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SPRAWL AND URBAN GROWTH

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ABSTRACT

Cities can be thought of as the absence of physical space between people and firms. As such, they exist to eliminate transportation costs for goods, people and ideas and transportation technologies dictate urban form. In the 21st century, the dominant form of city living is based on the automobile and this form is sometimes called sprawl. In this essay, we document that sprawl is ubiquitous and that it is continuing to expand. Using a variety of evidence, we argue that sprawl is not the result of explicit government policies or bad urban planning, but rather the inexorable product of car-based living. Sprawl has been associated with significant improvements in quality of living, and the environmental impacts of sprawl have been offset by technological change. Finally, we suggest that the primary social problem associated with sprawl is the fact that some people are left behind because they do not earn enough to afford the cars that this form of living requires.

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I. Introduction

In the early part of the 20th century, cities grew upward. Tenements and luxury apartment buildings replaced brownstones. Skyscrapers came to adorn urban landscapes. But at the end of the 20th century, urban growth has pushed cities further and further out. The compact urban areas of 1900 have increasingly been replaced by unending miles of malls, office parks and houses on larger and larger lots. At first, people continued to work in cities but lived in sprawling suburbs. But the jobs followed the people and now metropolitan areas are characterized by decentralized homes and decentralized jobs. In 2003 America, urban growth and sprawl are almost synonymous and edge cities have become the dominant urban form.

In this essay, we review the economic literature on sprawl and urban growth, and make four points. First, despite the pronouncements of academic theorists, dense living is not on the rebound. Sprawl is ubiquitous and expanding. Second, while many factors may have helped the growth of sprawl, it ultimately has only one root cause: the automobile. Suburbia, edge cities and sprawl are all the natural, inexorable, result of the technological dominance of the automobile. Third, sprawl's negative quality of life impacts have been overstated. Effective vehicle pollution regulation has curbed emissions increases associated with increased driving. The growth of edge cities is associated with increases in most measures of quality of life. Fourth, the problem of sprawl lies not in the people who have moved to the suburbs but rather the people who have been left behind. The exodus of jobs and people from the inner cities have created an abandoned underclass whose earnings cannot support a multi-car based lifestyle.

Plan of the Paper

In Section II, we begin with a characterization of sprawl in the United States. To us, the most striking fact about sprawl in the U.S. is its omnipresence. Employment is decentralized almost everywhere and traditional downtowns now contain only a tiny sliver of overall metropolitan employment. The overwhelming majority of Americans live in medium density census tracts miles from the city center.

After first describing the level of sprawl, in Section III, we turn to its roots. Many authors have argued that sprawl is caused by government policies such as highway subsidies, the home mortgage interest deduction, and insufficient funding of urban public services (such as subways). Others have claimed that sprawl comes from a desire to avoid blacks or the poor. While some of these forces abetted the rise of sprawl, the root cause of U.S sprawl is far more prosaic—the technological superiority of the automobile. Automobiles are so much faster than previous means of transportation that in most of America they have become really the only travel mode.

Cities have always been shaped by transportation technologies. The dense walking cities of 18th century Boston and New York crowded up against their wharves. The merchants, who traveled by foot, needed to be close to their much swifter goods, which traveled by boat. In the 19th century, the omnibus and later the streetcar opened cities up. Long, parallel streets replaced winding cow paths as people, particularly the wealthy, moved to newer, less dense neighborhoods. The subway and commuter rail moved people still further away from the downtown.

As important as prior transportation innovations have been, the car has had a more dramatic effect on the city than anything before it. Unlike the earlier transportation innovations, the car has radically reshaped cities because it eliminates walking almost entirely. People who took streetcars in 1900 still had to walk from the streetcar stop to their homes or their jobs. As such, businesses and homes needed to crowd against public transportation stations. Routine shopping and many other non-work related activities were generally done on foot before the automobile. As such stores, schools and restaurants needed to be within ready walking distance of consumers. Public transportation made it possible for consumers to live far from their work, but they still needed to live at high densities. Cars have changed that and as a result, inalterably changed city living forever.

The car should be understood as having two distinct effects on population decentralization. First, as almost all analysts of sprawl recognize (e.g. Alonso, 1962, Jackson, 1985, Brueckner, 2000)—cars reduce transport costs, thus increasing the possible distance between residences and jobs. But cars and trucks have one other equally important effect: they eliminate the scale economies involved in older transportation technologies. Ports and railway stations were massive pieces of infrastructure, and they could not be reproduced willy-nilly throughout metropolitan areas. As a result, traditional cities clustered around the port and the railroad hub. One may think that Wall Street developed because of agglomeration economies, but the history of the downtown suggests that the fixed costs of transportation were at least as important. As trucks and cars have replaced boats and trains, these scale economies have vanished and it has become possible for employment to decentralize throughout metropolitan areas and throughout the country.

But has the move to sprawl been socially beneficial? In Section IV, we consider the welfare consequences of sprawl. While many non-economists seem to think that sprawl is an unequivocal evil, we think that generally sprawl has yielded social benefits. Sprawl has been associated with large houses and short travel times. The median housing unit in Manhattan has 820 square feet. In the suburbs of Washington D.C, the median housing unit has 1,950 square feet. Across the United States, the median household lives in a housing unit with 1,395 square feet (data source 1999 American Housing Survey).

The commute time differences are also dramatic. While congestion may be slowing commutes in some edge cities, in most cases, the car-based urban frontier has far shorter commutes than the old public transportation cities (Gordon, Kumar and Richardson 1991). Cars are just so much faster than public transportation that commutes in the old dense cities are almost always much longer than in their newer, sprawling competitors. Thus, the average commute in New York City is the longest of any large city—39 minutes. In the edge cities, the average commute is 21 minutes about one-half of this amount. The savings of more than 30 minutes per day in travel time represents one of the biggest welfare effects of sprawling cities. While it may be optimal to introduce policies which would force people to internalize the congestion externalities from their driving, even without those policies, commute times have plummeted in edge cities.

We then turn to the other potential costs of sprawl— social segregation and environmental damage. There is a strong logic which argues that automobiles have facilitated segregation. Cars are expensive and the new car based cities have been much more accessible to the wealthy. Conversely, the poor have tended to circle around public transportation (Glaeser, Kahn and Rappaport 2000).

However, across metropolitan areas, cities with more sprawl are actually less segregated, both on the basis of income and on the basis of race. In general, the car-based edge cities have much more racial integration than the older public transportation cities than they replaced. Changes in income-based segregation are harder to assess, but across cities, the presence of public transportation tends to increase the level of income based segregation (Glaeser, Kahn and Rappaport, 2000). Multiple transport modes provide a natural explanation for this segregation phenomenon. When there are multiple modes, the rich will live in the car zones and use the more expensive, faster mode and the poor will live in areas with greater access to the cheaper, slower mode. Car-based edge cities feature only one mode and hence have less segregation. As a result, there is more segregation in the multiple mode traditional cities.

This implies that sprawl cities may actually both reduce segregation and hurt the well being of the poor. In sprawl cities, the poor are forced to spend more on transportation services. They are less segregated but they also have less cash. Consumer expenditure surveys make it clear that the poor in sprawl cities spend less on non-car expenditures. They may indeed be the losers from sprawl.

Finally, there is the question of the environmental consequences of sprawl and car reliance. These include local air pollution, Global Warming impacts, and lost farmland.

Car cities such as Houston and Los Angeles have had high smog levels. Suburban vehicle dependent growth leads to increased aggregate gasoline consumption. This raises the stock of greenhouse gases. Suburban growth also displaces farmland. Road construction and large suburban lots contribute to paving over farmland. Such open space offers aesthetic benefits and hard to measure “existence value” benefits.

Vehicle regulation has significantly reduced emissions per-mile over the last 30 years. As we document below, urban air quality has sharply improved in growing areas. We recognize that sprawl, through increasing driving during an era when little improvements in fleet fuel economy have been achieved, has increased greenhouse gas production. Some pollution-based taxation may increase social welfare, but current gas taxes already appear to cover most estimates of environmental damage.[1]

Some environmental advocates have argued that sprawl destroys forest, but over the past 20 years the amount of forest cover in the U.S. has increased, not decreased. Overall, residential real estate still covers a very small amount of the country and the increases in urban land area have been irrelevant to the overall amount of forest cover (Fischel 1987). Forests have by and large increased because low return agricultural activities have been discontinued and replaced by forests. Indeed, there is one argument that increases in housing construction actually increase the demand for wood and therefore lead to an increase in the amount of forest cover.

While our depiction of sprawl is generally positive, we do think that the rise in car based cities raises several important policy concerns. The first is that increasing reliance on the automobile increases the costs of failing to properly address congestion externalities. Without a more sensible approach to taxing drivers for using roads during peak travel times, it is likely that the welfare costs of traffic delays will continue to spiral (see Small and Gomez-Ibanez 1998). There is a growing optimism that London’s recent road pricing scheme is achieving its goals with little political backlash.

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[1] Parry and Small (2002) argue that the United States’ gasoline tax is too low while England’s is too high.

The second important policy concern is that small jurisdictions which were reasonable political units in an era of high transport costs may no longer be appropriate as the costs of movement have fallen. They make decisions which often impose externalities on neighboring jurisdictions which may well be quite costly. The most obvious example of this failure lies in the area of land use controls. Homeowners impose growth controls supposedly in an attempt to deter sprawl (Katz and Rosen 1987, Rosen and Katz 1981). However, these controls often simply push developers to the next town out and sprawl may indeed increase as a result of these policies. Some sprawling metropolitan areas, such as Atlanta with its Atlanta Regional Commission, have attempted to co-ordinate jurisdictional policy.

Our final policy concern relates to sprawl and the poorest Americans. As there are a large number of Americans who can not afford automobiles, the flight to edge cities has indeed left them behind. If we accept that America will be primarily a car-based nation, then it makes sense to ask whether car-based subsidies for the poor make sense. We summarize the work of Raphael and Stoll (2001).

II. The Extent of Sprawl

In this section, we review key facts about the growing edge cities in the United States. Our goal is to discuss the measurement of sprawl and apply those measures to American urban data. In general, there are two concepts which come together in the popular conception of sprawl: decentralization and density. Decentralization refers to the spreading of employment and population throughout the metropolitan area. Density refers to the degree to which employment and population are centered in high density living and working areas.

In principle, there could be decentralized, dense urban areas. These areas would be characterized by a large number of employment subcenters, where each subcenter is itself quite dense. This vision of urban sprawl is described in the work of Anas, Arnott and Small (1998), Brueckner (1979), Giuliano and Small (1992), McDonald and McMillen (2000) and McMillen and McDonald (1998), and by the edge city model of Henderson and Mitra (1999). But most popular views of sprawl seem to believe that decentralization and lower densities tend to go together. As such, when edge cities formed, they did not replace traditional dense downtowns with new dense job centers, but rather with low density employment areas.

We will use a number of measures to capture both decentralization and density (for an extensive review of different measures see Galster et. al. (2001)). Several intuitive measures of decentralization present themselves. Of course, for any measure of decentralization, we need some idea of where the metropolitan areas center actually is located. For this, we use the 1982 Special Census Survey which asked local leaders for the exact spot which is the geographical center of their city. These surveys are surely imperfect, but in general the survey tends to pick the spot that seems to be the natural center. For example, in New York, Wall Street was picked as the city's geographical center. In metropolitan areas with multiple cities, we chose the city with the largest population and used the city center of that city.

One natural test of the validity of these estimates is to ask whether these centers do appear to be focal points for employment, or put another way, is there an unusually high concentration of employment in and around those centers. To check this, we calculated the employment density (measured as employees per mile) in the zip code that contained each city center. The data source is the Department of Commerce's Zip Code Business Patterns 1996 data. We then compare this employment density with the employment density of other zip codes in the metropolitan area. Out of 301 metropolitan areas, we found that in 180 of them, the city center zip code had the absolute highest employment density in the metropolitan area. In 270 of the MSAs, the city center zip code was among the four most dense zip codes. These city centers are not mere arbitrary definitions. They almost always measure one of the densest employment spots in the city.

Using these city centers, we calculate a number of different measures of employment and population decentralization. The first and easiest measure is the share of employment within a five-mile radius of the city center. These measures have the virtue of capturing the extent to which the population or employment is really physically close to the center of the city. Table 1 provides some basic summary statistics. Across 150 major metropolitan areas, the average city has 42.6 percent of its total employment within a 5 mile radius around its CBD. This average masks wide variation. Ten percent of cities have more than 80 percent of their employment outside of the five-mile inner ring.

The level of decentralization is striking. Figure 1 shows the cumulative distribution of jobs and people for U.S. metropolitan areas as a whole, asking what share lies within different boundaries. Across all of the different metropolitan areas, we find that only 45 percent of employment and 38 percent of population lies with 5 miles of the city center.[2]

Population decentralization and employment decentralization go hand in hand. While, in general, jobs are more centralized than people, the cities that are centralized along one dimension are centralized along both. To show this, we estimate regression (1) separately by MSA using both employment density and population density as the dependent variables:

(1) Log(Density)=a+b*Distance from CBD + e.

In this regression, the coefficient "b" captures the extent to which density falls with distance from the CBD.[3] This functional form can be justified using a version of the Alonso-Muth-Mills model. After estimating equation (1) for 131 major MSAs, we took the population and employment gradient estimates of "b" and ran a second stage regression of the form: b = c + g*log(population) + Region + U. Controlling for a

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[2] The data source for population is the 1990 Census of Population and Housing.
[3] It should be noted that when we calculate population density using the square mileage of the zip code. We are unable to incorporate the fact that there are vacant lots within zip codes. Mieszkowski and Smith (1991) are able to calculate density gradients for Houston while accounting for the presence of vacant lots.

MSA's region and its population, we recover a residual for each MSA for its employment and population gradient. Figure 2 shows the correlation across metropolitan areas of the employment density-distance gradient residual and the residential density-distance gradient residual. There are very few cities which have centralized employment and decentralized residences (or vice versa).

As we turn to measuring density, there are a few possible alternatives. Most obviously, one can use jobs or residents per mile in the city as a whole. This certainly fits the popular conception of density, but does little to differentiate cities where the bulk of people live in skyscrapers that are surrounded by vacant land with cities where the bulk of people live in single-family dwellings at low densities.

One natural improvement is to look at density at the zip code level and to ask at what density does the average member of this city live or work, or more precisely: $\sum_{i=1}^{I} \frac{N_i}{N_{Total}} \frac{N_i}{A_i}$, where A_i refers to the square mileage of the geographic subunit. The geographical unit for our employment and population data is the zip code.

The bottom of Table 1 shows that across 150 major MSAs, the average person lives in a community of density 2952 people per square mile and works in an area featuring 3900 employees per square mile. Table 2 shows that major cities differ greatly with respect to their employment densities. The average worker in New York City works at a job density five times higher than the fourth most dense city (Boston). While New York City has the highest job density index, it does not have the highest share of all metro jobs within a three-mile ring around its CBD. The left column of Table 2 shows that San Francisco is the least sprawled metro area based on this criterion.

Given that different sprawl indicators yield different rankings of major cities, in Table 3 we present a correlation matrix of seven of our indicators for 150 major metro areas. While some correlations are quite high, such as the negative correlation of -.57 between "percent of employment within inner 3 mile ring around the CBD" and "median worker's distance in miles from the CBD", other correlations are quite low.[4] One interesting zero correlation is between "MSA Average Population Density" and the "Median Person's Distance in Miles from the CBD".

The population and job density measures provide a metric for investigating whether there are meaningful employment centers outside of core employment centers. To address this, we look at the distribution of employment densities close to the city center and away from the city center. We assign each zip code to one of five mutually exclusive and exhaustive categories based on five-mile rings around the CBD. For each of these five-mile rings, we calculate the weighted average of job and population density. Table 4 shows the distribution of these densities. Across the metropolitan U.S. as a whole, the average person works in a zip code with 10,371 workers per square mile and lives in a zip code with 5,651 people per square mile. The average worker, who works in the 5 to 10 mile ring around the CBD, works in an environment where there are 2,541 workers per square mile while the average resident who lives in the five to ten mile ring around the CBD lives in a community where there are 7,433 people per square mile. Outside of the inner ring, average population densities are higher than average employment densities. Employment outside of urban centers is not characterized by competing centers, but rather by dispersed employment.

Ideally, we would like to construct our sprawl measures at several points in time. Unfortunately, we can only access nationally representative employment distributions starting in the 1990s. To provide some facts about trends in density, we use population density data from the Texas Transportation Institute database. Using data from 1982 to 1999 for 68 major metropolitan areas, we graph population weighted population density over time. Figure 3 shows that population density has fallen over 10% during this period. Interestingly, the data suggest that over the last five years population density has slightly increased.

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[4] We calculate for each metro area, the distance from the CBD such that 50% of workers work further from the CBD than that point. The bottom of Table 1 shows that the median

III. The Causes of Sprawl

The simplest framework for understanding sprawl is the Alonso-Muth-Mills monocentric model. In its pure form, this model cannot address employment decentralization, but certainly helps us to understand the basic determinants of decentralization. Consider an open city with exogenously given wage w and commuting costs of t per unit distance (all quantities are in flows per time period), where distance to the city center is denoted "d".

We assume that individuals maximize a utility function defined over land area (denoted A) and a composite commodity (denoted C) or $C + \alpha Log(A)$. Commuting cost equals t times total distance spent commuting. Thus if an individual lives d units away from the city center, the commuting time equals td and total earnings to be spent on land and the composite commodity equals w-td. We also allow the possibility of a government subsidy of land consumption equal to "x" times overall expenditure on land. This subsidy attempts to capture the potential effects of policies ranging from the home mortgage interest deduction to zoning which might increase the appeal of buying bigger or more expensive land.

The rental price per unit of land (or rent gradient) is denoted P(d). Indifference among locations implies that –P'(d)A(1-x)=t. The first order condition for optimal land consumption implies that $P(d)A(1-x) = \alpha$. Together, these imply that $P(d) = P_0 e^{-\frac{td}{\alpha}}$, where P_0 is the price of land at the city center. We close the model by assuming that there is a reservation location with (1) wages net of transportation costs equal to

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worker works at 6.9 miles from the CBD but in 10% of cities, the median worker is located more than 12 miles from the CBD.

$(1-\theta_1)w-\theta_2 t$ and (2) land costs of $\hat{P}$.[5] Together, these assumptions imply a reservation utility of $(1-\theta_1)w-\theta_2 t-\alpha+\alpha Ln(\alpha/(1-x)\hat{P})$. Land on the edge of the city has value of $\underline{P}$ if used for non-residential purposes. The reservation utility level implies that $P_0=\hat{P}e^{\frac{w\theta_1+\theta_2 t}{\alpha}}$ and therefore $P(d)=\hat{P}e^{\frac{w\theta_1+t(\theta_2-d)}{\alpha}}$. The outer edge of the city occurs when $P(d)=\underline{P}$ or $\overline{d}=\theta_2+\frac{w\theta_1+\alpha Log(\hat{P}/\underline{P})}{t}$.

Two natural measures of sprawl exist in this model. The first measure is the furthest limit of the city's population. This will be the extent of the city or $\overline{d}$. The total population of the city is $\int_{d=0}^{\theta_2+\frac{w\theta_1+\alpha Log(\hat{P}/\underline{P})}{t}}\frac{1-x}{\alpha}\hat{P}e^{\frac{w\theta_1+\theta_2 t-td}{\alpha}}dd$ or $\frac{(1-x)}{t}\left(\hat{P}e^{\frac{w\theta_1+\theta_2 t}{\alpha}}-\underline{P}\right)$ so the average density equals $(1-x)\frac{\hat{P}e^{\frac{w\theta_1+\theta_2 t}{\alpha}}-\underline{P}}{w\theta_1+\theta_2 t+\alpha Log(\hat{P}/\underline{P})}$.

What variables will impact sprawl? Most obviously, things that will increase the city will tend to make it bigger and more dense. Thus, the value of $\overline{d}$ is increasing with w, θ_1, θ_2 and $\hat{P}$ and falling with $\underline{P}$. The average density level is rising with w, θ_1, θ_2 and $\hat{P}$, if $1>\alpha$ (which we assume).

These comparative statics represent the pseudo-sprawl that is perceived with the growth of any city. As cities become more attractive, they grow up and out. Thus, as New York grew throughout its 400 year history, wheat fields have gotten covered and skyscrapers have gotten built. Increases in "x"—the subsidy to land consumption—causes density to fall, but do not impact the overall spread of the city. As long as $\hat{P}$ is greater than $\underline{P}$, increases in α cause the density level of the city to fall and cause the overall spread of

[5] The parameters θ_1 and θ_2 capture the extent that changes in w and t influence the reservation utility. They measure the extent to which w and t are local parameters, or parameters that influence utility everywhere.

the city to rise. Thus, factors that would increase the demand for land cause the city to sprawl, using either measure.

Finally, if $1 > \alpha$ then increases in the value of "t" cause the city to contract and become more dense. This represents a primary comparative static of the model and the key to understanding most of the thinking about the link between transportation costs and urban sprawl. As transportation costs fall, it naturally becomes more attractive to live at further distances and commute further.[6]

Now, we follow Henderson and Mitra (1995) and others, and allow for multiple employment centers. We retain our assumptions about the utility function and transport costs, but now assume that x=0. In a spatial equilibrium, all individuals must be optimizing their consumption and be indifferent across locations. Furthermore, developers must be unable to earn positive profits by creating new employment subcenters.

We will refer to the original downtown as employment subcenter zero with wage w_O and location $d_O = 0$. Any additional employment subcenters are denoted with subscript "s" are characterized by a wage, distance pair (w_s, d_s), for s={1, 2, …S}, where $d_{s+1} > d_s$ for all s. We assume that wages in each subcenter are determined by the distance between the city center and the new subcenter. Agglomeration economies mean that proximity between the new center, and the old core are desirable and we assume that w(d) in each new subcenter equals w-zd, where z<t.

The implication of z<t is that we can define a vector of locations denoted $\hat{d}_s$ where individuals are indifferent between subcenter s and subcenter s+1. We know that $d_s < \hat{d}_s < d_{s+1}$, because individuals who live close to a subcenter will always prefer

[6] The overall impact on density depends critically on $\theta_2 > 0$. If $\theta_2 = 0$, then increases in transportation costs only impact the city and not the reservation locale, and increases in t cause population to fall by proportionately as much as the area of the city and there is no link between t and average density.

working there to commuting elsewhere (because z<t). We let $\hat{d}_s$ denote the point in the interval (d_s, d_{s+1}) where for all d greater than $\hat{d}_s$, subcenter s+1 is strictly preferred to subcenter s and for all d less than $\hat{d}_s$, subcenter s is strictly preferred to subcenter s+1. At $\hat{d}_s$, residents are indifferent between working at the two locations, which implies that $\hat{d}_s = .\frac{d_s + d_{s+1}}{2} + \frac{z(d_{s+1} - d_s)}{2t}$.

All residents in the interval $(\hat{d}_{s-1}, \hat{d}_s)$ commute to subcenter s. In this interval, the price gradient will equilibriate utility levels for all commuters. Thus if we let P_0^s denote the price of land at subcenter s, it must be true on the interval $(\hat{d}_{s-1}, \hat{d}_s)$, that the price vector is $P(d) = P_0^S e^{-\frac{t\left|d - d_S\right|}{\alpha}}$, and the reservation utility formula tells us that $P_0^S = \hat{P}e^{\frac{w - zd_S - w(1-\theta_1) + \theta_2 t}{\alpha}} = \Psi e^{-\frac{zd_S}{\alpha}}$, where Ψ denotes $\hat{P}e^{\frac{w\theta_1 + \theta_2 t}{\alpha}}$. The density levels around each subcenter will equal $1/\alpha$ times the price.

We assume that developers can open new employment centers for a fixed cost of "K" which is independent of the distance from the old downtown. They will continue to open these centers as long as there are profits to be made from new subcenters. In particular, we define a development equilibrium as one in which the costs of developing any new subcenter must be greater than the increase in land values that would be created by this new development. In this definition, we follow Henderson and Mitra (1996) and assume that developers are able to reap the full benefits that their construction has on property values. The logic that lies behind this condition is that presumably developers can buy up land at current prices, then develop and then resell the land at the new equilibrium prices.

There are two equilibrium conditions that are helpful for understanding the implications of this model for sprawl. First, we will develop conditions on the maximum distance between employment subcenters. This helps us to understand the degree to which employment centers will be spread throughout the metropolitan area. Second, we will provide comparative statics on the total extent of development within the area. If there are two existing subcenters, denoted s-1 and s+1, then the extra land value created by building a new subcenter (denoted "s") will equal:

$$(1) \qquad \frac{2\Psi\alpha e^{\frac{-zd_{s-1}}{\alpha}}}{t}\left(e^{\frac{-z\phi\Delta}{\alpha}} + e^{\frac{-(t+z)\Delta}{2\alpha}} - e^{\frac{-(t+z)\phi\Delta}{2\alpha}} - e^{\frac{-(1-\phi)t\Delta-(1+\phi)z\Delta}{2\alpha}}\right),$$

where Δ denotes $d_{s+1} - d_{s-1}$ and $\phi\Delta$ denotes $d_s - d_{s-1}$. If the developer enters, he will choose d_s (or equivalently ϕ) to maximize this amount, and he will only enter if this amount (given optimal selection of ϕ) is greater than K, the costs of building a new subcenter. This leads us to our first proposition.

Proposition 1: As long as $2\Psi\alpha e^{\frac{-zd_{s-1}}{\alpha}}\left(\left(\frac{2z}{t+z}\right)^{\frac{2z}{t-z}} - \left(\frac{2z}{t+z}\right)^{\frac{t+z}{t-z}}\right) > tK$, then there exists a unique value of Δ, denoted $\tilde{\Delta}$ at which developers earn exactly zero by building a new subcenter and locating it optimally. For values of Δ above $\tilde{\Delta}$, developers earn positive profits by building a new subcenter and for values of Δ below $\tilde{\Delta}$, developers lose money with new construction.

The value of $\tilde{\Delta}$, which can be interpreted as the maximum distance between two subcenters, rises with K, and d_{s-1}, and falls with w, $\hat{P}$, θ_1 and θ_2. The value of $\tilde{\Delta}$ falls with z when z is small.

The impact of t on $\tilde{\Delta}$ is ambiguous. For example, when $\theta_2 = 0$ and z=0, then $\tilde{\Delta}$ falls with t if and only if the cheapest lot in between the two centers costs more than 8.2 percent of the most expensive lost between the two centers.

The inequality $2\Psi\alpha e^{\frac{-zd_{s-1}}{\alpha}}\left(\left(\frac{2z}{t+z}\right)^{\frac{2z}{t-z}}-\left(\frac{2z}{t+z}\right)^{\frac{t+z}{t-z}}\right)>tK$ is needed to ensure that there exists some value of Δ at which profitable development can occur. The term $\tilde{\Delta}$ can be thought of as the maximum distance between any two subcenters in equilibrium. Any distance that is greater than this amount implies that there are profits from new entry. As such, the value of $\tilde{\Delta}$ gives us a measure of the degree to which employment subcenters will be spread throughout the metropolis.

When the value of K falls, we expect to see more employment subcenters. To us, this captures the role that the decline in big transportation infrastructure (rail stops, ports) and its connection to the rise of edge cities. As d_{s-1} rises, there will be fewer employment centers. This is a natural outcome of the assumption that productivity declines with distance from the center. The parameters w, $\hat{P}$, θ_1 and θ_2, all reflect general demand for the metropolitan area. As these rise, the demand for the metropolitan area rises and the maximum density between any two employment centers declines. Declining values of z, the extent to which productivity falls with distance from the urban center, also increases the attractiveness of subcenters.

The impact of changing transport costs is ambiguous. This occurs because transport costs have a number of different effects. First, rising transport costs make long commutes less attractive and therefore increase the demand for new employment subcenters. Second, rising transport costs limits the general returns to construction, because few people can use the new subcenter.

We now turn to the determinants of the location of the employment center that is furthest from the city. We examine this edge by assuming the existence of a subcenter "S", and asking whether a new developer will want to open a subcenter beyond this point. The net surplus from this development again equal the change in land values minus the cost of development. Assuming that the new center is built in an area that had been urbanized, the total increase in land value created by the new employment center equals:

$$\text{(2)} \qquad \frac{2\alpha\Psi e^{\frac{-zd_{S+1}}{\alpha}}}{t}\left(1-e^{\frac{-(t-z)(d_{S+!}-d_S)}{2\alpha}}\right)-\frac{t-z}{t}\underline{P}(d_{S+1}-d_S)$$

The value of d_{S+1} is chosen to maximize this quantity. This implies the following proposition:

Proposition 2: As long as $\frac{2\alpha\Psi}{t}\left(e^{\frac{-zx}{\alpha}}-e^{\frac{-(t+z)x}{2\alpha}}\right)-\frac{t-z}{t}\underline{P}x-K$ is positive for some positive value of x, then there exists a value of d_S, denoted $\tilde{d}_S$ at which the returns from developing a new center further from the urban core, are equal to zero. At values of d_S beyond that point, development yields losses and at values of d_S below that point development can yield positive profits.

The value of $\tilde{d}_S$ is declining with K, $\underline{P}$, and z and rising with w, θ_1, θ_2, and $\hat{P}$.

These comparative statics are also straightforward. The fixed infrastructure costs are certainly crucial. When these are high, there will not be sprawl. High values of land for non-urban purposes will also deter sprawl. It is also true that as the agglomeration parameter, z, rises sprawl will decline. If z were to fall, which might come about because of improvements in information technology which facilitated the connection between edge centers and the core, this would cause sprawl to rise. Finally, just as before, an increase in variables such as w, θ_1, θ_2, and $\hat{P}$, which make the urban area generally more attractive will increase the amount of sprawl.

These exercises have given us some sense of the likely determinants of sprawl. The basic monocentric model emphasized the importance of commuting technology, government subsidies, demand for land and basic demand for the urban area. The extended polycentric model further brought in the fixed infrastructure costs inherent in building a new subcenter, and the deterioration of productivity with distance from the core (i.e. the importance of agglomeration). We now turn to the empirical evidence on the importance of these forces.

IV. Evaluating the Transportation Cost Hypothesis

The model argues that transportation costs influence the degree of sprawl in two very different fashions. First, in the classic monocentric model, lower costs mean that the edge of the city expands and density decreases. As commuting costs fall, the amount of land area consumed increases and the edge of the city expands. Second, in the polycentric model, the switch from public transportation to cars severely reduces the fixed costs of opening new employment centers. Public transportation, even buses, requires a great deal of fixed cost infrastructure which makes large numbers of employment subcenters difficult. At the production level, the rise of the truck has made the large infrastructure inherent in rail depots unnecessary and has freed firms from the old centers. The switch from manufacturing to services also had the effect of reducing the fixed costs involved in opening new centers and increasing the advantages of locating near where people lived.

The overwhelming importance of transportation costs in these models pushes us towards the hypothesis that the ultimate driver of decentralization is the private automobile and its commercial equivalents, including the truck. In this section, we evaluate the empirical connection between sprawl and transport costs. We will do three things. First, we will begin by highlighting the remarkable fall in transportation costs over the 20th century. Second, we will show the cross-sectional relationship between the sprawl and automobile usage. Third, we will look at international evidence and show that plausibly exogenous factors that deter automobile development have led to decreases in the level of sprawl.

Transport Costs over Time

In the early part of the century, the Europeans had the lead in car ownership. After all, the big early innovations in the automobile occurred in Germany (with Karl Daimler's invention of the internal combustion engine) and France (where the marketing of the automobile really began). But by 1920, the Americans had leapt ahead of the Europeans as Henry Ford's mass production pushed prices down and low American densities created a strong demand. By 1950, the number of households per car reached five in America. In the European countries, this threshold would not be reached until much later. For example, despite being the home of Karl Daimler, it would take the Germans until 1970 to reach the same car ownership levels that America had reached by 1920.

Since 1950, car ownership has continued to expand. In 1950, the majority of households owned one automobile (52 percent), but only 7 percent owned two cars or more. By 1990, multi-car households were the norm. In that year, the U.S. census reports that 11 percent of households had no car and 33.4 percent had only one car. The rest had two or more automobiles. The last census reported that among households with two or more members, less than one-third of households had less than two cars. This should not surprise us—America's sprawl cities require a car for each adult.

In the United States, the reliance on the automobile as a means of commuting is also pretty complete. As late as 1960, 22 percent of workers took public transportation or walked and 64 percent drove (either alone or in carpool).[7] The 1960s saw the continuing decline of non-car transportation and by 1970, 78 percent drove and 16.3 percent took public transportation or walked. In 1980, 84 percent of workers drove and 6.4 percent took public transportation and 5.6 percent walked. By and large, transportation patterns have been relatively static since 1980. The share taking public transportation has continued to decline to 5.3 percent in 1990 and 4.7 percent in 2000. Carpooling has somewhat declined (presumably as incomes have increased), but the share of people commuting by car rose to 86.6 percent in 1990 and 87.9 percent in 2000. Public transit improvements to rail systems in cities such as Atlanta, Boston, Chicago, Portland and

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[7] The primary residual category is working at home which represented 7.2 percent of the population in 1960.

Washington D.C have only slightly increased public transit use (Baum-Snow and Kahn 2000). Billions of dollars of public transit subsidies have failed to significantly increase usage despite consistently rosy ex-ante forecasts of higher ridership (Kain 1991, 1997).

Why did the car triumph? While government policies may have subsidized this transport mode, at this point we focus on why individuals, when multiple modes are available, appear to prefer driving to taking public transportation. Cars are almost uniformly more expensive in terms of cash, both in terms of initial investment and in terms of operating costs. Public transportation twice per day rarely costs more than $2.50 (except for taxis). While it may be possible to operate an automobile for less than $912.50 per year, in many places insurance costs alone exceed that amount. Maintenance can easily be several hundred dollars per year and parking can also be quite expensive. The car certainly did not become ubiquitous because it is cheap.

Consumer expenditure survey data bears out this claim. The average consumer unit (essentially a household) spends $6963 per year or 18.3 of their total household expenditures on initial vehicle purchase, gasoline and other vehicle expenditures (including insurance). It is the largest category of expenditure other than housing, and it dwarfs private spending on health care or apparel or entertainment for most people.[8]

Cars offer tremendous time saving advantages. While those who have spent hours stuck in traffic may have trouble believing it, the average car trip is actually much shorter than the average trip made using public transportation. The median commute time in the year 2000 for those people who drove alone to work was 24.1 minutes. The median commute time for those people who took public transportation was 47.7 minutes. The average public transportation trip takes is almost twice as long as the average trip made using the automobile. Figure 4 uses 1990 cross-city data to document the clear relationship that people who live in public transit cities have longer commutes.

[8] As urban economics tends to focus on the interaction between transportation and housing, it is worthwhile noting that approximately one-half of families' expenditures go on those two categories.

Glaeser, Kahn and Rappaport (2000) investigate these time differences by mode using the 1995 National Personal Transportation Survey. We found that public transportation appears to involve a fixed time cost of approximately 16-20 minutes, regardless of length. After this fixed time costs, cars appear to be about 50 percent faster than buses and roughly as fast as trains. It is this fixed time cost that makes public transportation so costly. The time spent walking (or driving) to the station or bus stop plus the time spent waiting for the bus or train plus the time spent walking or driving to the final destination appears to take up as much time as driving ten miles. As time has gotten more valuable, the time costs of public transportation have become more severe and the population has continued to move entirely towards the automobile.[9]

The car is certainly the most important transportation technology to impact the city over the last two centuries, but it is far from being the only one. In general, transport costs have declined and this has enabled urban growth in places which are far from raw materials and far from waterways. Moreover, technological innovations have enabled trucks to replace boats and trains. In 1947, there were three times as many employees in rail as in trucking and warehousing. By 1961, trucking employment passed rail and now it is a far bigger industry. According to the most recent U.S. Statistical Abstract, by value, trucks carry 86 percent of total commodity shipments within the U.S.

This is particularly important because trucks require much less fixed infrastructure than trains and boats. Large fixed infrastructure appears to be a large element driving the monocentric city of the past. The 19th century urban booster's fondest wish was a railroad stop in their town. The decline in the need for proximity to the port or rail depot has made the decentralization of manufacturing, and employment more generally, feasible.

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[9] Whether the income elasticity of commuting costs equals one or not remains an open question. Calfee and Winston's (1998) contingent valuation study of household commuting costs suggests that the income elasticity of community is much less than one. One possible explanation for their finding is that richer commuters drive "more fun", higher performance vehicles.

The Empirical Connection between Cars and Sprawl

The best evidence on the claim that cars made sprawl possible is the high correlation between using automobiles and living in low density edge cities. This type of correlation certainly does not prove that cars caused sprawl, but it is strong evidence suggesting at least cars and low-density living are very strong complements. One of the easiest ways to see this connection is to look at the correlation between urban density and driving to work across U.S. cities. In this regression, we include all U.S. cities with population levels above 25,000 and density levels that are greater than one person per every four acres.[10]

Within this sample, the overall relationship between driving to work (as a percentage of all commutes) and the logarithm of people per acre is:

$$\text{(10) Percent Driving} = \underset{(.027)}{1.27} - \underset{(.003)}{.066}\text{*Log(People/Square Mile)}, \quad N=1071, R^2 = .255$$

Standard errors are in parentheses. The raw correlation between these variables is more than 50 percent. The t-statistic is 19 and the coefficient has a sensible economic magnitude. As the density roughly doubles, the share that drives drops by roughly 6.6 percent.

Another way of thinking about this is in the 56 cities with density levels above 10,000 people per square mile, 38 percent of workers commute by private car and 37 percent commute using public transportation. Out of the 232 cities in the U.S. in 1990 with more than 50,000 inhabitants and density levels less than 2500 people, exactly none of them had less than 59 percent of workers commute by private car and in none of those cities did public transportation usage exceed 6.3 percent. Of the 372 cities with more than 50,000 inhabitants and density levels below 5000 people per square mile, two cities less

[10] There are actually four cities in the 1990 census that fall below this cutoff: Anchorage (AK), Juneau (AK), Butte-Silverbow (MT) and Suffolk City (VA).

than 55 percent of workers driving alone and three cities had public transportation usage above 13.5 percent.

In sprawled metropolitan areas, people use their cars to do everything. To document this, in Table 5, we use the 1995 National Personal Transportation Survey's Daytrip file. In this data set, the unit of analysis is a trip. Each survey participant recorded all of his trips that day. In Table 5, we report what share of these trips were taken by private vehicle for the whole sample, and then broken out by above median sprawl and below median sprawl MSAs.[11] The first row of the table shows that in MSAs which have a sprawl index above the median, 92% of trips are taken by car while 81% of trips are taken by car in below median sprawl cities. Even for trips less than one mile, there is large difference in car use. In sprawl areas, 78% of 1 mile or shorter trips are done by car while 62% of such trips are taken by car in low sprawl cities. While 7% of all trips are walked, in northeastern cities whose sprawl index is below the median, 18% of trips are by foot.

Because cars are such a ubiquitous feature of American life, it is hard to empirically test what happens when cars are not available. In the year 2000, in 49 out of the fifty states more than 85 percent of households own a car. Only in New York City do almost 30 percent of households not own an automobile. It is true that car ownership correlates with density across states—only 4.5 percent of the households in Wyoming and Idaho are without cars—but there is no way of making an inference about the impact of cars on sprawl using state level variation. The range of car ownership is too narrow and the degree of car ownership is too endogenous.

To try and shed some light on this topic, we look at international evidence. In particular, we follow Ingram and Liu (1999) and Glaeser, Kolko and Saiz (2001) who look at the relationship between urban density, car ownership and gas taxes across countries. Gas taxes vary widely from country to country and places with higher gas taxes have many fewer cars per capita. Moreover, gas taxes are in part a result of the general regulatory

[11] We partition cities based on the sprawl index presented in Ewing, Pendall and Chen (2002).

regime and in principle instruments that impact the degree of regulation generally may be valid instruments for the level of gas taxes.

We start by showing the general connection between the degree of car ownership and the level of urban density. We use data from Liu and Ingram (1999) to look at connections between cars and urban density. In Table 6, we show these relationships. In regression (1), we regress the log of urban density (defined as people per square mile) on vehicles per-capita across a sample of 70 international cities. Controlling for real GDP per-capita and a time trend (to control for the fact that some of our observations come from different years), we find a positive correlation between low-density cities (what we call sprawl) and car ownership.

In the next regression, we replace our measure of car ownership with a measure of gas taxes provided in the Liu and Ingram (1999) data. A large amount of the international variation in the cost of operating an automobile is the result of different taxation of gasoline in different countries. For example, the price of gas per gallon is often two or three times higher in Europe than in the U.S. primarily because of government taxation of gasoline. Regressions (5) and (6) look at the connection between gas taxes and vehicle ownership. Regression (5) documents that places with higher gas taxes have lower levels of vehicle ownership.

While the fact that gas taxes are negatively associated with vehicle ownership across countries can be interpreted as a classic price effect, there is another interpretation. It is possible that vehicle ownership actually drives gas taxes and not the reverse. In countries, where a large share of people commute by car, the median voter is likely to be generally hostile to gas taxes. In countries where cars are luxury goods, gas taxes may be considerably more popular.

To address this endogeneity problem, we use country's legal origin as an instrument for the level of gas taxes. In a rich literature on the impact of legal origin, LaPorta, Lopes-de-Silanes, Shleifer and Vishny (1997, 2000) have shown that most of the countries in the world have legal origins that ultimately stem from one of a small number of basic legal systems (i.e. French, British, German or Socialist). The legal origin of the country tends to be strongly correlated with a rich number of features of the government and the economy and in particular, civil law (i.e. French legal origin) countries tend to be more regulated than common law (i.e. English legal origin) countries. In regression (7), we show that gas taxes are higher (controlling for GDP per capita and the time trend) in civil law countries than in common law countries. As legal origin significantly predates the invention of the automobile, we will use this as an instrument for the level of gas taxes. In regression (6), we show that there is still a sharp relationship between gas taxes and the level of vehicle ownership when we instrument for gas taxes using legal origin.

In regressions (3) and (4), we use first gas taxes and then legal origin as instruments for the level of vehicle ownership in explaining urban population density. In regression (3), we use gas taxes as an instrument for vehicle ownership and the coefficient changes little. In regression (4), we use legal origin as an instrument for vehicle ownership (legal origins' impact of vehicle ownership runs through increased gas taxes) and we find that the results look quite similar. We conclude that across countries at least, places that make it difficult to own cars have much less sprawl. To us, this serves as at least some evidence showing the extent that sprawl is dependent on the automobile.

Evaluating Other Causes of Sprawl: The Demand for Land and Flight from Blight

The rise of the automobile is certainly not the only factor driving the decentralization of population and employment. One factor that has surely played some role in explaining the increasing suburbanization of population is the demand for larger suburban lots. People who move into the suburbs are motivated to a significant degree by the desire for more living space. However, for a land-oriented view to explain the rise in suburbanization, it needs to explain why the demand for land should have risen so much over the twentieth century.

In fact, Margo (1992) proposes just such a theory. He argues that rising incomes over the past 50 years have increased the demand for land and that one-half of the increased suburbanization between 1950 and 1980 can be explained by people getting richer. His methodology is to look at the relationship between income and suburban living in 1950 and show that if that relationship stayed constant, rising incomes would have propelled a large number of people into suburban areas.

We certainly agree that rising incomes were an important factor in driving the suburbanization of population. Indeed, in our cross-national evidence above, we also found that richer countries had less dense cities, and that the coefficient on income is at least as important as the coefficient on vehicle ownership. Our view is that both the rising incomes and automobile ownership were necessary. After all, without rising incomes, Americans would not have had the money to pay for all those automobiles. However, without the automobile the car-based edge cities would really be impossible. If Margo had been able to look at the relationship between income and suburbanization in 1900, before the advent of the automobile, we suspect that this relationship would have been much weaker.

To address this theory, we look at the degree of metropolitan decentralization by city per-capita income. For each metropolitan area, we assign it to one of four mutually exclusive and exhaustive categories based on per-capita income data from the Regional Economic Information System. In Table 7, we display a number of our decentralization measures for these different quintiles. Based on MSA Average Population Density, richer MSAs feature higher population density. Across the three sprawl indicators, there is no evidence that richer MSAs are significantly more decentralized.[12] While it is certainly true that richer people are more likely to own more land, the level of decentralization is so common, even in the poorest metropolitan areas, we have trouble believing that rising incomes (without the technological innovation of the automobile) would have changed the spatial structure of the country so drastically.

[12] We recognize that a problem with comparing per-capita income across metropolitan areas is that the cost of living varies across cities.

A second major alternative hypothesis is that the growth of the suburbs has come about because people have fled the social problems of the inner city. As forcefully argued by Mills and Lubuele (1991) and Jackson (1985), central city problems may have led people to leave and seek solace in bucolic, socially controlled suburbs. At the individual level, this theory is irrefutable. Millions of Americans have surely been directly motivated in their move to the suburbs by the desire for a more attractive social milieu. Moreover, in the case of individual cities, such as Detroit, lack of downtown amenities has surely spurred suburbanization (as in Brueckner, Thisse and Zenou, 2000).

However, the problem with this theory is that while increases in crime may spur suburbanization (see Berry-Cullen and Levitt, 1999), the trend towards suburbanization is ubiquitous. Table 7's Panel B shows the degree of decentralizations across MSAs again dividing the metropolitan areas into quintiles. In this case, we split the metropolitan areas by the degree of central city poverty. Indeed, there is somewhat more decentralization in the metropolitan areas with more poverty. The results support the hypothesis that there has been more sprawl in more troubled cities; comparisons across groups seem to lend some credence to the Mills and Lubuele emphasis on flight from blight.[13]

However, to us the most striking thing about the table is not the small connection between inner city poverty and the degree of sprawl, but rather the fact that sprawl is so high in all five other groups. Even in the group of metropolitan areas that have the least central city poverty, the median worker works 6.5 miles away from the central business district. We conclude from this that inner city problems certainly encourage suburbanization, but that suburbanization is far too ubiquitous to be primarily the result of poor central cities.

Evaluating Other Causes of Sprawl: The Political Roots of Sprawl

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[13] Of course, establishing causality is hard, as Meyer, Kain and Wohl (1965) and many others have argued, the suburbanization of population may hurt central city residents.

A final set of theories concerning the flight to the suburbs emphasizes the role of politics. There are two variants of this hypothesis. The first variant is that federal and state governments through their favoritism of the automobile and through other anti-urban policies pushed people out of the central cities into the suburbs. This story is not particularly popular among economists, but urbanists in other disciplines are quite fond of the view that massive government spending on roads and highways, coupled with relatively low gas taxes and little subsidization of public transportation, made America's automobile culture inevitable (see e.g., Hart and Spivak, 1993).

There is certainly some truth to this view. Other governments have spent much less on roads and taxed gasoline much more severely. As we documented above, we believe strongly the high European gas taxes deter private automobile use. Indeed, total government spending on highways is somewhat awe-inspiring. According to the U.S. Department of Transportation, total highway expenditures by all levels of government reached $128.5 billion in 2000. Of that sum, $31 billion represents administration, bond interest and highway patrols. Another $31 billion represents maintenance on existence infrastructure. The remainder is new construction.

How is this vast expenditure financed? Is this actually a huge boondoggle, where motorists are subsidized by non-drivers? In fact, $81 billion is financed by user fees. A small fraction of that ($ 5 billion) represents tolls. The remainder comes primarily from gas taxes. Another $ 11 billion is paid for out of bonds which are at least supposed to be retired using future user fees. The remainder, almost $ 40 billion does seem to represent government subsidy. This is certainly a non-trivial subsidy and the subsidy's share of total expenditures appears to have been higher during the early era of highway construction.

However, this quantity needs to be put in the context of total automobile expenditures. If $40 billion represents $300 per household, this is tiny relative to other car related spending. The subsidy is no more than 5 percent of total per capita spending on automobile travel. By this, we do not mean to claim that subsidizing highways makes sense. However, it seems unlikely that reducing the price of automobile travel by two or three percent is likely to have made a huge difference in the transition to car based living.

Moreover, public transportation is also subsidized. The dollar amount is not as large as the subsidy towards highways, but total government expenditure on public transportation is more than $25 billion, and only a fraction of that is returned in government revenues. There is a subsidy of highways, but it seems impossible to believe that this subsidy was the crucial determinant of the growth of America's car-based sprawl culture.

The second variant of the government caused sprawl view is that local governments are responsible for suburbanization. The most classic story is that suburbanization is a form of Tiebout sorting where people move to the suburbs to get the bundle of public goods and services that they want. There is certainly truth to this view. Suburbanites value living in their own jurisdictions and that is one thing that makes suburbs attractive. This effect is exacerbated if central cities redistribute from rich to poor (as in Brueckner, 1983). No one can look at the development of the suburbs around Detroit and not think that the administration of Coleman Young encouraged some of the whites to leave.

The problem with this view is that again suburbanization is only weakly correlated with the number of jurisdictions. The degree of suburbanization in Philadelphia, the most fragmented metropolitan area in the country is not higher than the degree of suburbanization in Anchorage, the least fragmented area. To study this, in Panel D of Table 7, we split metropolitan areas by their degree of political fragmentation based on data from 1962. Here we see little excess suburbanization in more fragmented communities. Suburbanization is ubiquitous, even if the non-fragmented metropolitan areas. Our point is not that Tiebout sorting does not occur. Rather, our point is that the driving force behind sprawl is not jurisdictional sorting.

A second theory about how local governments create sprawl works through the zoning process. If districts that are closer to the city center, zone and make high density construction impossible, then this will surely increase the development of sprawl on the edge of the city. Districts on the edge, which contain primarily farmland, have no incentive to block new construction and rarely do so. In this way, the so-called Smart Growth movement may have unwittingly supported sprawl because it gave intellectual legitimacy to the idea that areas close to the city center should restrict new construction. Unless the district can actually prevent construction on the edge of the city, this type of policy will increase sprawl.

How important have land use controls actually been in creating sprawl? In particular metropolitan areas in California, this is surely a relevant factor. However, in most of the middle of the country zoning tends to be pretty weak. Still, sprawl is particularly ubiquitous in the South and Midwest. Houston, a city with no zoning, sprawls. Again, this force may have contributed to the suburbanization of jobs and people, but it cannot have been the driving force.

A final idea about how the government may have fomented sprawl is put forward by Voith (1999). Voith argues that through the home mortgage interest deduction, the government has subsidized housing consumption and that this has induced people to consume more housing and as a result live outside of urban areas. We are skeptical about the importance of this force (see Glaeser and Shapiro, 2002), but we agree that subsidizing homeownership will also support the move to sprawl.

IV. Is Sprawl Bad?

Finally, we turn to the fundamental question of whether sprawl deserves some major policy response. We have mentioned the primary benefits of sprawl already: a car culture that generally allows short commutes and large homes. However, these benefits may be offset by other social costs. Brueckner (2001) highlights three major areas where developers who build on the edges of cities may not be internalizing the full costs of their actions. First, these developments may increase traffic congestion. This is certainly the most obvious market failure in edge cities and we turn to the issue of congestion first.

Second, these developments may have environmental consequences. Brueckner focuses on the elimination of empty space at the edge of the city. We discuss that briefly, but rather focus on the environmental consequences of having so many drivers.

Third, developers may not pay for the full costs of the infrastructure that they use. We will not discuss this third possibility. In many cases this appears to be true, although in other cases the combination of taxes and impact fees probably pay for the costs of sprawl. We will not focus on this issue as the appropriate policy response seems obvious. If suburbanites are not paying for the costs of their infrastructure, then they should be made to do so. We suspect that in many cases, property taxes do cover the new infrastructure costs, but since there is likely to be a large amount of heterogeneity across the U.S., we will simply agree that impact fees are appropriate if developers are underpaying, and we will not discuss this topic further.

We also add two additional areas where policy concern might be merited. First, we discuss the productivity consequences of sprawl. In principle, when jobs move to the suburbs, this may reduce productivity in the city and this could yield social losses. Second, we consider the social consequences of suburbanization and ask whether there are externalities in that area that are worth addressing.

A final area that looms large as one of the major policy failures in the suburbanization context is the use of zoning laws. In theory, zoning laws provide localities with a means to induce developers to internalize externalities. However, there are two problems with zoning. First, if zoning pushes development off to the fringe of the city and this form of development has externalities, then zoning will be inefficient. Second, and we suspect more importantly, localities are incentivized to use zoning not only to internalize externalities but also to restrict supply to raise property values. This incentive means that localities will act like local monopolists and underprovide new construction. This appears to have had remarkable effects pushing real estate prices up in the 1990s and this is also a major topic for policy action.

Housing Prices and Quantities

Of course, the main benefit of sprawl for most consumers is cheaper, larger homes. Figure Five reports median square footage of floor area in new one-family houses from 1973 until 2001. Over the last 20 years, news homes have grown by roughly 20%. Using the 1999 micro data from the American Housing Survey, in Table 8 we present average housing consumption for households with at least three people for people and whose income is greater than $10,000. We present separate means for center city and suburban residents and present these results for a subset of 11 major MSAs and for the whole sample. The second row shows the amount of square feet per person. In the major cities, the average central city resident has 496 square feet per person. The average suburban resident has 570 square feet per person. This difference is large. In the next rows, we show that on average suburbanites have more bedrooms and bathrooms as well.[14]

In the fifth row, we look at the share of people who live in single family houses. In the suburbs, 70 percent live in such homes. In the central cities, 35 percent live in those homes. The difference is quite striking. In the next row, we look at the land area per person consumed in the two geographic locales. Finally, in the bottom rows, we look at housing and rent costs. While the average suburban owner's home is valued at $30,000 more than the average center city owner's home, in the major cities the price per square foot is 27% lower in the suburbs.[15]

Housing consumption in the U.S. is remarkably high by international standards even within central cities. For example, in Paris, the average person has less than 350 square

[14] Kahn (2001) uses 1997 American Housing Survey and documents that both blacks and whites live in larger housing units when they live in more sprawled MSAs. He uses the share of MSA jobs more than 10 miles from the CBD as the sprawl indicator. For some measures of sprawl, black households do enjoy greater gains relative to whites when they live in sprawled MSAs.

[15] Due to missing data for unit square footage, we can only calculate house price per square foot for a subset of owners.

feet. In Madrid, the average person has less than 260 square feet and in Tokyo the average person has less than 150 square feet. All of America has achieved levels of housing consumption that are astounding by world standards. But this is particularly true in the suburban areas where the car has made low densities and large homes possible.

Congestion and Cars

Congestion pre-dates the car. The concentration of people in crowded urban areas led to discomfort and the easy spread of disease. Furthermore, extreme density levels can slow food traffic because too many bodies share too little space. However, most pre-modern American cities had wide enough streets so that foot congestion was rarely a major problem. Given the small scale of most cities and given the absence of tall buildings, there were rarely high enough densities to crowd most 18th or 19th century American streets with pedestrians.[16]

Public transportation is usually centrally planned, so congestion can be limited by the firm or government that operates the trolley or omnibuses or subways. Subways do block each other's movement, but all of their trips are planned by a single operator so there are no externalities. The situation is completely different with the car. In most cases, streets can be freely accessed and there is a classic common pool problem. As generations of transport economists have noted, drivers will continue to use the street until the point that the marginal cost to them of driving is equal to the marginal benefit. Since their driving imposes costs on every other driver, this represents a classic externality.

As such, it makes sense to figure out sensible ways to make drivers internalize the social costs of their driving. Naturally, congestion fees are particularly attractive, especially if they can be implemented electronically so that there are few delays at the tollbooths.

[16] Congestion is much more of a problem with cars than with walking because automobiles, in motion, use as much as 50 times more room than walkers. A person, while walking, might enjoy having six or seven square feet of space. Each car, assuming it keeps one car length between itself and the car ahead, uses up approximately 300 square feet of road.

Alternatively, the use of stickers that allows driving on certain roads at certain times is also attractive. There are obviously particular advantages to getting people to commute at different times during the day. Gas taxes are a somewhat foolish means of addressing congestion since they equally influence drivers on empty highways and drivers on downtown streets. Moreover, since they specifically work against decentralization, they may have the effect of inducing more people to commute to one central location.

But while it is sensible to tax driving on crowded streets, it does not seem sensible to respond to congestion externalities by fighting sprawl. Before employment decentralization, when sprawl meant suburbanites driving downtown, the link between sprawl and added street traffic on congested roads was tight. However, the decentralization of employment actually reduces the pressure on crowded downtown streets. By moving to lower densities, the traffic problem is actually reduced. Indeed, one of the major appeals of sprawl cities is that they have shorter commutes than dense downtowns.

In Table 9, we use the micro data from the 1995 National Personal Transportation Survey to study differences in one way commuting times (in minutes) as a function of distance to work and residential block density. We find that average commute times rise with population density. The effect of density is actually less on car commuters than on non-car commuters. It is also true that across cities, there is a strong positive relationship between average commute times and the logarithm of population density (see Figure 6)

Sprawl and the Environment

Many of the harshest critics of suburbanization have been environmentalists. The move to edge cities has three major impacts on the environment. First, it uses up land that once used to be farmland or forest. Second, because sprawl is so car intensive, the move to sprawl may have increased car-related air pollution and increase the supply of greenhouse gas production. We consider all of these possibilities at this point.

While it is true that sprawl, by definition, increased the amount of developed land, it is worthwhile emphasizing that America is only slightly developed. Ninety-Five percent of the land in this country remains undeveloped. Only 6.6 percent on non-Federal land has been developed. Moreover, people start living on truly massive estates, residential development is unlikely to cover a large area of the country. For example, if every American lived on 1/4 of an acre of land, so each family of four had an acre, this would not fill up one half of the state of Texas. Thus, there is more than enough land to accommodate any reasonable level of development.

Moreover, forest cover in the U.S. is increasing, not declining. The big changes in land use in this country are the reduction of pasture and range land, not the increase in developed land. If there are environmental consequences from different forms of land use, then surely focusing on the conversion for pastures to forests is more important than anything concerning the small amount of total land that is developed. As an aside, given that sprawl needs housing and housing requires wood and wood needs forest, it may well be that the increase in sprawl has actually increased forest cover in the U.S. by increasing the demand for forest products.

Of course, the fact that the overall level of forest cover in the U.S. is rising does not mean that people have forests where they want them. There are a number of recreational, not environmental, reasons why people may want to have forests close to cities. This presumably calls for some targeted park development, not for limits on sprawl. The growth of land trusts such as the Nature Conservancy provides a free market solution for providing this local club good.[17]

[17] Even in Japan, the island of Honshu has approximately 56 million acres (excluding all other Japanese islands)—this is enough for all 47 million Japanese households to live in 3,000 square foot homes on quarter acres, and leave 75 percent of the land area (and all other Japanese islands) unoccupied. Currently, 50 percent of Japanese households together sit on less than two percent of the available land area in the Archipelago. High Japanese densities are not the result of lack of land, but of government policies that often reflect the goals of other lobbies. Currently, only 4.7% of Japanese land is used for building.

Two major environmental externalities associated with driving are greenhouse gas production and local smog. Driving is a major contributor to U.S greenhouse gas production. Between 1990 and 2000, CO_2 emissions per-capita have grown roughly 5% even though CO_2 emissions per unit of GDP have fallen over 15%. Increased driving has played a role in this increase. Both international cross-city evidence and domestic evidence shows that people drive more in more sprawled cities (Newman and Kensworthy (1998) and Kahn (2000)).

Given that there has been little change over the last 20 years in average fleet fuel economy, increased mileage translates into more fuel consumption and subsequent increases in greenhouse gas production. The recent Kyoto Protocol treaty would have required the U.S to reduce its greenhouse gas production by roughly 10%. Interestingly, suburbanization has increased the average driver's greenhouse gas emissions by around 10%. Annual U.S. carbon dioxide emissions per-capita equals 40,000 pounds. Every gallon of gasoline consumed creates 20 pounds of emissions. Thus, if a household, whose vehicle achieves 25 miles per gallon, reduced its driving from 22,620 to 16,950 miles a year this would reduce household emissions by over 4000 pounds (Kahn 2000). These mileage figures represent the sample means for suburban and city household drivers as reported in the 1995 NPTS data. The growing popularity of large fuel inefficient vehicles, such as SUVs, increases the climate change impact of suburban driving. It is possible that technological advances such as the development of a fuel efficient hydrogen car will help to offset the extra driving brought about by ongoing suburbanization (Hawken, Lovins and Lovins 1999). But, even optimists believe this will not take place for another 20 years.

Despite increased vehicle use over the last thirty years, the most polluted parts of the United States have experienced a dramatic drop in their smog levels. California has experienced sharp population growth, on going suburbanization, and due to its geography and concentration of economic activity it features the worst ozone smog problems in the nation. To document air pollution trends, we use the California Ambient Air Quality Data 1980-1999 (California EPA Air Resources Board). This CD-ROM provides all air quality readings taken in the state during this time period. In this data, the unit of analysis is a monitoring station. We partition California into two areas, the Los Angeles Basin and everywhere else in the state. The Los Angeles basin has suffered from the worst smog in the nation.

In Table 10, we break out the pollution data into two decades, the 1980s and the 1990s, and we explore pollution trends in the Los Angeles area and in the rest of the state. During both decades, total population grew by more in the Los Angeles area than in the rest of the state and vehicles per-capita continued to grow. This should have led to more smog and nitrogen dioxide pollution as car activity increases. Yet, the table highlights the sharp pollution progress in the Los Angeles basin relative to the rest of the state. In the Los Angeles Basin, people living near the median monitoring station in the 1980s were exposed to 33 polluted days per year while in the 1990s their exposure fell down to 5 days a year. This extra month of clean air is striking given that the median person in the rest of the state did not gain. The bottom two rows of the table document the Los Angeles Basin's progress based on two other ambient pollution criteria. Despite the growth in this region, the Los Angeles region is converging to the rest of the state's low pollution levels.

This environmental gain was achieved due to the greening of the automobile. New vintages emit much less emissions than pre-1975 makes (Kahn 2000). Table 11 reports California vehicle median hydrocarbon emissions by model year and calendar year. The California Air Resources Board has pulled different vehicles off of the road in different calendar years and conducted a "random roadside test". Pooling these repeated cross-sections provides evidence on the extent of the greening of fleet emissions. Each column of Table 11 reports cross-sectional facts about how vehicle emissions variation across vehicle vintage types. Reading across a row of Table 11 indicates how for a given model year, a vehicle's emissions changes as it ages. Two key facts emerge from Table 11. Vehicles built after 1975 have much lower emissions than pre-1975 vehicles (Kahn 1996). Second, post 1975 makes continue to have lower emissions relative to pre-1975 makes even as they age. For example, the median vehicle built between 1975 and 1979 has relatively low emissions in calendar year 1992 and in 1996. This table indicates that the average air pollution externality per mile of driving is falling over time.

Indeed, throughout the U.S. most major forms of pollution are actually declining. Carbon monoxide, particulates, ozone, sulfur dioxide, and lead have all decreased significantly. Sprawl may be increasing the scale of driving, but improvements in technology are more than compensating for this increase.

This is not to say that cars should not be taxed so that they internalize the environmental consequences of driving. Older cars that produce so much of the car fleet's pollution output are natural candidates for environmental taxes. Equity considerations, poor people own older vehicles than richer people, tend to discourage such differentiated taxes.

There are negative environmental externalities due to sprawl, but they do not seem overwhelming. Forest cover in the U.S. is rising, not falling. Automobile pollution is becoming a less serious problem. Certainly, targeted responses are appropriate. Setting aside land if there is demand for empty land seems like a sensible response to overdevelopment and gas taxes seem like the right response to car pollution (see Parry and Small 2002). Neither calls for a wholesale end to sprawl.

Agglomeration and Productivity Consequences of Sprawl

Another possible negative consequence of sprawl is that urban agglomeration economies may be reduced. There is a rich and impressive literature documenting the importance of agglomeration effects. This literature has shown the connection between density at the county level and agglomeration (Ciccone and Hall, 1996) and has documented that higher urban wages are not merely the result of more able workers moving to cities (Glaeser and Mare, 2001). Rauch (1993) shows that wages are higher in cities with higher human capital workers. Jaffe, Trajtenberg and Henderson (1993) provide the best evidence that ideas do move more quickly when people are in close proximity. Lucas and Rossi-Hansberg (2002) also argue for the importance of density in speeding productivity.

These papers all suggest that sprawl might indeed reduce agglomeration economies and deter overall productivity.

There is however some doubt about the level of agglomeration needed for spillovers to operate. While no one doubts that dense areas are more productive than the wilds of Sasketchewan, it is less obvious that downtown Detroit is more productive than Silicon Valley (a textbook example of sprawl). It is possible that some forms of agglomeration actually require working in a walking city. After all, the shear rush of new ideas associated with moving around Tokyo or New York is staggering. But we suspect that most agglomeration effects are based on ready access to other human being. After all, Lucas (1988) himself wrote "What can people be paying Manhattan or downtown Chicago rents for, if not for being near other people?"

It is exactly this type of reasoning that makes us suspect that sprawl is not so bad for productivity. After all, well functioning sprawl is full of people. The only difference between sprawl and conventional downtowns is that sprawl is built around the automobile, not around walking and public transportation. As such, we suspect that some sprawling car cities are more productive, and others are less so, just as some traditional cities are more productive and others not. Sprawl cities with higher levels of density and better transportation infrastructure appear (as in the case of Silicon Valley and Route 128) to be able to deliver very high levels of connection indeed.

As such, we think that some empirical evidence is appropriate to look at this issue. Again, we see this evidence as not disputing the general importance of agglomeration effects, but rather as informing the question as to whether these agglomeration effects can still work when people drive, rather than walk or take public transportation.

There are two pieces of evidence that bear on this issue. First, there is the question of whether output is less in lower density areas. Here there is no question. Per capita incomes are higher in MSAs with higher levels of density. Across major MSAs, the overall relationship in the year 2000 was:

$$\text{Log(Per Capita Income)} = \underset{(0.08)}{9.55} + \underset{(0.01)}{0.13}\text{*Log(Job Density), N=139, R-squared=.40}$$

Standard errors are in parentheses. This relationship is quite strong and mimics at the MSA level what Ciccone and Hall (1996) found using state level information on productivity.

However, when we repeat this regression using the share of jobs more than three miles from the city center as our measure of job decentralization, we find

$$\text{Log(Per Capita Income)} = \underset{(0.10)}{10.05} + \underset{(0.13)}{.27}\text{*Job Sprawl, N=139, R-squared=.03}$$

In this case, a 10-percentage point increase in job sprawl increases MSA per-capita income by 2.7%. Thus, aggregate density at the MSA level matters, but the degree to which those jobs are centralized in the central city appears to be irrelevant.

A second form of evidence is to actually calculate the job density within 30 minutes drive of a central location in the new edge cities and to compare this with the job density within the traditional CBD. By our calculations, it would take 25 minutes to go about three miles using public transportation. There are 81,000 jobs within a three-mile radius of the center of downtown St. Louis. In a car, even in moderate traffic, someone should be able to travel 12.5 miles in a modern edge city. The number of jobs within three miles of downtown Palo Alto or Tyson's Corner dwarfs the number of jobs in the traditional downtowns of most older cities. As such, the edge cities are true agglomerations, they just involve using automobiles.

Social Consequences of Sprawl

One particularly important question about sprawl is whether it creates segregation of rich and poor or racial segregation or social isolation more generally. First, it seems quite clear that the wealthy have found it easier to take advantage of the new edge cities than the poor. As Glaeser, Kahn and Rappaport (2000) document, the poor live downtown and the rich live in suburbs. We follow Gin and Sonstelie (1983) and argue that transportation technologies play a crucial role in explaining this segregation. Because cars are so expensive, the poor live in cities so that they can use public transportation. Glaeser, Kahn and Rappaport (2000) show that poverty rates are much higher closer to public transit stops and when areas increased access to public transportation their poverty rates increased.

While it is true that the automobile has led to the suburbanization of the wealthy, it is not clear what the solution to this problem should be. One approach might be to tax the car and push the rich back into cities. Alternatively, one might think that the right approach is to subsidize car ownership for the poor as advocated by Raphael and Stoll (2001).

One piece of information which is important in determining whether car cities should be taxed or public transportation cities should be subsidized is to ask which urban form is fundamentally more integrated. Cutler, Glaeser and Vigdor (1999) find that racial segregation is much lower in suburban census tracts than in urban census tracts. Moreover, the level of segregation has been lower in the newer, car-based cities of the west and the south than in the older, public transportation based cities of the northeast. Suburbs certainly don't seem like models of integration, but then older cities were pretty segregated as well. We take the Cutler, Glaeser and Vigdor (1999) 1970 and 1990 dissimilarity index and calculate the change in segregation over this 20 year period. In Figure 7, we graph the change in segregation with respect to the percent change in MSA population growth over that time period. A clear negative correlation is seen. Fast growing metro areas such as Orlando, Las Vegas, and Phoenix have experienced a sharper decline in segregation relative to slow growth areas.

The evidence on social isolation in the suburbs is quite mixed. As Putnam (1999) reports, people in suburbs are less likely to join formal social organization. Glaeser and Sacerdote (1999) show that people who live in single family detached houses are also less likely to interact with their neighbors than people who rent. The proximity involved in urban density and multi-unit buildings appears to abet connection. Presumably these facts help us to understand why some critics of suburban living argue that it is socially isolated.

However, many of these relationships are quite weak and other forms of social connection rise in the suburbs. For example, church attendance is higher in suburban areas. Time study diaries show almost no difference in the time per week spent in social activities between city-dwellers and suburbanites. As a result, we think that this is a provocative area for new research, but hardly a compelling basis for government action.

Zoning

The past ten years has seen a startling increase in housing prices in many east and west coast metropolitan areas. These increases have been highly localized. In most of the United States, housing prices are generally determined by the physical cost of construction (see Glaeser and Gyourko, 2002). Still, in some areas and in particular in the suburbs of wealthy cities, housing prices have reached astonishingly high levels.

In principle, this increase could just be the result of rising demand for land. After all, the urban model discussed above predicts that as a city growth, the value of land that is proximity to work areas should become quite high. However, the urban model doesn't really explain the experience of American housing prices very well. The urban model predicts that land should be equally valued on the intensive and extensive margins. In other words, the gap in price between a house on a quarter acre lot and a house on a half acre lot should be the same as the difference between the price of the house on a quarter acre lot and the construction cost of the house. If this wasn't true, then the owner of the house on the half-acre lot would subdivide and build a new house on one-half of his parcel.

Glaeser and Gyourko (2002) show that these two values diverge wildly in expensive areas. In some expensive areas, the price per acre as calculated by subtracting construction cost from housing value and dividing by land area is as much as ten times as much as the price per acre found comparing equivalent houses on different size lots. This can only occur if zoning, or other development controls have stopped new construction. Indeed, examination of new construction statistics in the 1990s show that expensive areas have indeed stopped allowing new construction, presumably through various forms of regulation.

This may in fact be efficient. Zoning may be internalizing externalities exactly as it is meant to. However, it seems just as likely that current homeowners are using zoning to restrict supply are thereby push up the price of their house. In this way, zoning enables homeowners to act like local monopolists and its effects may be quite costly socially. As we move forward, this area deserves more research and policy attention.

V. Conclusion

Over the past century, urban growth has taken the form of sprawl. First people and then jobs left the high density, walking and public transport cities of the 19th century. They moved into the lower density, car cities of the next century. The move to cars and trucks was important not only because it reduced transport costs, but also because it eliminate the fixed costs of rail depots and ports. These fixed costs had been a major force driving agglomeration and their disappearance has enabled employment to decentralize. Edge cities were made possible by the automobile and as long as the car remains the dominant transport mode, sprawl is likely to remain the dominant urban form.

The economic and social consequences of sprawl do not appear to be dire. Suburbanization is not linked to rapid decreases in intellectual creativity or to massive social unrest. New ideas seem to be created in Silicon Valley just as easily as they were in Detroit. After all, most theories about urban agglomeration leading to innovation stress connection, not transport mode. Since people who live in the new car cities are still quite close to their neighbors, when proximity is measured by travel time, we shouldn't have really expected a decline in the degree of intellectual progress.

Suburbanites are less connected than city-dwellers, but the difference seems slight. Suburbs are actually more racially integrated than central cities. There is a transitional problem as the poor can not pay for cars and remain stuck in central cities and this surely deserves policy attention. But it makes more sense to give the poor car vouchers (as advocated by Raphael and Stoll (2001)) rather than to stop suburbanization.

There are some market failures associated with sprawl. Highways have a common pool problem that is not shared by rail. Either we need to be accustomed to traffic jams, as Tony Downs (1992) eloquently argued in Stuck in Traffic, or we need to figure out how to be smarter about using electronic tolls to limit congestion. Pollution is an issue, but the phase-in of vehicle emissions control technology has reduced emissions per mile faster than vehicle mileage has increased. Finally, there is the issue of zoning. Local political units work well for many things, but they appear to be restricting housing supply to raise prices and we should probably rethink our current zoning laws.

Appendix: Proofs of Propositions

Proof of Proposition 1: The social surplus (or profits) generated by a new subcenter equals:

$$\text{(A1)}\quad \pi(\phi,\Delta,X)=\frac{2\hat{P}e^{\frac{w\theta_1+\theta_2 t-zd_{s-1}}{\alpha}}\alpha}{t}\left(e^{\frac{-z\phi\Delta}{\alpha}}+e^{\frac{-(t+z)\Delta}{2\alpha}}-e^{\frac{-(t+z)\phi\Delta}{2\alpha}}-e^{\frac{-(1-\phi)t\Delta-(1+\phi)z\Delta}{2\alpha}}\right)-K$$

Differentiation then gives us:

$$\text{(A2)}\quad \frac{d\pi}{d\phi}=\frac{2\Psi\alpha e^{\frac{-zd_{s-1}}{\alpha}}}{t}\left(\frac{-z\Delta}{\alpha}e^{\frac{-z\phi\Delta}{\alpha}}+\frac{(t+z)\Delta}{2\alpha}e^{\frac{-(t+z)\phi\Delta}{2\alpha}}-\frac{(t-z)\Delta}{2\alpha}e^{\frac{-(1-\phi)t\Delta-(1+\phi)z\Delta}{2\alpha}}\right),$$

which in turn implies $\frac{(t-z)\phi}{2\alpha}e^{\frac{-(1-\phi)t\Delta-(1+\phi)z\Delta}{2\alpha}}=\frac{-z\phi}{\alpha}e^{\frac{-z\phi\Delta}{\alpha}}+\frac{(t+z)\phi}{2\alpha}e^{\frac{-(t+z)\phi\Delta}{2\alpha}}$ or

$2z+(t-z)e^{\frac{-(1-\phi)(t+z)\Delta}{2\alpha}}=(t+z)e^{\frac{-(t-z)\phi\Delta}{2\alpha}}$. Differentiation also gives us that:

$$\text{(A3)}\quad \frac{d\pi}{d\Delta}=\frac{\partial\pi}{\partial\phi^*}\frac{\partial\phi^*}{\partial\Delta}+\frac{\partial\pi}{\partial\Delta}=\frac{2\Psi\alpha e^{\frac{-zd_{s-1}}{\alpha}}}{t}$$
$$\left(\frac{-z\phi}{\alpha}e^{\frac{-z\phi\Delta}{\alpha}}-\frac{t+z}{2\alpha}e^{\frac{-(t+z)\Delta}{2\alpha}}+\frac{(t+z)\phi}{2\alpha}e^{\frac{-(t+z)\phi\Delta}{2\alpha}}+\frac{t(1-\phi)+z(1+\phi)}{2\alpha}e^{\frac{-(1-\phi)t\Delta-(1+\phi)z\Delta}{2\alpha}}\right)$$

Using the fact that $\frac{(t-z)\phi}{2\alpha}e^{\frac{-(1-\phi)t\Delta-(1+\phi)z\Delta}{2\alpha}}=\frac{-z\phi}{\alpha}e^{\frac{-z\phi\Delta}{\alpha}}+\frac{(t+z)\phi}{2\alpha}e^{\frac{-(t+z)\phi\Delta}{2\alpha}}$, we can simplify

this expression to $\frac{d\pi}{d\Delta}=\frac{2\Psi(t+z)e^{\frac{-zd_{s-1}}{\alpha}}e^{\frac{-(t+z)\Delta}{2\alpha}}}{2t}\left(e^{\frac{(t-z)\phi\Delta}{2\alpha}}-1\right)>0$, It is obviously true that profits are negative when Δ is sufficiently small. Now change notation and let $\phi\Delta = -\frac{2\alpha}{t-z} Log\left(\frac{2z}{t+z}\right)$, then as Δ becomes sufficiently large, profits converge to $\frac{2\Psi\alpha e^{\frac{-zd_{s-1}}{\alpha}}\left(\left(\frac{2z}{t+z}\right)^{\frac{2z}{t-z}} - \left(\frac{2z}{t+z}\right)^{\frac{t+z}{t-z}}\right)}{t} - K$, which is positive when $2\Psi\alpha e^{\frac{-zd_{s-1}}{\alpha}}\left(\left(\frac{2z}{t+z}\right)^{\frac{2z}{t-z}} - \left(\frac{2z}{t+z}\right)^{\frac{t+z}{t-z}}\right) > tK$. Then continuity ensures the existence of a value of Δ, which satisfies $\pi\left(\phi^*(\widetilde{\Delta}(X), X), \widetilde{\Delta}(X), X\right) = 0$.

The equality $\pi\left(\phi^*(\widetilde{\Delta}(X), X), \widetilde{\Delta}(X), X\right) = 0$, which implies that $\frac{\partial\widetilde{\Delta}}{\partial X} = -\frac{\partial\pi}{\partial X}\Big/\frac{\partial\pi}{\partial\Delta}$, so that the sign of the effect of any variable X on $\widetilde{\Delta}$ is the opposite of the sign of the effect of any variable X on π. Differentiation then gives us that $\frac{\partial\pi}{\partial K} < 0$, $\frac{\partial\pi}{\partial\hat{P}} > 0$, $\frac{\partial\pi}{\partial w} > 0$, $\frac{\partial\pi}{\partial\theta_1} > 0$, $\frac{\partial\pi}{\partial\theta_2} > 0$ and $\frac{\partial\pi}{\partial d_{s-1}} < 0$.

(A4) $$\frac{\partial\pi}{\partial t} = \frac{2\Psi e^{\frac{-z(d_{s-1}+\phi\Delta)}{\alpha}}\alpha}{t^2}\left(\begin{array}{l} -\left(1 + e^{\frac{-t\Delta-(1-2\phi)z\Delta}{2\alpha}} - e^{\frac{-(t-z)\phi\Delta}{2\alpha}} - e^{\frac{-(1-\phi)(t+z)\Delta}{2\alpha}}\right) - \\ \frac{\Delta t}{2\alpha}\left(e^{\frac{-t\Delta-(1-2\phi)z\Delta}{2\alpha}} - \phi e^{\frac{-(t-z)\phi\Delta}{2\alpha}} - (1-\phi)e^{\frac{-(1-\phi)(t+z)\Delta}{2\alpha}}\right)\end{array}\right)$$

$$\frac{1}{t}\left(1 + e^{\frac{-t\Delta}{2\alpha}} - 2e^{\frac{-t\Delta}{4\alpha}}\right)$$

If z is small so $\phi \approx .5$, and using the notation $x = \frac{\Delta t}{2\alpha}$ the expression in brackets can be approximated by $(2+x)e^{-.5x} - (1+x)e^{-x} - 1$. This expression equals zero (to two decimal places) when x=2.5 and is positive for all values below that amount and negative for all values above that amount. When $2.5 = \frac{\Delta t}{2\alpha}$, then the land in between the two old subcenters traded at 8.2 percent of the value of land at the old subcenters, and is more than that amount when $2.5 > \frac{\Delta t}{2\alpha}$. As such, when z=0, the maximum spread between two subcenters falls with t when land in between the two old subcenters costs more than 8.2 percent of land at the subcenters and rises otherwise.

$$\text{(A5)} \quad \frac{\partial \pi}{\partial z} = \frac{-2\hat{P}e^{\frac{w\theta_1+\theta_2 t - zd_{s-1}}{\alpha}}}{t}\begin{pmatrix} (d_{s-1}+\phi\Delta)\left(e^{\frac{-z\phi\Delta}{\alpha}} + e^{\frac{-(t+z)\Delta}{2\alpha}} - e^{\frac{-(t+z)\phi\Delta}{2\alpha}} - e^{\frac{-(1-\phi)t\Delta-(1+\phi)z\Delta}{2\alpha}}\right) + \\ \frac{\Delta}{2}\left((1-2\phi)e^{\frac{-(t+z)\Delta}{2\alpha}} + \phi e^{\frac{-(t+z)\phi\Delta}{2\alpha}} - (1-\phi)e^{\frac{-(1-\phi)t\Delta-(1+\phi)z\Delta}{2\alpha}}\right) \end{pmatrix}$$

If z=0, so $\phi \approx .5$, this terms in brackets become $-(d_{s-1}+.5\Delta)\left(1+e^{\frac{-t\Delta}{2\alpha}} - 2e^{\frac{-t\Delta}{4\alpha}}\right)$ which is always strictly negative. The problem is continuous, so that for low values of z, the expression will remain negative.

Proof of Proposition 2: Define $\pi(d_{S+1}, d_S, X)$ as the net profits yielded from a new subcenter, where X refers to any other exogenous characteristic. This function equals:

$$\text{(A6)} \quad \frac{2\alpha\Psi e^{\frac{-zd_{S+1}}{\alpha}}}{t}\left(1-e^{\frac{-(t-z)(d_{S+!}-d_S)}{2\alpha}}\right) - \frac{t-z}{t}\underline{P}(d_{S+1}-d_S) - K$$

Also define $d^*_{S+1}(d_S, X)$ as the optimal value of d_{S+1} contingent upon the other characteristics. This is determined by the first order condition

$\frac{\Psi}{t}\left(-2ze^{\frac{-zd_{S+1}}{\alpha}} + (t+z)e^{\frac{-(t+z)d_{S+!}+(t-z)d_S)}{2\alpha}}\right) - \frac{t-z}{t}\underline{P} = 0$, or

$(t+z)P(\hat{d}_S) = 2zP(d_{S+1}) + (t-z)\underline{P}$.

At the optimal level of d_{S+1}, $\frac{d\pi}{dd_S} = \frac{\partial \pi}{\partial d_{S+1}} \frac{\partial d^*_{S+1}}{\partial d_S} + \frac{\partial \pi}{\partial d_S}$, or

$-\frac{(t-z)}{t}\left(\Psi e^{\frac{(t-z)d_S - (t+z)d_{S+1}}{2\alpha}} - \underline{P} \right)$, which is negative because $P(\hat{d}_S) > \underline{P}$. It is obvious that for a sufficiently large value of d_S, profits from a new subcenter become negative. As long as $\frac{2\alpha\Psi}{t}\left(e^{\frac{-zd_{S+1}}{\alpha}} - e^{\frac{-(t+z)d_{S+!}}{2\alpha}} \right) - \frac{t-z}{t}\underline{P}d_{S+1} - K$ is positive for some value of d_{S+1}, then it is profitable to build a new subcenter when $d_S = 0$. Then by continuity there must exist a value of d_S, where profits from building a new subcenter equal exactly zero.

Define $\tilde{d}_S$ as the value of d_S at which development yields exactly zero profits. From $\frac{d\pi}{dd_S} < 0$, it follows that for all distances beyond that point, development yields negative profits and for all distances nearer than that point development yields positive profits.

Totally differentiating the equality $\pi\left(d^*_{S+1}\left(\tilde{d}_S(X), X\right), \tilde{d}_S(X), X\right) = 0$, yields:

$\frac{\partial \tilde{d}_S}{\partial X} = -\frac{\partial \pi}{\partial X} \Big/ \frac{\partial \pi}{\partial d_S}$. This tells us that the sign of $\frac{\partial \tilde{d}_S}{\partial X}$ is the same as the sign of $\frac{\partial \pi}{\partial X}$.

Differentiation then tells us that: $\frac{\partial \pi}{\partial K} < 0$, $\frac{\partial \pi}{\partial \hat{P}} > 0$, $\frac{\partial \pi}{\partial w} > 0$, $\frac{\partial \pi}{\partial \theta_1} > 0$, $\frac{\partial \pi}{\partial \theta_2} > 0$, and $\frac{\partial \pi}{\partial \underline{P}} < 0$.

To see the comparative static on z, it is helpful to rewrite the basic land value change equation:

$$(1)\quad \int_{\hat{d}_S}^{d_{S+1}} \Psi\left(e^{\frac{-zd_{S+1}-t(d_{S+1}-d)}{\alpha}} - e^{\frac{-zd_S-t(d-d_S)}{\alpha}}\right)dd + \int_{d_{S+1}}^{\underline{d}_{old}} \Psi\left(e^{\frac{-zd_{S+1}-t(d-d_{S+1})}{\alpha}} - e^{\frac{-zd_S-t(d-d_S)}{\alpha}}\right)dd + \int_{\underline{d}_{old}}^{\underline{d}_{new}} \left(\Psi e^{\frac{-zd_{S+1}-t(d-d_{S+1})}{\alpha}} - \underline{P}\right)dd$$

The derivative of this with respect to z equals:

$$(2)\quad \int_{\hat{d}_S}^{d_{S+1}} \Psi\left(\frac{-d_{S+1}}{\alpha} e^{\frac{-zd_{S+1}-t(d_{S+1}-d)}{\alpha}} + \frac{d_S}{\alpha} e^{\frac{-zd_S-t(d-d_S)}{\alpha}}\right)dd + \int_{d_{S+1}}^{\underline{d}_{old}} \Psi\left(\frac{-d_{S+1}}{\alpha} e^{\frac{-zd_{S+1}-t(d-d_{S+1})}{\alpha}} + \frac{d_S}{\alpha} e^{\frac{-zd_S-t(d-d_S)}{\alpha}}\right)dd + \int_{\underline{d}_{old}}^{\underline{d}_{new}} \left(\frac{-d_{S+1}}{\alpha} \Psi e^{\frac{-zd_{S+1}-t(d-d_{S+1})}{\alpha}}\right)dd$$

Since for all d within the integrals, $\frac{d_{S+1}}{\alpha} e^{\frac{-zd_{S+1}-t(d_{S+1}-d)}{\alpha}} > \frac{d_S}{\alpha} e^{\frac{-zd_S-t(d-d_S)}{\alpha}}$, it follows that the returns from building a new subcenter are falling with z.

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Table 1: Summary Statistics For MSA Level Sprawl Indicators

MSA Measure for 150 Major MSAs	mean	s.d	10th Percentile	90th Percentile
Percentage of Population Within Inner 3 Mile Ring	18.26	10.82	5.78	32.9
Percentage of Population Within Inner 5 Mile Ring	34.72	15.71	17.54	55.94
Percentage of Population Within Inner 10 Mile Ring	63.95	16.51	40.17	86.13
Percentage of Employment Within Inner 3 Mile Ring	25.71	12.33	10.94	43.76
Percentage of Employment Within Inner 5 Mile Ring	42.59	18.09	19.29	66.67
Percentage of Employment Within Inner 10 Mile Ring	70.18	18.53	43.1	91.5
MSA Average Population Density	2952	3969	917	4971
MSA Average Employment Density	3900	9867	624	6519
Overall MSA Population Density	1008	1782	230	2031
Median Person's Distance in Miles from CBD	7.88	2.97	4.55	11.72
Median Worker's Distance in Miles from CBD	6.93	3.27	3.54	12.05

Average Population Density and Average Employment Density are defined as the weighted average of of zip code density where the weight is the zip code's share of total MSA activity.
Inner Rings refer to distance from the Central Business District.
Median Distance is the location such that 50Percentage of economic activity in the MSA is beyond that distance.

Table 2: High and Low Sprawl for 50 Major Metro Areas

Least Sprawled	Percentage of Employment within 3 mile ring around CBD		Employment Weighted MSA Job Density
San Francisco	48.3	NYC	108177
Providence	46.76	Chicago	40682
New York City	46.58	San Francisco	34620
Springfield	41.99	Boston	20050
Jersey City	41.76	Washington D.C	15263
Most Sprawled			
Los Angeles	7.3	Fresno	1386
New Haven	10.47	Tucson	1542
San Jose	11.41	Grand Rapids	1574
Anaheim	13.84	Saint Cloud	1654
Fort Lauderdale	14.86	Springfield	1987

Employment weighted MSA Job Density is constructed by taking the employment density by zip code as defined as employment per square mile and then calculating a MSA weighted average where the weight is a zip code's share of all jobs in the MSA.

Table 3: Correlation Matrix for Various MSA Sprawl Indicators

N=150		indicator					
	indicator						
		1	2	3	4	5	6
Percentage of Population Within Inner 3 Mile Ring	1	1					
Percentage of Employment Within Inner 3 Mile Ring	2	0.77	1				
MSA Average Population Density	3	-0.06	0.07	1			
MSA Average Employment Density	4	-0.13	0.13	0.9	1		
Overall MSA Population Density	5	-0.07	0.01	0.95	0.8	1	
Median Person's Distance in Miles from CBD	6	-0.48	-0.49	-0.02	0.04	0.04	1
Median Worker's Distance in Miles from CBD	7	-0.41	-0.57	-0.02	-0.02	0.06	0.89

Table 4: Work and Residential Densities by Distance from the CBD

	Population Density			Job Density		
	Mean	S.D	95th Percentile	Mean	S.D	95th Percentile
Distance from CBD in Miles						
0 to 5	7647	15745	26027	23497	67497	160821
5 to 10	7433	13509	35385	2541	3710	8035
10 to 15	3555	4876	11422	1926	2319	5482
15 to 20	2132	2610	7124	1508	2108	5072
20 to 25	1381	1718	4812	1216	3374	3708

We partition all zip codes by their distance from the Central Business District. Within each five mile ring, we calculate weighted population and employment density and the 95th percentile of these distributions.

Table 5: Transportation Modes and Times in Low Sprawl and High Sprawl MSAs

Variable	Whole Sample	Sprawled MSAs	Centralized MSAs	Centralized MSA in Northeast
Percentage of Trips by Private Vehicle	86.34	91.55	81.82	72.54
Percentage of Trips Walked	7.39	4.65	10.19	17.53
Percentage of 1 mile or shorter trips by private vehicle	68.47	77.6	62.27	51.07
Percentage of Shopping Trips by Private Vehicle	87.06	92.93	81.8	72.25
Percentage Went Out to Eat by Private Vehicle	84	90.36	77.95	69.16
Average Trip Time in Minutes	Whole Sample	Sprawled MSAs	Centralized MSAs	Centralized MSA in Northeast
All Trips	16.76	16.48	17	17.72
1 mile or shorter trips by private vehicle	4.7	4.52	4.85	4.86
Shopping Trips	12.07	12.29	11.87	11.75
Eating Trips	13.25	13.5	13.02	13.18
Non-Car Trips	19	17.2	19.93	21.15
Walking Trips	10.59	9.68	11.01	10.67
Bus Trips				35.57
Subway Trips				39.04

The data source is the 1995 National Personal Transportation Survey Day Trip File.
The unit of analysis is a trip. The NPTS Sample covers 46 MSAs.
Centralized MSAs are those above the median of the Smart Growth Index of Ewing, Pendall and Chen (2002).
Sprawled MSAs have an index score below this median.

Table 6: International Evidence on Transportation and Density

	Log of Urban Density			Vehicles Per-Capita			Log of Gasoline Price Regime
Regression	(1)	(2)	(3)	(4)	(5)	(6)	(7)
vehicles per-capita	-0.0047		-0.0075	-0.0052			
	(0.0006)		(0.0010)	(0.0013)			
gasoline price regime		0.0134			-1.7861	-2.1069	
		(0.0016)			(0.2547)	(0.4545)	
real GDP per-capita	0.0001	-0.0002	0.0002	0.0001	0.0445	0.0436	0.0000
	(0.0006)	(0.0000)	(0.0000)	(0.0001)	(0.0019)	(0.0025)	(0.0000)
French Legal Origin Dummy							0.5592
							(0.1772)
constant	9.1510	8.4910	8.9717	9.0864	64.2527	95.7327	4.2110
	(0.1358)	(0.1709)	(0.1642)	(0.1775)	(27.2768)	(44.3699)	(0.1536)
observations	70	70	70	62	70	62	62
R2	0.776	0.7902			0.8907		0.1632
Estimation	OLS	OLS	IV	IV	OLS	IV	OLS

The Data source is the Ingram and Liu (1999) International Data set. The time trend is suppressed.
In regression (3), the gasoline price regime is used as an instrument for vehicles per-capita.
In regression (4), legal origin dummies are used as an instrument for vehicles per-capita.
In regression (6), legal origin dummies are used as an instrument for gas price regime.
Vehicles per 1000 has a mean of 294 and a standard deviation of 207.4.
Gasoline price regime has a mean of 70.2 and a standard deviation of 33.14.
real GDP per-capita has a mean of 8297 and a standard deviation of 4331.

The cities in the sample include: Adelaide, Amsterdam, Bandung, Bangkok, Brisbane, Brussels, Chicago, Copenhagen, Denver, Detroit, Frankfurt, Guangzhou, Hamburg, Hong Kong Jakata, Los Angeles, London, Manila, Melbourne, Munich, NYC, Osaka, Paris, Perth Phoenix, San Francisco, Seoul, Singapore, Stockholm, Surabaya, Sydney, Tokyo, Toronto, Vienna and West Berlin.

Table 7: Sprawl As a Function of MSA Attributes

Each Cell Reports a Sample Average	MSA Average Population Density	Median Resident's Distance to CBD in miles	Median Worker's Distance to CBD in miles
All	2952.00	7.88	6.93
PANEL A			
MSAs in lowest 25% of per-capita income pdf	1614.00	7.62	6.26
MSAs in 25th-50th% of per-capita income pdf	2457.00	6.74	6.01
MSAs in 50th to 75th% of per-capita income pdf	2661.00	8.93	7.71
MSAs in Highest 25% of per-capita income pdf	5127.00	8.5	7.76
PANEL B			
MSAs in lowest 25% of poverty pdf	2027.00	7.56	6.46
MSAs in 25th-50th% of poverty pdf	2924.00	7.97	6.61
MSAs in 50th to 75th% of poverty pdf	2527.00	7.19	6.23
MSAs in Highest 25% of poverty pdf	3695.00	8.51	7.63
PANEL C			
MSAs in lowest 25% of black pdf	1892.00	7.14	5.89
MSAs in 25th-50th% of black pdf	2207.00	7.3	6.14
MSAs in 50th to 75th% of black pdf	3095.00	8.14	7.26
MSAs in Highest 25% of black pdf	3834.00	8.45	7.73
PANEL D			
MSAs in lowest 25% of Fragmentation pdf	2836.00	6.85	5.81
MSAs in 25th-50th% of Fragmentation pdf	2872.00	8.8	7.62
MSAs in 50th to 75th% of Fragmentation pdf	3641.00	7.68	6.73
MSAs in Highest 25% of Fragmentation pdf	3425.00	8.29	7.74

MSA per-capita income data is from the year 2000. The data source is the Regional Economic Information System.
Employment data is from 1996. Demographic data on poverty and % black is from the 1990 County Fact Book.
A MSA's poverty rate and % black is determined by its county that has the highest rate for these variables.
Fragmentation represents the number of city governments within the MSA in 1962.
There are 150 total MSAs.

Table 8: Housing Consumption in Center Cities and Suburbs

	Major MSAs	Major MSAs	Entire AHS Sample	
	Center City	Suburb	Center City	Suburb
Housing Measure Means by Cell				
Unit square feet	1755.30	2139.71	1726.96	1964.42
Unit square feet per person	496.34	570.21	485.42	539.12
Bedrooms	2.56	3.03	2.68	3.00
Bathrooms	1.32	1.61	1.41	1.64
% Living in a Single Family House	0.35	0.70	0.51	0.69
House price	165029.20	196013.30	144321.60	175868.90
House Price per unit square foot	142.19	104.00	96.55	92.87
Annual rent	8432.23	9668.27	7935.59	9074.82
Year built	1947.80	1958.61	1953.47	1961.64

Data Source is the 1999 American Housing Survey. The sample includes households where there are at least three people living in the unit and household income is greater than $10,000.
The Major MSAs include: Atlanta, Boston, Chicago, Dallas, Detroit, Houston, Los Angeles, NYC, Philadelphia, San Francisco and Washington D.C.

Table 9: Commuting Times and Speeds in Low and High Sprawl Areas

The Dependent Variable is the Time To Work in Minutes

	All Coummuters			Auto Commuters		
Miles to Work	1.4110	1.3438	1.3770	1.3793	1.5775	1.8013
	(0.0151)	(0.0216)	(0.0211)	(0.0195)	(0.0378)	(0.0867)
Miles to Work*Low Sprawl Dummy		0.1310	0.1412	0.1282	0.1770	0.2986
		(0.0301)	(0.0296)	(0.0279)	(0.0531)	(0.1187)
Residential Block Population Density			0.0003	0.0002	0.0002	0.0002
			(0.0001)	(0.0001)	(0.0001)	(0.0001)
Constant	8.0990	8.1237	5.3122	5.2077	3.9774	3.1434
	(0.1496)	(0.1496)	(0.1860)	(0.1708)	(0.1845)	(0.2252)
MSA Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Commute Distance in Miles	20 or less	20 or less	20 or less	20 or less	10 or less	5 or less
Observations	13571	13571	13508	10223	7042	4076
Adjusted R2	0.4341	0.4348	0.4589	0.5315	0.3921	0.2667

Each column reports a separate OLS regression. The data source is the 1995 National Personal Transportation Survey.
The "Low Sprawl Dummy" equals one if a MSA is above the median of the Smart Growth Index of Ewing, Pendall and Chen (2002).
Standard errors are presented in parentheses.
Residential Block Population Density has a mean of 7779 and a standard deviation of 8662.

Table 10: Smog Progress in California From 1980 to 1999

	Los Angeles Basin		California Outside of the Los Angeles Basin	
	1980-1989	1990-1999	1980-1989	1990-1999
Percent Change in Population	26.5	11.9	25.4	11.4
Annual Count of Days When Ambient Ozone Exceeded the National 1 Hour Standard	33	5	0	0
Mean of 30 Highest Annual 1 hour Readings of Ozone (parts per million)	0.149	0.112	0.086	0.083
Annual Mean for Nitrogen Dioxide (parts per million)	0.034	0.024	0.019	0.015
Annual Mean for Sulfur Dioxide (parts per million)	0.0034	0.0018	0.0009	0.0013

Note: The unit of analysis is an ambient monitoring station. This table's pollution entries are cell medians.
The data source is the California EPA's Air Resources Board's California Ambient Air Quality Data 1980-1999.
The Greater Los Angeles Area is defined as the following counties; Orange, Los Angeles, San Bernardino, Riverside, San Diego, Kern, and Ventura. In each cell, there are at least 303 monitoring stations.

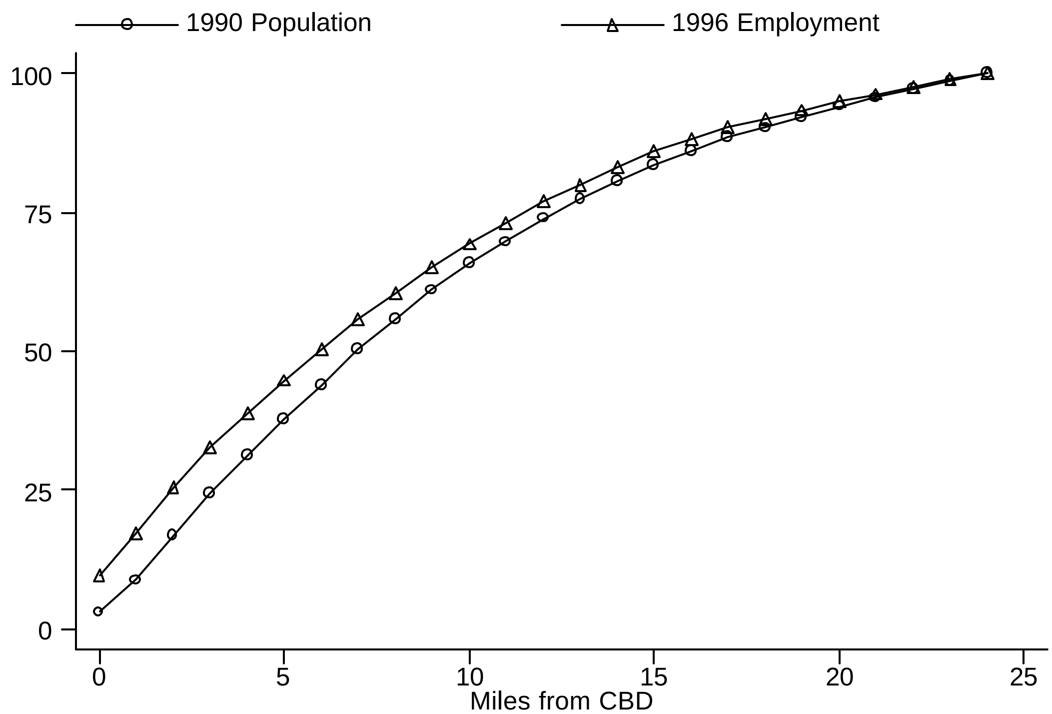
Table 11: California Vehicle Hydrocarbon Emissions

Median Emissions by Cell

Model Year	Calendar Year 1992	1993	1996
1965-1969	114	72	119.5
1970-1974	87	70	91
1975-1979	27	24.5	27
1980-1984	28	4	31
1985-1989	8	6.5	12
1990-1996			4

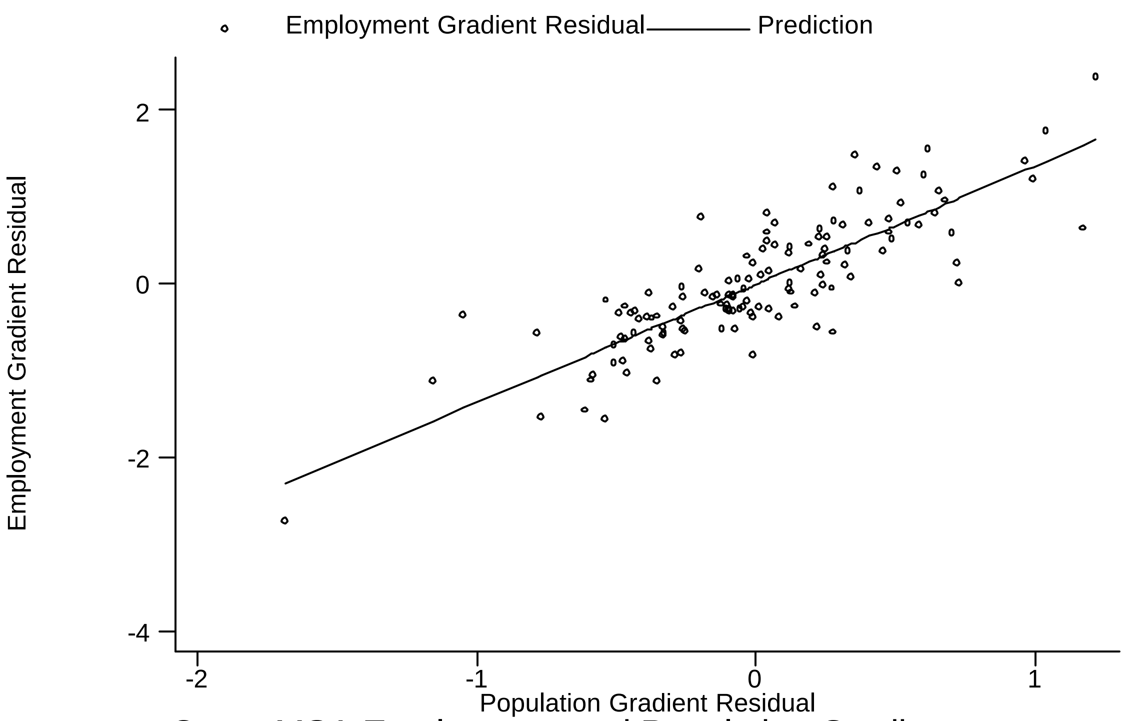
The data source is the California Random Roadside Emissions Test. This table reports sample medians for three separate cross-sectional data sets collected in 1992, 1993 and 1996. Each entry of the table reports emissions (measured in parts per million) by Model Year and Calendar Year. In calendar years 1992 and 1993, cars built after 1990 are included in the Model Year 1985-1989 category.

Figure 1



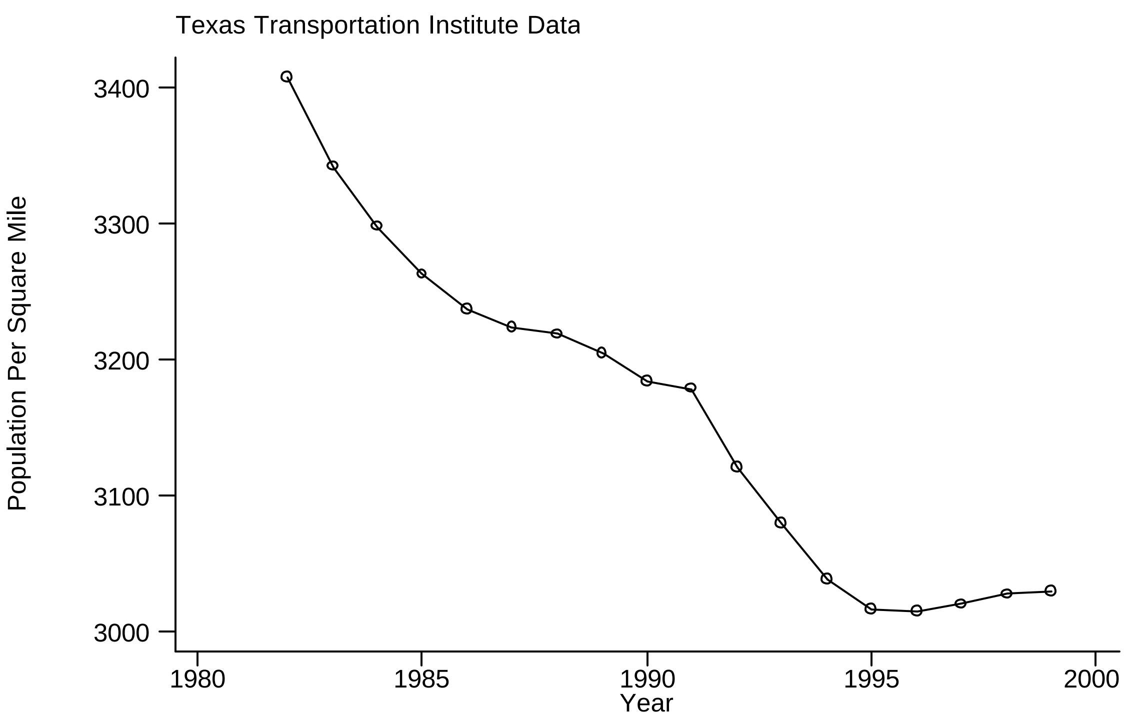
The Spatial Distribution of People and Jobs Within MSAs

Figure 2



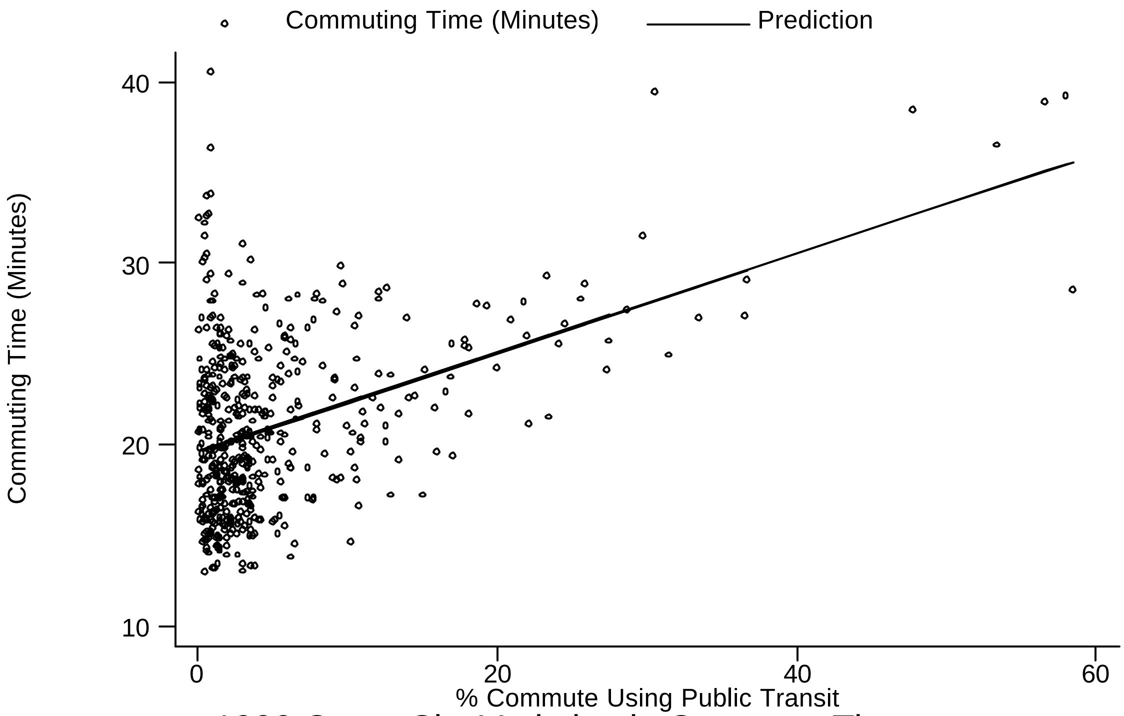
Cross-MSA Employment and Population Gradients

Figure 3



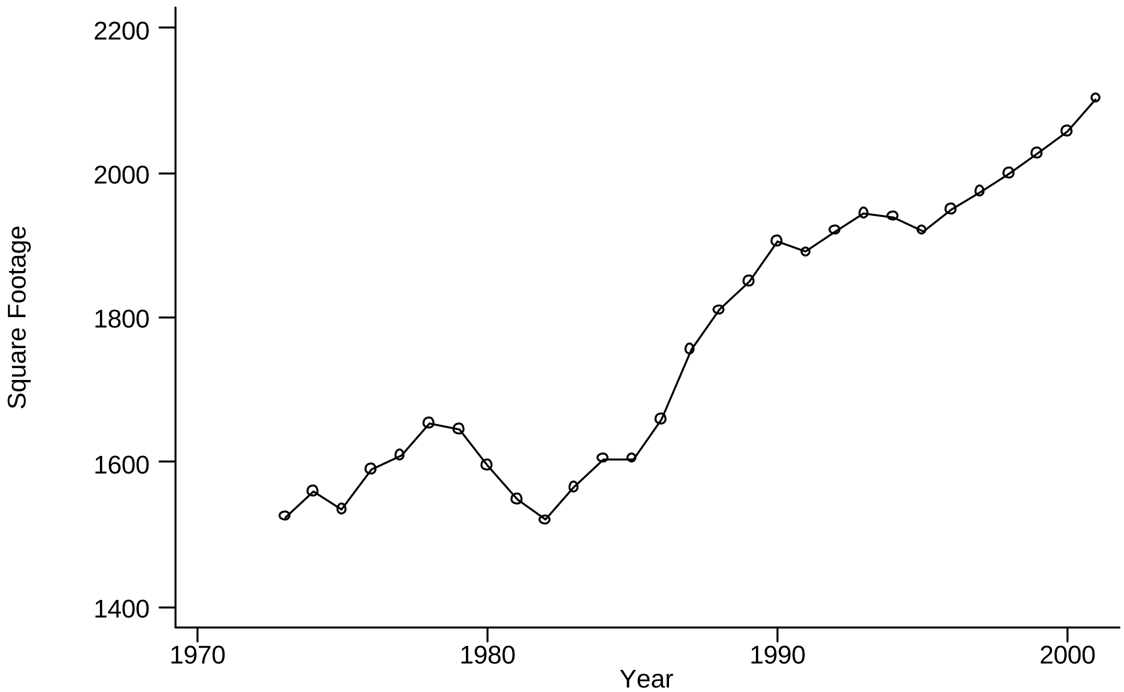
Population Density Time Trend for 68 Major MSAs

Figure 4



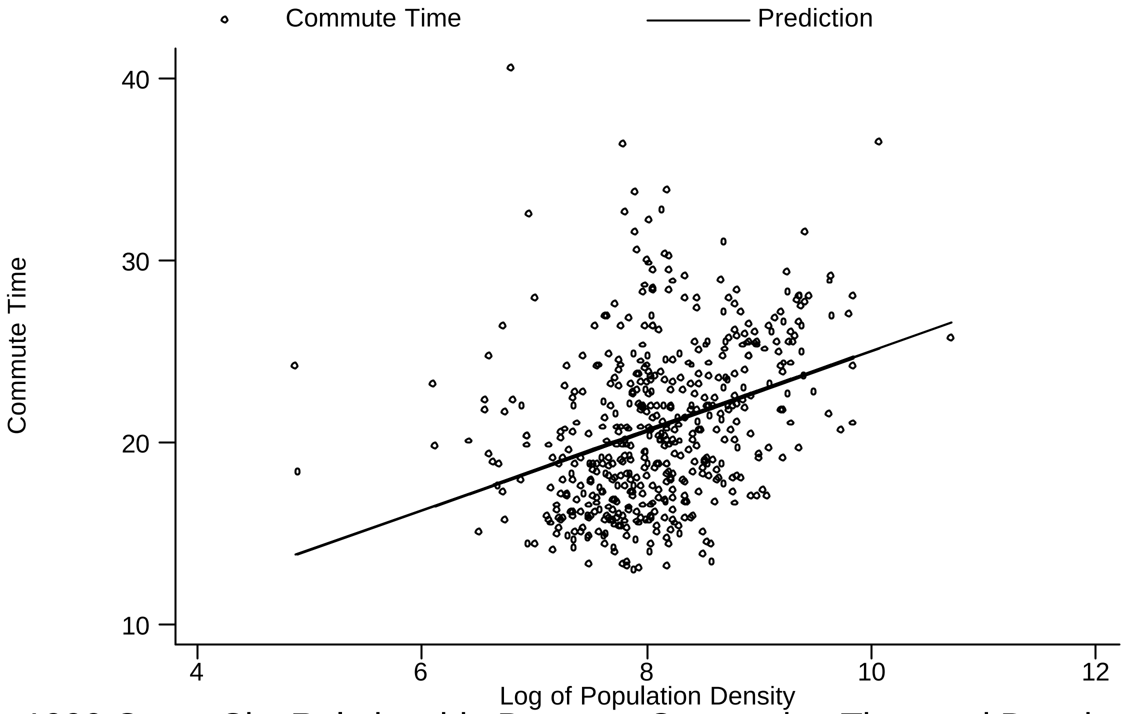
1990 Cross-City Variation in Commute Times

Figure 5



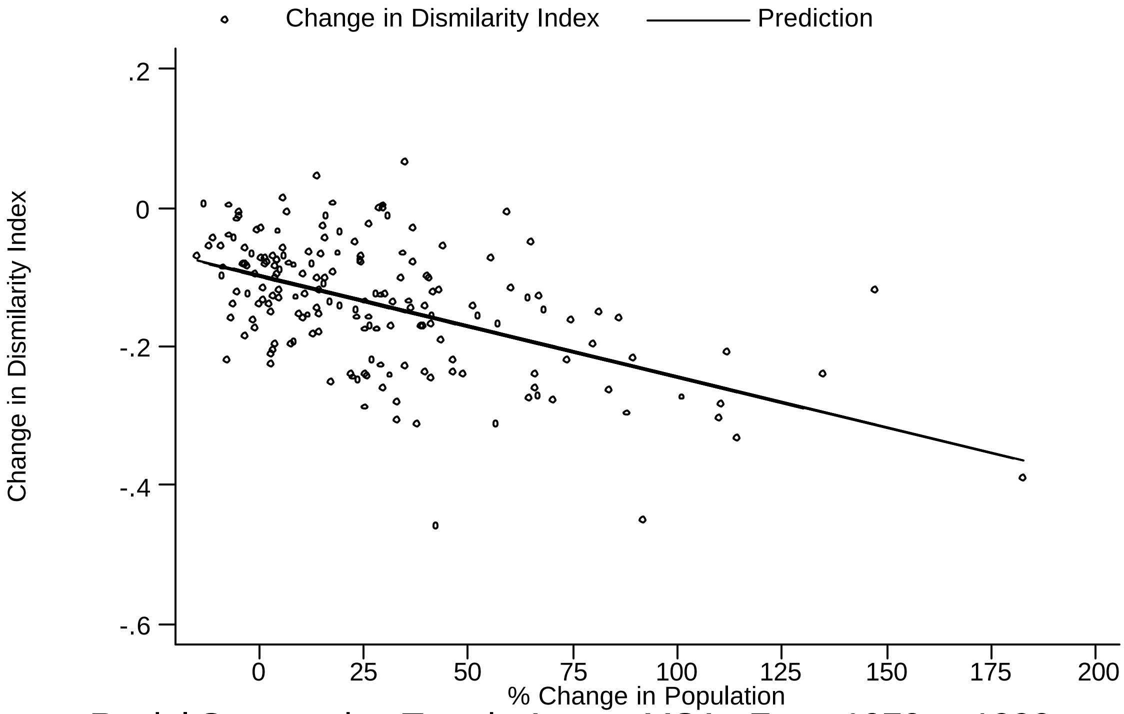
Median Square Footage of Floor Area in New One-Family Houses

Figure 6



1990 Cross-City Relationship Between Commuting Time and Density

Figure 7



Racial Segregation Trends Across MSAs From 1970 to 1990