socioeconomic variables. Since granular data on occupation are not available, I cannot include occupation as a control. However, the regressions do provide insight into other potential causes of sprawl.

First, auto regressors are statistically significant predictors of sprawl. Both the one-year lagged Zipf coefficient and the one-year lagged Clark Mills coefficient are statistically significant in their respective models and have positive coefficients. This suggests that trending exists in the data such that dispersion begets dispersion and concentration, concentration. In the model with all controls, a one unit increase in the one year-lagged Zipf coefficient is associated with a 0.234 increase in the Zipf coefficient one year later and a one unit increase in the one year-lagged Clark-Mills coefficient is associated with a .257 increase in the Clark-Mills coefficient one year later. Similarly a one point decrease in either coefficient is associated with equivalent *decreases* in the coefficients one year later.

Second, the rate of population decay from the center relative to rank also shows up as a statistically significant variable in some, though not all, versions of the model. This provides limited confirmation of the finding of Glaeser and Kahn that jobs appear to follow people out of the city. The chief grounds for asserting causality is temporal insofar as the population gradient is lagged. Full exploration of the interaction between population and employment density and direction of causal effect, if any, would require additional analysis, perhaps utilizing instrumental variables, but for my purposes it is notable that the coefficient is statistically significant in some versions of the model.

As discussed previously in the chapter on methodology, ideally, my dataset would have data on job sector by zipcode; but because the Census Bureau does not publish such data in order to protect the confidentiality of respondents, I must rely on sectoral data at the MSA level. I

nonetheless find that certain sectors appear to influence sprawl. In some variants of the model, I find that a higher percentage of workers in the fields of information technology, a field that one would expect to be knowledge-intensive, seems to reduce sprawl while a higher percentage of retail workers that one would presume to be low skilled tends to encourage it. This limited evidence is consistent with the empirical findings of Glaeser and Kahn (2001) and model of Rossi-Hansberg and Wright (2009).

In studying population density decay as an indicator of sprawl, I find support for socioeconomic determinants of sprawl. In particular, I found that sprawl appeared to be income elastic—consistent with sprawl exhibiting a positive income effect, and that percent black and hispanic correlated with sprawl—consistent with the idea of white flight from minorities contributing to sprawl.

The employment density models of sprawl are considerably less well suited to studying the role of household socioeconomic characteristics in sprawl since no data is available on workers by zip code and people rarely work where they live. Further firms not households make job location choice decisions. We might, however, expect income and other socio-economic variables to affect the local equilibrium of the city. Socioeconomic characteristics of workers must be inferred from household Census data that has been averaged for the overall MSA on the assumption implicit in the MSA concept that workers do work in the same MSA in which they live.

With these caveats, the employment data do not offer evidence in support of an income effect on job density-defined sprawl insofar as there is no statistically significant relationship between household income in 2000 multiplied by gas prices and the job density gradient across the urban areas studied. This finding may reflect the lack of more granular data and difficulty of mapping household Census data at the level of census tracts to firm-derived jobs data at the zipcode level.

The data provide limited, ultimately inconclusive support for the thesis that higher concentrations of minorities and Hispanics lead to sprawl. Coefficients for percent black and Hispanic are positive, in the main, implying a higher concentration of minorities equates to job dispersion, consistent with the idea of white flight. The coefficients are statistically significant at the 5% level, however, in only a few variants of the model, not in the majority of cases. For example, examining the Zipf model with the fullest set of controls, the coefficient for percent black is positive and the t-statistic is 1.64. The coefficient for percent Hispanic is positive with a t-statistic of 1.91. The signs of each fit the "white flight" hypothesis, however, neither coefficient is statistically significant at the 95% confidence level. However, if one omits the sector by establishments controls, in this variant of the model, both coefficients are positive and the t-statistic for percent Hispanic is 2.06 while that for percent black is 1.69. In this case, the coefficient for percent Hispanic is statistically significant. Examining the Clark Mills model, the coefficients are ambiguous, some positive and others negative; none are statistically significant. Overall, therefore, the jobs data do not support a robust role for socioeconomic determinants in job density-defined patterns of sprawl. This is not entirely surprising insofar as firms, not households, choose job location. More generally, it would appear that the job density data and

models are not as well suited as the population density ones to studying the socioeconomic determinants of sprawl.

Cross Sectional Analysis

As stated previously, my primary goal in this dissertation is to test the impact of gasoline prices on sprawl over time. I am primarily interested in exploring the within-group effects over time that have received scant attention previously. A longitudinal approach also has the advantage of controlling for a wide range of potential differences in metropolitan areas. The granular gasoline price data available from ACCRA COLI at the city level and included in my employment density dataset, however, offers a potential opportunity to study the effect of local differences in gasoline prices on sprawl at a specific point in time.

As previously discussed zip code level geography poses unique challenges as zip codes are not maintained for statistical purposes. Cross sectional analysis at a fixed point in time removes one problem specific to zip codes—changes in their definitions over time—but exposes other differences between metropolitan for which data may not be available or even observable. The latter variables drop out of fixed effects, time series analysis but reappear in cross sectional regressions.

One variable that can distort cross sectional analysis is the size of CBSAs as defined by the Bureau of the Census. The New York CBSA as now defined includes portions of New York, Connecticut, New Jersey and Pennsylvania while the Washington, DC CBSA includes the District of Columbia and portions of Virginia, Maryland and West Virginia. As previously noted, two metrics I have employed for sprawl, the rank and distance gradients, are sensitive in cross sectional analysis to number of zip codes. New York has shallower gradients, for example, than Allentown-Bethlehem-Easton although it exhibits far greater extremes in density because the New York metropolitan statistical area is so much larger. Percent of jobs within concentric rings around the center is also sensitive to city size (Glaeser and Kahn, 2003). With respect to the independent variable of greatest interest, gasoline prices, different states impose different gasoline taxes and prices may vary from one end to another of larger CBSAs due to proximity to refineries, transportation costs and other variables. It is possible to include size variables such as number of zip codes as potential controls or exclude multi-state CBSAs from the dataset, however, I am aware that many other unobserved variables may affect job location decisions by firms. Aware of these challenges, I test the effect of current and lagged gasoline prices on various metrics of sprawl including controls for city size, number of jobs, population gradient, sector composition and household socioeconomic characteristics.

As expected, testing the effect of gasoline prices on a variety of measure of sprawl including the rank and distance gradients and percent jobs at various distances from the center with controls does not yield statistically significant results. This confirms the relative benefits of longitudinal analysis using fixed effects that can adjust for unobserved or difficult-to-measure differences in metropolitan areas.

The Impact of Gasoline Prices on Sprawl Measured as Light Visible from Space

The third model that I employ explains sprawl—measured using a novel index of nighttime light visible from space developed by Burchfield et al (2005)—as a function of gasoline prices and controls. My choice of the Burchfield index as a metric of sprawl is motivated by the value of actual physical observation of quantifiable, anthropogenic light. Nighttime light visible from space—in the United States—provides an objective measure in geographic terms of human settlement. While focused on dwellings as opposed to workspace—where people spend their nights as opposed to days—and largely blind to vertical densities in settled regions, light visible from space provides an objective marker of land consumed in the course of growth. Burchfield et al perform this analysis on aerial photographs taken in 1976 and satellite images taken in 1992 providing a temporal as well as regional perspective on sprawl. I expand their dataset with gasoline price data and selected controls. I then regress their indices of sprawl on the latter as well as controls derived from their dataset. I find evidence of a temporal and cross sectional effect of gasoline prices on sprawl.

The Burchfield et al Methodology

As previously discussed, Burchfield et al explore a dimension of sprawl that has proven difficult to study, what they term the "scatteredness of development" (Burchfield et al, 2005, p. 1).

Their methodology is not so much designed to map the outer boundaries of development or the vertical density of development as captured by variables such as land use in the NRI maintained by the Department of Agriculture or Floor Area Ratio (FAR) or population density but rather the ratio of undeveloped space to developed space *around* developed areas. Working with aerial photographs from 1976 and satellite imagery from 1992, they employ digital techniques to divide the imagery into 8.7 billion 30x30 meter cells that fully cover the United States. They then code each cell—based on characteristics of the image--by land cover or use. They categorize each cell as: "residential development; commercial and industrial development and transportation networks; water; bare rock and sand; forest; range and grassland; agricultural land; or wetlands" (Burchfield et al, 2005, p. 3.)[7].

Having coded cells by use, they then map them to Metropolitan Statistical Areas as defined by the Bureau of the Census in 1999. For each MSA, they construct an index of sprawl described further below. They construct this index for the year 1976, the year 1992 and the period 1976 to 1992. Finally, drawing from a variety of data sources that can be mapped to MSA level geography, they assemble MSA-level data on other variables that may influence sprawl. These include geographic variables such as the nature of the aquifer, the ruggedness of terrain and temperature, historical ones such as early public transport and political ones such as unincorporated land at the urban fringe. In addition to drawing conclusions about the patterns and scatteredness of sprawl over the period in question from the land use data alone, they regress their indices of sprawl on potential determinants or explanatory variables to determine

[7] Burchfield et al source their aerial and satellite imagery data primary from two earlier sources. The primary source of their 1976 data is *Land Use and Land Cover Digital Data* (US Geological Survey, 1990, US Environmental Protection Agency, 1994) and the primary source of their 1992 satellite imagery data is 1992 National Land Cover Data (Vogelmann, Howard, Yang, Larson, Wylie, and Driel, 2001).

what variables may influence sprawl to a statistically significant degree. They find that sprawl remained largely unchanged overall in the United States during the period 1976 to 1992 (though sprawl varied dramatically across metropolitan areas) and that variables that influence sprawl include "ground water availability, temperate climate, rugged terrain, decentralized employment, early public transport infrastructure, uncertainty about metropolitan growth, and unincorporated land in the urban fringe."

The Burchfield et al Sprawl Index

To best understand the implications of their findings as well as the applicability of their data to the purpose of my dissertation— the effect of gasoline prices on sprawl—it is important to understand how they calculate their index.

They define their index as "the percentage of undeveloped land in the square kilometer surrounding an average *residential* development in each metropolitan area" (Burchfield et al, 2005, p. 11). In other words, using the land use coding of cells within metropolitan areas, they first identify residential cells. In turn, they calculate the percentage of undeveloped land in the square kilometer around each residential cell. They then take the average of this measure across "all *developed* cells in a metropolitan area" to obtain an index of sprawl for the metropolitan area. For the 1976 index, they perform these steps on the 1976 data and for the 1992 index, on the 1992 data. The sprawl index is therefore focused on residential development

or dwellings. Non-residential development such as office buildings, malls, parking, roads, train tracks and other commercial uses, however, does enter into the index by reducing open space. For the 1976 to 1992 index, in each metropolitan area, the authors "identify 30 meter cells that were not developed in 1976 but were subject to residential development between 1976 and 1992, calculate the percentage of land not developed by 1992 in the square kilometer containing each of these 30 meter cells, and average across all such newly developed cells in the metropolitan area" (Burchfield et al, 2005, pp. 10-11.) It differs from the 1976 and 1992 measures, therefore, in focusing only on that portion of land developed *between* 1976 and 1992 (and surrounding one square kilometer tracts) as opposed to developed land overall. Placed on a scale of 100, the index is bounded by 0—if all land is developed as it might be in a center city—and 100 if no land is developed. Table 5-21 gives summary statistics for the index values.

Table 5-25

Measures of Central Tendency of Burchfield et al Indices of Sprawl

	Mean	Standard Deviation	Minimum	Maximum
1976	45.94425	10.52678	20.03	73.64
1992	46.54262	10.82096	20.73	75.1
1976-1992	64.37961	11.16658	22.9625	88.47

As Table 5-25 suggests, sprawl—measured as scatteredness captured through light visible from space at night—did not change dramatically between 1976 and 1992. However, the portion of

land that did undergo development during the interim—the land that is the focus of the 1976-1992 measure—was, at the end of the period, more sprawling than developed land overall. While only about half of the land around and between residential developments was undeveloped in both 1976 and 1992, leaving about half open, of the land that underwent development over this period, about 65% remained open at the end, suggesting more scattered development. It is likely that the overall mean remained unchanged due to fill in developed areas, highlighting the fact that changes in sprawl can occur through new development as well as in fill of--or exodus from—existing development.

As with my previous measures of sprawl, it is important to understand how the Burchfield et al "scatteredness" index fits into models of the city and through what pathways gasoline prices might be expected to influence it. The index does not flow directly out of the prevailing AMM model nor is *scatteredness* a variable that has figured prominently in urban theory. The AMM model explains population density relative to distance from a hypothesized center on the basis of transportation cost and the benefits of agglomeration. Offshoots of the model, as discussed, model population density relative to a CBD and sub-centers as a function of exogenous or endogenous variables *or* employment density relative to a CBD and sub-centers relative to variables such as spillovers and cost of transportation (Rossi-Hansberg and Wright, 2002). They do not model scatteredness per se. However, a number of scholars have researched scatteredness and the phenomenon of leap frog development and a scatteredness index clearly bears a relation to living and working density. It is important to understand the degree to which this innovative metric of sprawl correlates with others and how it may be expected to react similarly—or dissimilarly—to exogenous variables such as gasoline cost.

Burchfield et al briefly summarize the literature of the city and note that it predicts that cities that are car friendly and specialize in non-agglomerative sectors should sprawl more. They note that sprawling cities should exhibit large yards. In turn, they note that standard models of the city do not explain the phenomenon of "leapfrogging", where developers skip over parcels of land, giving rise to scattered development. Scholars have sought to explain "equilibrium leapfrogging" that leads to less compact development and therefore longer driving times as a result of a preference for open space amenities constrained by expectations about the duration of open space. Another line of inquiry has focused on the expectations of developers building under uncertainty. Some may choose to develop and others withhold land from the market. Prevailing theory does not directly address the concept of scatteredness. However, it does address the question of open space—whether due to large lots, amenities such as parks or private land withheld for future development. The authors note that their metric of scatteredness is likely to be influenced by many of the same variables that influence other metrics of sprawl. However, they also note that their index is far from identical to other measures. After calculating the index by MSA, they compute its correlation with other measures.

They find their index to exhibit a -0.070 correlation with the Glaeser and Kahn measure of employment over three miles from the city center. Their index exhibits considerably higher correlation of 0.521 with minimum lot size as reported in the American Housing Survey 1994–98. This is not surprising since minimum lot size captures the idea of open land surrounding a dwelling. While it may track the density of exurban living, it does not take account the vertical

heights of dwellings in center city settings and, in the opposite direction, excludes commercial structures from its definition of open space. A few dwellings sprinkled through a CBD would register as low population density if one simply divides number of dwellings by land. In contrast, it would register as low sprawl—due to the presence of adjoining commercial structures—following the Burchfield et al methodology.

Notwithstanding the above limitations, because the locational advantages at the center of a city promote development and density—even in the face of congestion costs—scatteredness is likely to be at a minimum near the city center and increase as one moves outward. Scatteredness of the metropolitan area as a whole should increase as the city sprawls outwards and correlate with sprawl.

It is, of course, possible to imagine a city with high density *and* high scatteredness, for example, a Le Corbusier city consisting of vertical towers surrounded by green space. Many cities contain parks and parks or water that, strategically placed, could lead to scatteredness coexisting with density. Such a city could have a steep population gradient and a high index of scatteredness. It is more reasonable, however, to hypothesize that scatteredness correlates on the whole negatively with population density and positively with measures of population density decay from the center.

Unfortunately, the stark definitional differences between MSAs, analyzed by Burchfield et al, and PMSAs for which I calculate population density-derived metrics of sprawl, prevent relating

my population density metrics for PMSAs and the Burchfield index for MSAs in a statistically significant way. Comparing the 19 metropolitan areas that are both PMSAs and MSAs (but differ in boundaries) as in Table 5-26 nonetheless yields predicted correlations between the Burchfield index and my metrics in most cases (the exception being the Clark gradient) The correlation with sprawl intensity, for example, is .63.

Table 5-26

Correlation of Burchfield et al Index and Moynihan Dissertation Measures of Sprawl

	Burchfield index	Gini (weighted)	Clark Gradient	Zipf gradient	Sprawl intensity	Urban intensity	Urban index
Burchfield index	1						
Gini (weighted)	-0.2939	1					
Clark Gradient	0.0649	-0.1307	1				
Zipf gradient	-0.0983	0.1981	0.015	1			
Sprawl intensity	0.6261	-0.2259	-0.0464	-0.4216	1		
Urban intensity	-0.625	0.2063	0.0524	0.4279	-0.9996	1	
Urban index	-0.6155	0.1599	0.0441	0.4341	-0.9924	0.9943	1

In turn, a scattered metropolitan area, like one sprawling using a population density-derived metric, is likely to be gasoline-intense and therefore sensitive to gasoline prices for similar reasons. First, scatteredness implies greater distances between dwellings and the CBD, implying higher commuting costs that if, by car, are sensitive to gasoline prices. Second, scatteredness suggests that living is more driving dependent—relative to urban living—due to

lack of walkability. Burchfield et al find a correlation of 0.271 between scatteredness and miles driver per person based on the 1995 Nationwide Personal Transportation Survey (Burchfield et al, 2005, p. 15). In short, it is reasonable to hypothesize that higher gasoline prices (by making driving intense, scattered living at the urban periphery more expensive) should exert a negative influence on scatteredness and lower gasoline prices should encourage scattered living. Accordingly, I hypothesize that higher gasoline prices will lead to lower indices of sprawl and lower gasoline prices will lead to higher values of the indices.

The two period, time-indexed, longitudinal metric for 1976 and 1992 comprised of S_{B76} and S_{B92} that I designate S_{Bt} constitutes my nighttime light visible from space-derived measures of sprawl. I regress it on gasoline prices and controls.

Additions to the Burchfield et al Dataset

To permit regression of the Burchfield indices of sprawl on gasoline prices and controls, I expand their dataset in several ways. As discussed in Chapter 4, I introduce state-level gasoline prices from the Energy Information Agency (EIA). I use state-level data from the EIA as my primary gasoline price source, though MSA level data, if available would be preferable, because state level data is the most granular level available for the time periods in question. I experiment with ACCRA-COLI data that are available for the year 1992 for selected MSAs but ultimately rely on the EIA data. I experiment with different time lags that include two-year lagged prices, one year lagged prices, current prices and various averages of prior year prices before focusing on two-

year lagged data. I further expand the dataset with socioeconomic controls for the MSA from the decennial census contained in the Neighborhood Change Database (NCDB). For between census years, I employ straightline estimation based on 1970 and 1980 values to estimate 1976 values and straightline estimation based on 1990 and 2000 censuses to estimate 1992 values. Finally, the Burchfield et al dataset has many interesting explanatory variables, particularly topographic ones that might influence sprawl. These include notably ruggedness of terrain at the fringe, elevation and aquifer. The explanatory variables in the Burchfield dataset vary by place but not by time. In order to take advantage of the two time period nature of their dataset and incorporate unchanging variables in panel analysis, I create interactive variables by multiplying time-independent variables such as ruggedness at the fringe by time-variant gasoline prices. This makes it possible to examine the effect of gasoline prices on sprawl in the presence or absence of certain fixed variables that may influence the relative course of sprawl across geographic areas.

Ultimately, I test the longitudinal model (and variants) of sprawl as follows:

$$S_{Bt} = \alpha + \beta GASOLINE\ PRICES_{t-l} + \gamma CONTROL\ VARIABLES_{t}$$

Table 5-27 summarizes a variety of regressions performed using Ordinary Least Squares Regression with Fixed Effects of the Burchfield et al sprawl index on two year-lagged local gasoline prices over the period 1972 to 1992. The results with and without controls show a statistically significant impact of gasoline prices on sprawl, defined as undeveloped share of land

around residential development. Lower gas prices, the regressions show, increase sprawl while higher gas prices reduce it.

Table 5-27					
Fixed Effects Regression of Burchfield et al Sprawl Index on Lagged Gasoline Prices and Controls, 1976 to 1992					
Dependent variable: Burchfield et al Index of Sprawl (S_{Bt})					
	(1)	(2)	(3)	(4)	(5)
	2-Year Lagged Gasoline Prices	With basic controls	With socio-economic controls	With basic and socioeconomic controls	With extended controls
2-Year lagged gasoline Prices	-6.188 (5.30)**	-55.461 (2.29)*	-9.402 (4.79)**	-58.111 (2.32)*	-62.768 (2.12)*
2-year lagged gas prices*centralized sector employment(1977)		2.387 (1.92)		2.431 (1.88)	1.397 (1.07)
2-year lagged gas prices*street car passengers per capita (1902)		0.429 (0.44)		0.250 (0.23)	0.812 (0.63)
2-year lagged gas prices*mean cooling degree days		0.627 (0.39)		0.355 (0.20)	2.019 (0.49)
2-year lagged gas prices*percent urban fringe incorporated (1980)		1.403 (0.95)		1.037 (0.67)	0.864 (0.23)
Population (000000)			-0.570 (1.02)	-0.441 (0.71)	1.288 (1.67)
Proportion white			0.298 (0.06)	-0.405 (0.08)	-7.362 (1.22)
Proportion black			2.426 (0.22)	5.673 (0.50)	-14.111 (1.15)
Real average household income (000)			-106.627 (0.51)	-107.488 (0.51)	-60.905 (0.28)
Real family income (000)			122.574 (0.54)	184.813 (0.81)	232.448 (0.97)
Working age population (%)			-5.051 (0.30)	-3.313 (0.19)	-23.003 (1.20)
Percent child			9.437 (0.85)	9.613 (0.87)	0.858 (0.07)

2-year lagged gas prices*mean decennial % population growth 1920-1970					2.973 (0.75)
2-year lagged gas prices*standard deviation decennial % population growth 1920-1970					-2.914 (0.61)
2-year lagged gas prices*percent urban fringe overlaying aquifers					-18.413 (1.08)
2-year lagged gas prices*percent overlaying aquifer, MSA					0.455 (1.00)
2-year lagged gas prices*mean heating degree-days					0.277 (0.08)
2-year lagged gas prices*elevation range in urban fringe					-23.451 (3.99)**
2-year lagged gas prices*elevation range, MSA					0.031 (3.68)**
2-year lagged gas prices*terrain ruggedness index in urban fringe					28.550 (4.30)**
2-year lagged gas prices*terrain ruggedness index, MSA					-2.476 (3.80)**
2-year lagged gas prices*percent of urban fringe incorporated (1980)					0.237 (0.32)
2-year lagged gas prices*intergovernmental transfers as % of local revenues (1967)					2.144 (1.23)
2-year lagged gas prices*percent population growth 1970-1990					5.307 (1.50)
2-year lagged gas prices*bars and restaurants per thousand people					2.918 (1.01)

2-year lagged gas prices*Major road density in urban fringe (m./ha.)					0.097 (0.05)
2-year lagged gas prices*Herfindahl index of incorporated place sizes					-1.203 (0.77)
Constant	54.128	52.982	58.723	54.699	69.210
	(31.72)**	(28.73)**	(3.93)**	(3.61)**	(4.00)**
Observations	446	446	444	444	444
Number of msa	223	223	222	222	222
R-squared	0.11	0.14	0.14	0.16	0.31
Absolute value of t statistics in parentheses					
* significant at 5%; ** significant at 1%					

Discussion

Gasoline Prices and Sprawl

Table 5-27 show the results of Ordinary Least Squares Regression using fixed effects of the Burchfield index of sprawl on gasoline prices and controls over the two periods 1976 and 1992. The regressions with and without controls demonstrate a consistent, statistically significant impact of gasoline prices on sprawl. The goodness of fit captured by R-squared of .31 in the fully specified variant of the model is respectable though not high. As with the other fixed effects models, within group effects are far higher than between group effects. The goodness of fit does not reach that of the cross sectional models included by Burchfield et al in their paper that range from .40 to .47 (Burchfield et al, 2005, p. 22). This may reflect the fact, however, that the

determinants included in their model are time invariant and can only be represented in a fixed effects model through interactive variables as well as the temporal focus of the model itself.

Table 5-27 suggests that a one dollar change in 2000 gasoline prices causes a -62.768 percentage point drop in the sprawl index multiplied by ten over a 16 year period after controlling for other variables, i.e. a -6.28% drop. This implies that a ten cent change in real 2000 gasoline prices caused a 63% point change in the sprawl index. To provide more context, it is useful to link the index of sprawl to real world examples. In 1976, the Fresno California MSA had an index of 37.97. In 1992, its index was 44.651992, a difference of about 6.6. Therefore, a $.10 change in gasoline prices is associated with a change in sprawl almost as significant as that which occurred in Fresno between 1976 and 1992. As a second example, Fort Myers, Florida had a sprawl index value of 44.44 in 1976. It declined to 38.08 in 1992. The decline of 6.36 points is approximately equal to the influence, holding all other variables constant, of a ten cent real increase in gas prices over this period.

Perhaps the most powerful way to interpret the results is as follows. Since the Burchfield et al index equals the average of the percent of one square kilometer areas around dwellings that remain open space in each MSA, on average a $.10 drop in gasoline prices, all things being equal, is associated with the covering up of .0628 of a square kilometer or the consumption of 62,800 square meters (6.26 hectares) of open space in each square kilometer over 16 years. Conversely, a $.10 increase in gasoline prices is associated with the preservation of 63,600 square meters (6.36 hectares) of open space over 16 years. This equates to an annual change of about 0.3923 hectares/$.10 change in gas prices per square kilometer or about 4 hectares of

land consumed (or preserved) per square kilometer annually per $1 change in gasoline prices. One can further interpret this as a 4% annual change in land covered per $1 change in gasoline prices. While this may not seem like a huge number, it suggests that a $1 sustained real price change over 10 years would result in 40% more or less land being covered, all other things being equal.

Fleet Economy

As with the other metrics of sprawl previously discussed, it is useful to test the robustness of results to changes in fleet economy. As previously discussed, fleet economy has increased modestly in recent decades. The period 1976 to 1992 coinciding with the oil shocks of the 1970s, was one of the more rapid periods of mileage improvement in history. For cars, it increased from 13.9 in 1975 to 21 in 1992 (Davis, 2011, Table 4.1)[8]. Table 5-28 reprises Table 5-27 except that gas prices have been normalized for mileage. It indicates that normalizing the data does not alter the significance of findings. Normalized gas prices remain statistically significant and R-squared of the fully specified model remains .31.

Table 5-28					
Fixed Effects Regression of Burchfield et al Sprawl Index on Lagged Gasoline Prices and Controls, 1976 to 1992					
Dependent Variable: Burchfield et al Sprawl Index					
	(1)	(2)	(3)	(4)	(5)
	Normalized gasoline Prices	With interactive controls	With socio-economic controls	With interactive and socioeconomic controls	With Extended Controls

[8] 1976 figures are not published.

2-year lagged gasoline prices normalized for fleet mileage	-1.307 (4.17)**	0.445 (0.65)	-4.812 (4.66)**	-2.862 (1.92)	-3.973 (2.46)*
2-year lagged gas prices*centralized sector employment(1977)		-0.514 (3.11)**		-0.329 (1.79)	-0.564 (0.67)
2-year lagged gas prices*street car passengers per capita (1902)		0.607 (0.62)		-0.005 (0.01)	0.490 (0.38)
2-year lagged gas prices*mean cooling degree days		0.744 (0.45)		0.464 (0.27)	-0.258 (0.07)
2-year lagged gas prices*percent urban fringe incorporated (1980)		1.356 (0.90)		0.990 (0.64)	1.876 (0.51)
Population			-0.816 (1.43)	-0.619 (0.98)	0.880 (1.11)
Proportion white			0.845 (0.17)	1.500 (0.31)	-6.311 (1.05)
Proportion black			-2.780 (0.24)	-0.279 (0.02)	-23.276 (1.87)
Real average household income			-265.704 (1.23)	-213.732 (0.98)	-101.462 (0.47)
Real family income			188.273 (0.83)	151.177 (0.66)	141.039 (0.59)
Working age population			17.069 (0.89)	12.004 (0.62)	1.344 (0.06)
Percent child			49.622 (2.79)**	37.698 (2.00)*	44.423 (2.12)*
2-year lagged gas prices*mean decennial % population growth 1920-1970					-0.736 (0.19)
2-year lagged gas prices*standard deviation decennial % population growth 1920-1970					-1.973 (0.42)
2-year lagged gas prices*percent					-14.452 (0.85)

urban fringe overlaying aquifers					
2-year lagged gas prices*percent overlaying aquifer, MSA					0.336 (0.75)
2-year lagged gas prices*mean heating degree-days					-1.441 (0.45)
2-year lagged gas prices*elevation range in urban fringe					-23.154 (3.95)**
2-year lagged gas prices*elevation range, MSA					0.031 (3.61)**
2-year lagged gas prices*terrain ruggedness index in urban fringe					27.623 (4.16)**
2-year lagged gas prices*terrain ruggedness index, MSA					-2.456 (3.79)**
2-year lagged gas prices*percent of urban fringe incorporated (1980)					0.007 (0.01)
2-year lagged gas prices*intergovernmental transfers as % of local revenues (1967)					0.109 (0.06)
2-year lagged gas prices*percent population growth 1970-1990					7.856 (2.19)*
2-year lagged gas prices*bars and restaurants per thousand people					3.154 (1.09)
2-year lagged gas prices*Major road density in urban fringe (m./ha.)					-1.265 (0.68)

2-year lagged gas prices*Herfindahl index of incorporated place sizes					-1.032 (0.66)
Constant	46.697 (118.10)**	55.289 (16.96)**	27.764 (1.60)	37.598 (2.05)*	43.629 (2.10)*
Observations	446	446	444	444	444
Number of MSAs	223	223	222	222	222
R-squared	0.07	0.12	0.14	0.15	0.31
Absolute value of t statistics in parentheses					
* significant at 5%; ** significant at 1%					

Other Variables

Burchfield et al found, using a cross sectional approach, that ground water availability, temperate climate, rugged terrain, decentralized employment, early public transport infrastructure, uncertainty about metropolitan growth, and unincorporated land in the urban fringe all increase sprawl. In contrast, including gasoline prices as an explanatory variable and employing a longitudinal approach with the Burchfield et al fixed variables present as interactive variables with gasoline prices. I find that only rugged terrain—operationalized as elevation and ruggedness—exerts a statistically significant effect. My findings suggest that while gasoline prices influence sprawl over time, the sprawl is not materially affected by the presence of many fixed variables such as early public transport infrastructure or uncertainty about metropolitan growth that Burchfield et al find to be significant predictors of sprawl. One possible reason for the divergent findings is that they conduct cross sectional regressions while I employ longitudinal analysis. My methodology accounts for the fixed effects of unobserved variables that may distort values obtained in cross sectional regressions. Another possibility is that these variables, while responsible for between group effects, do not have a statistical bearing on

within group effects and due to error in my gasoline price data, my between group effects are biased as discussed further below.

In contrast to ground water availability, temperate climate, decentralized employment, early public transport infrastructure, uncertainty about metropolitan growth, and unincorporated land in the urban fringe, the coefficients for ruggedness of terrain and elevation are statistically significant. The authors hypothesize and subsequently find that ruggedness of terrain, a measure designed to capture hilliness at the urban fringe, exerts a positive effect on sprawl. They theorize that hills lead to an alternating pattern of development of flat land and undeveloped hills (i.e. open space) that increases overall scatteredness. In contrast, they hypothesize and find that elevation, a measure designed to capture exceedingly steep hills or mountains, exerts a negative effect on sprawl because it prevents development, turning it inward.

In my regression analysis, I find that ruggedness of terrain at the fringe exerts the predicted positive effect (coefficient, 28.55 and t-statistic, 4.30) and that elevation at the fringe exerts the predicted negative effect (coefficient, -23.451 and t-statistic, 3.99) . This suggests that topographic conditions at the fringe do, in fact, guide development with mountains blocking sprawl and passable barriers promoting it. My findings that restaurants and bars, as well as roads, have no bearing on sprawl, confirms their results.

At the same time, I do not find household socioeconomic variables to have significance in any variant of the model. In particular, race and income that proved significant in some variants of my population density model of sprawl do not show significance in any variants of this model. Several reasons may account for this difference. First, my measures for these socioeconomic variables for 1976 and 1992 are interpolated using straight line estimation from decennial data. It is possible that this methodology distorts the real values for each year that are unobserved. Second, as discussed, scatteredness while related to other metrics of sprawl does not correlate exactly with population density-derived metrics such as the Gini coefficient of density, decay by rank or decay by distance from the center for the reasons described above. While higher incomes, as we saw earlier, correlate with some population density-derived metrics of sprawl, higher incomes do not correlate with scatteredness of dwellings. One possible explanation is that scatteredness, if due to leapfrog development as opposed to large yards, could be the result of variables other than a preference for space, for example, reservation of land by owners in expectation of rising prices or road location. It bears mention that the evidence for an income effect on sprawl as found by Margo (1992) is somewhat ambiguous (Glaeser and Kahn, 2001). Similarly, demographic characteristics including race and age do not yield a consistent, statistically significant effect. This may also reflect errors from interpolating intra-decade values from decennial data or could reflect differences between scatteredness and more conventional population density-derived metrics of sprawl.

Cross Sectional Analysis

In addition to the longitudinal model employed above, I also test three cross sectional models, regressing the Burchfield et al indices for 1976, 1992 and 1976 to 1992, S_{76}, S_{92} and S_{7692} on

gasoline prices and controls. As with previous cross sectional regressions at the MSA, CBSA or PMSA level, the lack of gasoline prices data that accurately describes prices within the metropolitan boundaries poses a significant challenge to a cross sectional approach. The MSAs in the Burchfield et al dataset (though not as large as CBSAs defined in 1999 which posed challenges to cross sectional regressions of employment density data) include several multi-state metropolitan areas. The New York MSA, for example, includes portions of New Jersey, Connecticut, New York and Pennsylvania, states with starkly different taxes and prices in effect. I experiment with state gasoline prices that are available for all of the MSAs in the Burchfield et al dataset and city gasoline prices that are available only for the year 1992 for a select group of 177 cities. I experiment with gasoline prices for the year in question, as well as lagged prices and average prices over three and five year periods, some lagged, prior to the year in question. I include the Burchfield et al variables as well as socioeconomic variables for the years in question. As expected, however, I do not find conclusive evidence of a consistent, statistically significant effect of localized energy prices on sprawl at a given point in time. Given the challenges posed by regressing MSA level data on state level gasoline prices, a longitudinal approach that screens out the effects of unobserved or unobservable differences in metropolitan areas, including subtle differences in gasoline prices across the MSA would appear to be the preferred approach.

Chapter 6: Conclusion

The foregoing chapters have tested the hypothesis that gasoline prices influence sprawl. Using a variety of datasets, metrics and models, the findings demonstrate a statistically significant causal effect. Higher gasoline prices lead to less sprawl, over time; lower gasoline prices lead to more. In addition, state level evidence suggests that local gasoline prices influence local sprawl with higher local gasoline prices constraining sprawl and lower gasoline prices encouraging it. The effect is not merely correlative but causal as evidenced by analysis using instrumental variables and time sequence analysis. While my dissertation presents a new finding, not previously described in urban literature--that gasoline prices influence sprawl--the finding is very much in keeping with the canonical theory of the city that gives a prominent role to transportation cost. In this chapter, I review the key conclusions of the dissertation and also make several policy suggestions based on the findings related to a common intervention in markets, imposition of a tax.

Table 6–1

Key Measures of the Impact of Gasoline Prices on Sprawl

Dataset	**Measure of Sprawl**	**Time Period**	**Model Type (FE or CS***)**	**Level of Analysis**	**Unit of Data**	**Coefficient (t–statistic**
NCDB as amended	Gini coefficient*100	1970 to 2000, decennial	FE	PMSA	Census tract	10.021 (4.22)**
	Population Density to Rank Gradient (β_Z) *100	1970 to 2000, decennial	FE	PMSA	Census tract	–1.237 (3.45)**
	Population Density to	1970 to 2000,	FE	PMSA	Census tract	–8.458 (2.70)**

	Distance Gradient (β_C)*100	decennial				
	Log of % Tracts Sprawling	1970 to 2000, decennial	FE	PMSA	Census tract	–0.244 (5.08)** (log–log)
	Log of % Tracts Urban	1970 to 2000, decennial	FE	PMSA	Census tract	0.209 (4.55)** (log–log)
	Log of Urban Intensity Index	1970 to 2000, decennial	FE	PMSA	Census tract	2.307 (5.29)** (log–log)
	Standard Deviation of Density	1970 to 2000, decennial	FE	PMSA	Census tract	2,131.400 (3.63)**
	Tract Conversion*100	1970 to 2000, decennial	FE	Census Tract	Census tract	–18.502 (13.39)**
	Zipf Gradient Regressed on Gas Prices Normalized for Fleet Mileage	1970 to 2000, decennial	FE	PMSA	Census Tract	–18.428 (4.56)**
	Clark–Mills Gradient Regressed on Gas Prices Normalized for Fleet Mileage	1970 to 2000, decennial	FE	PMSA	Census Tract	–99.994 (3.01)**
	Cross Sectional Clark–Mills Gradient	1970 to 2000, decennial	CS	PMSA	Census Tract	–41.303 (2.71)**
	% Tracts Sprawling by State	1970 to 2000, decennial	FE	State	Census tract	–0.519 (2.80)**
	% Tracts Urban by State	1970 to 2000, decennial	FE	State	Census tract	0.526 (2.83)**
	Predicted State Urban to Sprawl Ratio Using Excise Tax as Instrument*10	2000	CS	State	Census tract	0.233 (2.73)**
	Predicted State Percentage Sprawling Using Excise Tax as Instrument	2000	CS	State	Census tract	–0.873 (2.45)*
	Predicted State Percentage	2000	CS	State	Census tract	0.884 (2.48)*

	Urban Using Excise Tax as Instrument					
Zipcode Business Patterns as amended	Employment Density to Rank Gradient (β_z) *100	1998 to 2008, annual	FE	CBSA	Zipcode	–1.986 (2.17)*
	Employment Density to Distance Gradient (β_c) *100	1998 to 2008, annual	FE	CBSA	Zip code	–0.781 (2.29)*
Burchfield et al (20030 as amended	Burchfield et al Index of Sprawl	1976 to 1992, interval	FE	MSA	30x30m cell	–62.768 (2.12)*
	Burchfield et al Index of Sprawl gas prices normalized for fleet mileage	1976 to 1992, interval	FE	MSA	30x30m cell	-3.973 (2.46)*
*significant at 5% ** significant at 1% *** Fixed Effects (FE) or Cross Sectional (CS)						

Findings

Table 6–1 summarizes the findings and the effects of gasoline prices on sprawl using the three primary models and datasets. Based on the different metrics of sprawl used, it is clear that gasoline prices influence the gradient of population and employment density around cities, steepening or flattening it, alter the average density of tracts—shifting the proportion sprawling and urban upwards or downwards, alter the "inequality" or variance of population density captured by the Gini measure and standard deviation, alter the amount of open space consumed year–by–year in the course of development, and at a state level, alter the relative

amounts of sprawl from region to region. There is some evidence that gasoline prices also alter metropolitan levels of sprawl. A lack of long term, consistent data on gasoline prices at the level of metropolitan areas, however, limits the granularity of the findings on regional sprawl. All told, however, the dissertation demonstrates that higher gasoline prices exert a strong effect on sprawl that is robust to a wide variety of other variables including income, race, age, foreign born status, fleet economy and topographic and political variables.

While all of the metrics tested showed elasticity to gasoline prices, as discussed at greater length in the text, some can be interpreted in more intuitive terms than others. I now highlight four metrics that permit especially intuitive interpretations.

Population Density to Distance Gradient

The venerable population density to distance gradient permits a reasonably intuitive interpretation. On average, over the ten year intervals between 1970 and 2000, metropolitan areas witnessed a –1.237 decline in the gradient measure times 100. Dividing by 100, the rate of change in the gradient per $ change in gasoline prices was .01237. This can be compared with the mean gradient of –.1562097. Thus a $1 change in gasoline prices is associated with a –7.91884% change in the mean logged density–to–distance gradient.

Percent Sprawling Tracts

This measure is even more intuitive. It suggest that the log–log (or log linear) relationship of percent tracts sprawling to gasoline prices is –0.244. A log log relationship can be interpeted as a percent to percent relationship. Accordingly, it suggests that a 1% change in gasoline prices is associated with a .244% change in percentage of tracts that are sprawling implying elasticity of .244. Equivalently, a 100% change in gasoline prices is assocated with a 24.4% change in the pecentage of tracts that are sprawling. This is quite a significant effect in that at times of high volatility, gasoline prices have frequently registered large changes of 100% or more. It suggests, for example, that the gentrification that ocurred in American cities in the 1980s may have had as a partial cause the 1970s oil shocks. Simply put, it suggests that about a quarter of the change in tracts sprawling is attributable to gasoline prices, holding all else constant.

Percent Urban Tracts

Because of the close to reciprocal relationship between percent tracts sprawling and percent tracts urban, this variable exerts an equally intuitive, significant effect on urban intensity. Specifically, the coefficient of log of urban intensity regressed on log of gasoline prices has a value of 0.209. This suggests a 1% change in gasoline prices causes a .209% change in percent of tracts that are urban implying an elasticity of .209. Accordingly, a 100% change in gasoline prices causes a 20.9% change in percent of tracts that are urban. All in all, it shows that gasoline prices account for about a fifth of urban intensity measured as percentage of tracts that are urban, holding all else constant.

Burchfield et al index of sprawl.

Perhaps the most intuitive and powerful heuristic to emerge from my study arises from the regressions of the Burchfield et al index of sprawl on gasoline prices and controls. A unit (dollar) change in 2000 gasoline prices causes a –62.768 percentage point drop in the sprawl index multiplied by ten over a 16 year period after controlling for other variables, i.e. a –6.28% drop over 16 years in the index. This implies that a ten cent change in real 2000 gasoline prices caused a 63% point change in the sprawl index over the interval. As discussed, the Burchfield et al index equals the average of the percent of one square kilometer areas around dwellings that remain open space in each MSA. Therefore, a $.10 drop in gasoline prices, all things being equal, is associated with covering up .0628 of a square kilometer or the consumption of 62,800 square meters (6.28 hectares) of open space in each square kilometer over 16 years. Conversely, a $.10 increase in gasoline prices is associated with the preservation of 63,600 square meters (6.36 hectares) of open space over 16 years. This equates to an annual change of about 0.3923 hectares/$.10 change in gas prices per square kilometer or about 4 hectares of land consumed (or preserved) per square kilometer annually per $1 change in gasoline prices or 40 hectares over a decade. One can further interpret this as a 4% annual change in land covered per $1 change in gasoline prices. Thus, a $1 sustained real price change over 10 years would result in 40% more or less land being covered, all other things being equal and a $2 change would result in an 80% change in coverage. Of course, not everything has remained the same. Population increased, for example, placing additional pressure on land. Nonetheless, the finding that a $2 change in gasoline prices could lead to an 80% delta in land covered, holding population and other variables constant, is a remarkable finding.

Policy Implications

The role of gasoline prices in mediating sprawl revealed in the preceding analysis creates both policy challenges and opportunities. It creates challenges insofar as gasoline price is a volatile and largely exogenous variable in the United States economy that does not admit of easy regulation; moreover, gasoline price changes create winners and losers complicating the political economy of intervening in the market. For example, higher prices may benefit the environment and lower sprawl–while helping the energy industry but at the cost of others.

It creates opportunities, however, in that gasoline prices are also a single lever with potentially broad, cross cutting effects as regards urban development. Past efforts to slow sprawl and achieve environmentally sustainable development have employed other levers that often involve complex regulations and enforcement including intervention in housing markets, banking and finance regulation, land use policy and environmental regulation. In contrast, the lever of gasoline prices may be an equally powerful policy lever that is both simple to wield and comprehensive in impact.

Before delving into the policy implications of my findings it is important to note that econometric analysis must be used with care in formulating policy interventions. As explored by Lucas (1976) in the macroeconomic context, policy intervention in a market based on

econometric findings is likely to alter the very conditions that produced the observed effects. Nonetheless, the challenges of using gas prices as a tool to influence urban sprawl are not insurmountable. Though gas prices cannot be readily lowered (without drastic intervention in the market) they can be raised through a simple tax. And raising gasoline prices, my research suggests, lowers sprawl.

Taxes obviously impose costs, notably, the deadweight loss that results from a loss of welfare to consumers and producers in excess of the gain to the government. The deadweight loss and cost to specific actors in the economy may be addressed by using the proceeds of a tax to reduce a tax elsewhere. Perhaps the greatest single challenge is that a policy intervention that may be beneficial with respect to one outcome category of sprawl such as the environment, may be harmful in another area–such as economic equity. To untangle the complex interactions surrounding sprawl and energy cost, I discuss sprawl policy along a three dimensional vector of non orthogonal outcomes, recognizing that *desiderata* may involve tradeoffs. The dimensions though not all inclusive are instructive. They are the Environment, Efficiency and Equity.

Environment

As discussed in Chapter 3, research suggests that sprawl is, on balance, detrimental to the environment. The chief negative environmental consequences of sprawl are excessive land consumption and air pollution from burning fossil fuels due to higher energy intensity relative to

denser living. (It is not clear that either solid waste or water pollution vary by density.) Higher gasoline prices, therefore should aid the environment, not only by lowering emissions from driving, thanks to the price elasticity of gasoline demand, but also by reducing sprawl.

A variety of policy tools are in use to mediate gasoline price while others have been proposed. Gasoline taxes are perhaps the most obvious way to raise the price of gasoline. Existing taxes imposed at diverse levels of government include the federal gas tax (introduced to support the Highway Trust Fund at the time of the creation of the interstate highway system), excise taxes and sales taxes (that are *ad valorem*). Proposed carbon taxes of the type used in some countries would effectively tax gasoline. Tariffs on imported oil would raise the price of gasoline. Finally, many variants of a cap and trade regime covering the emission of heat trapping gases would also raise the final price of gasoline. All of these taxes, by raising the price of gasoline, my findings suggest, would lower sprawl.

A question that arises in evaluating a gasoline tax is whether an excise or *ad valorem* tax is preferable. If the goal is to secure a specific quantity of revenue, for example, to service a class of bonds, then an excise tax has certain advantages. Excise taxes are generally viewed as less distortive of economic behavior than *ad valorem* taxes because they do not fundamentally alter supply and demand curves. However, if the goal is to alter behavior, an *ad valorem* tax may be preferable because it retains a fixed percentage level of bite over time (compensating for inflation). An excise tax indexed for inflation would be stable and inflation protected. Since many metropolitan areas span multiple state and cities, a federal tax would have the advantage

of universal coverage. Other proposed revenue tax schemes for gasoline include a floor on gasoline prices that would support alternative energy.

While a variety of taxes are possible, federal or state, excise or *ad valorem*, any one would raise the price of gasoline. A federal excise tax indexed for inflation would have the advantage of influencing the entire country in a consistent manner over time, removing uncertainty from consumer and firm-level decision-making.

In short my research suggests that a gasoline tax on imposed at the federal level would have a large cross cutting effect on sprawl going forward. Specifically, using the Burchfield et al metric described above and subject to the Lucas critique, a .10 tax on gasoline per gallon would cut the level of space covered over the next ten years in half, holding all else constant. Thus a simple gas tax could go a long distance to mitigating the environmental cost of sprawl, at no significant net cost to the public. It would be possible to design a carbon tax or cap and trade regime to act like a gasoline tax with respect to gasoline. The other effects of a carbon tax or cap and trade regime, however, are likely to be extensive and lie outside the scope of this dissertation.

Before leaving the environment, it is appropriate to contrast this policy intervention with many other approaches that have been tried or are under discussion.

Table 6-2 provides a listing of policy interventions that have been tried or proposed and how they would influence sprawl. It indicates that many policy proposals have mixed effects. Electric cars, for example, would eliminate certain environmental costs of sprawl, substituting smokestack emissions from power plants for tailpipe emissions from cars. To the extent, power becomes less carbon intensive, electric cars could be cleaner than gasoline–based vehicles. However, due to the lower cost of electricity relative to gasoline, electric cars would promote dispersion, encouraging land consumption.

Fleet mileage standards are one way that the government has intervened in gasoline markets through the vehicles that consume gasoline. Evidence suggests that fleet mileage standards have cut gasoline consumption although there is some evidence that better mileage has led to more driving. Fleet mileage, however, my findings suggest, did not significantly alter the effect of gasoline prices on sprawl.

Another new method of taxing driving within cities is the congestion tax introduced in London and elsewhere. A congestion tax increases the price of driving into the city but, if mass transit exists, does not necessarily raise the cost of commute. Proponents argue it shifts the *mode* of commute to rail with associated environmental benefits. However, if levied on residents of the city, as it normally is, it provides no incentive to work and live in the city. Rather it promotes exit from the city to escape the tax. Thus, the congestion tax while it may reduce emissions in and about the city may have the unintended consequence of increasing sprawl outside it.

Table 6–2					
Effect of Selected Policy Measures on the Environment, Efficiency and Equity					
Policy Intervention	**Affected/Price Effect**	**Type***	**Environment**	**Efficiency**	**Equity**
State excise tax with offset	Gasoline +	D	+	+	–
Federal excise tax, inflation adjusted with offset	Gasoline +	D	++	+	–
Ad valorem or sales tax with offset	Gasoline +	D	++	+	–
Tax – No offset	Gasoline +	D	++	–	–
Tariff on oil	Oil +	I	+	–	–
Production subsidy of oil (pecuniary i.e. oil depletion allowance)	Oil -	I	–	–	+
Production subsidy of oil (non pecuniary i.e. drilling on federal lands)	Oil -	I	–	–	+
Consumption subsidy of gasoline (developing countries)	Gasoline -	D	–	–	+
Geo political intervention	Oil -	I	–	–	+
Vehicle Mileage Tax (VMT)	Transportation +	I	+	+	–
Congestion taxes	Transportation +	I	+	–	–
Bridge and Highway tolls	Transportation +	I	+	–	–
Parking fees/citations	Transportation +	I	+	–	–
New highways	Transportation -	I	–	+	+
HOV Lanes	Transportation =	I	+	–	–
Fleet mileage standards	Vehicles -	I	+	=	–
Tariff protection SUVs	Vehicles +	I	–	=	–
Subsidies for	Vehicles =	I	+	depends on	–

fuel efficient cars/Penalties for inefficient cars				pay-for/offset	
Electric car support	Vehicles -	S	+	+	=
Emissions Inspections	Vehicles +		+	+	–
Alternative energy technologies support	Other -	S	+	+	=
Mass transit subsidies	Transportation -	S	+	+	+
Means tested transport passes	Transportation -	S	–	–	+
Carbon tax with offset	Gasoline +	D	+	+	–
Cap and trade with offset	Gasoline +	D	+	–	–
Arterial highway construction	Transportation -	I	–	+	+
Bike lanes	Transportation +	S	+	–	=
Traffic calming	Transportation +	I	=	–	=
*D = Direct, I = Indirect, S = Substitutive					

All told, taxing gasoline at the national level to achieve stimulus or debt reduction as the case may be, at no substantial net cost to the public, compares favorably with other proposals at the environmental level.

<u>Efficiency</u>

Sprawling development, most research suggests, is less than Pareto efficient, relative to denser living. Cities, even under the best of circumstances, theory suggests, are inefficient due to the very externalities without which they would cease to exist. In the words of Lucas and Rossi-Hansberg (2002): "there is no reason to believe that market prices--land rents and location-specific wage rates--give firms and households the right incentives for making land use decisions." In the presence of externalities, the first fundamental theorem of welfare economics that an economy in equilibrium is *Pareto* efficient does not apply (Fujita and Thisse, 2002, p.26). Sprawl, the evidence suggests is the inefficient product of socially non-optimal decision-making based on prices that reflect external effects. While a general equilibrium analysis of the effect of a gas price increase on welfare lies outside the scope of this dissertation, the literature suggests that sprawl is inefficient and, therefore, any measure that reduces sprawl may be good for efficiency. The immediate cause of inefficiency is time and money spent in travel that reduces spillovers and positive externalities from agglomeration. However, the underlying source of excessive dispersion are the incorrect pricing signals that drive the actions of firms, developers and consumers whose private actions are not socially optimal. Brueckner and Fansler (1983) identify three market failures that lead to inefficient dispersion: lack of congestion pricing, not accounting for the value of open space and not charging for new infrastructure required by development. Despite a plethora of zoning, taxing and other interventions by governments designed to correct for these failures, sprawl remains ubiquitous and efficiency sub-optimal. My suggestion of an appropriately designed gasoline tax has the potential to influence sprawl in one stroke. Therefore, it is worth examining the efficiency consequences of intervening in gasoline price markets, recognizing that a full, general equilibrium analysis lies outside the scope of this dissertation.

A gas tax obviously imposes a cost on those who pay it. Apart from welfare issues, there are problems of political economy with any tax due to the natural objection of those who bear its burden. In the case of a gasoline tax, tax incidence affects producers and consumers alike due to similar price elasticities of supply and demand. Political objections by producers and consumers have, at times, combined to block or limit gasoline tax levies. The political problem can be solved, however, as evidenced by the large number of gas taxes in place.

However, a welfare problem also arises from the cost to consumers. Taxes create a deadweight loss to the economy that lowers overall welfare unless the benefits of changed behavior plus the return on proceeds of the tax outweigh the loss. If one accepts the view that government, on the whole, generates more value than its cost in taxes, then counting the tax revenues as general revenue and directing it to the funding of government may be sufficient to justify the tax. However, to secure political support for a tax and better calibrate its costs and benefits, many taxes direct proceeds to a specific goal. The federal tax on gasoline originally funded construction of roads through the highway trust fund, (though in 1991 the ISTEA legislation[9] refocused funding on intermodal transit). Since the tax originally funded roads, it stood to benefit producers and consumers of gasoline as much as it cost them and eventually secured enactment (Hall, 2002). Some states place gas tax revenues in an infrastructure fund. And some proposed variants of a carbon tax would use proceeds to lower the payroll tax[10]. Thus, for both political economy and policy purposes, a strong case can be made for using gasoline tax revenues to offset other taxes such as the payroll tax, or use proceeds to accomplish other

[9] "Intermodal Surface Transportation Efficiency Act of 1991 – Summary**" ,** http://ntl.bts.gov/DOCS/ste.html

[10] See Shapiro, Robert, " Midterm Advice for Congress: Tax Carbon Instead of Jobs", http://www.huffingtonpost.com/robert–j–shapiro/tax–carbon–instead–of–job_b_682744.html

worthy positive or normative goals that contribute to the public weal. Examples include debt reduction, general tax relief, investment in infrastructure or even sprawl mitigation measures such as mass transit or open space preservation. The precise welfare benefits of a payroll tax cut or debt reduction would depend on a host of variables that lie outside the scope of this dissertation; however, if tax cuts are matched to taxes collected, the deadweight loss can be largely offset before even counting the benefits derived from more efficient cities. If so by promoting denser structure, the tax *could* raise efficiency while lowering sprawl as measured by any of the metrics listed in Table 6-1. Thus, using the lever of gasoline prices to influence sprawl is not only environmentally sound but potentially economically efficient.

But is this the whole story? Countervailing the efficiency gains from greater factor substitution at the center is the tendency, observed by Rossi-Hansberg (2004) and others for firms to exit the center in response to higher commuting costs that cause higher land and labor costs at the core. Indeed, theory suggests that with commuting cost sufficiently high, the entire central business district might disappear. With travel disabled by excessively high costs, production would, in the limit, disperse entirely across the urban space, leading to "backyard capitalism" and a diffusion of local autarkies (Fujita and Thisse, 2002, p. 27). Short of this theoretical extreme, movement away from the center is one potential response to rising transport costs if it brings firms closer to labor, markets and suppliers. In sub-centers at or near the fringe, firms find lower levels of location externalities than at the center. But lower land and, potentially, labor costs can make up for fewer spillovers, particularly in some business sectors and occupations (Rossi-Hansberg et al, 2009). Indeed since the early 20th Century, certain employment activities have been exiting the core. The lowering of freight cost through invention of the gasoline

powered truck in the early 20th Century, launched a movement of certain forms of manufacturing plants away from railheads at the urban core to trucking depots outside the city (Jackson, 1985)

While land costs are generally cheaper at the fringe, labor costs are not necessarily lower for all skill and occupational levels. Rare skills that can only be sourced from a large distribution of people are likely to be scarce at the periphery. And having to draw rare skilled labor from the center or entire metropolitan area negates the labor cost advantage of moving to the fringe. A hub and spoke system of transport further advantages the center relative to the fringe. However, if skill requirements are low and transport is non-radial, then local workers at the fringe are likely to suffice. Local workers at the fringe may be expected to lower labor as well as land costs since they need not commute. Thus higher transportation costs can shift jobs to sub-centers even as they concentrate population density.

The problem for efficiency with employer exit from the core is that it may reduce spillovers and increase the gap between the optimal and equilibrium land allocation (Rossi-Hansberg 2004). This effect is mitigated by the fact that population shift to the center is likely to raise efficiency as workers near the center benefit from economies of scale in public infrastructure and shorten time spent commuting. Firm dispersal can be reduced through zoning—promoting commercial zoning at the center and residential zoning at the fringe, or less easily, through location specific labor subsidies. (Conversely, it can be widened by limiting downtown density through height requirements on buildings as in Washington DC or even New York City, encouraging the outward

movement of firms.) Finally, movement to sub-centers is more likely in some industry sectors than others—and therefore in some cities than others. Indeed it so happens that the sectors or occupations with less to gain from spillovers at the center are precisely those likely to disperse. Overall, the efficiency effects of raising the price of gasoline are probably positive with an offsetting tax reduction. Higher prices may promote transfer of some industry segments to the sub-centers. But on the whole, my research shows, they reduce sprawl measured using the metrics in Table 6-1 and, so, raise efficiency.

Once again, it is worth comparing this potential intervention with other common policy prescriptions.

A congestion tax may increase agglomerative benefits in the city by reducing friction to interaction. However, it may also reduce agglomerative benefits by limiting people downtown. And taxing downtown driving may promote sprawl.

The construction of radial arteries in and out of cities (such as the expressways built by Robert Moses in New York, or the elevated highways being built in Chinese cities today) may improve efficiency by speeding up traffic; however, they are also likely to increase population dispersion by lowering the price of commute.

Once again a gas tax would appear to compare favorably with other policy alternatives.

Equity

Finally sprawl is associated in the literature with spatial segregation by income and race that is inequitable to disadvantaged cohorts. (For an alternative view, see Glaeser, 2001) Those with the means to leave the core are able to escape redistributive taxation, enjoy positive externalities through association with others of like means, and exercise greater political power in smaller, homogeneous communities, all while free riding on the services of the city (Jackson, 1985). In contrast, those lacking the means to exercise locational choice may spatially segregate into areas of high taxation, concentrated negative externalities and diluted political power. When choice is limited by formal or informal racial barriers, the inequity can be pernicious and persistent.

It is important to note that the separation of a metropolitan area into zones is not necessarily *Pareto* inefficient. Concentrating negative externalities associated with poverty such as crime, physical decay and drug trafficking in one place through zoning or other means, removes them from the rest of the city. During the 20th Century many municipalities tolerated skid row neighborhoods and red light districts populated by alcoholics and marginal residents using loitering laws to separate them spatially. The policy mitigated the problem of alcoholism for others through spatial separation but was hardly equitable for the alcoholics or residents. Even if Pareto efficient, separation by income or some variable closely linked with income, is likely to be inequitable.

The reasons that the poor and disadvantaged congregate in cities have been well studied. While land costs are high in center cities, density and divisibility of housing compensate sufficiently that housing, on balance, can be obtained less expensively. Recent ethnic groups may prefer to live near other immigrants due to shared language and culture and the social capital present in an enclave (an effect that diminishes in subsequent generations (Portes and Manning, 1986). Inner city residents–if they can find work nearby—do not have to pay for transportation that costs them more as a proportion of their income, relative to the affluent. They do no need to buy cars (Glaeser and Kahn, 2003). They are more likely to find work in cities in most occupations. The effective cost of moving out of the inner city is even higher than the nominal cost due to barriers to moving that include high search costs and discrimination. The result in the United States has frequently been economic and racial separation, notably the formation of inner city "ghettoes" during the 20th Century (Massey and Denton, 1993).

Increasing the cost of gasoline would have little immediate effect on low income residents of center city neighborhoods insofar as distances are small and public transportation advantaged in larger inner cities relative to driving. However, higher gas costs would make leaving the city more expensive and, thus, could reinforce spatial separation by income. In general, therefore, using gasoline taxes to influence sprawl would be detrimental to economic equity. Taken to the extreme, high transport costs to and from the city could recreate the social divisions in place during the early 20th Century when suburban living was the exclusive province of the well-to-do (Jackson, 1985). This motivates the search for a regime that would raise prices to achieve the

environmental and efficiency benefits of closer living without the equity cost imposed on the poor and disadvantaged who can ill afford even moderate increases in the price of necessities.

One potential solution to the equity issues imposed by higher gasoline prices is to subsidize mass transit. Mass transit is the mode of transportation used most often by the income constrained. Accordingly, spending a portion of the proceeds of the tax on mass transit, subject to precise price elasticities that lie beyond the scope of this dissertation, could alleviate the equity issue.

Conclusion

In conclusion, therefore, my dissertation has shown that gasoline prices have a statistically significant, causal effect on sprawl that suggests a potentially powerful, but so far untried method of controlling sprawl and its negative outcomes. A simple gasoline tax imposed at the federal level with proceeds used to lower other taxes and fund mass transit could aid the environment and improve economic efficiency. Depending on the precise levels of subsidy and tax relief elsewhere, it could maintain or even improve equity within metropolitan areas. While the key finding that gasoline prices influence sprawl offers evidence in support of the sprawl mitigating effect of other potential policy initiatives to influence gasoline prices, such as a carbon tax, cap and trade regime or tariff on imported oil, a simple gas tax with a corresponding offset offers a promising, potentially powerful solution to the negative outcomes linked to sprawl.

APPENDICES

Appendix A: A Theoretical Model of the City

The Alonso Mills Muth (AMM) model of the city provides a well understood framework with which to analyze the city. As anticipated by von Thunen (1966), pioneered by Alonso (1964), Muth (1969) and Mills (1972) and further developed by Wheaton (1974), Brueckner (1987), Fujita (1989), Rossi-Hansberg (2009), Bertaud and Malpezzi (2003) and others, the canonical model describes a monocentric city where agents bid for proximity to a central location until the price of housing precisely offsets that of commuting. At equilibrium, utility is constant across the city. Lower priced housing at the fringe causes consumers to substitute housing for other goods and higher priced land at the center causes producers to substitute structure for land leading to exponential decline in population density by distance. Key variables in the model are housing transport quantities and cost, a composite other good, its cost, distance from the center, wages, working age population, the size of the city in people and externalities a firm enjoys at the center. Different models highlight different variables that play a role in urban structure and growth.

Building on the canonical model, in particular, Brueckner (1987) and Bertaud and Malpezzi (2003), I make several adjustments[11]. A model rich enough to capture the effect of gasoline prices on population density, employment and light visible from space, while controlling for

[11] My model embodies features from a wide variety of models in the economics literature. I make use of the simplification of Brueckner (1987) of setting the budget constraint equal to wage minus the cost of commuting and setting the price of the non-housing good =1; I follow Muth (1969, p. 70-74) rather than Mills in allowing workers to reside outside the CBD; I follow Rossi-Hansberg et al (2009) in allowing firm fragmentation. I follow Malpezzi and Bertaud (2003) in my derivation of the function of population density decay. The explicit use of the arguments ***g***, gasoline prices and ***α*** to allow for social and demographic variables in the function ***t*** of transport cost is, as far as I know, original to my model.

economic and demographic factors, must include additional variables. I adjust the model to highlight the role of gasoline prices, allow for non-economic, social variables such as race and account for topographical heterogeneity. I do this by adjusting transport cost, setting the marginal cost of transportation to the cost of fuel and adding a separate parameter that absorbs the effect of social and demographic variables, and by adjusting the production function for housing to account for diversions of space from a featureless plane.

The Basic Model

Consider a city, ***C***, populated by ***N/s*** agents where ***s*** is the percentage and ***N*** the number of agents who work, occupying space, ***L-θ*** where ***L*** is circular and ***θ*** represents unbuildable land. Citizens or agents work at a firm, ***F***, with two locations, l_1 and l_2 that produce goods as described below. Location in the city is described uni-dimensionally as ***l(d)*** where ***d*** is the distance from the center. l_1 is located at the center of the city, ***l(0),*** while l_2 is located at the city edge, ***l(r),*** where ***d=r*** is the city's radius.

The firm pays wage, ***kW (W=ωc***) where ***ω*** is an exogenous wage***, E(c) = 1*** and ***k(d)*** $\in$ ***[0,1]. k*** varies by firm location so that l_1 pays wage ***W (k=1)*** while l_2 pays wage ***Wk (k<1)***. The variable ***c*** absorbs differences in human and social capital. Agents have, on average, ***E(k)W*** and, in aggregate, ***NE(k)W*** income to spend. One can think of the city as having a primary industry located at the center ***l(0)*** that benefits from spillovers and returns to scale and a secondary

industry located at the fringe ***l(r)*** to minimize costs that produces local goods. The agglomerative benefits of the center can be modeled as increasing returns to production at the center or, as I do here, by discounting the wage away from the center by the factor ***1-k***.

The Consumer Problem

Agents consume three goods, housing, ***H*** in proportion, ***j*** to land, ***L***, initially fixed at ***1*** so that ***h=jL*** (where ***h*** denotes h_D in the consumer side of the problem***)***, transport to and from work, ***T(d),*** dependent on the distance of commute, ***d***, and a residual, composite good, ***O***. Goods cost ***P*** where ***P*** is a vector of prices, $P_H(d)$ for housing, dependent on location, ***d***, $P_T(g, a)$ for commuting, dependent on the cost of fuel, ***g***, where ***g*** is set exogenously, and other variables, ***a***, and P_O for the residual good, set exogenously. We can think of ***a*** as a composite variable able to perturb commuting cost that may represent deviation of the space from a featureless plane, social barriers to mobility or omitted variables. Note that prices, P_H and P_T are endogenous to the model while P_O is exogenous Agents choose bundle ***(h, t, o)*** over the opportunity set ***H x T x O*** according to locally non-satiated economic preferences that can be represented by a utility function, ***U (h, t, o)***. To satisfy the mathematics, this utility function is assumed to be quasi-concave and twice continuously differentiable in all its arguments.

Each agent therefore seeks to maximize utility:

(E 1) $\boldsymbol{Max\ u(h,t,o)}$

$$\boldsymbol{s.t.\ hP_H+tP_T+oP_O= E(k)W}$$

Partial equilibrium in the city is achieved when the agents Pareto maximize their overall utility, ***U***.

$$\boldsymbol{Max\ U = max\ \Sigma_{1\ to\ n}\ u_i(h,t,o)}$$

To solve the problem, begin with the simplified case where $\boldsymbol{k = 1}$, $\boldsymbol{c=1}$ and ***O*** and ***a*** are unavailable. In this case, by assumption, everyone works at $\boldsymbol{I_1}$, the city center earning ***W,*** the agents spend all their income on housing and commuting and the cost of commute is set exclusively by ***g***, the cost of fuel. The problem reduces to:

(E 2) $\boldsymbol{Max\ U(h,t)}$

$$\boldsymbol{s.t.\ hP_H +tP_T = W}$$

Let $\boldsymbol{L = U(h,t)+\lambda(W-hP_H-tP_T)}$

The first order conditions are:

$\frac{\partial L}{\partial h} = U_h - \lambda P_H = 0 \qquad U_h = \lambda P_H$

$\frac{\partial L}{\partial t} = U_t - \lambda P_T = 0 \qquad U_t = \lambda P_T$

$\frac{\partial L}{\partial \lambda} = (W - hP_H - tP_T) = 0 \qquad hP_H = W - tP_T$

Accordingly,

$\frac{U_h}{U_t} = \frac{P_H}{P_T} \qquad MRS = \frac{-U_h}{U_t} = \frac{-P_H}{P_T}$

We have set the daily price of commuting, $P_T(g,a) = g$. We also know that the quantity of the daily commute, $t(d)$, is $2d$ so that the cost of the commute, tP_T is $2dg$. Agents choose their level of t=$2d$, by choosing d, their location such that a one unit change in d becomes a $2d$ change in t. At the maximum where $u=\underline{u}$, $U_T dt = - U_H dh$. Thus any change in utility resulting from a small change in $t=2d$, $U_T * 2dd$ requires an offsetting change in utility derived from a small change in h, $U_H * dh$. At equilibrium, the same is true of expenditure. A small change in d that raises commuting cost by $2gdd$ also necessitates a $-2g$ change in $P_H h$, the share of income spent on housing so that $2gdd + dP_H h = 0$.

Rewriting this as:

(E 3) $$\frac{dP_H}{dd} = \frac{-2g}{h},$$

yields a formulation that has been called the fundamental theorem of urban economics (Brueckner, 1987, Bertaud and Malpezzi, 2003). It states that at equilibrium, the change in housing price with respect to distance is the negative of commuting cost normalized by housing.

Equivalently:

(E 4) $$\frac{dP_H}{dd} h = -2g$$

We have not yet specified a utility function but from the budget constraint:

(E.5) $$h = (w-2dg)/P_H.$$

If we constrain agents to identical quantities of housing, set to 1 for convenience, they maximize their individual utility, $u=\underline{u}$ along the line, $P_H = w-2gd.$ The partial derivative of P_H with respect to d is $\partial P_H/\partial d = -2g$. The partial of P_H with respect to w is 1.

This leads to the diagram in Figure A-1 on the axes of housing price and distance from the center.

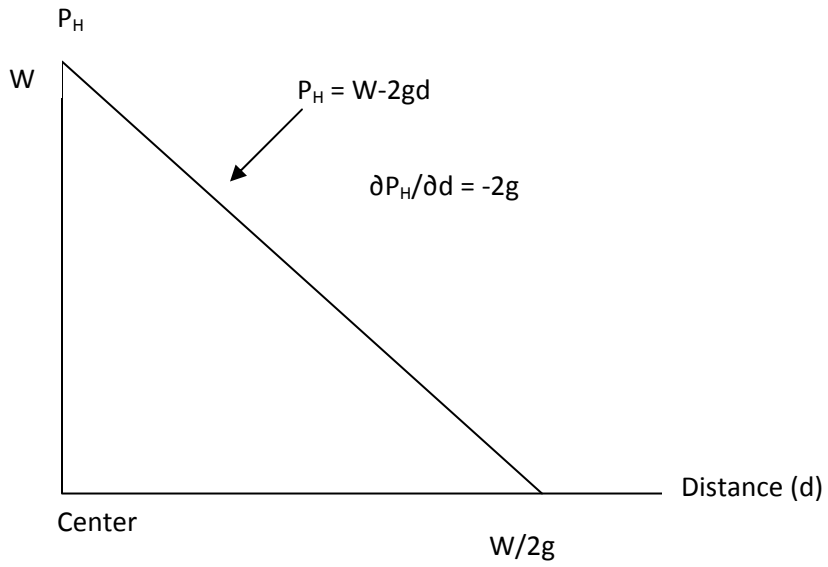


Figure A-1: A Simple Model of the City

I now carry out comparative statics to examine how different variables affect $\boldsymbol{P_H}$, the price of housing.

The price of energy, ***g***, is exogenous. The partial derivative, $\boldsymbol{\partial P_H/\partial d = -2g}$ captures how $\boldsymbol{\partial P_H/\partial d}$ changes with respect to ***g***. If energy prices, ***g***, rise, holding all else constant, the slope of the line will decrease. Conversely, if ***g*** declines, the slope will increase. Energy prices will therefore rotate the line clockwise if ***g*** goes up and counterclockwise if ***g*** goes down, steepening or flattening the gradient. The change in housing price with respect to energy $\boldsymbol{\partial P_H/\partial g = -2d}$ is a negative constant at a given ***d***, so that housing price varies negatively with cost of transport. Note that $\boldsymbol{P_H}$ must absorb residual wealth changes in this simple model because ***h***, $\boldsymbol{P_T}$ and ***t*** are fixed for a given ***d*** and ***g.***

The wage of the agents, $W=\omega$, is also exogenous, entering the model through the budget constraint. The partial derivative of P_H with respect to wages, $W, \partial P_H/\partial W=1>0$ captures the effect on prices. A higher W will lead to a higher P_H. Thus P_H is increasing in W.

In turn, the outer boundary of the city, $W/2g$, that we called r, is increasing in W. For now, W is exogenous so as wages rise, the city grows. If we imagine one city, C with wage, W and another city, C' with wage $W'>W$ such that $W'=zW$ where $z>0$, then C' will be larger in radius by a factor of z.

Finally, $w/2g$, that we called r is decreasing in g which is also exogenous. As gasoline prices rise, the city shrinks. This fact is important to efficiency as cities, in the real world, do not shrink costlessly.

The key implications of the model, so far, are therefore:

(1) $\partial P_H/\partial d = -2g < 0$

(2) $\partial P_H/\partial W = 1>0$

(3) $\partial r/\partial W>0$

(4) $\partial r/\partial g < 0$

Next, I relax the assumption that ***h = 1***, so that agents can consume more or less housing and make ***O*** available so that they may choose between ***H*** and ***O***. The variable, ***α*** denoting other influences on transportation cost, remains unavailable. Agents now optimize utility over ***(HxTxO)*** with ***T=2d***. However, to simplify the mathematics, following Brueckner (1987), I adjust the wage, ***W*** to incorporate the fixed transport expense = ***2dg*** and also set $P_O = 1$ for convenience. This transforms the problem into one where the agents maximize utility over two commodities ***(H, O)*** subject to income = ***W-2dg***.

$$Max\ U(h,o)$$

$$s.t.\ \ hP_H + o = W - 2dg$$

Solving for P_H^* and P_O^*, as above, yields the following equations:

(E 6) $\dfrac{U_h}{U_o} = P_H \qquad MRS = \dfrac{-U_h}{Uo} = -P_H$

As before, ***u(h, t, o)*** = ***u***, a constant at equilibrium.

In this revised version of the model, the adjusted wage, ***W-2dg***, now reflects the cost of commuting ***-2dg.***

Figure A-2 depicts new budget constraints for different values of ***d***, $d_0<d_1$ graphed on the axes, ***O*** and ***H***:

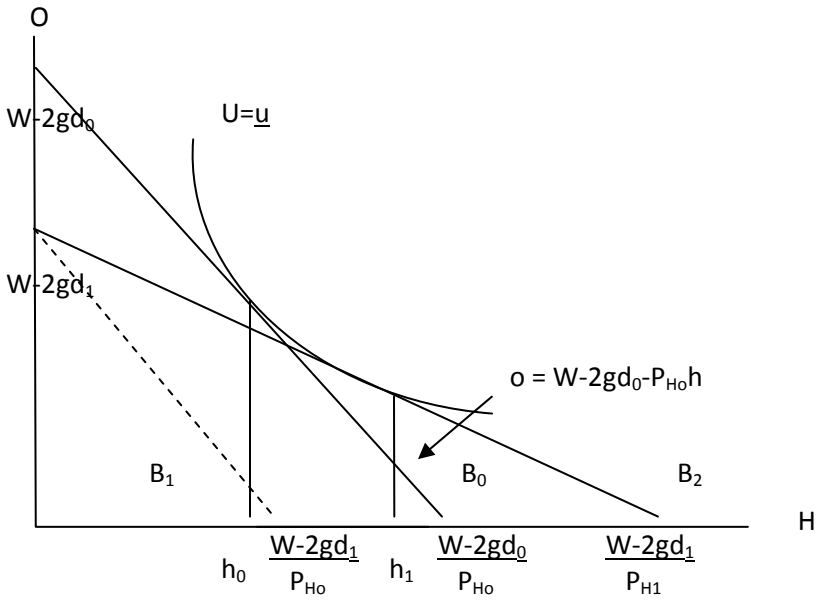


Figure A-2: A Three Good Model of the City

It is clear from this diagram that if $d_1>d_0$, then, holding P_H constant, the budget constraint based on d_1 would shift southwest from B_0 to B_1 reflecting a decrease in the ***O*** intercept, ***W-2dg*** as ***d*** increases. The slope would remain fixed at $-P_H$. Utility would also decline to the point of tangency with the reduced hypothetical budget line, ***B1***. $P_H(d)$, however, is itself dependent on ***d*** such that ***u(h, o))***= constant. It declines as ***d*** increases. Accordingly, the budget line does not shift to the southwest but rather rotates ***(B2)*** to a new point of tangency with the utility curve that preserves utility, ***u*** at the new price, $P_H(d_1)$.

Significantly, this change is accompanied by an increase in housing consumption, ***h,*** from h_0 to h_1. This increase, equal to the substitution effect arising from the drop in P_H from P_0 to P_1 means that housing consumption is increasing in ***d***. The substitution effect is exactly equal to the slope of the compensated (Hicksian) demand curve times the change in P_H with respect to h[12]. Thus agents consume more housing when they move out from the center, a consequence of the model that conforms with intuition.

Let us now examine mathematically how variables in the model affect ***h.*** Given the number of endogenous relationships in the model, I evaluate the total derivative that includes direct and indirect effects. The following assumes constant utility, ***u*** and from E 3, $\frac{dP_H}{dd} = \frac{-2g}{h}$,

The total differential of $h(P_H, P_O, d, g, w)$ is:

$$dh = \frac{\partial h}{\partial P_H} dP_H + \frac{\partial h}{\partial P_O} dP_O + \frac{\partial h}{\partial d} dd + \frac{\partial h}{\partial g} dg + \frac{\partial h}{\partial w} dw$$

Examining the derivatives in turn:

$$\frac{dh}{dP_H} = \frac{\partial h}{\partial P_H} + \frac{\partial h}{\partial P_O}\frac{dP_O}{dP_H} + \frac{\partial h}{\partial d}\frac{dd}{dP_H} + \frac{\partial h}{\partial g}\frac{dg}{dP_H} + \frac{\partial h}{\partial w}\frac{dw}{dP_H}$$

[12] The Hicksian or compensated demand function, $h_h(H_P,u)$ solves the expenditure minimization problem, $min\ E(H_P,u)$, subject to $utility = u$, a constrained optimization problem. The well known solution using Sheppard's Lemma is $h_h = \partial E/\partial P_H$.

As P_H decreases, ***h*** increases (and vice versa). This is due to a substitution effect as agents substitute between ***h*** and ***o.*** The own price elasticity of ***h***, $\partial h/\partial P_H = \partial h_h/\partial P_H \,|_{u=constant} < 0$[13]. P_H has no effect on ***w***, ***g***, ***d*** or $P_O=1$. The second term is zero as P_0, fixed at 1, is not affected by a change in wage. The third term is negative as housing declines with distance. Accordingly, since the total derivative is negative, ***h*** is decreasing in P_H

$$\frac{dh}{dw} = \frac{\partial h}{\partial w} + \frac{\partial h}{\partial P_H}\frac{dP_H}{dw} + \frac{\partial h}{\partial P_O}\frac{dP_O}{dw} + \frac{\partial h}{\partial d}\frac{dd}{dw} + \frac{\partial h}{\partial g}\frac{dg}{dw}$$

It is also clear that $\partial h/\partial w = 1/P_H > 0$ so that consumption of housing is wage elastic. Wages have no impact on ***g, d*** or $P_O=1$ and now P_H . With the normal good, ***h*** freed to vary, it now absorbs wealth changes. Thus, $\partial h/\partial W > 0$. Since housing is a normal good, this finding is consistent with intuition. People consume more housing as income increases.

$$\frac{dh}{dg} = \frac{\partial h}{\partial g} + \frac{\partial h}{\partial P_H}\frac{dP_H}{dg} + \frac{\partial h}{\partial P_O}\frac{dP_O}{dg} + \frac{\partial h}{\partial o}\frac{do}{dg} + \frac{\partial h}{\partial d}\frac{dd}{dg} + \frac{\partial h}{\partial w}\frac{dw}{dg}$$

$\partial h/\partial g = -2d/P_H < 0$. Gas prices have no effect on ***w***, ***d***, or P_O. The other key terms for ***o*** and ***PH*** are negative as well. Accordingly, $dh/dg < 0$ so that as gasoline prices rise, people will consume less housing and as gasoline prices fall, they will consume more, consistent with intuition..

[13] The negativity of $\partial h_h/\partial P_H \,|_{u=constant}$ follows from the assumption of a diminishing MRS. It can also be derived from the properties of a rational binary preference relation. For a proof, see Nicholson (2005, p. 150.)

$$\frac{dh}{dd} = \frac{\partial h}{\partial d} + \frac{\partial h}{\partial P_H}\frac{d_H}{dd} + \frac{\partial h}{\partial P_O}\frac{dP_O}{dd} + \frac{\partial h}{\partial o}\frac{do}{dd} + \frac{\partial h}{\partial g}\frac{dg}{dd} + \frac{\partial h}{\partial w}\frac{dw}{dd}$$

The direct effect of ***d*** on ***h***, holding all else constant, $\partial h/\partial d=0$. Distance also has no effect on ***w***, ***g*** or ***Ho***. However, ***d*** has an indirect effect on ***h*** through price of housing, H_P as $\partial h/\partial P_H > 0$.

As in E 3, $\partial P_H/\partial d = -2g/h$ so that P_H is decreasing in ***d*** (to compensate for the cost of commute). Having allowed ***h*** and ***o*** to vary, the falling H_P as ***d*** increases, provokes a substitution effect, enticing agents to consume more ***h*** and less ***o***. Accordingly, ***h*** is *increasing* in ***d***. This is a significant finding in that it indicates that housing is ***not*** uniform across the city but increases away from the center. This prediction of the model clearly also conforms with intuition.

To the earlier implications that continue to hold, we can therefore add:

(5) $dh/dP_H<0$

(6) $dh/dW > 0$

(7) $dh/dg < 0$

(8) $dh/dd >0$

Next, recall that housing per agent is the inverse of agents per housing. Let $\delta = 1/h$ = agents per housing unit. Since we have set ***housing=land*j, δ*** is none other than a measure of agent or population density that varies inversely with ***h***.

Since $\delta = 1/h$, using the chain rule, $d\delta/dd<0$. As one moves away from the center, density decreases. Thus δ is also decreasing in d.

(9) $d\delta/dd<0$

Density as the inverse of housing is similarly decreasing in W and increasing in g.

(10) $d\delta/dW < 0$

(11) $d\delta/dg > 0$

Finally, recall that N agents maximize the total utility of the city $U = \Sigma_{i=1 \text{ to } n} u$. Housing is increasing in n such that $\Sigma_{i = 1 \text{ to } n} h < \Sigma_{i = 1 \text{ to } n+1} h$. As N rises, the total area, $Nh/j = \pi r^2 = 2\pi \int d^* \, dd$ and radius, r, of the city rise as well. However, because density is decreasing in d, the outer rings of the city with area $2\pi d^* \, dd$ are less dense than those at the center. Accordingly, as N rises and, consequently, r rises, density $1/h$ declines and change in density, $\partial\delta/\partial d<0$, the population density gradient flattens or rises, i.e. $\partial^2\delta/\partial d^2>0$. Thus, $\partial\delta/\partial n <0$. Intuitively, this suggests that as population grows, cities spread out and their density declines but their (negative) density gradients flatten or rise.

(12) $\partial\delta/\partial n<0$.

Now let ***β=∂δ/∂d<0,*** the density gradient. It is interesting to see what variables may influence ***β***, a negative number. Examining the above relations, it is clear, that ***∂β /∂w >0.*** As wages rise, causing agents to consume more housing, the gradient will flatten or rise:

(13) ∂β /∂w >0

Similarly, ***dβ/dg<0***. As gasoline prices fall, commuting costs, ***2dg*** will fall, wealth after commuting, ***W-2dg*** will rise and housing consumption will rise, lowering density. Thus, change in density with respect to distance, ***β*** will rise. Accordingly, lower gas prices will raise or flatten the gradient, while higher ones will lower or steepen it:

(14) dβ /dg<0.

The key results of exploring the consumer side of the problem so far are that gasoline prices, income and population size will all influence gradients of housing price and population density by distance within a city. I now turn to the producer side.

<u>The Producer Problem</u>

The producer side of the market explains how housing density, δ changes when we relax the assumption that land and housing are in fixed proportion. It also sheds light on why a CBD and suburban sub-center may exist and the role of industry sector in city structure.

The firm's problem is to maximize profits over a vector g of inputs and outputs, given a production function $f(g)$ and prices p. We can distinguish between input prices, p, and output prices, w so that the firm seeks to:

(E 7) $$\underset{g}{Max}\ \Pi = pf(g)-wg$$
$$s.t.\ \ g \geq 0$$

Let us also distinguish two different production plans pursued by the Firm at its two locations, $l(0)$ and $l(r)$ for making different goods. Let us examine production of housing, h (where h denotes h_S in the producer side of the problem). Focusing on location l_1 first, assume the Firm uses three inputs, capital, K, labor, W and land, L to produce h. The inputs have rental rates, P_K, exogenous and set to 1 for convenience, $P_W=kw\ (0\leq k\leq 1)$, as previously described, and P_L, land rent. Initially, I exclude labor, W, so that the problem simplifies to one of using two inputs, K and land, L to produce housing, $h(k,l)$. In the consumer problem, we held the ratio of housing to land to one ($j=1$). Relaxing that assumption to allow factor substitution between structure and land permits taller buildings that supply more housing per unit of land.

The simplified problem is:

(E 8) $$\underset{k,l}{Max}\ \Pi = P_H f(k,l) - P_K k - P_L l$$

The first order conditions of the problem are:

$$\Pi_K = P_H f_K - P_K = 0$$

$$\Pi_L = P_H f_L - P_L = 0$$

The MRTS =

$$\frac{\Pi_K}{\Pi_L} = \frac{MP_K}{MP_L} = \frac{P_K}{P_L}$$

Assuming that the firm is a price taker and malleable inputs can be freely substituted for one another in any increments, the firm will choose a production plan in proportion to prices subject to marginal productivity. Since we have set $P_K=1$, the firm will substitute capital for labor after accounting for productivity, at the rate of $1/P_L$. If we assume the production function, f is of Cobb Douglas form with constant returns to scale such that:

(E 9) $$h = f(L,K) = AL^{\alpha}K^{1-\alpha}$$

then differentiating ***f*** gives the marginal production functions:

(E 10) $$MP_L = \alpha h/L \quad \text{and} \quad MP_K = (1-\alpha)h/K$$

(We note for later use that $\alpha=a\sigma$ where $\alpha= a, \sigma=1$ when space is a featureless plane, and $\sigma \in [1, 1/\alpha)$. As discussed further on, we can think of σ as an unobserved variable that perturbs the capital to labor ratio when space is not featureless.)

At equilibrium, a unit of labor costing P_L yields αh share of housing worth $\alpha h P_H$ and a unit of capital costing P_K yields $(1-\alpha)h$ housing worth $(1-\alpha)hP_H$. Therefore, we can write:

$$P_L L = \alpha P_H h \quad \text{and} \quad P_K K = (1-\alpha)P_H h$$

Rearranging:

(E 11) $$L = \frac{\alpha P_H h}{P_L} \quad \text{and} \quad K = \frac{(1-\alpha)P_H h}{P_K}$$

And:

$$P_L = \frac{\alpha P_H h}{L} \quad \text{and} \quad P_K = \frac{(1-\alpha) P_H h}{K}$$

Substituting the production functions obtained above into E 9, the production function, $h = f(K,L) = AL^{\alpha}K^{1-\alpha}$ and rearranging yields:

(E 12) $$P_H = [A\alpha^{\alpha}(1-\alpha)^{1-\alpha}]^{-1} P_K^{1-\alpha} P_L^{\alpha}$$

E 12 shows that P_H varies with P_L but at the exponential rate, $\alpha<1$. Accordingly, as land rent rises, housing rent rises more slowly and therefore falls behind, a consequence of factor substitution. The (negative) decay of land rent from the center is steeper than that of housing and its rise toward the center steeper.

(15) $\partial P_H/\partial d > \partial P_L/\partial d$

Differentiating with respect to distance, ***d*** yields the housing price-to-distance gradient:

(E 13) $$\frac{dP_H}{dd} = A^{-1}(\alpha P_K/(1-\alpha))^{1-\alpha} P_L^{\alpha-1} P_{LD}$$

where P_{LD} is the derivative of P_L with respect to d.

To calculate the land price-to-distance gradient, let us now return to the consumer problem and the equality established E 4 of $(dP_H/dd)*h = -2g$. At equilibrium, the market for housing supply and demand must clear so we can equate h from the two sides of the problem:

(E 14) $$H_D = H_S$$

where $H_S = Nh_D$, i.e. aggregate housing.

Assuming constant price elasticity of demand, $h = B(w-2dg)^{\varepsilon^w} P_H^{-1}$ where B is a scaling factor, income elasticity$=\varepsilon_w$ and price elasticity$=-1$[14] and substituting for h in E 4 gives:

$$(dP_H/dd)B(w-2dg)^{\varepsilon^w} P_H^{-1} = -2g$$

Substituting the producer price-to-distance gradient in E 13, dP_H/dd into E 4, in turn, gives:

$$A^{-1}(\alpha P_K/(1-\alpha))^{1-\alpha} P_L^{\alpha-1} B(w-2dg)^{\varepsilon^w} P_H^{-1} P_{LD} + 2g = 0$$

Then substituting for P_H from E 12 yields:

[14] Empirical evidence suggests that price elasticity of 1 is a reasonable assumption in the case of housing. See Bertaud and Malpezzi, p. 84.

$$A^{-1}(\alpha P_K/(1-\alpha))^{1-\alpha} P_L^{\alpha-1} B(w-2dg)^{\varepsilon w}[[A\alpha^{\alpha}(1-\alpha)^{1-\alpha}]^{-1} P_K^{1-\alpha} P_L^{\alpha}]^{-1} P_{LD} + 2g = 0$$

This can be reduced to:

$$B(w-2dg)^{\varepsilon w}\alpha\, P_L^{-1} P_{LD} + 2g = 0$$

If to simplify notation, we set $\Psi^{-1} = B(w-2dg)^{\varepsilon w}\alpha$, then we can write:

$$\Psi^{-1}\, P_L^{-1} P_{LD} + 2g = 0$$

Thus:

$$P_L = B(w-2dg)^{\varepsilon w}\alpha P_{LD}/-2g$$

And, in turn:

(E 15) $$P_L = P_{LD}/(-2g\, \Psi)$$

Now let P_A equal the rent at the city edge when $d=r$, sometimes called the agricultural or reservation rent. Solving E 15 yields the urban land rent function $P_L(d)$ or land price-to-distance gradient:

(E 16) $$P_L = P_A e^{-\Psi 2g(r-d)}$$

Where e is the base of the natural log, P_A is a parameter equal to the reservation rent of land if not used for housing, ***i.e.*** land at the perimeter of the city (where ***d=r***), and ***Ψ2g*** is a parameter that captures the steepness or shallowness of the land price-to-distance gradient. Note that -***Ψ2g*** is negative so that land rent is decreasing in ***d.*** Note also that its determinants include not only ***g*** but the determinants of ***Ψ***, ***α, w*** and ε_w, underscoring the influence not only of gas prices but capital or land intensity of production, wages and income elasticity of housing demand on the land rent gradient. Note finally, the measurement of ***d*** relative to the city radius.

(16) $\partial P_L/\partial d<0$

Since the decay is exponential, the second derivative is positive.

(17) $\partial P_L^2/\partial d>0$

We turn next to population density with respect to distance, the population density gradient.

From E 11:

$$K = \frac{(1-\alpha)P_L L}{\alpha P_K}$$

Substituting for ***K*** in the production function, E 9 yields:

$$h = A[(1-\alpha)/(\alpha P_K)]^{1-\alpha} P_L^{1-\alpha} L$$

At equilibrium, $Nh_D = H_S$ so we can set h supplied to total h demanded, yielding:

$$A[(1-\alpha)/(\alpha P_K)]^{1-\alpha} P_L^{1-\alpha} L = NBw^{\varepsilon^w} P_H^{-1}$$

Substituting for P_H from E 12 yields:

$$A[(1-\alpha)/(\alpha P_K)]^{1-\alpha} P_L^{1-\alpha} L = NBw^{\varepsilon^w} [[A\alpha^{\alpha}(1-\alpha)^{1-\alpha}]^{-1} P_K^{1-\alpha} P_L^{\alpha}]^{-1}$$

Reducing and rearranging:

$$P_L L = NBw^{\varepsilon^w} \alpha = N\Psi^{-1}$$

where Ψ is the notation simplification expressed above. Rearranging:

$$\Psi P_L = N/L$$

Population density, $\delta = N/sL = \Psi P_L/s$, where s is the labor participation rate. We now rescale Ψ, setting it to Ψ/s for convenience and write the above as:

$$\delta = \Psi P_L$$

Thus the density gradient is simply the land gradient P_L times Ψ. Substituting for P_L from E 16 gives:

(E 17) $$\delta = \Psi P_A e^{-2g\Psi(r-d)} = \alpha e^{-\beta(d)}$$

where P_A is the reservation or agricultural rent, $\alpha = \Psi P_A e^{-2g\Psi r}$ and $\beta = 2g\Psi$ is a negative parameter that determines the steepness or shallowness of the gradient. It is clear from the above that when $d=0$, at the city center, $\delta = \alpha$ so α is the theoretical density at the center (rarely observed since the center is usually occupied by firms).

The logged version has the advantage of being conveniently linear:

(E 18) $$\ln \delta = \ln\alpha + \beta d$$

where β is normally negative.

This is the formulation of the density decay to distance relationship that forms the basis of much empirical analysis using the AMM model. Note that determinants of β include gas prices, capital or land intensity of production, wages, wage elasticity of housing demand and labor participation. City radius also enters into the formula. Since radius increases with population, city size will influence the parameters.

This constitutes the basic AMM model whereby 1) agents bid for land at the center until it precisely matches the cost of commuting from further out; 2) higher land prices at the center through a substitution effect cause lower density at the fringe; and 3) the price gradient leads to factor substitution of capital for land, creating an exponential rise in price and density at the center relative to the fringe. Key variables in the model are population size, population density, wage, energy cost, the cost of land, the cost of housing and labor participation. Accordingly, the model suggests that a full regression model specification for the population density gradient might be:

(E 19) $$\textit{Logged Population Density Gradient} = \alpha + B_1 \textit{Energy Prices} + B_2 \textit{Population} + B_3 \textit{Wage} + B_4 \textit{Labor Participation}$$

Model Extensions

While wages figured prominently in the consumer side of the problem, influencing city size, housing and other goods consumption and their prices, I held them constant in the producer problem. They nonetheless helped determine the value of β, the population density gradient as well as the gradients of housing and land cost through the budget constraint that figures prominently in the preceding analysis. Indeed, the role of constant wages is sufficiently large that most models of the city treat wages as exogenous.

Real cities, however, exhibit wage variety. Accordingly, I now allow wages to vary according to the variables c and k and assess how this affects the model. First, consider the case where there

are two wages groups, one "rich", one "poor". It is obvious that they will have separate indifference curves that vary in a way that is analogous to how otherwise identical cities would vary with ***W***. Since housing is a normal good, the rich will use their additional income to consume more of it. One can only consume so much transport and transport is less income elastic than housing. Indeed we fixed $P_T = g$ and transport cost, $tP_T = 2gd$ in the model so that ***t*** is wage inelastic. As we saw in (3) above, the indifference curve when ***w*** is high is shallower than when ***w*** is lower (Bertaud and Malpezzi, 2003, p. 22) as P_H is increasing in ***w*** but ***Pt*** is not. The rich spend more on housing in ***w***, ***w-2gd*** but transport cost stays fixed at ***2gd***, varying only with ***d***. When we allow ***h*** to vary as in (6), the rich consume more.

I now decompose ***w*** into the exogenous wage ω and local parameter***, c. C*** is a composite variable that absorbs differences in human capital, ***e*** and social capital, ***s*** that may influence wages. I define $c=e+s$ and set its expected value to ***1***. It is obvious that ***c*** is increasing in ***e*** and ***s*** as $\partial c/\partial e = \partial c/\partial s = 1 > 0$. If we define a group, η composed of $m<N$ agents with $E(c) = c_m$, due to their mix of ***e*** and ***s***, it is immediately clear that $W(\eta,c)$ will be increasing in $E(e)$ and $E(s)$. Therefore, one can expect to find the same dependencies of other variables in the model on ***e*** and ***s***, as we found on ***W***. Of key importance, we should find in the simpler model where ***h*** is held constant that housing price, P_H , land price, P_L and city size are increasing in ***e*** and ***s***. When we let housing, ***h*** vary, it, population density, ***n*** and the population density gradient, δ are rising in ***e*** and ***s*** as well. Even if ***e*** and ***s*** are unobserved, their effect should be discernible through ***W***.

For example, if a certain income group has income less than ***W*** such that $E(c)<1$ one might expect its presence to reduce sprawl through the income pathway as the cohort chooses less

housing closer to the center. To test this empirically, one would include a variable representing the cohort η in a regression of the dependent variable of interest on determinants. The parameter, c, whether or not observed, therefore, provides an analytical framework for studying income cohorts.

Social and Demographic Variation

While wages absorb the effect of income groups; they may also absorb the effect of ethnic, racial or demographic groups whose wages closely correlate with income. If an ethnic cohort has a low expected value of $W\,(E(c)|_{\eta=\underline{\eta}} < 1)$ we might also hypothesize it would seek out lower cost housing closer to the center. Again empirical testing should include a variable representing the group. However, while wages may absorb some variation by social or demographic cohort, in the common case of partial correlation between income and group, η, the group identity or identifying variable may exert an independent effect. Provision for this possibility in the model is made not through wages but through inclusion of the variable α, in transportation cost as discussed below.

Employment Location Variation

Allowing wages, W, to vary by $l(d)$ such that $W=kw(l)\ (0<K(l)<1)$, provides a way to model wage variation by location. Consider the case where some workers work at location l_2 at $l(r)$ on the urban fringe. These workers earn kw where $K<1$ making a locally traded good. The existence of a second work location at $l(r)$ allows its workers to bid more for housing near l_2 than workers employed at l_1. By working at l_2, however, they take a pay cut equal to $(1-k)w$.

In this example, we continue to impose the constraint of constant utility across the city at equilibrium. Gas prices remain exogenous. While agents working at l_1 will continue to bid up housing until its cost precisely matches that of their commute to the center, a separate group working at l_2 will bid up housing until its cost precisely matches the commuting cost to l_2.

For simplicity, assume that l_2 consists of a ring, rather than a point, of zero thickness. (It would be possible to model f_2 as a point using trigonometry but a ring simplifies the mathematics.) The distance of agents to l_2 equals $r-d$ if I constrain the radius to r. Allowing the city to expand, a change of notation form r to r_0 makes it possible to describe the distance of commute as $2|d-r_0|$. The price per unit, d, of their daily commute is g so that daily commute costs $2|d-r_0|g$.

Prior to the opening of the $l(r)$ location, all workers work at $l(0)$ earning W. Housing and land prices make agents indifferent to any location, $l(d)$. However, when allowed to work at the new location $l(r)$, prior to any change in cost of housing price, agents improve their welfare near $l(r)$ by an amount equal to the difference in commute cost to $l(0)$ vs. $l(r)$ net of the difference in wage. This difference equals $2gd-2g|d-r_0|= 2g(d-|d-r_0|) = 2g(2d-r_0)$ within r_0 (or $2gr_0$ beyond it). They weigh this benefit against a $(kW-W)$ wage penalty according to the tradeoff (inside r_0) of $2g(2d-r_0) + (kW-W) = 0$. When $k = 1$, the improvement to agents from working at l_2, before allowing housing cost to vary, ends at $\mathbf{d=r_0/2}$ where commuting costs are equal in either direction. However, if $k<1$, then $d^* =(w(1-k) + 2gr_0)4g$, so that the breakeven point now depends on k, W and g the cost of transport. The possibility of improving welfare by living and working near l_2, however, violates our earlier assumption of constant utility.

Accordingly, the benefit of living near l_2 disappears at equilibrium, as agents bid up the cost of housing until the benefit disappears. In the case where commuting is a perfect substitute for housing, housing cost will rise to offset exactly savings in commuting cost $2g(d-|d-r_0|)$ net of loss in wages $W-kw$.

We can therefore modify **E 5** in the case where $h=1$ and $d<r_0$ to allow for working at l_2 as follows:

(E 20) $P_H = \max(W-2dg, kw-2gr+2gd)$

Figure A-3 illustrates the relation of PH to d when agents can work at L_1 or L_2:

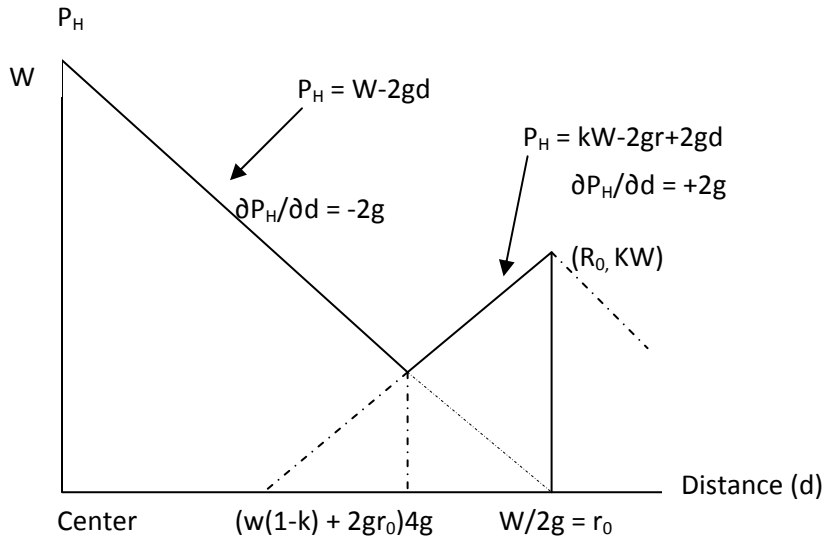


Figure A-3: Formation of a Sub-Center

From figure A-3, it is apparent that the presence of an alternative work location at ***l(r)***, in effect, creates a suburban sub-center, represented by an inflection point in $P_H(d)$ and a new local maximum at $l(r_0)$. It bears notice that P_H is rising in $K\ (\partial P_H/\partial k>0)$. When wages at the sub-center are very low, the gradient will experience minimal disturbance, however, when wages at $l(r_0)$, $kW(k=1) = W$, P_H at $l(r_0)$ will equal that at ***l(0)***. Moving to the three good case of ***(HxTxO)*** where ***h*** is allowed to vary, the presence of an alternative work location, past the inflection point, will alter the substitution effect from the decline in P_H that causes ***h*** to rise and density to decline. Density, in fact, will resume rising as P_H increases. Finally, in the producer side of the problem where we allow factor substitution of structure for land, the presence of an alternative work location, is certain, beyond the point of inflection to alter factor substitution that causes density to decline exponentially. Instead, density will resume rising at the inflection point. Accordingly, empirical analysis of city structure should contemplate existence of sub-centers. In particular, the model suggests that price-to-distance gradients and density-to-distance gradients may require modification in the presence of sub-centers. Potential methodological approaches include examining density-to-rank (Zipf) gradients where units of geographical analysis are re-sorted by rank, the use of sectoral and occupational control variables that may influence ***k*** or the segmenting of analysis to examine quasi-concave segments of the line separately from one another.

<u>Social and Demographic Variation Not Captured by Wages</u>

Whereas wages capture variation by social and demographic characteristics when those characteristics highly correlate with wages, it is often more interesting to examine wage independent effects. The parameter, ***c***, above, affects wage income available for all purchases,

o, t and ***h***. By including a parameter, ***α***, that affects transportation cost, P_T only but is allowed to vary by demographic group, it is possible to model demographic locational patterns. For example, if African Americans face barriers to moving to the suburbs, this can be modeled as a high cost of *effective* transport P_T due to ***α.*** An outright ban on mobility as in apartheid could be modeled as $a \rightarrow \infty$.

If we define a group, ***η*** composed of $m<N$ agents with $E(a) = \alpha_m > 1$, then the ratio m/N describes the weight of this cohort in the total population of agents. If α_m is statistically different from 1, then we can expect the observed P_T to vary from an unbiased P_T free of the group effect in proportion to m/N and α_m. While α_m is unobserved, controlling for m/n, helps to isolate the effect not only on P_T but its dependencies.

Accordingly, let $P_T = g\alpha$ where $\alpha \in [1,\infty]$. It is immediately clear that P_T is increasing in α ($\partial P_T/\partial \alpha > 1$), just as it is in ***g***, energy prices. In turn, variables with dependencies on P_T will have dependencies on α as well. Notably, these include the gradients of P_H, P_L and density, μ, or $\partial P_H/\partial d$, $\partial P_L/\partial d$, and δ, respectively. The direction of the effects of α on each are negative such that a higher value of α correlates with a lower (or more negative and, therefore, steeper) value of the gradient:

(18) $(\partial P_H/d)/\partial \alpha < 0$

(19) $(\partial P_L/d)/\partial \alpha < 0$

(20) $\partial\delta/\partial a<0$

Because cohorts of the population may have an effective transport cost far higher than the nominal price of fuel or public transportation, therefore, it is advisable to include controls for groups thought to face barriers to mobility in the regression model.

Note that two other possible ways to adapt the canonical model of the city to allow for demographic heterogeneity are imaginable. One could assume heterogeneous preferences and, in turn, utility functions and condition utility for agents on group identity. For example, foreign born agents might have a preference for dense communities (i.e. enclaves). One could adjust their utility function accordingly relative to other agents. This approach would, however, require a substantial sacrifice of generality.

A second approach would be to constrain a group from choosing a given location. For example one could define $\boldsymbol{d: 0<d<r/2}|_{\eta=\text{African American}}$. This approach, too, however, would sacrifice generality and tractability. Accordingly, I have adopted the formulation described above.

Topographical Variation

In the canonical AMM model, space is modeled as a featureless plane. Without sacrificing this simplifying feature, my model includes two parameters with the ability to absorb the effects of topographical variation in city structure (Burchfield et al, 2005). The first variable is ***d.*** One can simply limit ***d*** to a set value, fixing the radius of the city. A second variable is σ, as defined earlier, that perturbs the ***K/L***, capital to labor ratio.

Burchfield et al (2005) do not modify the classic model in studying topographic variation but merely state that space is not a featureless plane. They then include topographic controls in their regression specification. They do distinguish, however, between two types of topographical barriers, absolute ones such as mountains and relative ones such as ruggedness that they hypothesize exert *opposite* effects. They hypothesize that mountains, by hemming development in, promote density. In contrast, ruggedness may promote expansion as developers leap across rugged terrain. These effects can be independently accommodated in my model: the absolute barrier as a limit on ***d***, and rugged terrain through σ which alters the capital to labor ratio.

Bounding ***d*** clearly has many consequences. For example, increasing ***N***, reducing ***g*** or raising ***W*** normally increases the size of the city. With ***d*** bounded, as by a mountain or water, altering these variables will leave city land area and radius unchanged: $\partial r/\partial g = \partial L/\partial g = \partial r/\partial w = \partial L/\partial w = \partial r/\partial N = \partial L/\partial N = 0$. However, with land area fixed, other variables will absorb the effects. Key endogenous variables in the structure of the city are P_H, $\partial P_H/\partial d$, $\partial P_L/\partial d$, μ and δ. Let us survey how they respond to ***N***, ***g*** and ***W*** when ***d*** is bounded.

With ***d*** bounded, it is trivially true that P_H and μ are increasing in ***N***. Similarly, P_H is increasing in ***W*** and decreasing in ***g***. Thus:

$$dP_H/dN > 0 \mid_{d<constant}$$

$$d\mu/dN > 0 \mid_{d<constant}$$

$$dP_H/dW > 0 \mid_{d<constant}$$

$$dP_H/dg < 0 \mid_{d<constant}$$

Untangling the effect of ***N, g*** and ***W*** on the gradient variables is more complex.

With ***d*** and ***2d***, length of commute to the center, bounded, there is less opportunity for P_H to decline. The latter is the source of the substitution effect toward ***h*** that drives rising housing consumption in the classic model and contributes to declining density in ***d***. In contrast, bounding ***d***, limits land area, encouraging factor substitution of capital, ***K***, for land, ***L***, leading to taller structures and more density in ***N*** within the bounded city, potentially creating an ambiguous effect. Because effects may be indirect, I now focus on one variable, the population density gradient, $\delta = d\mu/dd$ and examine its total derivative.

The differential of $\delta(N,W,h,P_H,P_L,g,a)$ is:

$$d\delta = \frac{\partial \delta}{\partial N} dN + \frac{\partial \delta}{\partial W} dW + \frac{\partial \delta}{\partial h} dh + \frac{\partial \delta}{\partial P_H} dP_H + \frac{\partial \delta}{\partial P_L} dP_L + \frac{\partial \delta}{\partial g} dg + \frac{\partial \delta}{\partial a} da$$

Examining the derivatives in turn:

$$\frac{d\delta}{dN} = \frac{\partial \delta}{\partial N} + \frac{\partial \delta}{\partial W}\frac{dW}{dN} + \frac{\partial \delta}{\partial h}\frac{dh}{dN} + \frac{\partial \delta}{\partial P_H}\frac{dP_H}{dN} + \frac{\partial \delta}{\partial P_L}\frac{dP_L}{dN} + \frac{\partial \delta}{\partial g}\frac{dg}{dN} + \frac{\partial \delta}{\partial a}\frac{da}{dN}$$

More people create more demand for housing that with land fixed translates directly to density, enabled through capital. More people must therefore raise the overall capital to land ratio, but not necessarily change in the ratio in ***d***. The price differential between the center and boundary will not change as commute cost remains the same. For this reason the first and third terms are zero. Regarding the other terms, population has no effect on ***W***, ***g***, P_L (as we have assumed ω is exogenous) or unobserved transportation cost α. Accordingly, N will have no effect on δ providing that ***d*** is *entirely* bounded.

If the city expands in some directions but not others or leapfrogs a barrier, then N may influence δ, either by increasing the contrast between added structure at the center and the fringe—or if population spreads out where no barriers exist, flattening the gradient. In this case, the effect is ambiguous

$$\frac{d\delta}{dW} = \frac{\partial \delta}{\partial W} + \frac{\partial \delta}{\partial N}\frac{dN}{dW} + \frac{\partial \delta}{\partial h}\frac{dh}{dW} + \frac{\partial \delta}{\partial P_H}\frac{dP_H}{dW} + \frac{\partial \delta}{\partial P_L}\frac{dP_L}{dW} + \frac{\partial \delta}{\partial g}\frac{dg}{dW} + \frac{\partial \delta}{\partial a}\frac{da}{dW}$$

Wages have no effect on population or land. They enter the model through the budget constraint that governs quantity of goods demanded. With land fixed, additional housing demand can only be met through structure, increasing ***h*** but not population density relative to land. With ***d*** entirely bounded, there is no reason to expect the gradient within ***d*** to change from additional structure. However, if the city extends outward through breaks in the barrier then, as with above, the effect is ambiguous.

$$\frac{d\delta}{dh} = \frac{\partial\delta}{\partial h} + \frac{\partial\delta\, dN}{\partial N dh} + \frac{\partial\delta dW}{\partial W dh} + \frac{\partial\delta dP_H}{\partial P_H dh} + \frac{\partial\delta dP_L}{\partial P_L dh} + \frac{\partial\delta d\, g}{\partial g dh} + \frac{\partial\delta da}{\partial a dh}$$

Housing quantity is endogenous to the model and can only play a mediating role in other effects.

$$\frac{d\delta}{P_H} = \frac{\partial\delta}{\partial P_H} + \frac{\partial\delta dN}{\partial N dP_H} + \frac{\partial\delta dW}{\partial W dP_H} + \frac{\partial\delta dh}{\partial h dP_H} + \frac{\partial\delta dP_L}{\partial P_L dP_H} + \frac{\partial\delta dg}{\partial g dP_H} + \frac{\partial\delta da}{\partial a dP_H}$$

The price of housing changes in ***d*** in response to commuting cost, distance from the center and population. However, secular changes have no effect on the density gradient whether or not ***d*** is bounded.

$$\frac{d\delta}{dP_L} = \frac{\partial\delta}{\partial P_L} + \frac{\partial\delta\, dN}{\partial N\, dP_L} + \frac{\partial\delta dW}{\partial W dP_L} + \frac{\partial\delta dh}{\partial h dP_L} + \frac{\partial\delta dP_H}{\partial P_H\, dP_L} + \frac{\partial\delta dO}{\partial O dP_L} + \frac{\partial\delta d\, g}{\partial g dP_L} + \frac{\partial\delta da}{\partial a dP_L}$$

The price of land shapes the capital to labor ratio and therefore factor substitution. The density gradient is decreasing, normally, in the price of land as higher priced land drives more structure and density and, therefore, a steeper gradient. Bounding city size will not alter the gradient However, if the city extends outward through breaks in the barrier then, as above, the effect is ambiguous.

$$\frac{d\delta}{dg} = \frac{\partial\delta}{\partial g} + \frac{\partial\delta\, dN}{\partial N dg} + \frac{\partial\delta dW}{\partial W d g} + \frac{\partial\delta dh}{\partial d g h} + \frac{\partial\delta dP_H}{\partial P_H dg} + + \frac{\partial\delta dPL}{\partial O d g_H} + \frac{\partial\delta da}{\partial a dg}$$

The density gradient is decreasing in gasoline prices. When gasoline prices rise, bounding of d will have no effect. However, when gasoline prices decline, a bounded d will prevent expansion and a flattening of the gradient, subject, of course, as above, to breaks in the topographic barrier

$$\frac{d\delta}{da} = \frac{\partial\delta}{\partial a} + \frac{\partial\delta\, dN}{\partial N\, da} + \frac{\partial\delta dW}{\partial W da} + \frac{\partial\delta dh}{\partial h\, da} + \frac{\partial\delta dP_H}{\partial P_H\, da} + + \frac{\partial\delta dPL}{\partial PL\, da} + \frac{\partial\delta d\, g}{\partial g da}$$

Finally, the density gradient is decreasing in unobserved variables that raise effective transport costs for some, just as it is for gas. A bounded city is unlikely to interact with this effect as higher effective transport costs constrain transport in any case without recourse to a topographical barrier.

The other common deviation of space from a featureless plane involves ruggedness or terrain or barriers to development that impede it but do not block it entirely. It is not clear *a priori* how

ruggedness will influence the population density gradient. Inhospitable terrain could slow development by making it, for example, more costly. For example, it is possible to build on hills or wetlands but more expensive. For this reason, developers may delay building on rugged terrain, only to develop it later. On the other hand, as Burchfield et al observe, inhospitable terrain if passable could speed up consumption of land as developers consume more land to make up for portion of the rugged terrain that is unusable. In either case, one can model this effect as a disturbance in the capital to land ratio, ***K/L.*** For this purpose we earlier defined the variable $\sigma=\alpha/a$ where $\sigma \in (0, 1/\alpha)$.

As derived earlier, with a Cobb Douglas production function, the capital to land ratio depends on the parameters (α, 1- α) and prices such that:

(E 21) $$K/L = ((1-\alpha)P_H h/K)/ \alpha P_H h /P_L = (1- \alpha)P_L/ \alpha P_K$$

Unbuildable terrain results in less structure than would otherwise be built. Accordingly, it can be modeled as a suppression of ***K/L*** or, equivalently, increase in ***α*** relative to what would obtain otherwise. The variable ***σ*** defined above performs this function. As it rises, ***α*** rises as well, and ***1-α*** declines. The parameter ***α*** enters the parameter ***β*** representing the population density gradient derived above such that ***β*** is increasing in ***α.*** Accordingly, a higher σ leads to a higher ***β*** and flatter density gradient. Note that the model does not predict this effect. It merely allows for the possibility that rugged terrain may lower density by suppressing building relative to land. Empirical analysis is needed to test whether rugged terrain, in fact, contributes to sprawl.

Conclusion

In conclusion, the model just presented produces a set of results in the AMM tradition that are consistent with a wide body of empirical research. Its key prediction is that population density in an urban area declines exponentially from the city center according to the formula: ***Population Density = Ae^{-Bd}*** where ***A*** is a parameter equal to the density of non-residential land at the center when ***d=0*** and ***B*** is a parameter equal to the population density gradient that absorbs the effect of a wide variety of variables that include gasoline prices, the population of the city, wages, labor participation and in suitable variants of the model, sub-centers, industry sector and firm fragmentation, race, ethnicity, demographic variables and divergence of the city from a featureless plane.

Notably, the model does not address all features of the city found in real life such as leapfrog development, the effect, if any, of amenities such as schools and parks, open land or a greater proportionate role in political decision-making outside the center city or disamenties such as taxes and crime. However, it does address enough features to permit extensive empirical testing and, by virtue of the variables included, recommends appropriate model specifications for empirical regression analysis.

Appendix B: Zipf's Law and the Population Density of Urban Tracts

Named for George Kingsley Zipf, a Harvard linguist who pioneered the pairing of rank and size in linguistics and other areas of human ecology, Zipf's law (1949) describes a quantitative relationship between rank and size of the values of a variable whereby their product equals a constant. As applied to cities, Zipf's law states that the rank of a city times its population approximates a constant. In the United States, the largest city, New York with rank 1, for example, has about twice the population of Los Angeles with the rank of two and about three times that of Chicago with the rank of three and so forth.

The intuition for Zipf's Law is that large things like megacities and earthquakes are rare whereas small things—like towns and tremors are common. Zipf's Law provides a precise quantitative formula to describe this apparent regularity.

Mathematically, any pairings of values of a variable and their ranks must exhibit an offsetting relation between size and rank by virtue of the definition of rank, ie the mapping of a variable, ***X*** to the natural numbers.

If ***X*** is a set on the real numbers ***R*** of n elements, ***P*** is a subset of the natural numbers, ***N,*** {1…n} and r:X→P ranks the elements of ***X*** ∈ if $\boldsymbol{x_p} >= \boldsymbol{x_{p+1}}$ then

$x_p > x_{p'} \Longrightarrow p<p'$ and, conversely, $p>p' \Longrightarrow x_p < x_{p'}$

Thus, values of ***x*** having rank ***p*** will decrease as ***p*** increases and vice versa.

Zipf distributions, however, have the far stronger property of exhibiting a power law relation between the variable and its rank of degree one. Power relations take the form $x = f(p) = ap^{-b}$. Zipf relations are a special case in which $b=1$ so that $f(p)=ap^{-1}$.

Let X be a set on the real numbers, R, P be a subset {1..n} of the natural numbers, N such $x_p > x_{p+1}$ and Z be the set of their ordered pairs, $X \times P$.

Z is a Zipf distribution iff $x = ap^{-1}$ for any (x,p) belonging to Z.

It follows from taking the log of both sides that $ln(x) = ln(k)-ln(p)$. (This is a special case where $b=1$ of the analogous law for power relations by which $ln(x) = ln(k)-bln(p))$.
Because a Zipf distribution is linear in the logs of x and p but is unique in having $b=1$, a common test of a Zipf distribution is to regress the log of size on the log of rank and test if the coefficient $b \approx 1$ (Gabaix and Ioannides, 2004).

Power law functions including Zipf's Law have the important property that they are scale independent. Empirical studies of Zipf's Law of the size-rank relation of population of cities have found it to apply reasonably well not only to large cities but also to small settlements around the world (Krugman, 1996, Ioannides and Overman, 2000, Hinloopen and Van Marrewijk, 2006.)

For the purposes of this dissertation, it is not necessary that the population density of census tracts within a city be a Zipf distribution to use the rate of decay of population density with

respect to rank over time as a measure of sprawl. In fact, were Zipf's law to hold *for tract density* exactly in all cities for all years such that ***b*** was always equal to 1, then it would be of no value to track changes in *b* over time.

However, empirical studies of Zipf's Law with respect to city size and rank have found that ***b*** is generally somewhat different than 1 (Gabaix and Ioannides, 2004). Variance from unity is ascribed by scholars to a variety of factors impacting urban growth that include growth paths, factor accumulation and technology or factor shocks. (Rossi-Hansberg and Wright, 2003). While most scholars have focused on differences in production externalities as driving deviations from Zipf's law, insofar as city structure is held in many models to reflect the tradeoff of production externalities and transportation costs, change in transportation costs could also impact urban population and distribution.

To the degree the distribution of *tracts within cities*—my subject, as opposed to the distribution *of cities, t*he problem to which Zipf's law is ordinarily applied—resembles that of cities, there is ample basis to expect variation in the coefficient, ***b*** due to the influence of other variables.

Thus, whether or not a variation of Zipf's law holds for *tract density within cities* as well as the rank and size of cities themselves, there is precedent for measuring change in **b** over time—the coefficient obtained by regressing log of population density on log of rank assuming a power law relation, instead of ***β,*** the coefficient obtained by regressing log of density on rank assuming an exponential relation after Clark--as an indicator of sprawl.

I begin by determining an estimator of **b** across the population of 72 PMSAs at four points in time. I find that population density of tracts within cities does approximate Zipf's Law insofar as the values of ***-b*** converge on -1

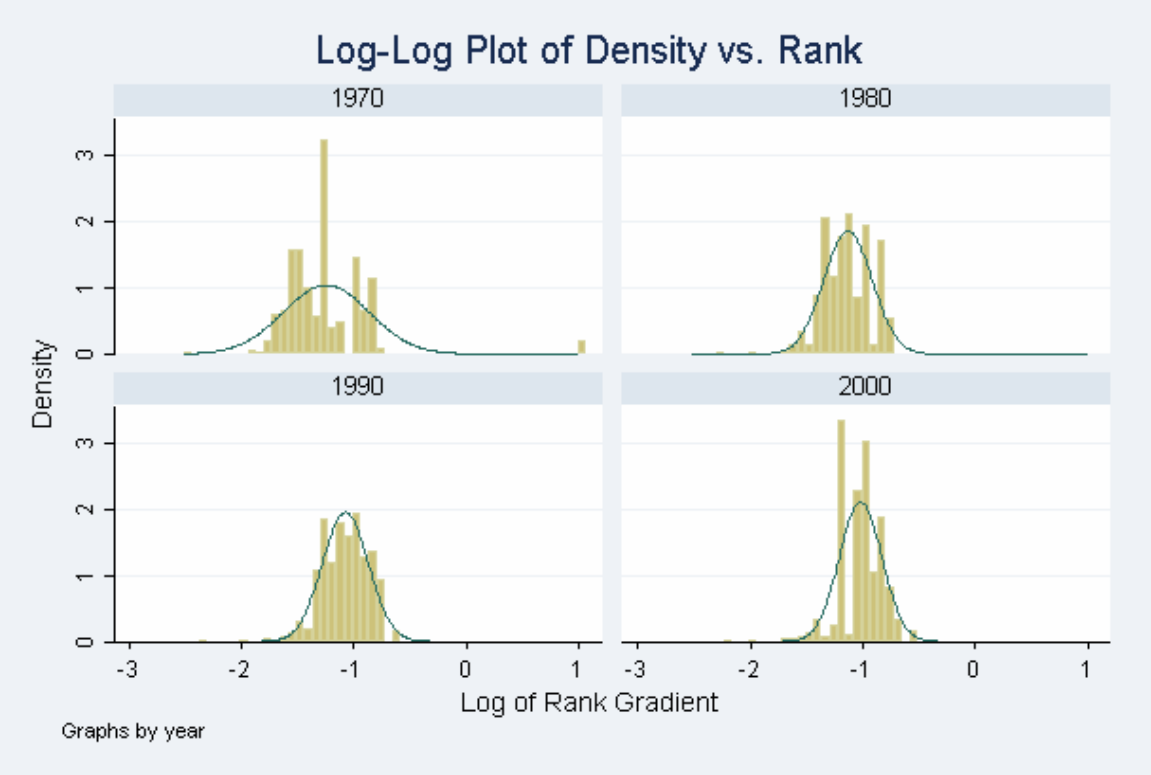


Figure A-4

Figure 5-3 illustrates the density of values of the coefficient, ***b***, obtained from regressing log of population density on log of rank for 72 PMSAs. It reveals the log-log coefficient, ***-b,*** to have a mean in the neighborhood of -1, i.e., the coefficient ***b ≈ 1***. The values are as follows: 1970(-

1.248053), 1980(-1.132777), 1990(-1.075384) and 2000(-1.021531). While t-tests comparing the means and -1 show them to be unequivocally, statistically different, they are as close to -1 as the mean commonly found in empirical testing of Zipf's law. (Gabaix and Ioannides, 2004) Accordingly, population density by tract within cities would appear to follow a Zipf distribution as commonly defined.

Figure A-5 provides a scatter plot illustrating as well the linear correlation of log of size and log of rank of tract density and a slope of the order of -1. However, while the mean rate of decay over all four years is -1.113398, the coefficients change by year as follows: 1970 (-1.445615), 1980 (-1.209857), 1990 (-.9530362) 2000 (-.8654724), reflecting increasing dispersion.

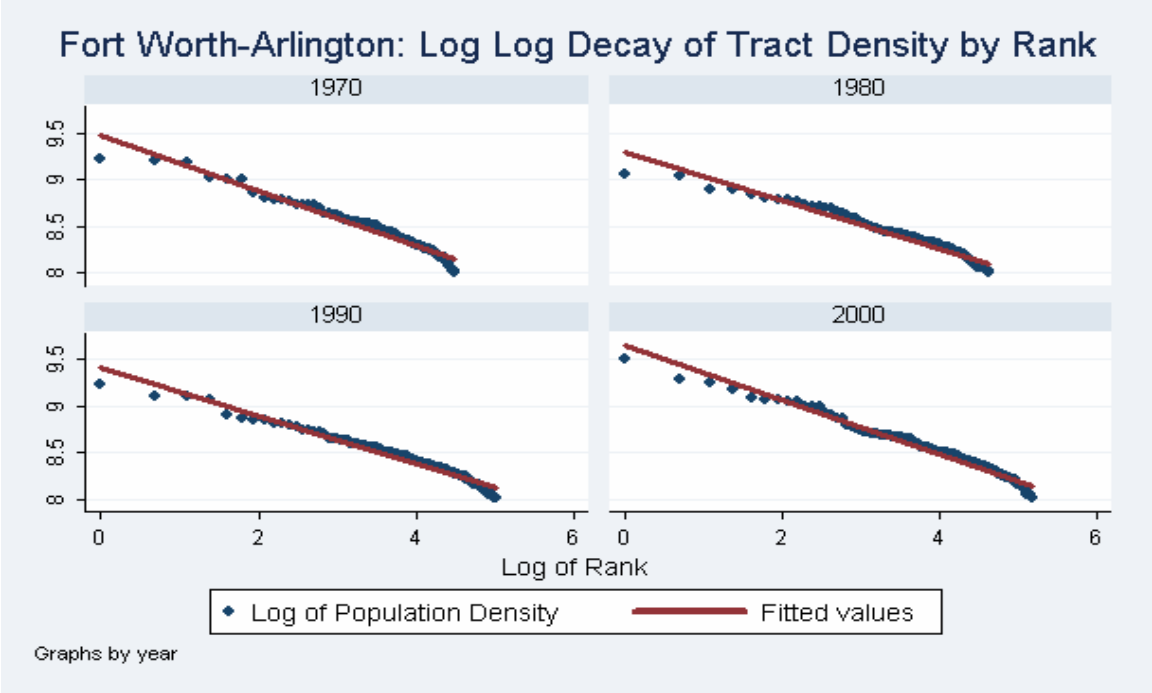


Figure A-5

Using ***b*** as my indicator of sprawl and regressing it on gasoline prices and the control variables motivated as above, I find that gasoline prices have a statistically significant impact on ***b*** as well as ***β*** (as shown in Table 5-2) with goodness of fit or R-squared reaching .69 when including controls**.**. Table A-I summarizes the findings.

Table A-1			
Fixed Effects Regression of Log-Log Density to Rank Decay on Gasoline Prices and Controls 1970 to 2000			
Dependent Variable: Coefficient of Regression of Log of Tract Density on Log of Rank * 100			
	(1)	(2)	(3)
	Gasoline Prices		
2-Year Lagged State Gasoline Prices	-0.581 (14.49)**	-0.542 (8.01)**	-0.321 (4.57)**
Population (millions)		0.115 (4.64)**	0.151 (5.79)**
Average Household Income (000)		-0.016 (3.72)**	-0.045 (2.99)**
Proportion White		-0.301 (1.72)	0.466 (1.76)
Family Income (000)			0.036 (2.51)*
Proportion Foreign Born			0.273 (0.79)
Proportion Black			1.145 (2.36)*
Proportion Hispanic			-0.159 (0.57)
Proportion Working age (18-64)			1.568 (5.31)**
Constant	-0.518 (9.76)**	-0.268 (1.45)	-2.459 (5.90)**
Observations	288	288	288
Number of PMSAs	72	72	72
R-squared	0.49	0.59	0.69
Absolute value of t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Higher gasoline prices are associated with a more negative value of ***b***, a steeper slope and, therefore, less city dispersion. This method which tracks the log-log regression coefficient assuming a power law relation (as opposed to the one used in Table 5-3 in the text that assumes an exponential relation following Clark) provides additional confirmation of the validity of using a Zipf size-rank measure of decay in population density as a marker of sprawl. I include this appendix as recognition of this additional confirmation; however, I use the coefficient, ***βz***, derived from assuming an exponential relation which also yields statistically significant results in the text due to the stricter analogy of the latter with the widely used logged density to *distance* coefficient, ***βc*,.**

Appendix C: Tract Population Density: Measures of Central Tendency

Table A-2				
Tract Population Density: Measures of Central Tendency, 1970 to 2000 for Selected Areas				
	1970	1980	1990	2000
Tract Level, All Tracts within All PMSAs	**Mean:**10716.93 **Var**:19474.58 **Min**:.0838926 **Max**:241320	**Mean**:9619.144 **Var**:16502.76 **Min**: .3355705 **Max**:226880	**Mean**: 9943.963 **Var**:17112.5 **Min**:.2992353 **Max**:227400	**Mean**: 10565.8 **Var**: 17989.79 **Min**:.0946298 **Max**: 223600
City Level All PMSAs	**Mean**: 1766.197 **Var**: 2375.69 **Min**: 22.36689 **Max**: 13040.42	**Mean**: 1719.498 **Var**: 2136.314 **Min**: 30.91383 **Max**: 11910.53	**Mean**: 1826.219 **Var**: 2180.621 **Min**: 33.01782 **Max**: 11841.13	**Mean**: 2000.37 **Var**: 2371.444 **Min**:45.31988 **Max**: 13037.36
Los Angeles PMSA (34)	**Mean**: 8842.105 **Var**: 6228.044 **Min**: .3290993 **Max**: 47057.14	**Mean**: 9785.688 **Var**: 7851.261 **Min**: 1.252798 **Max**: 73175	**Mean**: 11858.44 **Var**: 10255.48 **Min**: .597015 **Max**: 96150	**Mean**:12575.29 **Var**: 10878.37 **Min**: .4024145 **Max**: 99080
New York City PMSA (45)	**Mean:** 45200.77 **Var:** 39616.66 **Min:** 18.3908 **Max:**: 241320	**Mean:** 38794.53 **Var:** 33929.08 **Min:** 17.28972 **Max::** 226880	**Mean:** 40036.82 **Var:** 35850.96 **Min:** 5.494505 **Max**: 227400	**Mean:** 43680.51 **Var:** 36861.05 **Min:** 4.316547 **Max:** 223600
Boston PMSA (6)	**Mean:** 11046.57 **Var:** 13056.57 **Min**: 42.23433 **Max**: 106800	**Mean:** 9230.345 **Var:** 11135.48 **Min**: 95.38421 **Max**: 96475	**Mean:** 9335.114 **Var**: 11218.88 **Min** 133.3596 **Max**: 86600	**Mean:** 9647.83 **Var**: 11829.11 **Min** 127.451 **Max**: 105033.3
Forth Worth-Arlington PMSA (23)	**Mean:** 1800.83 **Var:** 2050.917 **Min** 4.731574 **Max**: 10136.67	**Mean:** 2042.407 **Var**: 1805 **Min**: 4.094632 **Max**: 8571.666	**Mean:** 2624.421 **Var**: 1932.635 **Min**: 19.17899 **Max**: 10229.79	**Mean:** 3051.287 **Var**: 2167.17 **Min**: 25.1453 **Max**: 13295.75
San Francisco PMSA (58)	**Mean:** 14816.54 **Var**: 17204.06 **Min**: 9.002976 **Max**: 123233.3	**Mean:** 14289.68 **Var**: 15963.56 **Min**: 13.654 **Max**: 102800	**Mean:** 15610.98 **Var**: 18016.11 **Min**: 13.69048 **Max**: 150450	**Mean:** 16614.23 **Var**: 18772.95 **Min**: 12.4628 **Max**: 159050

Appendix D: Gini, βz and βc Coefficients for Top 10 PMSAs by Size – 2000

Table A-3				
PMSA	**βz Rank gradient (Zipf)**	**βc Distance gradient (Clark)**	**Gini (land weighted)**	**Population**
Los Angeles--Long Beach, CA	-0.00172	-0.07879	0.801107	9,519,338
New York, NY	-0.00166	-0.11216	0.649859	9,314,235
Chicago, IL	-0.00227	-0.08198	0.717676	8,272,768
Philadelphia, PA--NJ	-0.00372	-0.10409	0.653449	5,100,931
Washington, DC--MD--VA--WV	-0.00469	-0.08269	0.746084	4,923,153
Detroit, MI	-0.0029	-0.07139	0.704453	4,441,551
Houston, TX	-0.0054	-0.10195	0.787903	4,177,646
Dallas, TX	-0.00625	-0.08235	0.792383	3,519,176
Boston, MA—NH	-0.00668	-0.10198	0.540243	3,405,985
Riverside—San Bernardino, CA	-0.0088	-0.03635	0.932887	3,254,821

Appendix E: Mono and Polycentric Cities: Historical Division

While intuition suggests that some cities are more monocentric and others more polycentric in character, today virtually all urban areas have sub-centers. Due to the ubiquity of sub-centers, it is difficult to distinguish between mono- and polycentric cities using statistical techniques alone. The literature suggests that identifying suburban sub-centers quantitatively is difficult even within one urban area (McMillen and Lester, 2003) let alone across multiple urban areas. Developing a formulaic rule (or rules) to identify sub-centers across cities and distinguish between mono- and polycentric urban areas is complicated by the sensitivity of sub-centers to city size and cutoff points What qualifies as a sub-center in a smaller city would not qualify in a large one so that a definition developed for a large city would be likely to exclude sub-centers in small cities. Census Bureau definitions of urban areas also can combine and conflate population centers.

While distinguishing between mono- and polycentric cities using statistics presents formidable challenges, one can readily identify cities with a monocentric past based on their age and history. Due to the rigidity of urban form over time, a monocentric past ensures the presence of a city center today even if sub-centers have developed around it. In 1900, the largest 20 cities all had concentrated centers and those centers persist today. Accordingly, using historical data from the Census Bureau (Gibson, 1998) I distinguish between cities that were among the largest 20 cities in population in 1900 and others as follows:

Table A-4	
Historically Monocentric Cities as Measured by Population in 1900	
Not Among Largest 20 Cities in 1900	**Among Largest 20 Cities in 1900 (city population*)**
Akron, OH	Baltimore, MD (508,957)
Ann Arbor, MI	Boston, MA—NH (560,892)
Atlantic City--Cape May, NJ	Chicago, IL (1,698,575)
Bergen--Passaic, NJ	Cincinnati, OH—KY—IN (325,902)
Boulder--Longmont, CO	Cleveland--Lorain--Elyria, OH (381,768)
Brazoria, TX	Detroit, MI (285,704)
Bremerton, WA	Jersey City, NJ (206,433)
Bridgeport, CT	Milwaukee--Waukesha, WI (285,315)
Brockton, MA	Newark, NJ (246,070)
Dallas, TX	New York, NY (3,437,202)
Danbury, CT	Philadelphia, PA—NJ (1,293,697)
Denver, CO	San Francisco, CA (342,782)
Dutchess County, NY	Washington, DC--MD--VA—WV (278,718)
Fitchburg--Leominster, MA	
Flint, MI	
Fort Lauderdale, FL	
Fort Worth--Arlington, TX	
Galveston--Texas City, TX	
Gary, IN	
Greeley, CO	
Hagerstown, MD	
Hamilton--Middletown, OH	
Houston, TX	
Kankakee, IL	
Kenosha, WI	
Lawrence, MA--NH	
Los Angeles	
Lowell, MA--NH	
Manchester, NH	
Miami, FL	
Middlesex--Somerset--Hunterdon, NJ	
Monmouth--Ocean, NJ	
Nashua, NH	
Nassau--Suffolk, NY	
New Bedford, MA	
New Haven--Meriden, CT	
Newburgh, NY--PA	
Oakland, CA	

Olympia, WA	
Orange County, CA	
Portland--Vancouver, OR--WA	
Portsmouth--Rochester, NH--ME	
Racine, WI	
Riverside--San Bernardino, CA	
Sacramento, CA	
Salem, OR	
San Jose, CA	
Santa Cruz--Watsonville, CA	
Santa Rosa, CA	
Seattle--Bellevue--Everett, WA	
Stamford--Norwalk, CT	
Tacoma, WA	
Trenton, NJ	
Vallejo--Fairfield--Napa, CA	
Ventura, CA	
Vineland--Millville--Bridgeton, NJ	
Waterbury, CT	
Wilmington--Newark, DE--MD	
Worcester, MA--CT	
*Population within center city limits in 1900; names and states for each city are those of modern PMSA.	

Appendix F: Sensitivity of Gasoline Price Effect on Sprawl to Time Lag

Table A-5					
Coefficient and T-Statistic of Fixed Effects Regression of Sprawl Metrics on Gasoline Prices, Various Lags					
	3-year price average, 1 year lagged	**3-year lagged gas prices**	**2-year lagged gas prices**	**1 –year lagged gas prices**	**Gas prices (no lag)**
Gini * 100	11.92488 (8.55)**	14.58675 (10.53)**	15.82436 (12.30)**	3.768544 (3.51)**	-.0007031 (1.04)
Rank gradient (Zipf)*100	-1.468033 (7.41)**	-1.850354 (9.36)**	-1.914624 (10.06)**	-.4555155 (3.07)**	.1309431 (1.48)
Distance gradient (Clark-Mills) * 100	-.0572097 (4.12)**	-.0844507 (5.98)**	-.0803984 (5.75)**	-.0100865 (1.03)	.0110112 (1.92)
* significant at 5% level **significant at 1% level color red denotes highest t-statistic					

Appendix G: Demonstrating Causality

The evidence presented in the text demonstrates that there is a statistically significant correlation between metrics of sprawl and gasoline prices. However, to demonstrate causality, a higher standard of proof is required. Causality can be made incontrovertible when there is a controlled experiment. Absent that, it is necessary to rule out the possibility of spurious regression or reverse causality through a combination of statistical techniques and qualitative analysis. As discussed in Chapter 4, it is unlikely that correlation between gas prices and sprawl is spurious given the obvious connection between travel by gas-powered automobile and sprawl. As additional protection against spurious correlation, I include control variables in my regression analysis and employ fixed effects to screen out unknown between-group differences. A more serious risk is simultaneous or reverse correlation. While consumers are clearly price takers in global energy markets, one can readily imagine that greater aggregate demand for gasoline due to sprawl *could* influence the price of gasoline, with more sprawl raising prices. Accordingly, I employ a variety of techniques to demonstrate causality. The first technique that I employ is the use of instrumental variables.

Instrumental Variables

Instrumental variables are typically employed when there is suspicion that the error term of a regression is correlated with the explanatory variable. This can arise when there is reverse causality between the dependent and explanatory variables so that the dependent variable

influences the explanatory variable, when there is measurement error or when there are omitted variables. If so, the coefficient of the explanatory variable is not a consistent estimator of the true effect. Instrumental variables using Two Stage Least Squares (TSLS) regression offers a way to isolate and remove any correlation between the error term and the explanatory variable. This in turn, makes it possible to demonstrate causality by ruling out the possibility of reverse causality.

With TSLS, one first regresses the explanatory variable that may be correlated with the error term (i.e. the endogenous regressor) on a third variable, the instrument that one knows is completely independent of any influence by the dependent variable and uncorrelated with the error term. Having established a statistically significant effect of the instrument on the explanatory variable, one can replace the explanatory variable in the model with an expression in terms of the instrument. Since this expression is in terms of a variable, the instrument, that exerts no influence on the dependent variable, there is no possibility of reverse causality. In the second stage regression, one regresses the dependent variable on this expression. Any correlation between the original explanatory variable and the error term due to reverse causality is thereby removed. The resulting coefficient provides a consistent estimator of the effect of the original explanatory variable on the dependent variable and demonstrates a causal influence of the original predictor on the predicted variable within the limits of its statistical significance.

As discussed in Chapter 4, scholarship has not identified an ideal instrument for gasoline prices. All of the instruments tested have shortcomings. For example, other oil-based products such as kerosene and naptha that do correlate with gasoline prices could be influenced by gasoline prices through the common precursor of oil (Hughes et al, 2006) Like gasoline prices, those of other oil products could correlate with the error term. However, an instrument that has been used with some success for other commodities (Becker et al, 1994) is excise taxes. It is generally acknowledged that governments set taxes in response to revenue needs and political realities. They adjust taxes infrequently according to the calendar of the legislature and politics. There is no reason to think that sprawl influences excise taxes on gasoline. As of the year, 2000, for example, Georgia had not changed its excise tax since 1971 and seven other states had not changed them since the 1980s. (Reynolds, 2001, Table MF-121T) Nor do excise taxes correlate with high tax states as states collect revenue in different ways. The states with the three highest gasoline excise taxes in 2000 were Rhode Island, Wisconsin and Montana. Excise taxes promise to satisfy the two requirements for a valid instrument: **corr (Sprawl, Taxes) ≠ 0** and **corr (Taxes, μ) = 0** where μ is the error term. Accordingly, I test state excise taxes on gasoline as my instrument for gasoline prices.

It would not be feasible to use excise taxes at the metropolitan level because not all cities levy taxes and also because many metropolitan areas straddle multiple cities and states. Apart from federal taxation of gasoline, most taxation occurs at the state level. State excise taxes therefore promise to serve as the best instrument for gasoline prices. The choice of state gasoline excise taxes, in turn, however, motivates use of *state* gasoline prices and state level geography as well as cross state analysis. It would not be advisable to use fixed effects methodology to test the

temporal effect of excise taxes on sprawl because state taxes change so infrequently. Rather, the choice of state geography motivates using cross state analysis at a single point in time. Cross sectional analysis, further, argues against using variables that change in time but do not vary by location such as national gasoline prices. Accordingly, I use *state* level taxes, state level prices, state level sprawl and, in general, state level geography to perform cross state regression analysis.

The use of state taxes on gasoline as opposed to diesel or other fuels also motivates using household metrics of sprawl as opposed to employment metrics. Retail gas prices are most applicable to consumers, not businesses. Larger businesses may pay taxes in multiple states based on complex apportionment formulas. This issue does not arise in analyzing household location decisions. I therefore use household data from the NCDB and metrics of population density-derived sprawl as opposed to employer data. State state level geography also motivates using a state level dataset as opposed to data compiled by metropolitan area such as the Burchfield Puga dataset. As a result, I use NCDB tract level data for the year 2000 but aggregate it to the state level (as opposed to PMSA or MSA).

Finally the choice of state level geography has implications for metrics of sprawl. Most of the metrics that I used earlier were relevant to metropolitan areas, notably, the Zipf density-rank size gradient and the Clark-Mills density-distance gradient. While it is possible to calculate a Gini coefficient of "equality" of tract densities at the state level, the time frame of 2000 suggests that interpreting the Gini may be complicated by the role of new suburban sub-centers. While such

sub-centers raise the Lorenz curve and therefore lower the Gini coefficient, indicative of greater density equality among tracts and, therefore, sprawl, they concentrate density at urban levels, indicative of urbanization, an ambiguous overall effect. I reject using standard deviation of population density in a cross-state regression since it is significantly higher in large population states and lower in lightly populated states. There are two metrics, however, that do provide a meaningful and consistent metric of sprawl at the state level: percent tracts with sprawling density and percent tracts with urban density. The former can be readily and consistently interpreted as indicative of sprawl. The latter can similarly be readily and consistently interpreted as indicative of urban intensity. Accordingly, I use these indicators as metrics of state-level sprawl. As indicated by Figure 5-A-2, sprawling tracts as a proportion of the total are negatively correlated with gasoline prices at the state level, just as fixed effects analysis at the PMSA level revealed similar negative correlation previously. Urban tracts are similarly positively correlated with higher prices as shown by Figure 5-A-3.

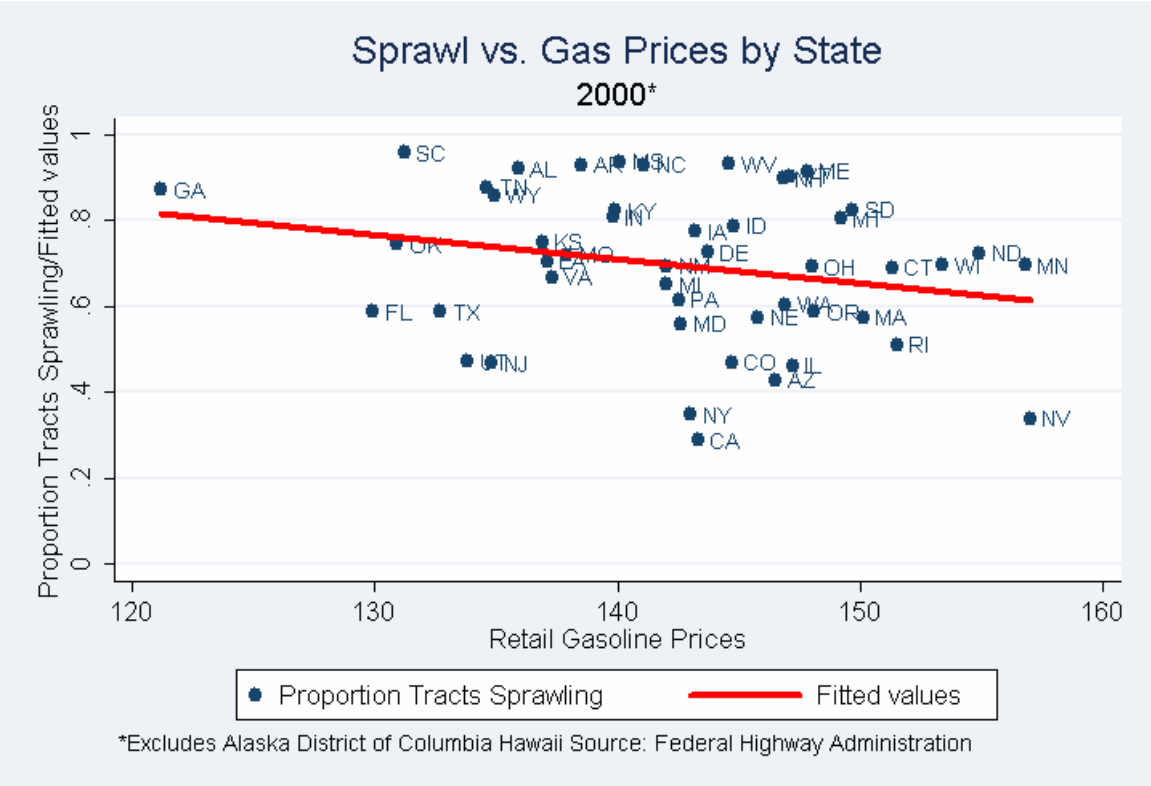

Sprawl vs. Gas Prices by State
2000*
Proportion Tracts Sprawling/Fitted values
0
.2
.4
.6
.8
1
120
130
140
150
160
Retail Gasoline Prices
SC
GA
AL
TN
WY
WV
ME
NH
SD
MI
IN
KY
IA
ID
KS
OK
DE
NM
OH
CT
WI
ND
MN
VA
MI
PA
FL
TX
MD
NE
WA
OR
MA
RI
NJ
CO
IL
AZ
NY
CA
NV
Proportion Tracts Sprawling
Fitted values
*Excludes Alaska District of Columbia Hawaii Source: Federal Highway Administration

Figure A-6

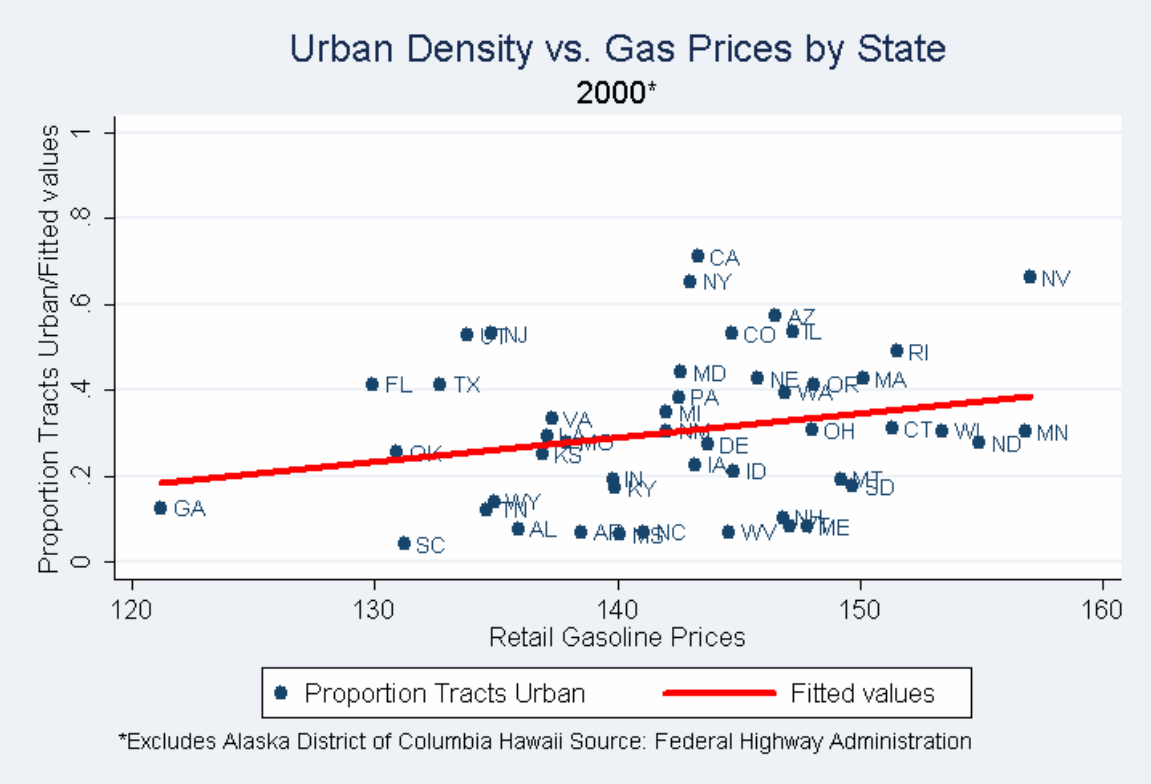


Figure A-7

Tables A-6 and A-7 (identical to 5-14 And 5-15) provide the results of least squares regression of sprawling and urban tracts as proportions of the state total on retail prices and controls. Both show a statistically significant effect at the 1% or 5% level and a goodness of fit measured as R-squared of up to .78.

Table A-6			
Cross State Regression of Sprawl on Gasoline Prices and Control Variables - 2000			
Dependent variable: Proportion Tracts Sprawling by State			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
State retail gasoline prices (2000 US$)	-0.840 (2.95)**	-0.741 (2.02)*	-0.519 (2.80)**

State population (10,000,000)	-17.364 (6.96)**	-11.319 (4.20)**	1.118 (0.27)
Average household income (000)		-0.833 (2.82)**	-0.278 (0.19)
Proportion white		21.351 (0.77)	28.065 (0.45)
Family income (000)			0.111 (0.08)
Proportion black			35.401 (0.59)
Proportion Hispanic			23.955 (0.68)
Proportion foreign born			-249.489 (3.37)**
Working age population			335.550 (1.92)
Proportion 65+			205.358 (1.50)
Constant	198.537 (4.84)**	209.375 (5.17)**	-93.248 (0.68)
Observations	48	48	48
R-squared	0.39	0.52	0.78
Robust t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Table A-7			
Cross State Regression of Urban Intensity on Gasoline Prices and Control Variables - 2000			
Dependent variable: Proportion State Tracts with Urban Density			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
State Retail Prices (2000 US$)	0.846 (2.96)**	0.748 (2.03)*	0.526 (2.83)**
State Population (millions)	17.436 (6.94)**	11.346 (4.19)**	-1.103 (0.26)
Average household income (000)		0.835 (2.83)**	0.282 (0.19)
Proportion white		-21.797 (0.79)	-29.555 (0.47)
Family income (000)			-0.108 (0.08)
Proportion black			-36.375 (0.60)
Proportion Hispanic			-24.077 (0.68)

Proportion foreign born			248.562 (3.34)**
Working age population			-341.038 (1.94)
Proportion 65+			-204.463 (1.49)
Constant	-99.411 (2.42)*	-110.217 (2.71)**	196.571 (1.43)
Observations	48	48	48
R-squared	0.39	0.52	0.78
Robust t statistics in parentheses			
* significant at 5%; ** significant at 1%			

The question remains, however, whether the coefficients shown are, indeed, consistent estimators of the true effect or whether simultaneous or reverse causality running from gasoline prices to sprawl may render the coefficients biased.

Using an instrument for retail prices (specifically excise taxes on gasoline) allows us to isolate any correlation between gasoline prices and the error term due to causality running from gasoline prices to sprawl that may exist and calculate a true, consistent estimator of the real, one-way effect. In the first stage regression, I regress state gasoline prices on the instrumental variable, state gasoline taxes:

GASOLINE PRICES = a +b(GASOLINE TAXES),

or expanding the model to allow for controls:

GASOLINE PRICES = a +b(GASOLINE TAXES)+ c(CONTROLS)

This makes it possible to express gasoline prices in terms of variables free of any causal influence on sprawl as follows:

P = f(GASOLINE TAXES, CONTROLS)

Such that:

P = a+b^(GASOLINE TAXES) + c^(CONTROLS)

In the second stage regression, I then regress sprawl metrics on the predicted value of prices, ***P*** as follows:

$$S = \alpha + \beta P$$

or, more generally,:

$$S = \alpha + \beta P + \gamma y$$

where α is the constant, ***P*** is the predicted value of price, β is the coefficient of ***P,*** ***y*** is a vector of control variables and γ is a vector of the coefficients of the controls**.**

Since ***P*** is clearly uncorrelated with the error term, the resulting coefficient, ***β*** provides a consistent measure of the effect of gasoline prices on sprawl that is indisputably free of reverse causality.

For state excise taxes, I use 2000 data from the Federal Highway Administration (FHA) and for gasoline prices, I use 2000 data published by the FHA that adjusts figures supplied by the Energy Information Agency to include taxes. I exclude Alaska and Hawaii as outliers and the District of Columbia for which the FHA does not publish price data (Reynolds, 2001). Figure 5-A-4 shows, shows the correlation of gasoline prices with excise taxes.

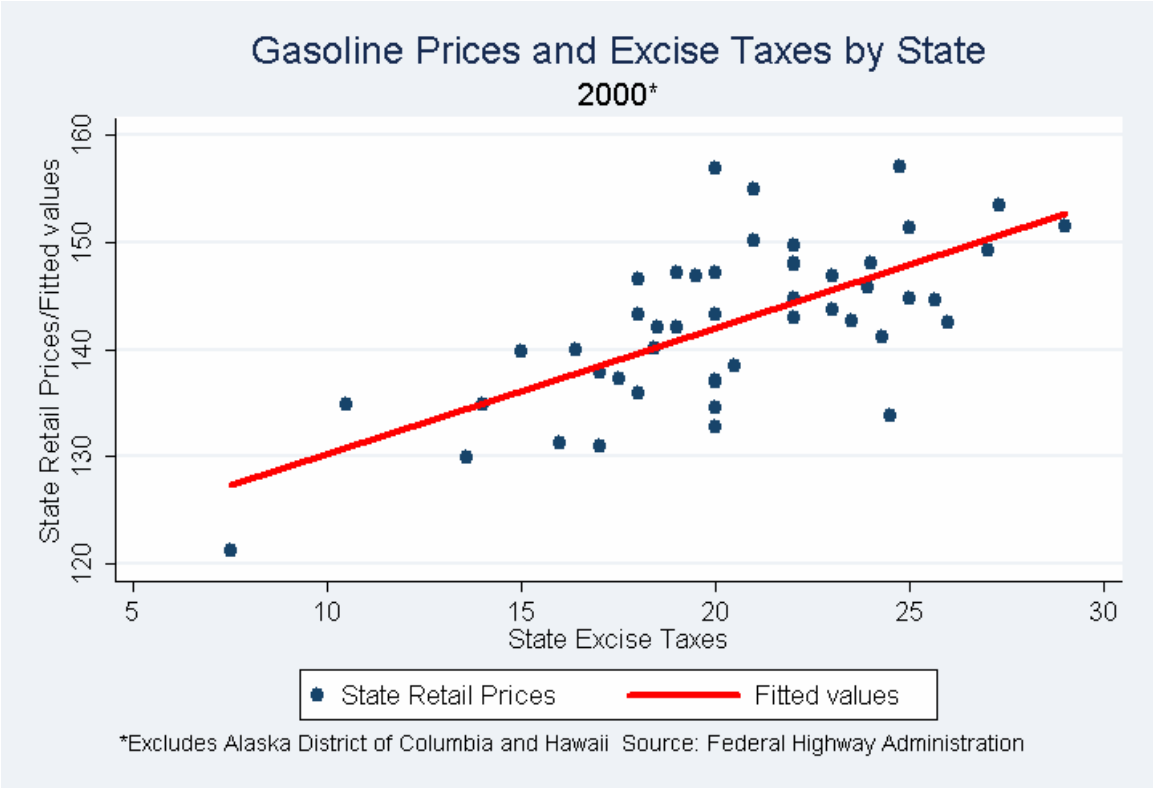


Figure 5-A-4

Correlation is equal to 0.6698. Regressing state gasoline prices on excise taxes reveals a statistically significant relationship at the 1% level. Table 5-A-8 summarizes the results of the first stage regression of gasoline prices on excise taxes alone.

Table A-8	
Cross State TSLS IV Regression of Gasoline Prices on Excise Taxes – First Stage (2000)	
Dependent Variable: State Retail Gasoline Prices Including Taxes	
State excise taxes	1.173371 (7.01)**
Constant	118.5744 (34.10)**
Number of observations	48
R-squared	0.4486
F-statistic	49.11
Robust t statistics in parentheses. Excludes Alaska, District of Columbia and Hawaii	
* significant at 5%; ** significant at 1%	

It is clear from the t-statistic, goodness of fit or R-squared of .45 and F-statistic of 49.11 (well in excess of 10, the threshold commonly used to separate weak and strong instruments (Stock and Watson, 2003, p. 350) that gasoline excise taxes are a valid instrument for retail prices. The expression of prices in terms of taxes is:

P = 118.5744 + 1.173371*(GASOLINE TAXES)

Since I hypothesize that the other control variables in the model are exogenous, to obtain an unbiased value for $\boldsymbol{\beta}$ I must include the controls as instruments as well in these variants of the model. The generalized expression ***P*(GASOLINE TAXES, CONTROLS)** is:

P = a + B*(GASOLINE TAXES) + C*(CONTROLS)

This leads to the following regression results and specifications for **P**:

Table A-9			
Cross State TSLS IV Regression of Gasoline Prices on Excise Taxes – First Stage (2000)			
Dependent variable:			
	(1)	(2)	(3)
	State Retail Prices	With Controls	With Extended Controls
State Gasoline Excise Taxes	1.150 (6.66)**	1.016 (6.53)**	0.897 (4.75)**
State population (10,000,000)	-0.764 (0.54)	-0.339 (0.21)	-1.860 (0.80)
Average household income (000)		0.227 (2.59)*	-1.268 (1.19)
Proportion white		20.582 (2.57)*	-42.604 (1.03)
Average family income (000)			1.358 (1.32)
Proportion black			-60.405 (1.52)
Proportion hispanic			-11.430 (0.57)
Proportion foreign born			-2.915 (0.07)
Proportion working age			78.461 (0.81)
Proportion 65+			48.391 (0.62)
Constant	119.448 (31.41)**	92.832 (9.88)**	98.193 (1.25)
Observations	48	48	48
R-squared	0.45	0.55	0.66
Robust t statistics in parentheses. Not including Alaska, District of Columbia and Hawaii			
* significant at 5%; ** significant at 1%			

Having established that gasoline excise taxes are a valid instrument for prices, in the second stage regressions, I regress my metrics of population density-defined sprawl, the ratio of urban to sprawling tracts as well as proportion of tracts with urban or sprawling densities calculated at the state level, for the year 2000 on ***P*** and controls. The models return significant values for ***β*** consistent with my thesis. Tables A-10, A-11 and A-12 summarize the results of the second stage regressions.

Table A-10			
Cross State TSLS IV Regression of Urban to Sprawl Ratio on Gasoline Prices and Controls – Second Stage (2000)			
Dependent variable: Ratio of Urban to Sprawling Tracts * 10			
	(1)	(2)	(3)
	Gasoline prices	With Controls	With Extended Controls
State Retail Gasoline Prices	0.256 (1.96)	0.307 (2.17)*	0.233 (2.41)*
State population (10,000,000)	5.974 (5.51)**	4.424 (3.23)**	0.606 (0.56)
Average household income (000)		0.146 (1.92)	0.607 (1.27)
Proportion white		-11.681 (1.49)	-17.724 (0.82)
Average family income (000)			-0.673 (1.47)
Proportion black			-16.428 (0.75)
Proportion Hispanic			-18.612 (1.43)
Proportion foreign born			87.205 (4.28)**
Proportion working age			-50.496 (1.20)
Proportion 65+			-48.731 (1.28)
Constant	-34.025 (1.84)	-38.999 (2.61)*	29.409 (0.73)
Observations	48	48	48
R-squared	0.42	0.52	0.85

Robust t statistics in parentheses. Excludes Alaska, District of Columbia, Hawaii
* significant at 5%; ** significant at 1%

Table A-11			
Cross State TSLS IV Regression of Sprawl Intensity on Gasoline Prices and Controls – Second Stage (2000)			
Dependent Variable: Proportion State Tracts with Sprawling Density			
	(1)	(2)	(3)
	Predicted gasoline prices	With controls	With extended controls
Predicted Gasoline Prices (***P***)	-0.967 (2.02)*	-1.096 (2.35)*	-0.873 (2.47)*
State population	-17.682 (7.82)**	-11.641 (4.28)**	0.024 (0.01)
Average household income		-0.743 (2.51)*	-0.869 (0.52)
Proportion white		33.346 (1.21)	5.275 (0.09)
Average family income			0.726 (0.48)
Proportion black			2.648 (0.04)
Proportion Hispanic			14.347 (0.39)
Proportion foreign born			-248.679 (3.59)**
Proportion Working Age			347.772 (2.14)*
Proportion 65+			221.216 (1.75)
Constant	216.766 (3.18)**	245.444 (4.71)**	-34.753 (0.24)
Observations	48	48	48
R-squared	0.34	0.51	0.78
Robust t statistics in parentheses			
* significant at 5%; ** significant at 1%			

Table A-12			
Cross State TSLS IV Regression of Urban Intensity on Gasoline Prices and Controls – Second Stage (2000)			
Dependent variable: Proportion State Tracts with Urban Density			
	(1)	(2)	(3)
	Predicted gasoline prices	With controls	With extended controls
Predicted gasoline prices ***(P)***	0.977 (2.04)*	1.109 (2.37)*	0.884 (2.50)*
State population	17.765 (7.81)**	11.674 (4.29)**	0.009 (0.00)
Average household income		0.743 (2.51)*	0.883 (0.53)
Proportion white		-34.003 (1.23)	-6.391 (0.10)
Average family income			-0.733 (0.48)
Proportion black			-3.085 (0.05)
Proportion Hispanic			-14.312 (0.38)
Proportion Foreign Born			247.739 (3.56)**
Proportion Working Age			-353.460 (2.17)*
Proportion 65+			-220.581 (1.74)
Constant	-118.288 (1.73)	-146.921 (2.81)**	137.119 (0.94)
Observations	48	48	48
R-squared	0.34	0.52	0.78
Robust t statistics in parentheses			
* significant at 5%; ** significant at 1%			

The coefficients obtained are identical to those obtained in a single step in Stata using the ivreg command as shown below in Tables A-13, A-14 and A-15. The standard errors are slightly incorrect due to a failure to account for loss of degrees of freedom from using *predicted* values in the second stage regression. The Stata ivreg command makes the necessary adjustment (Stock and Watson, 2003, pp 346-347). The corrections do not, however, materially affect significance.

Table A-13			
Cross State TSLS IV Regression of Urban to Sprawl Ratio on Gasoline Prices and Control Variables Using IVREG Command - 2000			
Dependent variable: Ratio of Proportion Tracts Urban to Proportion Tracts Sprawling * 10			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
State Retail Gasoline Prices	0.256 (2.17)*	0.307 (2.41)*	0.233 (2.73)**
State Population (10,000,000)	5.974 (6.99)**	4.424 (4.27)**	0.606 (0.65)
Average household income (000)		0.146 (1.91)	0.607 (1.53)
Proportion white		-11.681 (1.62)	-17.724 (0.94)
Average household income (000)			-0.673 (1.86)
Proportion black			-16.428 (0.88)
Proportion Hispanic			-18.612 (1.60)
Proportion foreign born			87.205 (4.52)**
Proportion working age			-50.496 (1.09)
Proportion 65+			-48.731 (1.24)
Constant	-34.025	-38.999	29.409
	(2.04)*	(2.70)**	(0.75)
Observations	48	48	48
R-squared	0.48	0.56	0.86
Robust t statistics in parentheses. Excludes Alaska, District of Columbia, Hawaii			
* significant at 5%; ** significant at 1%			

Table A-14			
Cross State TSLS IV Regression of Urban Intensity on Gasoline Prices and Control Variables Using IVREG Command-2000			
Dependent variable: Percentage tracts with urban density 2000			
	(1)	(2)	(3)

	Gasoline Prices	With Controls	With Extended Controls
State Retail Gasoline Prices	0.977 (2.24)*	1.109 (2.53)*	0.884 (2.48)*
State population (10,000,000)	17.765 (7.14)**	11.674 (4.05)**	0.009 (0.00)
Average household income (000)		0.743 (2.48)*	0.883 (0.58)
Proportion white		-34.003 (1.24)	-6.391 (0.08)
Average family income (000)			-0.733 (0.55)
Proportion black			-3.085 (0.04)
Proportion hispanic			-14.312 (0.34)
Proportion foreign born			247.739 (3.41)**
Proportion working age			-353.460 (1.91)
Proportion 65+			-220.581 (1.55)
Constant	-118.288 (1.91)	-146.921 (2.81)**	137.119 (0.83)
Observations	48	48	48
R-squared	0.39	0.51	0.76
Robust t statistics in parentheses. Excludes Alaska, District of Columbia, Hawaii			
* significant at 5%; ** significant at 1%			

Table A-15			
Cross State TSLS IV Regression of Sprawl Intensity on Gasoline Prices and Control Variables Using IVREG Command(2000)			
Dependent variable: Percentage Tracts with Sprawling Density 2000			
	(1)	(2)	(3)
	Gasoline Prices	With Controls	With Extended Controls
State Retail Gasoline Prices	-0.967 (2.23)*	-1.096 (2.51)*	-0.873 (2.45)*
State population (10,000,000)	-17.682 (7.18)**	-11.641 (4.06)**	0.024 (0.01)
Average household		-0.743	-0.869

income (000)		(2.48)*	(0.58)
Proportion white		33.346 (1.22)	5.275 (0.07)
Average family income (000)			0.726 (0.55)
Proportion black			2.648 (0.03)
Proportion Hispanic			14.347 (0.34)
Proportion foreign born			-248.679 (3.44)**
Proportion working age			347.772 (1.89)
Proportion 65+			221.216 (1.56)
Constant	216.766	245.444	-34.753
	(3.51)**	(4.72)**	(0.21)
Observations	48	48	48
R-squared	0.39	0.51	0.77
Robust t statistics in parentheses. Excludes Alaska, District of Columbia, Hawaii			
* significant at 5%; ** significant at 1%			

Altogether, cross-state analysis using TSLS instrumental variables provides strong evidence that gasoline prices influence sprawl, rather than the other way around.

Other Support for Causality

While the aforementioned findings offer compelling support for the existence of causality running from gasoline prices to sprawl, qualitative analysis and logic supply further support for a casual effect.

It is notable that the correlation between sprawl and gasoline prices is strongest when prices are lagged. Traditionally, the arrow of time has been used in regression literature to refute or support the hypothesis of a causal effect. Its ability to refute the assertion of causality is often asserted. For example, if the dependent variable is indexed earlier in time than the independent variable it is difficult to argue that the independent variable *caused* what came before it. One might argue, therefore, in the present context that it would be unlikely that sprawl in the year 2000 causally influenced gasoline prices in 1998. Thus, the arrow of time might be used to refute a hypothesis of simultaneous or reverse causality running backwards in time.

An important caveat, however, is that in the presence of autocorrelation over time in either variable may render the time indexing essentially moot. If sprawl in the year 2000 is highly correlated with sprawl in the year 1998, then the finding that sprawl in 2000 is correlated with gasoline prices in 1998 would not rule out causaility running from sprawl to gasoline prices rather than (or in addition to)the other way around. The same is true of autocorrelation over time in the independent variable, gasoline prices.

Analysis of sprawl metrics and simultaneous gasoline prices where the lag, ***l*** is equal to zero fails to show a statistically significant relationship for virtually every sprawl metric. Analyzing the sensitivity of correlation to the lag in time as shown in Appendix 5-A-5, I find that the effect is strongest at two years and diminishes using one or zero lagged data (as well as three or more

year data.). Two-year lagged data, in most instances, shows the greatest degree of statistical significance as measured by the number of standard deviations (t-statistic) by which the standard error varies from the coefficient. Accordingly, prices do not appear to influence sprawl immediately but rather to influence it two or more years into the future. This is logical as builders and other involved in the sprawl process are likely to take decisions that influence sprawl well in advance of sprawl becoming revealed.

According to the classic view that causality always runs in the same direction as time and a future event can never influence one in the present, the time lag in correlation between gasoline prices and sprawl would be sufficient to suggest a causal relationship between prices and sprawl.

However, while time is experienced as uni-directional, this does not mean that future states cannot influence current ones. Theory going back to Bernoulli suggests that in an environment of complete certainty, as in a closed system, a future state can entirely explain a current one if a rational decision-maker is present. For example, the present value of a US government security maturing in several days is almost entirely determined by its redemption value. In an environment of uncertainty, a future state can influence a current one within the constraints imposed by uncertainty. Heating oil futures, for example, fluctuate relative to *expected* weather conditions in the future. Expected value under uncertainty is often modeled as the sum of probability adjusted outcomes:

$$E(X) = \Sigma_{i=1 \text{ to } n}\ x_i p_i$$

or:

$$E(X) = x_i p_i + \ldots + x_n p_n$$

(The assumption of risk neutrality makes it possible to assume linearity in the distribution, ***E(X)***). The key issue as regards time backwards causality is, therefore, the degree of uncertainty, or weight of an outcome, p_i, and the weighted value of the outcome, $x_i p_i$, relative to other potential outcomes, $\Sigma x_i' p_i'$. For example, a bond issued by a country in financial distress can plummet when the chance of it being redeemed at face value at some point in the future drops to zero. One can model an uncertain future variable, ***F***, in a regression model as:

$$Y = a + bX + cZ + dE(F)$$

Where ***Y*** is the dependent variable, ***X*** is the independent variable of interest, ***Z*** is a vector of other variables, ***E(F)*** is the expected value of the future variable ***F*** and ***b, c*** and ***d*** are their respective coefficients.

In the case of the relative causal impact of gasoline prices and sprawl, a comparison of two contrasting models of causality, ***(1)*** and ***(2)*** below shows that a key difference is the value of p_i,

or probability weighting of potential states of the explanatory variables: $E(p_i Sprawl_{it+2} \mid p_i' Sprawl_{it+2}')$ and $E(p_i GasPrices_{it-2} \mid p_i' GasPrices_{it-2}')$

1) $\textbf{GASOLINE PRICES}_{t-2} = a + b\, E(p_i Sprawl_{it} \mid p_i' Sprawl_{it}')] + c[\text{CONTROLS}]$

2) $\textbf{SPRAWL}_t = e + f[E(p_i GasPrices_{it-2} \mid p_i' GasPrices_{it-2}'))] + g[\text{CONTROLS}]$

In model (2) since gas prices in period ***t-2*** are known, the actual prices have a probability, ***p*** of 1 and all other possible states, a probability ***p'*** of zero. The expected value of gasoline prices is simply ***p x GasPrices***.. However, in model (1) where future sprawl (at time ***t***) is modeled as influencing prior prices (at time **t-2**)**,** sprawl is only one possible future outcome with probably ***<1***. Other future outcomes with positive probability weight may include no sprawl or some fraction of sprawl—perhaps due to a new anti-sprawl regulation, population loss or economic disruption. P_i is less than 1 and the expected value of sprawl unknown. In fact, sprawl two years out is unlikely to influence current prices materially due to the huge uncertainty attendant on a two year time frame. Future effects on gasoline prices from sprawl are, moreover, likely to be modest relative to other potential future events such as supply or demand shocks. Accordingly, it is unlikely that two year forward sprawl would have a meaningful effect on current prices. Thus the lag observed in the correlation of gasoline prices and sprawl provides further support for causality running from gasoline prices to sprawl.

A second argument for causality emerges from further analysis of the determinants of gasoline prices. The literature suggests that the principal components of gasoline cost are the cost of oil, accounting for about half the cost of gasoline, the cost to refine oil into gas, taxes and marketing

and distribution (which includes transport). Of these, oil prices change daily but the latter components change infrequently (Wells, 2005). For this reason, the chief determinant of *temporal* gasoline price changes is the price of oil which accounts for 85% of gasoline price change (Seesel and Mathias, 2005). Oil also trades globally meaning that consumers of oil are price takers. The one determinant that most drives frequent gas price changes, oil, being traded on global markets, is insulated from local changes in sprawl. Local prices vary from one another not due to the global price of oil but due to other determinants that do vary locally For example, taxes and transportation to and from refineries vary locally, accounting for a large share of regional gasoline price differences. However, there is no obvious way that sprawl could influence taxes or fuel transport costs and therefore, local gasoline price differentials.

Regression analysis contained in the literature of gasoline prices suggests that the principal determinants of gasoline prices are current and lagged oil prices, supply shocks, taxes, state-specific pollution laws and type of gas station (Chouinard and Perloff, 2004). A further component of gasoline cost is distance from refineries (Wells, 2005) Sprawl is unlikely to influence supply shocks, pollution laws, type of gas station or, as mentioned, taxes or distance from refineries (which are largely concentrated near points of oil production or import such as the Gulf Coast and New Jersey.) The primary pathway through which sprawl would appear to have the potential to affect prices in the near term is through demand for oil which would show up as temporal changes in the price of gas. But the evidence suggests that gasoline prices respond, in the short term, to changes in oil prices, as revealed by the global spot market price, not the other way around. (In 2004, US refiners kept about a 23 day inventory of gasoline (Wells, 2005)).

While in the short term, causality would appear to run from oil prices to gasoline, over the long term, gasoline demand must certainly enter into the demand curve for oil and therefore influence the price of oil. (About half of oil lifted is refined into gasoline.) Since, as we have seen, higher spot oil prices lead to higher gasoline prices and vice versa (with some stickiness on the downside (Borenstein and Shepard, 2002)), sprawl could influence gasoline prices through this circular pathway. Higher gasoline demand from sprawl would first lead to higher demand for oil. Higher demand for oil would raise oil prices. Finally, the latter would influence gasoline prices. Indeed, in the long run, this scenario describes how gasoline demand probably enters into the demand curve for oil.

However, as discussed, the price of oil is set globally. With fungible markets, demand in the US, Europe and the developing world is pooled Oil prices in the US are influenced by Chinese as well as US demand and, within the US, refiners in the Gulf Coast must pay the same price, net of transportation, as those in New Jersey. The pooling of oil demand suggests that sprawl can only influence prices in the aggregate and therefore, incremental local demand from sprawl must be measured against overall global demand. If so, its effect is likely to experience considerable dilution. While gasoline usage in the United States from sprawl certainly must contribute hugely to demand for gasoline, it must be weighed against demand for oil from other sources such as rising car ownership in the developing world.

Of note, oil demand is highly price inelastic, on the order of -0.26 as measured during the 1970s in the short term and .6 in the long term and as little as -0.034 in the short term from 2001 to 2006 (Hughes et al, 2006, p. 1). As a result, it takes a large change in demand to influence price,

on the order of a four fold percent change in demand relative to change in price in the short term using the more conservative 1970s data.

Finally, one cannot ignore the role of supply in the oil market. Supply of oil is also price inelastic (price elasticity<1), meaning an outsized shift in price is necessary to shift supply. Oil production is expensive and oil companies normally develop only finds that stand to be profitable regardless of the inevitable fluctuations in price. Saudi Arabia, which enjoys a low cost of production, has particular flexibility in setting levels of production and the oil cartel, OPEC manages supply to hit price targets and achieve political goals with varying success. For this reason, price changes based on demand have traditionally had only a limited effect on supply (Hamilton, 2009). In short, due to the fungibility of oil, the capital intensity of production and the market power of producers, demand due to sprawl has a limited chance to influence the price of oil and therefore gasoline.

Lastly, while it does not address the issue of causality *per se*, my methodology of fixed effects does reduce the chance of endogenity leading to bias in coefficients. Fixed effects controls for unobserved differences in metropolitan areas due to the presence of omitted variables that might lead to biased results. While the fixed effects methodology does not establish causality per se, it does increase confidence in the consistency of coefficient estimates.

All told I find compelling evidence for a casual effect of gasoline prices on sprawl.

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