# The Environmental Impact of Suburbanization

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***Abstract***

*The U.S. population is increasingly spreading out, moving to the suburbs, and migrating from the Rust Belt to the Sun Belt. This paper uses recent household-level data sets to study some of the environmental consequences of population suburbanization. It measures the increase in household driving, home fuel consumption, and land consumption brought about by population dispersion. Suburban households drive 31 percent more than their urban counterparts, and western households drive 35 percent more miles than northeastern households. Despite increased vehicle dependence, local air quality has not been degraded in sprawling areas, thanks to emissions controls. Technological innovation can mitigate the environmental consequences of resource-intensive suburbanization. © 2000 by the Association for Public Policy Analysis and Management.*

## INTRODUCTION

Over the last 50 years, the two dominant geographical trends in the United States have been suburbanization and regional migration from the Rust Belt to the Sun Belt. In 1950, the share of metropolitan area residents who lived in central cities was 57 percent, but by 1990 had fallen to 37 percent (Mieszkowski and Mills, 1993). In 1940, 49 percent of the nation lived in the New England, Middle Atlantic, and East North Central divisions. By 1990, this area's share had fallen to 37 percent. Households are increasingly choosing to live in low-density, vehicle-dependent suburban areas. For all urban areas, population grew by 92.3 percent while land area increased by 245.2 percent between 1950 and 1990.[1]

Suburban growth, while offering private benefits to new suburbanites, may impose social costs such as lowering local quality of life. This paper seeks to measure some of the environmental consequences of suburbanization. It estimates the impact of population dispersion on several environmental indicators such as vehicle mileage, residential energy consumption, housing lot size, and county farm acreage. It contrasts the resource consumption of a city dweller living in a multi-unit building who walks to stores and commutes using mass transit, versus the suburb dweller living in a

[1] Land area increases over this period for specific cities include; Phoenix 1247.3 percent, Los Angeles 125.7 percent, Cleveland 112 percent, Atlanta 972.6 percent, New Orleans 21.6 percent, New York 136.8 percent, and Detroit 164.5 percent (Mieszkowski and Mills, 1993).

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house who commutes by a fuel-inefficient “sports utility vehicle” (SUV). The latter family is likely to impose larger environmental costs by degrading local air quality, increasing greenhouse gas production, and reducing available open space. Results of the study here reported show that suburbanites drive 31 percent more than their city counterparts and consume more than twice as much land.

While this paper studies a number of environmental indicators, it is not possible to exhaustively study the full impact of sprawl on the environment. Suburbs differ with respect to their endowment of environmental assets, such as biodiversity and wetlands. Only on a case-by-case basis could the environmental impact of recent development be evaluated.[2]

It is important to measure the social costs of suburbanization because the justification for anti-sprawl policy hinges on the proposition that these costs are large. Vice President Gore has clearly stated his concerns about suburban growth. “In the last 50 years, we’ve built flat, not tall: because land is cheaper the further out it lies, new office buildings, roads, and malls go up farther and farther out, lengthening commutes and adding to pollution. This outward stretch leaves a vacuum in the cities and suburbs which sucks away jobs, businesses, homes and hope; as people stop walking in downtown areas, the vacuum is filled up fast with crime, drugs, and danger (1998). Given that household suburbanization rates rise with income and that income continues to grow, suburban growth will continue to be an important public policy issue.[3]

Technological change, such as reduced emissions per mile or increased vehicle fuel economy, can sharply reduce the environmental costs of increased resource consumption. Section III presents new evidence on the “greening” of the auto such that new cohorts of vehicles produce much lower emissions per mile driven. Given the continued growth in vehicle mileage spurred by income growth and population dispersion, further policies will be needed to reduce vehicle emissions and to increase fleet fuel economy in order to reduce the impact of increased vehicle dependence on greenhouse gas production.

## DOES SUBURBANIZATION SIGNIFICANTLY INCREASE RESOURCE CONSUMPTION?

Suburbanization is posited to increase a typical household’s resource consumption. In the suburbs, land is cheap. This encourages spread-out economic activity. Households use more resources to commute and to perform daily chores and consume more housing than they would if they lived in cities. Lower-density suburbs feature less public transit infrastructure and thus, unlike city residents, suburbanites must use private vehicles to travel.

This section addresses the relationship between resource consumption and suburbanization. The social costs of increased suburbanization are a function of how much extra resources such households consume. The focus is on vehicle mileage, land consumption, and home energy consumption. Several different data sets are used to study resource consumption differentials.

[2] For a comprehensive review of the economics of land use and its links to environmental quality see Bockstael and Irwin (1999).

[3] Margo (1992) estimates that more than 40 percent of suburban growth between 1950 and 1980 can be explained by household income growth.

## Vehicle Usage

Miles driven are an important indicator of resource consumption. Suburban sprawl is believed to have significantly contributed to increased vehicle use.[4] Cross-national studies suggest that gasoline consumption could be 20 to 30 percent lower in cities like Houston and Phoenix if their urban structure more closely resembled that of Boston or Washington (Newman and Kenworthy, 1989, 1999).

Here suburbia's impact on vehicle dependence is measured by estimating a cross-sectional regression for 1995 using household-level data where the dependent variable is annual household miles driven. This regression is presented in equation (1).

$$\text{miles} = \beta * X + \gamma * \text{Density} + U \tag{1}$$

In equation (1), X is a matrix of household attributes and U is an error term. The variable, population density, is an indicator of how suburban is the area where the household lives. The higher the population density, then, all else equal, household driving should be lower. In estimating equation (1), households are assumed to choose their optimal location (population density) for reasons other than resource consumption. It is plausible that some households choose low-density suburban locations in the pursuit of lower crime, or better school districts. Under this assumption, ordinary least squares (OLS) yields consistent estimates of how suburbanization affects the average household's miles driven.[5]

To study driving patterns, the 1995 wave of the *Nationwide Personal Transportation Survey* (NPTS) is used. This 1995 random survey of 22,000 households' travel patterns identifies city and suburban dwellers and includes a detailed set of questions considering transport usage. Here, households who do not live in a metropolitan area are excluded from the sample. Table 1 presents six regression estimates of the vehicle miles equation presented in equation (1). The dependent variable in these cross-sectional regressions is the log of 1 plus the total annual number of miles the household reported driving. This variable is regressed on the standard metropolitan statistical area (SMSA) level fixed effects and the central city dummy. Not controlling for household attributes, the results in specification #1 show that central city residents drive 60 percent fewer miles than their suburban counterparts. Because suburban households are on average richer than city households, in specification #2, to control for household-level differences in driving, the log of household income and the log of household size are included in the regression specification. The coefficient on the city dummy decreases to –0.311, which is highly statistically significant. Suburbanites drove 31 percent more than central city residents in 1995. The income elasticity of miles traveled is 1.39 and the household size elasticity is 0.18. When this regression was re-run stratifying the data by Census Division, it revealed that in the Northeast, central city households drove 43 percent less than observationally identical suburban households, while in the West this city–suburb differential shrank to 17 percent (results available from the author on request).

[4] Many urban planners, concerned with the declining use of public transit, point to the large social costs of vehicle dependence that are exacerbated by sprawl while other transport experts have concluded that the auto on net is an efficient transportation technology (Meyer, Kain, and Wohl, 1965; Winston and Shirley, 1998).

[5] If households who have a preference for driving self-select into the suburbs, then estimates of equation (1) yield an upper bound on how much more a random central city household would drive if they moved to the suburbs.

**Table 1.** Metropolitan household vehicle mileage in 1995.

| | MSA fixed effects | MSA fixed effects | MSA fixed effects | MSA fixed effects | no MSA fixed effects | |
|---|---|---|---|---|---|---|
| Specification | 1 beta (s.e) | 2 beta (s.e) | 3 beta (s.e) | 4 beta (s.e) | 5 beta (s.e) | 6 beta (s.e) |
| City dummy | -0.604 (0.044) | -0.311 (0.043) | -0.246 (0.047) | | -0.401 (0.078) | -0.262 (0.072) |
| Log density for Census Block | | | -0.056 (0.016) | -0.088 (0.014) | | -0.057 (0.024) |
| Log density for SMSA | | | | | | -0.359 (0.069) |
| Midwest region | | | | | 0.339 (0.158) | 0.274 (0.102) |
| South region | | | | | 0.267 (0.133) | 0.075 (0.096) |
| West region | | | | | 0.294 (0.152) | 0.356 (0.093) |
| log (household size) | | 0.181 (0.039) | 0.176 (0.039) | 0.182 (0.039) | 0.190 (0.064) | 0.179 (0.062) |
| log (household income) | | 1.389 (0.031) | 1.384 (0.031) | 1.400 (0.031) | 1.351 (0.067) | 1.372 (0.067) |
| constant | 9.237 (0.026) | 7.082 (0.059) | 7.513 (0.134) | 7.648 (0.132) | 6.923 (0.172) | 10.434 (0.656) |
| observations | 19762 | 16315 | 16315 | 16315 | 16315 | 16315 |
| *R2* | .02 | .14 | .14 | .14 | .13 | .13 |

*Note:* This table reports OLS regression coefficients. Standard errors are presented in parentheses. 1995 NPTS is the data source. The omitted region is the northeast. For specifications #5 and #6, the standard errors are adjusted for within MSA correlation. All summary statistics are available on request. MSA fixed effects control for differences across metropolitan areas. The dependent variable is the log(1+annual total miles driven.

The newer Western metropolitan areas feature less public transit infrastructure and much less pre–World War II housing stock. In such areas, the distinction between city and suburb is blurred (Mieszkowski and Smith, 1991). In addition, some of these metropolitan areas may increase the size of their central city by annexing the suburbs.

Such misclassification of suburban observations in the NPTS data would lead to an underestimate of the true effect of low-density suburbanization on miles traveled. All of these factors would contribute to finding little evidence of a city–suburb differential in newer metropolitan areas. NPTS data provide each household's population density by block group. Census block population density is a more refined indicator of a household's suburbanization. In specification #3 in Table 1, both the center city dummy and the local population density are included. Both variables have negative coefficients that are statistically significant. The log density variable decreases the central city coefficient from –0.31 to –0.25. This coefficient is suggestive evidence of the impact of access to public transit on reducing vehicle mileage. The next regression drops the central city dummy from the specification. The elasticity of mileage with respect to housing residential density—controlling for metropolitan area fixed effects, household size, and income—is –0.09.

To measure regional differences in vehicle driving in Table 1's specifications #5 and #6, the SMSA fixed effects were dropped from the specification and four region dummies were included. The average westerner drives 30 percent more than the average northeasterner. Newer southwestern metropolitan areas are low density and feature more highway infrastructure and less public infrastructure than northeastern metropolitan areas. The final regression adds the log of the metropolitan area's population density to the specification. More densely populated metropolitan areas should feature less driving. In this regression, the city dummy, block density, and metropolitan area density coefficients are all negative and statistically significant. A 10 percent increase in metropolitan area density reduces driving by –3.6 percent. This effect is 6 times larger than the effect of block density. Pickrell (1999) and Schimek (1996) report similar findings: evaluated at the sample means, small increases in block density have little effect on vehicle usage.

Using the NPTS micro data, average miles driven were predicted for 55 major metropolitan areas, holding household income and size at their sample means. Figure 1 illustrates the average mileage with respect to average density. New York, San Francisco, and Newark are outliers characterized by high density and low mileage while Orlando, Detroit, Portland, and Fort Worth are characterized by low density and high mileage. This graph is comparable to a 1980 study that presented the stark differences among cities by graphing annual gasoline use per capita with respect to urban density (Newman and Kenworthy, 1989, 1999). Cities such as Houston, Phoenix, Detroit, and Denver exhibit very high use and lower density, while Hong Kong, Moscow, and Tokyo exhibit high density and low fuel use. Unlike the Newman and Kenworthy study, Figure 1 is based on micro-data to control for household level attributes, such as income and size, to tease out the independent effect of density.[6]

In analyzing these results, several caveats are important. The private transport resource consumption has been quantified for similar households in the city versus those in the suburbs and across regions. Per-capita share has not been imputed for how much public infrastructure urban and suburban residents "rent" by using public buses and public subways. In addition, given that the NPTS is a 1995 cross-sectional sample, the data set features no significant variation in gasoline prices. Thus, how the city–suburb driving differential would change if gasoline prices changed sharply cannot be predicted. The city–suburb mileage differential estimated from 1995 data

[6] Critics of cross-national comparisons point out that to estimate the independent effects of urban density on auto dependence, one should control for the effects of income and gas prices and other variables (Gomez-Ibáñez, 1991).

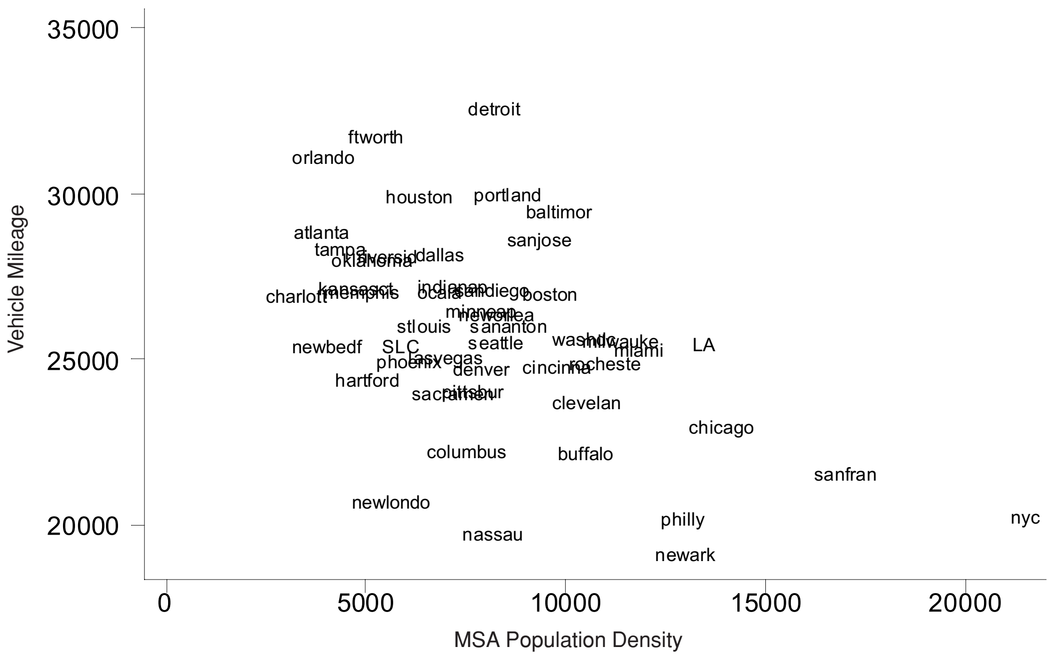


**Figure 1.** Vehicle mileage as a function of population density.

depends on the location of suburban households and where they choose to work. In the long run, as more businesses relocate in the suburbs, it is possible that commuting distances could fall as theoretically fewer commuters would travel to the central city. Recent research has documented the "commuting paradox" that commute times are falling in sprawling metropolitan areas (Gordon and Richardson, 1989; Gordon, Kumar, and Richardson, 1991; Gordon, Richardson, and Jun, 1991).

## Land Consumption

Sprawl opponents have been concerned that development eats into open space.

> If a young family is looking for a place to live, or an entrepreneur is looking for a place to start an exciting new business, what kind of message is sent by a community that has no parks and green spaces; nowhere to shop and walk and play with your children; no running paths to help people stay well and productive; no nearby countryside or family farms? (Gore, 1998).

How much extra land do households consume when they live in suburbs rather than in cities? The EPA's "sprawl index" is based on per-capita land consumption (see www.epa.gov/region03/greenkit/2sprawl.html). Land in urban areas totaled 55.9 million acres in 1990, up from 47.3 million acres in 1980. Annual growth slowed from 1.3 million acres a year in the 1970s to 0.9 in the 1980s. For the nation as a whole, open land is abundant. According to Garreau (1991, p. 390), "If you housed every household in the United States in that beloved suburban 'sprawl' density of a quarter acre lot each, that would still take only about 23 million acres, 1.222 percent of all the land in the United States, even if Alaska were excluded.[7]

Specific metropolitan areas have been experiencing sharp growth at their fringe. This growth can occur either because of population growth or because suburban households consume much more land than their central city counterparts. The 1995 American Housing Survey (AHS) data are used to estimate this differential resource consumption, and the regression presented in equation (2).

$$\text{land consumption } \beta^*X + \gamma^*\text{Suburb} + U \qquad (2)$$

The dependent variable is either the unit's square footage or the home's lot size measured in square footage. The AHS provides data on suburban and central city resident land consumption. Since "land lovers" are likely to be overrepresented in the suburbs where they can purchase land at a lower price, the average suburban household's land consumption represents an upper bound on how much land a city resident would purchase if that resident moved to the suburbs.

Table 2 reports regression-adjusted predictions of differential land consumption between city and suburb residents. Each row of the table reports estimates from a separate regression estimate. Based on the national regression, a home owner whose income is $50,000 and who lives in a central city has an average lot size of 7.8 thousand square feet (less than a quarter of an acre), while the average home owner in the suburbs whose income is $50,000 has an average lot size of 12.33 thousand square feet. The city–suburb land consumption differential varies among cities. Outside monocentric older cities such as Chicago, Detroit, New York, and Philadelphia, suburbanites consume much more land than central city residents. In newer areas such as Houston there is a much smaller suburban–city differential.

Suburbanites consume more land per-capita. As suburban land grows, farmland is likely to decline. The idea of "sprawl" conjures up images of concrete roads and parking lots replacing farmlands. As the population of metropolitan areas grows, it is likely that land at the fringe of such areas will be converted for urban use.[8] In the absence of suburbanization, land at the fringe of cities remains farmland, forest, and undeveloped open space.

How has increased suburbanization affected fringe farmland? To study whether farmland is vanishing in areas where population is growing sharply, data from the *City and County Factbook* for 3,053 counties (http://www.lib.virginia.edu/socsci/ccdb/county94.html) were used to estimate the regression presented in equation (3).

$$\Delta \text{ farmland} = c + \beta^*\Delta \text{ population} + e \qquad (3)$$

The dependent variable is the percentage change in a county's farmland between 1982 and 1987. It is regressed on the county's percentage of change in population between 1980 and 1992. Controlling for states' fixed effects, reveals a very small elasticity of –0.02 in a regression of the percentage of change in farmland regressed on the percentage of change in population. Running separate regressions for each state, indicates some evidence that population growth reduces farmland, in particular

[7] The U.S. Department of Agriculture's Economic Research Service (ERS) has devoted considerable attention to farmland degradation. The ERS is optimistic that the popular press overstates the "crisis" with respect to land conversion. Heimlich, Vesterby, and Krupa (1991) write, "Despite claims to the contrary the amount of U.S. rural land and level of agricultural production is not threatened by the present rate of urbanization. Urbanization is not paving over the nation's rural areas any more than in the past. Urbanization is not consuming all of our farmland nor is it taking all the best land out of production."

[8] One local cost of sprawl is historic farming communities being irreversibly converted into exurbs as demand for suburbs drives up the price of land (Brueckner and Fansler, 1983).

**Table 2.** Predicted owner housing consumption in 1995 by metro area.

| | Suburb | | | | City | | | |
|---|---|---|---|---|---|---|---|---|
| | unit square feet (1000s) | | lot size (1000s) | | unit square feet (1000s) | | lot size (1000s) | |
| Area | income 50,000 | income 100,000 | income 50,000 | income 100,000 | income 50,000 | income 100,000 | income 50,000 | income 100,000 |
| Nation | 1.78 | 2.10 | 12.33 | 14.6 | 1.70 | 1.99 | 7.8 | 8.7 |
| Atlanta | 2.01 | 2.74 | 22.7 | 23.9 | 1.73 | 2.11 | 19.3 | 35.5 |
| Chicago | 1.79 | 2.14 | 8.9 | 10.4 | 1.59 | 1.83 | 4.6 | 5.3 |
| Dallas | 1.82 | 2.09 | 8.5 | 8.8 | 1.75 | 2.21 | 8.3 | 8.6 |
| Detroit | 1.78 | 2.12 | 15.5 | 18.6 | 1.78 | 1.93 | 5.3 | 5.1 |
| Houston | 1.86 | 2.20 | 11.2 | 11.3 | 1.87 | 2.19 | 10.1 | 10.0 |
| Los Angeles | 1.60 | 1.93 | 7.7 | 8.9 | 1.58 | 1.76 | 7.6 | 8.4 |
| Miami | 1.71 | 1.94 | 9.6 | 11.4 | 1.84 | .93 | 7.5 | 8.3 |
| NYC | 1.80 | 2.14 | 15.6 | 14.0 | 1.41 | 1.59 | 3.7 | 4.4 |
| Philadelphia | 2.01 | 2.41 | 15.5 | 20.4 | 1.38 | 1.71 | 2.5 | 3.6 |
| San Diego | 1.46 | 1.97 | 9.3 | 8.1 | 1.65 | 1.84 | 6.1 | 6.4 |
| San Francisco | 1.62 | 1.63 | 7.2 | 7.7 | 1.54 | 1.48 | 2.5 | 3.2 |

Each row reports predictions from a different OLS regression for home owners. Land consumption is regressed on a household income quadratic, a center city dummy and interactions of this dummy with household income and its square. The data source is the 1995 American Housing Survey. For the nation regression, MSA fixed effects are included. There are 22,000 square feet in a 2-acre lot. All summary statistics are available on request.

in Illinois, Indiana, Mississippi, North Carolina, Pennsylvania, and Washington. For these states, the population elasticity averaged around –0.2.

Not all suburban land has equal environmental value as measured by its variety of species or how it contributes to the local ecosystem. Farmland conversion will lead to smaller environmental costs if nonprofits, such as the Nature Conservancy and state-led "green-belt initiatives," can target the most valuable environmental assets and protect them. Nonprofits are playing a growing role in preservation. These organizations have overcome free-rider problems to collect tax-deductible donations to purchase environmentally sensitive resources. Livability ballots are playing an increasing role in preserving space. Kline and Wichelns (1996) present voting referendum data from Rhode Island and Pennsylvania documenting that fast-growth county voters are more likely to vote in favor of initiatives that purchase land using state tax dollars.[9]

[9] For an overview of the outcomes in numerous livability ballots in the 1998 elections see HREF="http://www.brook.edu/ES/urban/myers.pdf".

## HOUSEHOLD ENERGY CONSUMPTION

Suburbanites own larger homes that are more likely to be single detached units, but they own newer homes that are more likely to incorporate state-of-the-art energy-conservation technologies. To study whether suburbanites consume more energy, household-level energy consumption was estimated and shown as regressions, equation (4).

$$\text{household energy consumption} = \beta^{*}X + \gamma^{*}\text{suburb} + U \qquad (4)$$

Household energy consumption was studied using the United States Residential Energy Consumption Survey for 1993 (U.S. Department of Energy, 1993). For 7,040 households, this survey identifies each household's location and detailed information on housing structure, aggregate household annual consumption of various fuels, and the household head's attributes. The data set includes information on each household's climate exposure as indicated by cooling and heating "degree days." Since the housing stock differs among regions and between cities and suburbs, housing structure attributes are not controlled for; instead, household size and income and the climate of the location are.

Table 3 presents five consumption regression estimates of equation (4). The left-most regression aggregates the fuels into a total fuel consumption measure. For total fuel consumption, the central city dummy is statistically insignificant. Suburbanites do not consume more energy than their central city counterparts. The climate variables, cooling degree days (CDD55) and heating degree days (HDD75) have a positive and statistically significant effect on housing energy consumption. CDD55 is cooling degree days, which measures climate as the annual number of degrees that the daily average temperature rises above 55 degrees. HDD75 is heating degree days, which measures climate as the annual number of degrees that the daily temperature is less than 75 degrees. At the bottom of Table 3, each census division's mean for heating and cooling degree days is listed. The next four regressions divide housing fuel consumption into electricity, natural gas, liquid propane, and fuel oil consumption. Electricity and fuel oil feature large negative city dummies. Natural gas has a very large positive dummy.

### Are There Large Regional Per-Capita Energy Consumption Differentials?

This paper's empirical work has focused on suburbanization's impact on resource consumption. It presents new facts based on large cross-sectional data sets. State-level time-series data on energy consumption provides an additional source of information for documenting regional per-capita energy differentials. This is relevant because the population is increasingly migrating toward the Sun Belt. The United States Department of Energy's State Energy Report was used to investigate the implications of this trend for energy use. This data set covers the years 1969–1994. Each state's energy consumption is subdivided into residential and transport. Energy is measured in trillions of British thermal units (BTU).

Household energy consumption may vary across regions because the South and West feature a different climate and because the Sunbelt features a newer housing stock, less public transit and more vehicle friendly infrastructure. I measure trends in per-capita energy consumption differentials across census divisions by estimating the regression presented in equation (5).

$$\begin{aligned}&\text{Log(per-capita energy)} = \\ &\text{census division} + \text{post 1980 dummy} + \text{Interactions} + B^{*}\text{income} + U \qquad (5)\end{aligned}$$

**Table 3.** Household fuel consumption in 1993.

| | All | | Electricity | | Natural gas | | Liquid propane | | Fuel oil | |
|---|---|---|---|---|---|---|---|---|---|---|
| | beta | s.e | beta | s.e | beta | s.e | beta | s.e | beta | s.e |
| City dummy | -0.002 | 0.015 | -0.349 | 0.016 | 3.137 | 0.127 | -1.285 | 0.067 | -0.487 | 0.084 |
| CDD55 | 0.102 | 0.023 | 0.583 | 0.025 | -2.261 | 0.199 | 0.377 | 0.105 | -0.341 | 0.132 |
| HDD75 | 0.164 | 0.005 | 0.035 | 0.006 | 0.116 | 0.046 | 0.063 | 0.024 | 0.358 | 0.031 |
| log (household income) | 0.151 | 0.009 | 0.181 | 0.010 | 0.264 | 0.077 | -0.267 | 0.040 | 0.129 | 0.051 |
| log (family size) | 0.342 | 0.013 | 0.337 | 0.014 | 0.610 | 0.111 | 0.250 | 0.059 | 0.144 | 0.074 |
| constant | 9.091 | 0.094 | 7.966 | 0.102 | 2.697 | 0.796 | 3.650 | 0.421 | -0.769 | 0.527 |
| observations | 7041 | | 7041 | | 7041 | | 7041 | | 7041 | |
| R2 | 0.27 | | 0.26 | | 0.11 | | 0.06 | | 0.05 | |

*Note:* This table reports results from five OLS regressions based on the 1993 household Residential Energy Consumption Survey. The omitted category is a suburban household. CDD55 are cooling degree days measured in 1000s and HDD75 are heating degree days measured in 1000s. The dependent variable is the log(1+x) where x is the energy level measured in annual BTU thousands.

| Division | Mean CDD55 | Mean HDD75 |
|---|---|---|
| Nation | .35 | 2.59 |
| NE | .09 | 4.02 |
| MA | .18 | 3.49 |
| ENC | .12 | 4.16 |
| WNC | .15 | 4.45 |
| SA | .63 | 1.37 |
| ESC | .51 | 1.73 |
| WSC | .89 | 1.15 |
| M | .59 | 3.15 |
| P | .08 | 1.15 |

East North Central is = IN, WI, OH, MI, IL
East South Central is = AL, TN, KY, MS
Middle Atlantic is = NJ, NY, PA
Mountain is = NM, CO, WY, UT, MT, ID, NV, AZ
New England is = NH, RI, VT, CT, ME, MA
Pacific is = CA, WA, OR
South Atlantic is = GA, WV, NC, FL, VA, DE, SC, MD
West North Central is = IA, NE, KS, MN, SD, ND, MO
West South Central is = AR, LA, OK, TX

All summary statistics are available on request.

Equation (5) models a state's log of annual per-capita energy consumption as a function of state real per-capita income, census division fixed effects, a post-1980 calendar year dummy and the interactions of census division dummies with the post-1980 dummy.

Table 4 reports three regression estimates of equation (5). Per capita energy consumption is an increasing function of real income. Controlling for state annual per-capita income, per-capita energy consumption varies greatly from one census division to another. Relative to the New England division, total energy consumption by commercial plus the transport plus the residential sector was 19.8 percent higher in the Pacific Division and 26.1 percent higher in the West North Central division after 1981. While regional differences in residential energy consumption had narrowed after 1991, regional differences in transport energy consumption per-capita have increased. Before 1981, the East South Central's per-capita energy consumption was 33.7 percent higher than the New England division. After 1981, this differential has grown to 43.9 percent. Household energy consumption is higher outside of the Rust Belt. As Sun Belt migration continues, resource consumption will rise.

## TECHNOLOGY'S ROLE IN MITIGATING THE CONSEQUENCES OF RESOURCE CONSUMPTION GROWTH

The environmental impact of increased resource use depends on the technologies used. For example, if households drive vehicles with cleaner engines or that achieve more miles per gallon, then an extra 30 percent increase in vehicle mileage will not have large environmental consequences. This section explores some of the environmental consequences of increased vehicle use for local air quality and for increasing the contribution of the transport sector to global warming.

Suggestive evidence of technology's role in mitigating the consequences of growth's impact is presented in Table 5. This table presents trends in air pollution between 1988 and 1997 for 13 metropolitan areas. For example, Phoenix is a sharply growing, sprawling metropolitan area. In 1988, Phoenix experienced 29 days of "unhealthful" air as defined by a Pollution Standard Index exceeding 100. This index is based on the level of pollutants covered under the Clean Air Act's Ambient Air Quality Standards. In 1997, Phoenix experienced only 15 "unhealthful" days.

California's population has increased sharply as has its ongoing suburbanization. Its geography and concentration of economic activity combine to give it the worst ozone smog problem in the nation. To document air pollution trends, the California Ambient Air Quality Data 1980–1996 (California EPA's Air Resources Board) were used. This CD-ROM provides all air quality readings taken in the state during this period. Table 6 presents trends in California ozone within the greater Los Angeles area and for the rest of the state. Outside the Los Angeles area, the average location experienced 3.084 exceedences of the national 1-hour ozone standard between 1980 and 1984. In the 1990s, mean ozone outside the Los Angeles area exceeded the standard only 0.9 times a year. The Los Angeles area has experienced greater population growth during this period but at the same time it has experienced a sharp reduction in pollution. Between the early 1980s and the early 1990s, mean ozone exceedences in the Los Angeles area fell by 27. This means that households living in this area experienced an extra month of clean air in the 1990s relative to the 1980s. The improvement in air quality was achieved despite sharp population growth. Households do value an extra month of clean air a year. Health-based research suggests a willingness to pay between \$2 and \$9 per month per-capita to reduce ozone exposure by one polluted day (Hall et al., 1989; Dickie and Gerking, 1991).

One major contributor to the decline in air pollution in California has been reduced vehicle emissions per mile. New vehicles face tighter emissions standards and used

**Table 4.** State annual per-capita energy consumption.

| | Transport + residential + commercial | | Residential | | Transport | |
|---|---|---|---|---|---|---|
| | beta | s.e | beta | s.e | beta | s.e |
| Real per-capita income | 0.279 | 0.083 | 0.121 | 0.080 | 0.222 | 0.142 |
| Post-1980 | -0.104 | 0.032 | -0.186 | 0.045 | -0.076 | 0.040 |
| Middle Atlantic | -0.065 | 0.045 | -0.173 | 0.073 | -0.059 | 0.072 |
| Middle Atlantic*(Post-1980) | 0.089 | 0.060 | 0.113 | 0.041 | 0.075 | 0.135 |
| East North Central | 0.064 | 0.043 | 0.027 | 0.046 | 0.056 | 0.065 |
| East North Central*(Post-1980) | 0.076 | 0.035 | 0.112 | 0.042 | 0.054 | 0.056 |
| West North Central | 0.171 | 0.052 | -0.029 | 0.051 | 0.313 | 0.078 |
| West North Central*(Post-1980) | 0.090 | 0.033 | 0.176 | 0.052 | 0.028 | 0.030 |
| South Atlantic | 0.036 | 0.050 | -0.222 | 0.053 | 0.220 | 0.077 |
| South Atlantic*(Post-1980) | 0.114 | 0.029 | 0.242 | 0.044 | 0.043 | 0.030 |
| East South Central | 0.129 | 0.050 | -0.116 | 0.063 | 0.337 | 0.085 |
| East South Central*(Post-1980) | 0.118 | 0.033 | 0.207 | 0.046 | 0.102 | 0.031 |
| West South Central | 0.259 | 0.051 | -0.102 | 0.064 | 0.502 | 0.091 |
| West South Central*(Post-1980) | 0.113 | 0.034 | 0.173 | 0.048 | 0.109 | 0.045 |
| Mountain | 0.294 | 0.066 | -0.146 | 0.066 | 0.538 | 0.105 |
| Mountain*(Post-1980) | 0.017 | 0.033 | 0.140 | 0.043 | -0.069 | 0.031 |
| Pacific | 0.126 | 0.066 | -0.115 | 0.121 | 0.300 | 0.059 |
| Pacific*(Post-1980) | 0.072 | 0.051 | 0.084 | 0.059 | 0.073 | 0.043 |
| constant | -4.296 | 0.781 | -3.691 | 0.747 | -4.742 | 1.342 |
| observations | 1248 | | 1248 | | 1248 | |
| R2 | .50 | | .30 | | .56 | |

*Note:* The unit of observation is a state/year. The data source is the State Energy Report data. The regressions are estimated using GLS. The omitted region dummy is New England pre-1980. Robust standard errors with heteroskedasticity correction and clustering by state to allow for state correlation. Regions as in Table 3. Dependent variable: log of state per-capita energy consumption in each sector in each year from 1969-1994.
All summary statistics are available on request.

**Table 5.** Air quality trends for selected metropolitan areas.

| Metropolitan area | Total sites | 1988 | 1997 |
|---|---|---|---|
| Atlanta | 9 | 44 | 26 |
| Chicago | 43 | 40 | 9 |
| Denver | 20 | 35 | 0 |
| Houston | 26 | 72 | 47 |
| Los Angeles | 36 | 239 | 83 |
| Miami | 10 | 8 | 3 |
| New York | 28 | 57 | 23 |
| Nashville | 19 | 55 | 20 |
| Phoenix | 23 | 29 | 15 |
| Riverside | 36 | 185 | 106 |
| Seattle | 16 | 20 | 1 |
| San Diego | 20 | 123 | 14 |
| San Francisco | 9 | 1 | 0 |

*Notes:* This index is based on ambient measures of the five major pollutants for which the EPA has established National Ambient Air Quality Standards under the Clean Air Act. A PSI level of 100 indicates that air quality is below "moderate" and is at low scale of being "unhealthful" (USEPA, 1997). Number of days where the pollutant standards index was greater than 100 at trend sites (at at least one site).

vehicles face rigorous emissions tests. To monitor the effectiveness of its used-vehicle emissions testing program, the California Environmental Protection Agency Air Resources Board (2000) created the Random Roadside Emissions database. In calendar years 1992, 1993, and 1996, vehicles were randomly subjected to an emissions test to measure their hydrocarbon emissions levels. Hydrocarbons are an important input in the creation of ozone smog which has been one of the most difficult ambient pollutants to clean up (as the Clean Air Act dictates).

Table 7 reports California vehicle median hydrocarbon emissions by model year and calendar year. Each column of Table 7 reports cross-sectional facts about the variation in vehicle emissions by vehicle vintage and types. Reading across a row of Table 7 indicates how a given vintage's emissions changes as the vehicle ages. Two key facts emerge: 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.[10] This table indicates that the average air pollution externality per mile of driving

**Table 6.** California ambient ozone trends 1980–1996.

| | The Greater Los Angeles Area | | | California but not the Greater Los Angeles Area | | |
|---|---|---|---|---|---|---|
| | 1980-1984 | 1985-1989 | 1990+ | 1980-1984 | 1985-1989 | 1990+ |
| Population growth percent | 8.9 | 11.7 | 5.0 | 8.2 | 8.7 | 5.3 |
| Count of days exceeding national 1-hour standard | 47.611 (44.257) | 39.750 (41.553) | 20.275 (27.440) | 3.084 (10.589) | 1.886 (4.596) | 0.983 (4.187) |
| Count of days exceeding state 1-hour standard | 82.453 (52.673) | 79.193 (54.009) | 52.681 (43.590) | 13.032 (19.975) | 12.823 (19.385) | 8.987 (14.863) |
| Count of days exceeding national 8-hour standard | 61.558 (46.274) | 59.017 (45.651) | 37.559 (35.901) | 8.720 (16.947) | 8.903 (16.272) | 6.588 (13.105) |
| Observations | 285 | 300 | 454 | 439 | 464 | 866 |

*Note:* This table presents means by cell. Standard deviations are presented in parentheses. The data source is the California EPA's Air Resources Board's California Ambient Air Quality Data 1980-1996. The Greater Los Angeles Area is defined as the following counties: Orange, Los Angeles, San Bernardino, Riverside, San Diego, Kern and Ventura. The unit of analysis is an ambient monitoring station.

is falling over time. Further future emissions reductions per mile can be expected as new emissions technologies are phased in (Howitt and Altshuler, 1999).

Vehicle emissions per mile of driving are falling faster than total miles of driving are increasing. This shows that the environmental costs of dispersion are being mitigated by environmental regulation. Air quality would have declined in the absence of Clean Air Act regulation. The Clean Air Act's ozone standard is based on whether an area experiences more than one ozone exceedence per year; it is unlikely that sprawling areas are more heavily regulated than this.[11]

Emissions control technology has outpaced vehicle fuel economy improvements. Suburban growth has increased fuel consumption and contributed to the United States' aggregate production of greenhouse gases. This reduces the United States' ability to honor any global warming treaty commitments. The Kyoto Protocols have attempted to create a binding global pact to achieve emissions reductions. Under the Kyoto Protocols, the United States has agreed to reduce its greenhouse gas emissions by 7 percent below their 1990 levels by the year 2010. To judge the impact of suburbanization on greenhouse gas emissions consider the following facts. Per-capita U.S. carbon dioxide emissions 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 16,946 miles a year this would reduce household emissions by over 4000 pounds.[12] This reduction alone would meet the Kyoto target for U.S. compliance with the treaty.

[10] Different vehicles were sampled in each calendar year.
[11] Even if major metropolitan areas, such as Houston or Los Angeles, featured higher-density living, they would still not attain the ozone standard and would have the same regulation.

**Table 7.** California vehicle hydrocarbon emissions.

| Medians by model year/by calendar year | Calendar year | | |
|---|---|---|---|
| model 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 |

*Note:* Data source is the California Random Roadside Emissions test. Each entry is a median for the cell. Units are parts per million; for 1992 and 1993, 1985 category includes post-1990 makes.

Technological change breaks the link between energy consumption and environmental consequences. The relationship between miles driven and gasoline consumption depends on vehicle fuel economy. The booming light truck market (partially created because of differential CAFÉ (corporate average fuel economy)

**Table 8.** Spatial resource consumption differentials.

| Vehicle Mileage | Extra resource consumption |
|---|---|
| Suburban drivers relative to city drivers | 31 percent |
| Western drivers relative to northeast drivers | 35.6 percent |
| Land Consumption | |
| Suburban/center city lot size differential | 58.1 percent |
| Household fuel consumption | |
| Suburban/center city differential for all fuels | 0 percent |
| Suburban/center city differential for fuel oil | 48.7 percent |
| South Atlantic Division versus New England for all fuels | –38 percent |

*Note:* Vehicle mileage findings are based on the results in Table 1 land consumption results are based on the results in Table 2. Household fuel consumption results are based on the results in Table 3.

standards between cars and light trucks) reduces average fleet fuel economy. Given the growth in suburbanization, tighter CAFÉ standards or "gas guzzler" taxes may be needed to reduce greenhouse gas emissions (Goldberg, 1998). Such incentives will help spur technological innovation to produce vehicles that economize on fuel, such as the hybrid car, a reality in the near future (Hawken, Lovins, and Lovins, 1999).

## CONCLUSION

As household income grows, more households move to the suburbs. Richer households are attracted to larger, newer suburban homes and are pushed from the central cities by concern about crime and public school quality (Berry-Cullen and Levitt, 1999). An unintended consequence of suburban growth is greater resource consumption leading to greater environmental damage than if more households stayed in the city. Government policies—such as mortgage interest deduction, highway construction, and cheap gasoline—have encouraged suburban growth (Gyourko and Voith, 1997; Nivola, 1999).

This paper documents the extra resource consumption caused by suburbanization. Table 8 summarizes the results. Suburban households drive 31 percent more and consume more than twice as much land as their central city counterparts. The environmental consequences of vehicle dependence are directly related to the technologies used. Air quality has not been degraded in sprawling areas because emissions per mile have fallen faster than miles driven have increased. While progress has been impressive, air pollution could rise in the future in sprawling metropolitan areas. Now that almost all of the high-pollution–emitting pre-1975 vehicles have exited the fleet and given the continued growth in the number of high-polluting light trucks and SUVs on the roads, future emissions reductions will take place only if the next generation of emissions control technology significantly reduces emissions.

As suburbia grows, political support for higher gasoline taxes and greater urban subsidies for public transit will both fall. The United States is unlikely to reduce its greenhouse gas production through higher carbon taxes and greater public transit infrastructure investments. Promoting technological change to increase vehicle fuel economy appears to be the most politically viable option for reducing the global warming contribution of suburbanization. A key public policy issue here is whether vehicle producers will be able to make vehicles that consumers perceive to be safe and fuel efficient. Given the large number of huge SUVs on the roads, environmentally conscious drivers face a "prisoner's dilemma"; purchasing a fuel efficient (smaller) vehicle puts them at a greater risk when an accident occurs.

To preserve environmentally valuable pieces of the hinterland from suburban development, public goods mechanisms such as Land Trusts and state "green belts" should be encouraged. State ballot initiatives are an increasingly popular mechanism for allowing voters to express their preferences for environmental preservation. Reducing the transaction costs of putting such a piece of green legislation on the ballot would allow voters the opportunity to minimize the costs of suburban growth.

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[12] These numbers represent the sample means for suburban and city residents as reported in the 1995 NPTS data. To judge the social costs of this "excess driving," one recent study measures the social cost of gasoline consumption at $1.6 per gallon (Cobb, 1998). Assuming that the average suburban driver's vehicle achieves 25 miles per gallon, then the suburban driver imposes an extra $300 per year externality relative to that driver's city counterpart (www.edf.org/want2help/b_gw20steps.html).

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