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The Impact of Center City Economic and Cultural Vibrancy on Greenhouse Gas Emissions from Transportation

MTI Report 11-13

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REPORT 11-13

THE IMPACT OF CENTER CITY ECONOMIC AND CULTURAL VIBRANCY ON GREENHOUSE GAS EMISSIONS FROM TRANSPORTATION

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16. Abstract

Urban planners and scholars have focused a great deal of attention on understanding the relationship between the built environment and transportation behavior. However, other aspects of the urban environment – including the vibrancy and quality of life in urban areas – have received little attention. This report seeks to close this gap by analyzing the effects of both land-use and urban vibrancy on transportation patterns. Analysis of data from a variety of sources suggests that in addition to the built-environment, the vibrancy of the urban environment also affects transportation behavior. Moreover, vibrancy affects land-use patterns. By integrating objective measures of center-city quality of life into transportation choice models, our new statistical results inform public policy. We discuss specific public policy options for reducing greenhouse gas emissions and increasing public transit use.

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EXECUTIVE SUMMARY

Policy makers across the country are keenly interested in reducing emissions from driving and increasing public transit use. A large literature has documented that urban sprawl is associated with more driving and less public transit use, suggesting land-use policy might be effective in achieving these objectives. This report corroborates previous studies by using the most recent data to quantify the relationship between urban form and urban transportation patterns; however, the existing literature provides policy makers little guidance on how to reverse sprawl and achieve lower emissions. One potentially important variable, which has largely been ignored in the literature, is the vibrancy of the urban core. A vibrant urban core may plausibly affect both land-use and transportation patterns. Thus a key question remains: Can policy makers promote green cities through fostering a vibrant center core?

This report documents that vibrant downtown areas are associated with lower greenhouse gas (GHG) emissions from driving, and greater public transit use. We recognize that “vibrancy” can be an ambiguous, hard to define concept, but we have outlined objective indicators that we believe correlate with what most people seek out in center cities in terms of employment, leisure, and other opportunities. We have defined “vibrancy” based on a downtown’s share of residents who are college graduates, the crime rate, the number of cultural and consumer-oriented establishments, and the share of the metropolitan area’s jobs and population growth downtown.

The analysis of data from a large, national survey of U.S. households in 2009, supplemented with the vibrancy measures, uncovers economically and statistically significant relationships between vibrancy, emissions, and public transit use. Many of these relationships are verified through analyses of data from multiple sources.

Why are vibrant downtowns associated with less GHG production and more public transit use? Analysis of Census data from 2000 and 2010 finds that metropolitan areas with more vibrant downtowns experienced less sprawl over this time period. Some metropolitan areas, like San Francisco, Miami, and New York, experienced sprawl rates that were less than one percent; however, metropolitan areas like Memphis, Tucson, and Phoenix experienced sprawl rates greater than ten percent. Was downtown San Francisco objectively more vibrant than downtown Memphis? In the year 2000, San Francisco had a murder rate less than half compared to Memphis, more than twice the rate of downtown residents had college degrees, and there were 75% more restaurants per capita than in Memphis. Simply put, if downtown is a place where people want to be, then people choose to live closer to it. Therefore, one effect of vibrancy is to influence land-use patterns, and land-use patterns in turn influence driving and public transit use.

However, vibrancy also strengthens the effect of land-use patterns on transportation behavior. In the household-level analysis, households that live close to vibrant city centers drive less than households that live close to city centers that lack vibrancy. The fact that vibrancy interacts with land-use and transportation in interesting ways highlights the need for an integrated approach to land-use and transportation planning. Although many of these results may be as expected, it is important to document these relationships.

In fact, many of these results likely run counter to the expectations of policy makers. For example, regarding federal policy, measures enacted to encourage home ownership, such as the income tax deduction for mortgage interest, have had the unintended consequence of hastening urban sprawl. According to data from the Department of Transportation, U.S. households in metropolitan areas who lived more than five miles from downtown consumed 200 more gallons of gasoline on average than households who lived less than five miles from downtown. Thus, by encouraging sprawl, these home ownership policies have unintentionally increased greenhouse gas emissions.

The results of this analysis may also run counter to the expectations of local policy makers. The results indicate that seemingly unrelated efforts, such as fighting crime and improving urban schools, actually make for good environmental policy, as these efforts enable people to live in higher density, more compact neighborhoods where people are comfortable driving less and walking and using transit more. In addition, building regulations that limit new construction of high-density, multi-family units are often bad for the environment. When established cities block new construction, it forces households to seek housing in far-flung suburbs where their carbon footprint will be greater.

INTRODUCTION

Climate change looms as a medium- and long-term threat to quality of life in the United States. Economic activity in our cities is a major contributor to our nation's greenhouse gas (GHG) emissions. If we could identify and implement policies that encourage the development of "low carbon" cities, then we could sharply reduce our nation's greenhouse gas emissions.

Consider the sharp contrast between New York City and Houston. The former city features a vibrant center in which millions of people live in multi-family housing within walking distance to stores and public transit. In this densely populated city center, the average person produces less GHG emissions because this person is not driving and lives in a relatively small housing unit. According to data from the 2009 National Household Travel Survey, the average household in Manhattan consumes only 585 gallons of gasoline annually. In contrast, in Houston the average person is living at low population density, far from the city center, not using public transit, driving to work and errands, and living in a relatively large home that requires much electricity. The average household in the Houston metropolitan area consumes 1,285 gallons of gasoline annually—more than twice as much as their Manhattan counterpart.

The fundamental policy problem is to identify cost-effective strategies that will strengthen center cities so that more households across the United States will choose to live a higher density, urban lifestyle rather than a lower density, suburban lifestyle. In recent years, the population has suburbanized. In 1970, the average person who lived in a metropolitan area lived 9.8 miles from the city center; by the year 2000, this distance grew to 13.2 miles. This suburbanization has offered households private benefits, but has imposed environmental costs on society. Per-capita urban GHG production would be lower if more people within a metro area lived closer to the city center at higher density.

This report pursues two main goals. First, it generates new econometric results using several new micro and macro data sets to examine how proximity to the city center affects a household's GHG production from driving, as well as its likelihood of using public transit. The payoff of this part of the project is new knowledge concerning the interrelationships among transportation, land-use, and the environment measured by GHG emissions. Our second main goal is to examine the effect of downtown vibrancy on transportation and land-use. The vibrancy of downtown areas—where vibrancy is measured along multiple dimensions such as crime rate, jobs, and restaurants—affects GHG production both directly and indirectly. For example, if downtown areas are safer, people will be willing to get out of their cars and walk; this is one direct effect of vibrancy. In addition, many people will want to live closer to vibrant downtown areas, and this will in turn indirectly lower GHG emissions.

We focus equally on GHG emissions from driving, as well as public transit use. The effects of land-use patterns and downtown vibrancy may have an even stronger effect on increasing public transit use than on decreasing driving. This is due to the nature of public transit technology—it is a technology that is focused on bringing people downtown.

Therefore, if downtown is a place where people want to be, public transit use might increase dramatically.

All working age households seek employment. Urban economists have documented that households are more likely to live downtown if they work downtown. Since public transit lines focus on bringing people downtown, workers are more likely to commute using public transit if they work downtown and live at high population density. The fundamental challenge that center cities face is that employment has been suburbanizing. Even financial jobs have been leaving Wall Street as more hedge funds trade from the distant New York City suburbs. If people want to live in the suburbs and they want a short commute, then this creates strong incentives for employers to suburbanize.

The remainder of this report is divided into five main sections and a conclusion, each of which explores one set of specific research questions:

1. Is city living back? Population migration to the suburbs and the Sunbelt is a decades long phenomenon, but evidence from the 2000 census showed some signs this trend may be slowing. Using data from the 2010 Census, we examine population growth in cities and metropolitan areas over the 2000 to 2010 period.

2. How does a household's location within a city, the population density in its immediate neighborhood, and the overall population density of the metropolitan area affect its GHG production from driving? We use data from the National Household Travel Survey to explore this question, as well as whether the vibrancy of a metropolitan area's downtown affects driving patterns, and whether the land-use-transportation connection is stronger in more vibrant areas.

3. Can the land-use-vibrancy connections with respect to driving be identified at the metro-level? We use aggregate data to examine our research questions at the level of the metropolitan area. This macro-analysis, using Highway Statistics data, serves as a robustness check on our results.

4. How does the land-use-vibrancy connection affect public transit use? We return to our micro-data to answer similar questions as in Section Two, but substitute public transit use for GHG emissions as the dependent variable.

5. Can the land-use-vibrancy connections with respect to transit use be identified at the metro-level? We employ data from the National Transit Database as a further robustness check.

Finally, considering all of our results, we investigate the role of local public policies in reducing GHG from driving and increasing public transit use. We also point out some of the limitations of our work, and suggest directions for future research.

Before turning to the first piece of our analysis, we will briefly summarize the findings of our report.

In the 1990s, after decades of decline, New York City's population grew by nine percent, and Chicago's by four percent. This led some to conclude that city living, and a demand for a New Urbanist lifestyle, may become widespread. This has important implications for the environment because, as we document in Section 2 and elsewhere, households that live in compact cities produce less GHG emissions than households that live in sprawling suburbs. However, analysis of the growth in U.S. cities and metropolitan areas by Edward Glaeser and Jesse Shapiro[1] revealed that these two cities were largely outliers. Population growth in the 1990s was still disproportionately a suburban phenomenon, although they did present some evidence that the decline of dense cities started to slow.

We update Glaeser and Shaprio's analysis using data from the 2000s. Unfortunately, the results do not bode well for dense cities, and by extension, the environment. While New York City grew by a little more than two percent, the population of Chicago fell by seven percent. We investigate the growth rates in over 1,000 cities in Section 1, and find that although density was not as bad for growth as it was in the 1980s, it was worse for growth than in the 1990s. Our results indicate that dense cities have quite a long way to go before we can say they are "back."

In Section 2 we show why the decline of dense cities is bad from an environmental perspective. The models we estimate in this section perform almost exactly as our theory predicts. People who live in higher density neighborhoods and closer to the city center drive less and consume less gasoline, thereby producing fewer GHG emissions. In the individual level regressions, we find that four out of the eleven vibrancy measures we used were also associated with less driving: percent of downtown residents with college degrees, a declining murder rate, a large number of live-music performers downtown, and a large percent of metropolitan area jobs downtown. When stratifying our sample based on the first three of these, we find the coefficient on a household's distance to downtown in a model explaining GHG emissions is about twice as large in the vibrant versus non-vibrant subsamples, and this difference is statistically significant.[2] In this analysis of driving, the only result that runs counter to our theory concerns job growth downtown, which was associated with more driving.[3] We take this as strong evidence that dense, vibrant cities are green cities.

In Section 3 we explore the same basic questions as in Section 2 by using aggregate MSA-level data. We are able to verify many of our results in this macro-data, as well as to produce some new findings. We verify that average vehicle miles traveled (and hence GHG) are lower in denser metropolitan areas, and also in metro areas where the average person lives closer to downtown. When including our vibrancy measures, we find that downtowns with more hotels and more restaurants per capita are also associated with less driving. In addition to validating the results from Section 2, some new findings presented in this section concern the determinants of where in the metropolitan area households decide to live. We find that sprawl, as measured by the rate of change over the 2000-2010 period in the distance the average person lives from downtown, is lower in places with more jobs downtown, a lower murder rate, and more restaurants. This suggests that vibrancy affects urban form, and because urban form affects GHG emissions from driving, vibrancy therefore indirectly affects GHG emissions.

In Section 4 we turn our attention to the effect of land-use and vibrancy on public transit. Our findings with respect to the land-use-public transit connection are exactly as our theory predicts. Households that live at higher density and closer to the city center are more likely to use public transit. We also find that in twenty-one cities with rail transit systems, the distance a household lives from rail stops is extremely important for predicting whether a household uses public transit. Our findings with respect to the vibrancy-public transit connection show that places that have an educated downtown population, a low murder growth rate, and a high number of live-music performers are associated with higher public transit use. Importantly, for these findings we quantify the magnitude of all relationships.

A few results reported in Section 4 ran counter to our expectations. We explored whether households who live close to downtown are more likely to use public transit in vibrant versus non-vibrant areas, and we were surprised that although the coefficient on distance to downtown is significantly larger in communities with vibrant downtowns, when we stratify by jobs and the murder growth rate, this coefficient was actually significantly smaller in the communities with vibrant downtowns. Though surprising, these results do suggest some promising directions for future research, and we consider these in the Conclusion.

In Section 5 we again use metropolitan-area data, this time to explore the effect of urban form and vibrancy on public transit use. Our findings regarding urban form are validated, as are several regarding vibrancy. However, as in Section 4, other vibrancy measures perform counter to our expectations, which again requires us to advocate for future study of the vibrancy-public transit connection.

Despite obtaining some mixed results in the public transit sections, overall many of our results are surprisingly robust. Therefore, considering what we can and cannot say with confidence, in the conclusion we reflect on our findings and offer policy recommendations.

I. URBAN GROWTH IN THE 2000S: IS CITY LIVING BACK?

Before we begin our main analyses regarding the role of urban form and downtown vibrancy on travel behavior, in this section we set the stage by examining population growth patterns between 2000 and 2010. Has the decades-long migration to the suburbs and the Sunbelt continued in the 2000s, or did the first decade of the new millennium witness a real change in preferences for more compact living?

In their 2003 article, "Urban Growth in the 1990s: Is City Living Back?" Edward Glaeser and Jesse Shapiro examined growth trends in U.S. cities and metropolitan areas from 1980 to 2000. Evidence that some large cities that had been in decline for decades actually grew in the 1990s—in particular the prominent examples of New York City's nine percent and Chicago's four percent population growth— led some to conclude that demand for city living and a "New Urbanist" lifestyle[4] may be on the rise.

Beyond the prominent examples of Chicago and New York, the analysis by Glaeser and Shapiro did not find evidence of a return to city living in the 1990s. Instead, the migration towards places with low population density; strong human capital; warmer, drier climates; and automobile-based infrastructure continued. They did find that these trends were somewhat weaker in the 1990s compared to the 1980s, however, which suggested a slowing of the decline of dense cities. This offered a glimmer of hope for those championing the large, dense city.

Did the migration to sprawl finally reverse in the 2000s? New York City did grow by a little more than two percent in the 2000s; however, the population of Chicago fell by seven percent, and looking at all 1,179 cities that had a population of 25,000 or more in the year 2000, we find that dense cities shrank faster in the 2000s than in the 1990s. City living did not make a comeback in the 2000s. The only shred of optimism we can offer urbanists is that the decline of dense cities was not as fast as in the 1980s.

In addition to exploring growth in all cities, we also look at growth in the same set of 275 metropolitan statistical areas (MSAs) as did Glaeser and Shaprio. The evidence is somewhat more encouraging for metropolitan areas. In the 2000s, denser MSAs actually grew faster than they did in the 1980s or 1990s. Overall, we attempted to follow Glaeser and Shapiro's methodology exactly, so that the findings of our analysis of the 2000-2010 period could be directly compared to their findings of the 1980-1990 and 1990-2000 periods. Therefore, we refer the interested reader to their article for complete methodological details, and here we offer only a brief description.

The basic approach we followed was to estimate population growth models of the form:

$$Ln\left(\frac{2010\ Population_i}{2000\ Population_i}\right) = \beta_0 + \textstyle\sum_j \beta_j X_{ij} + \varepsilon_i$$

Where the subscript i indexes an urban area, the subscript j indexes various urban characteristics that impact urban growth, X is a variable that refers to the value of characteristic j, $\sum$ is a summation operator, the β's are parameters measuring the impact of each characteristic to be estimated using Ordinary Least Squares (OLS), and ε_i is the error term.

The approach we followed involves estimating three models of this general form. A number of control variables are common to each model, including region dummies, median age of residents, percentage of the labor force in manufacturing, and land-area growth. The main independent variables of interest in the three models relate to the following characteristics: (1) population density, (2) weather, and (3) human capital. The density-related variables include overall population, population density, percentage driving alone to work, and percentage taking public transportation. The weather variables include mean daily January temperature, July temperature, and average annual precipitation. Finally, the human capital variables include the percentage of college and high school graduates, per capita income, and percentage below the poverty line.

We look at both cities and MSAs. For cities, we examine every city that had a 2000 population greater than 25,000. We excluded eleven cities that more than doubled in population, and four more cities that more than doubled in land area, as these cities likely absorbed other jurisdictions. No cities in this sample lost more than 50% of their population or land area. We followed the data rules specified by Glaeser and Shapiro in the original study.

Intuitively, in the "density" specifications, the most relevant for our purposes, we are estimating population growth using various measures of "cityness," which range from population to percentage taking public transit, to describe the characteristics of cities that grew. Hence, these specifications are not meant to estimate causal relationships—for example, we do not interpret the parameter estimate of the coefficient on the percentage of people taking public transit as an estimate of the causal impact of public transportation on growth. Instead we interpret these estimates as indicating whether the trend away from older cities, built around public transit technologies, is continuing or reversing. Hence, population, population density, and public transit use are all included as proxies for "cityness."

Table 1 and Table 2 contain summary statistics for the city and MSA samples, respectively. The actual regression results from the three models, for both samples, are reported in the Appendix to this Section.

Having followed Glaeser and Shapiro's methodology as precisely as possible makes it appropriate to compare our findings to theirs. We present these comparisons below in Tables 3 and 4. For the 2000-2010 period, the values reported are the estimated coefficients from several multiple regression analyses, which are reported in Tables 5 through 10. Note that these coefficient estimates do not all come from the same model. We report the estimated coefficients from the specifications that include city measures individually (we do not report the estimates from the last column of Tables 5 through 10, which combines multiple city measures). The values in the 1980-1990 and 1990-2000 columns were the corresponding coefficient estimates reported in Glaeser and Shapiro's original study, and the values in the 2000-2010 column are the new estimates we produced.

The variable names presented in Table 1 and Table 2 are short descriptors, and for the most part the variables these names represent should be obvious. One exception may be >=2.1% Public Transport Commuters, which is a dummy variable equal to one if the fraction of city (or MSA) workers commuting by some form of public transit was larger than the 2000 median value for this variable (2.1%). Ln refers to the natural logarithm. We report more detailed data notes in the Data Appendix.

Table 1. Summary Statistics, City Sample (n=1,179)

Variable	Mean	Std. Dev.	Min	Max
Ln(Population Growth)	0.09	0.14	-0.34	0.67
Ln(Land Area Growth)	0.06	0.11	-0.41	0.66
Northeast	0.13	0.34	0.00	1.00
Midwest	0.25	0.43	0.00	1.00
South	0.29	0.45	0.00	1.00
West	0.32	0.47	0.00	1.00
Median Age	38.48	4.49	22.20	53.00
Manufacturing Share	13.22	6.86	1.20	47.34
Population (2000)	100,374.00	300,286.00	25,070.00	8,008,278.00
Population (2010)	108,318.90	307,428.66	25,024.00	8,175,133.00
Population Density (per square mile)	3,849.54	3,777.16	11.57	51,796.57
% Driving to Work Alone	76.35	8.84	24.89	91.06
% Commuting via Public Transportation	3.76	5.37	0.00	57.16
Mean Daily January Temperature (F)	37.75	14.26	-9.70	68.10
Mean Daily July Temperature (F)	75.55	5.84	55.00	95.60
Mean Annual Precipitation (inches)	34.91	14.88	2.96	82.86
% Age 25+ Graduated High School	81.28	10.51	29.58	98.35
% Age 25+ Graduated with Bachelors Degree or Higher	26.69	13.57	2.31	74.38
Per Capita Income (USD)	22,002.39	7,679.34	7,287.00	66,776.00
% with Income Below Poverty Level	12.80	7.60	1.36	46.93

Table 2. Summary Statistics, MSA Sample (n=275)

Variable	Mean	Std. Dev.	Min	Max
Ln(Population Growth)	0.10	0.08	-0.11	0.34
Northeast	0.13	0.33	0.00	1.00
Midwest	0.25	0.43	0.00	1.00
South	0.43	0.49	0.00	1.00
West	0.17	0.38	0.00	1.00
Median Age	35.40	3.69	23.30	54.30
Manufacturing Share	0.13	0.06	0.02	0.42
Population (2000)	824,408.00	1,949,342.00	57,813.00	20,300,000.00
Population (2010)	912,670.00	2,091,033.00	60,580.00	21,000,000.00
Population Density (per square mile)	278.25	260.17	5.41	0.00
% Driving to Work Alone	79.31	4.32	55.07	86.43
% Commuting via Public Transportation	1.59	2.19	0.11	25.98
Mean Daily January Temperature (F)	35.77	13.20	5.30	73.00
Mean Daily July Temperature (F)	76.88	5.73	58.40	94.10
Mean Annual Precipitation (inches)	37.45	14.68	3.01	66.29
% Age 25+ Graduated High School	81.55	6.30	50.45	93.66
% Age 25+ Graduated with Bachelors Degree	22.98	6.91	11.05	47.60
Per Capita Income (USD)	19,542.68	3,012.58	9,899.00	31,195.00
% with Income Below Poverty Level	12.85	4.37	5.18	35.87

Table 3. Comparison of Estimated Coefficients, City Sample*

Estimated Coefficient	1980/1990	1990/2000	2000/2010
Ln(Land Area Growth)	0.3771	0.4428	0.6590
Northeast	-0.1648	-0.1204	-0.0595
Midwest	-0.1674	-0.1079	-0.0881
South	-0.1171	-0.0473	-0.0057
Median Age	-0.0019	-0.0015	0.0001
Manufacturing Share	0.0195	0.0206	-0.0003
Ln(Population)	-0.0109	-0.0062	-0.0137
Ln(Population Density)	-0.0530	-0.0354	-0.0406
Percent Driving Alone	0.0030	0.0034	0.0020
>= 2.1% Public Transport Commuters	-0.0452	-0.0310	-0.0365
Mean Temperature January	0.0047	0.0014	0.0009
Mean Temperature July	0.0050	0.0065	0.0038
Average Annual Precipitation	-0.0010	-0.0005	-0.0011
Percent High School+	0.0038	0.0040	0.0017
Percent Bachelors+	0.0023	0.0021	0.0013
Ln(Per Capita Income)	0.1178	0.1603	0.0600
Percent Below Poverty Level	-0.0059	-0.0077	-0.0039

** The numbers listed in the columns labeled 1980/1990 and 1990/2000 are the values of the estimated coefficients on the variable listed in the corresponding row in a population growth regression model, reported by Glaeser and Shapiro. The number listed in the 2000/2010 column are the values of the estimated coefficients on the variable listed in the corresponding row in a population growth regression model, estimated by Holian and Kahn.*

Table 4. Comparison of Estimated Coefficients, MSA Sample

Estimated Coefficient	1980/1990*	1990/2000*	2000/2010*
Northeast	-0.0971	-0.1469	-0.0866
Midwest	-0.0945	-0.0912	-0.0535
South	-0.0302	-0.0411	-0.0081
Median Age	0.0101	-0.0006	-0.0044
Manufacturing Share	-0.0057	-0.0021	-0.0033
Ln(Population)	0.0100	0.0131	0.0109
Ln(Population Density)	0.0074	0.0054	0.0102
Percent Driving Alone	-0.0041	-0.0023	-0.0012
>= 2.1% Public Transport Commuters	-0.0124	0.0064	-0.0022
Mean Temperature January	0.0051	0.0017	0.0004
Mean Temperature July	0.0046	0.0059	0.0030
Average Annual Precipitation	0.0003	-0.0003	-0.0006
Percent High School+	0.0014	0.0033	0.0022
Percent Bachelors+	0.0066	0.0068	0.0042
Ln(Per Capita Income)	-0.1196	0.2114	0.1680
Percent Below Poverty Level	0.0059	-0.0043	-0.0064

**The numbers listed in the columns labeled 1980/1990 and 1990/2000 are the values of the estimated coefficients on the variable listed in the corresponding row in a population growth regression model, reported by Glaeser and Shapiro. The number listed in the 2000/2010 column are the values of the estimated coefficients on the variable listed in the corresponding row in a population growth regression model, estimated by Holian and Kahn.*

Table 3 and Table 4 report the most important parts of our analysis, as these contain a comparison of the coefficient estimates, reported by Glaeser and Shapiro in 2003 for the first two time periods, and reported here for the first time for the latest time period. For the purposes of this report, the most important variables to consider here are those in the density model for the cities sample.

As a general summary, the density variables reported in Table 3 indicate that cities with higher density are associated with lower rates of population growth in all three decades. Consider first Ln(Population) in Table 3. In all three time periods, the estimated coefficient on this variable was negative, meaning that population growth does not tend to occur in larger cities. And larger cities shrunk faster in the 2000s than in the 1980s and the 1990s. Specifically, in the 1980-1990 period, the estimate was -0.0109, and this estimate fell (in magnitude) to -0.0062 over the 1990-2000 period. The decrease in this estimated coefficient was encouraging for urbanists. However, this trend did not continue in the 2000-2010 period, as the estimated coefficient on Ln(Population) grew (in magnitude) to -0.0137, larger even than the coefficient from the 1980-1990 period.

With respect to the estimated coefficient on the Ln(Population Density) variable, we see that dense cities shrunk faster in the 2000s than in the 1990s, but they shrunk faster in the 1980s than in the 2000s. Although the coefficient on Ln(Population Density) was larger in magnitude (at -0.0406) in the 2000-2010 period than in the 1990-2000 period (where it was -0.0354), population density had the most negative association with growth in the 1980-1990 period (at -0.0530). The estimated coefficient on the >=2.1% Public Transit Commuters variable shows the exact same pattern; it was associated with the greatest declines in growth in the 1980-1990 period, and the smallest declines in growth in the 1990-2000 period.

The final variable in the density specifications is Percent Driving Alone, where the positive sign in Table 3 across all three decades indicates that higher rates of driving alone have been associated with population growth. Here, we see the estimated coefficient was larger in the 1990s than the 1980s; however, it was actually smaller in the 2000s than in either of the preceding time periods. Despite the discouraging findings discussed so far, proponents of cities may at least take some comfort in the fact that car cities (cities where the overwhelming majority of residents drive to work alone) do not have quite the same attraction as they had in earlier decades.

With respect to metropolitan statistical areas, the results presented in Table 4 show that large, dense MSAs continued to grow in population, and in some cases, there is an indication that density begets density. See, for example, the positive signs for the population and population density variables, and the negative signs on the drive alone variable. The public transit variable is mixed across the decades in its association with population growth in MSAs. As we will see, this is good news for those who are interested in reducing GHG emissions from driving and increasing public transit use. But because cities correspond more closely to traditional downtown areas, these refined geographical areas that make up the main central core of the MSAs are most relevant to this report. Therefore, for our purposes, the results from the cities sample reported in Table 3 are the most important.

Although our primary focus is on the density model, we briefly consider the effect of weather and human capital to provide a more complete picture of the determinants of growth. In Table 3, average July and average January temperatures were less important for growth than in previous decades, and the average annual precipitation variable was more important for growth than in the 1990s, and about as important as in the 1980s. All of the proxies for human capital—the percentage of the population aged 25 or greater with at least a high school diploma or bachelors degree, the log of per capita income, and the percentage of the population below the poverty line—were all less important in the 2000s than in the 1980s or the 1990s.

The goal of this section was to update Glaeser and Shapiro's study with the most recent data, because migration patterns across cities are directly related to the analyses we carry out in the remainder of our paper. The results of our analysis shown in Tables 3 and 4 show that Americans' taste for suburban living has not changed much over the last twenty years. This is bad news for proponents of center city living. Can anything be done to reverse the trend towards sprawl? In the Conclusion we focus on recommendations for local policy makers. However, national policy has an important role to play, and here we briefly mention some changes to national policy that could help cities. According to Edward Glaeser:[5]

> *The long, passionate love affair between American politicians and home ownership is a curse to the cities that power the American economy. More than 85 percent of people living in multifamily dwellings rent their living quarters. More than 85 percent of people in single-family detached dwellings own them. This connection isn't a random statistical artifact. It makes sense to have one roof, one owner. When people rent single-family homes, they often take bad care of them. Homes depreciate by 1.5 percent more per year if they are inhabited by renters rather than owners, who work hard to take care of their important asset. By contrast, in multifamily dwellings, dispersed ownership is a big headache. Think of the battles that roil co-op boards. Because dense cities are filled with multi-unit buildings, they're also filled with renters. In Manhattan, 76 percent of housing units are rentals. When the federal government encourages people to own, it is implicitly encouraging people to leave dense cities.*

A variety of federal policies directly and indirectly encourage homeownership. The most important of these is almost certainly the home mortgage interest deduction. Therefore, although the policy recommendations we focus on in the Conclusion focus on the role of local policy, we believe it is impossible to ignore the dynamics shaping migration patterns at the macro level. Federal tax policy can play an important role in reversing the decades long decline of dense cities.

The most straightforward recommendation to help cities would be to simply repeal the income tax provision providing for the home mortgage interest deduction. Obviously, this would be a major change and would dramatically affect housing markets; therefore, substantial care should be taken to minimize the negative impacts of such a change. Perhaps a graduated phasing out would be preferred to an overnight elimination. One comprehensive analysis of federal housing policy[6] proposed phasing such a reform in over time so that it affects only new home owners, and rather than eliminating the deduction altogether, they propose capping it at $300,000. We have not carried out a comprehensive cost-benefit analysis of modifying this policy, and we are not in a position to offer detailed policy recommendation. Though as we will see, by encouraging Americans to live a higher-density, urban lifestyle, we believe revising the home mortgage interest deduction would have measurable environmental benefits, the size of which could be estimated using the results we present in subsequent sections. Therefore, we believe that policy makers should seriously reconsider whether the size and scope of the current home mortgage interest deduction is appropriate, and the environmental benefits that we refer to here should be taken into account in proposals to modify this influential policy.

Table 5. City Growth and Density

Variables	Population Growth	Population Growth	Population Growth	Population Growth	Population Growth
Ln(Land Area Growth)	0.6590***	0.6380***	0.6600***	0.6330***	0.6260***
	(0.0323)	(0.0316)	(0.0321)	(0.0327)	(0.0321)
Northeast	-0.0595***	-0.0446***	-0.0465***	-0.0499***	-0.0434***
	(0.0115)	(0.0113)	(0.0117)	(0.0115)	(0.0115)
Midwest	-0.0881***	-0.0907***	-0.0972***	-0.0901***	-0.0936***
	(0.0094)	(0.0091)	(0.0096)	(0.0093)	(0.0094)
South	-0.0057	-0.0271***	-0.0126	-0.0154*	-0.0285***
	(0.0086)	(0.0088)	(0.0087)	(0.0088)	(0.0088)
Median Age	0.0001	0.0008	0.0000	0.0000	0.0007
	(0.0008)	(0.0008)	(0.0008)	(0.0008)	(0.0008)
Manufacturing Share	-0.0003	-0.0002	-0.0005	-0.0003	-0.0003
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Ln(2000 Population)	-0.0137***				-0.0046
	(0.0044)				(0.0045)
Ln(Density)		-0.0406***			-0.0353***
		(0.0047)			(0.0055)
% Driving to Work Alone			0.0020***		0.0002
			(0.0004)		(0.0005)
>= 2.1% Commuting via Public Transportation				-0.0365***	-0.0132
				(0.0072)	(0.0082)
Constant	0.2330***	0.3840***	-0.0605	0.1050***	0.3900***
	(0.0580)	(0.0476)	(0.0453)	(0.0333)	(0.0856)
Observations	1,179	1,179	1,179	1,179	1,179
R-squared	0.3610	0.3940	0.3680	0.369	0.3970

- *All specifications contain the following unreported control variables: ln(growth in land area), region dummies, median age, and percentage of civilian employment in manufacturing.*
- *Standard errors in parentheses.*
- *"***", "**", and "*" refer to statistical significance at the 1, 5, and 10 percent levels, respectively.*
- *Independent variables correspond to the 2000 period for each panel.*
- *The dependent variable is the logarithmic growth rate of population over the 2000-2010 period.*

Table 6. MSA Growth and Density

Variables	Population Growth	Population Growth	Population Growth	Population Growth	Population Growth
Northeast	-0.0866***	-0.0955***	-0.0848***	-0.0857***	-0.0799***
	(0.0170)	(0.0179)	(0.0173)	(0.0173)	(0.0187)
Midwest	-0.0535***	-0.0621***	-0.0509***	-0.0562***	-0.0474***
	(0.0148)	(0.0153)	(0.0160)	(0.0150)	(0.0171)
South	-0.0081	-0.0167	-0.0057	-0.0107	-0.0057
	(0.0126)	(0.0131)	(0.0136)	(0.0129)	(0.0149)
Median Age	-0.0044***	-0.0042***	-0.0038***	-0.0043***	-0.00433***
	(0.0012)	(0.0012)	(0.0013)	(0.0013)	(0.0013)
Manufacturing Share	-0.0033***	-0.0035***	-0.0031***	-0.0034***	-0.0032***
	(0.0007)	(0.0007)	(0.0008)	(0.0007)	(0.0008)
Ln(2000 Population)	0.0109***				0.0166***
	(0.0039)				(0.0063)
Ln(Density)		0.0102*			-0.0021
		(0.0056)			(0.0085)
% Driving to Work Alone			-0.0012		-0.0014
			(0.0014)		(0.0015)
>= 2.1% Commuting via Public Transportation				-0.0022	-0.0321**
				(0.0117)	(0.0147)
Constant	0.1910***	0.2790***	0.4020***	0.3290***	0.2400**
	(0.0651)	(0.0506)	(0.0922)	(0.0445)	(0.1190)
Observations	275	275	275	275	275
R-squared	0.3440	0.3330	0.3270	0.3250	0.3560

- *All specifications contain the following unreported control variables: ln(growth in land area), region dummies, median age, and percentage of civilian employment in manufacturing.*
- *Standard errors in parentheses.*
- *"***", "**", and "*" refer to statistical significance at the 1, 5, and 10 percent levels, respectively.*
- *Independent variables correspond to the 2000 period for each panel.*
- *The dependent variable is the logarithmic growth rate of population over the 2000-2010 period.*

Table 7. City Growth and Climate

Variables	Population Growth	Population Growth	Population Growth	Population Growth
Ln(2000 Population)	-0.0048	-0.0083*	-0.0066	-0.0089**
	(0.0044)	(0.0044)	(0.0044)	(0.0044)
Ln(Density)	-0.0394***	-0.0358***	-0.0363***	-0.0375***
	(0.0054)	(0.0051)	(0.0052)	(0.0055)
>= 2.1% Commuting via Public Transportation	-0.0126	-0.0073	-0.0098	-0.0052
	(0.0078)	(0.0078)	(0.0079)	(0.0079)
Mean Daily January Temperature (F)	0.0009**			0.0004
	(0.0004)			(0.0005)
Mean Daily July Temperature (F)		0.0038***		0.0031***
		(0.0007)		(0.0009)
Mean Annual Precipitation			-0.0011***	-0.0007*
			(0.0004)	(0.0004)
Constant	0.429***	0.195**	0.452***	0.267***
	(0.0647)	(0.0762)	(0.0654)	(0.0883)
Observations	1,179	1,179	1,179	1,179
R-squared	0.399	0.409	0.401	0.411

- *All specifications contain the following unreported control variables: ln(growth in land area), region dummies, median age, and percentage of civilian employment in manufacturing.*
- *Standard errors in parentheses.*
- *"***", "**", and "*" refer to statistical significance at the 1, 5, and 10 percent levels, respectively.*
- *Independent variables correspond to the 2000 period for each panel.*
- *The dependent variable is the logarithmic growth rate of population over the 2000-2010 period.*

Table 8. MSA Growth and Climate

Variables	Population Growth	Population Growth	Population Growth	Population Growth
Ln(2000 Population)	0.0167***	0.0146**	0.0157**	0.0130**
	(0.0063)	(0.0062)	(0.0063)	(0.0062)
Ln(Density)	-0.0032	-0.0016	0.00023	0.0033
	(0.0087)	(0.0083)	(0.0086)	(0.0087)
>= 2.1% Commuting via Public Transportation	-0.0274**	-0.0246*	-0.0256*	-0.0217
	(0.0137)	(0.0135)	(0.0137)	(0.0135)
Mean Daily January Temperature (F)	0.0004			-0.0007
	(0.0005)			(0.0006)
Mean Daily July Temperature (F)		0.0030***		0.0038***
		(0.0009)		(0.0011)
Mean Annual Precipitation			-0.0006	-0.0006
			(0.0004)	(0.0004)
Constant	0.144**	-0.0637	0.147**	-0.116
	(0.0696)	(0.0941)	(0.0693)	(0.1020)
Observations	275	275	275	275
R-squared	0.355	0.378	0.358	0.387

- *All specifications contain the following unreported control variables: ln(growth in land area), region dummies, median age, and percentage of civilian employment in manufacturing.*
- *Standard errors in parentheses.*
- *"***", "**", and "*" refer to statistical significance at the 1, 5, and 10 percent levels, respectively.*
- *Independent variables correspond to the 2000 period for each panel.*
- *The dependent variable is the logarithmic growth rate of population over the 2000-2010 period.*

Table 9. City Growth and Human Capital

Variables	Population Growth	Population Growth	Population Growth	Population Growth	Population Growth
Ln(Density)	-0.0312***	-0.0360***	-0.0357***	-0.0337***	-0.0373***
	(0.0052)	(0.0050)	(0.0050)	(0.0049)	(0.0051)
Mean Daily July Temperature (F)	0.0038***	0.0038***	0.0037***	0.0036***	0.0038***
	(0.0008)	(0.0008)	(0.0008)	(0.0007)	(0.0007)
% Age 25+ Graduated with High School Degree or Higher	0.0017***				-0.0018***
	(0.0003)				(0.0006)
% Age 25+ Graduated with Bachelors Degree or Higher		0.0013***			0.0036***
		(0.0002)			(0.0005)
Ln(Per Capita Income)			0.0600***		-0.168***
			(0.0106)		(0.0270)
% with Income Below Poverty Level				-0.0039***	-0.0082***
				(0.0004)	(0.0008)
Constant	-0.071	0.0672	-0.477***	0.157**	1.936***
	(0.0856)	(0.0737)	(0.1350)	(0.0700)	(0.2780)
Observations	1,179	1,179	1,179	1,179	1,179
R-squared	0.421	0.424	0.424	0.447	0.472

- *All specifications contain the following unreported control variables: ln(growth in land area), region dummies, median age, and percentage of civilian employment in manufacturing.*
- *Standard errors in parentheses.*
- *"***", "**", and "*" refer to statistical significance at the 1, 5, and 10 percent levels, respectively.*
- *Independent variables correspond to the 2000 period for each panel.*
- *The dependent variable is the logarithmic growth rate of population over the 2000-2010 period.*

Table 10. MSA Growth and Human Capital

Variables	Population Growth	Population Growth	Population Growth	Population Growth	Population Growth
Ln(Density)	0.0119*	0.0053	-0.000011	0.0062	0.0009
	(0.0062)	(0.0061)	(0.0067)	(0.0061)	(0.0064)
Mean Daily July Temperature (F)	0.0040***	0.0046***	0.0044***	0.0043***	0.0043***
	(0.0010)	(0.0009)	(0.0009)	(0.0009)	(0.0009)
% Age 25+ Graduated High School	0.0022**				-0.00626***
	(0.0009)				(0.0014)
% Age 25+ Graduated College		0.0042***			0.0069***
		(0.0008)			(0.0013)
Ln(Per Capita Income)			0.168***		-0.126**
			(0.0385)		(0.0626)
% with Income Below Poverty Level				-0.0064***	-0.0112***
				(0.0013)	(0.0021)
Constant	-0.202*	-0.221**	-1.572***	0.176**	1.723***
	(0.1220)	(0.0933)	(0.3730)	(0.0880)	(0.6310)
Observations	275	275	275	275	275
R-squared	0.387	0.433	0.415	0.428	0.497

- *All specifications contain the following unreported control variables: ln(growth in land area), region dummies, median age, and percentage of civilian employment in manufacturing.*
- *Standard errors in parentheses.*
- *"***", "**", and "*" refer to statistical significance at the 1, 5, and 10 percent levels, respectively.*
- *Independent variables correspond to the 2000 period for each panel.*
- *The dependent variable is the logarithmic growth rate of population over the 2000-2010 period.*

II. HOUSEHOLD GHG PRODUCTION FROM DRIVING

The previous section documented that demand for city living, measured by population growth, is on the decline. Although we have suggested that this is bad news for the environment, it is not immediately obvious to everyone whether we are, in fact, correct. What are the environmental consequences of more or less urbanization? In this section and the next, we attempt to shed some light on these questions by quantifying the effect of a more compact urban form on GHG emissions from driving. We also seek to explore the role downtown vibrancy plays in transportation choices. Obviously, what makes a place vibrant will mean different things to different people. It is our hope that by analyzing the effect of a large number of vibrancy measures, we will be sure to capture the most important aspects of vibrancy.

A lively urban planning literature has examined the relationship between density, centrality, and transit access to low vehicle miles traveled (VMT). Recent surveys of this literature[7] reveal that most studies find transit access and centrality reduce VMT, but when these variables and others are controlled for, population density may play a small role. It is probable that some of the observed effects of urban form on travel behavior are due not to the effects of density, transit access, and centrality per se but to the fact that those who have an innatepreference for certain travel behaviors self-select into communities that permit these preferences to be expressed. An active research agenda in the planning field examines the importance of attitudes, beliefs, and preferences in determining residential location choice and travel behavior.[8]

Our study builds on this literature because we use the most up-to-date transportation data available, including the 2009 National Household transportation Survey (NHTS). The Department of Transportation has recently released the 2009 NHTS,[9] and this is the main source of data we analyze in this section. The NHTS is a distinctive micro data set because it reports gasoline consumption for a large representative sample of households. We have been able to access a special version of the data set that has census tract identifiers. For each household, we observe which metropolitan area it lives in, its distance to the city center, and the population density of the census tract in which it resides. We also have data on MSA density, and a variety of vibrancy measures that we discuss later in this section.

The dependent variable is gallons of gasoline consumed by the household annually, which we convert into GHG emissions. In the first subsection, we estimate our baseline driving regression. Here, we seek to measure the impact of proximity to downtown, tract-level population density, and MSA-level density on driving behavior. The next subsection explores the role of vibrancy. In particular, we re-estimate the baseline driving regression eleven times, replacing MSA density with one of the eleven vibrancy measures each time. After presenting these results, a concluding subsection explores the interaction between land-use patterns and vibrancy. In particular, we ask whether proximity to downtown is a more important predictor of GHG emissions in MSAs that have vibrant downtowns.

As we will see, the results by and large confirm our expectations—people drive less in compact cities that feature vibrant downtown areas. To provide a sense of just how large these differences can be, consider again the two metropolitan areas mentioned briefly in the Executive Summary above. In the Memphis metropolitan area (Crittenden, De Soto, Marshall, Tate, Tunica, Fayette, Shelby, and Tipton counties), average population density was 263 people per square mile, while in the San Francisco metropolitan area (Alameda, Contra Costa, Marin, San Francisco, and San Mateo counties), average population density was 1,667 people per square mile in the year 2000. In the same year, the city of San Francisco had half as many murders per person, and its downtown had twice the rate of residents with college degrees, and 75% more restaurants per capita than Memphis. According to these data, the San Francisco MSA is objectively more compact than the Memphis MSA, and downtown San Francisco is objectively more vibrant than downtown Memphis. Do people drive less in San Francisco? Yes. In the survey data we describe below, the average household in the Memphis MSA consumed 1,382 gallons of gasoline per year, whereas the average household in the San Francisco MSA consumed 1,009 gallons of gasoline per year. The average household consumes about 38% more gasoline in the Memphis MSA than the average household in the San Francisco MSA —this is only one example illustrating that people drive less in compact metropolitan areas that feature vibrant downtowns.

GHG EMISSIONS AS A FUNCTION OF URBAN FORM

In this subsection, we estimate ordinary least squares (OLS) regressions using observations on 65,955 households based on the equation below, which is our primary approach to modeling GHG emissions.[10]

$$GHG_i = \sum_j \beta_j Z_k^j + \sum_q \gamma_q X_i^q + \mu_k + \varepsilon_i$$

In this regression, the dependent variable is the level of annual household GHG emissions produced by household i, Z_k refers to the value of characteristic j in tract k, β_j refers to the impact of those variables, X_i^q refers to the value of individual characteristic q for household i, γ_q is the coefficient on that characteristic, and the last two terms are tract and household level error terms, respectively.

We calculated GHG emissions from driving for each household in two steps. First, we obtained the estimate of annual household gasoline consumption contained in the NHTS,[11] and then we converted gallons of gasoline into carbon dioxide emissions by multiplying by 20.98. A standard conversion factor used by the Department of Energy is 19.64;[12] however, this conversion factor includes only the direct emissions from a gallon of gasoline, not the indirect emissions associated with refining and transporting gasoline to the pump.[13] Therefore, we increase the factor by seven percent, and assume that each gallon of gas is associated with 20.98 lb of carbon dioxide emissions.

To ensure that anomalous households or computer errors do not skew our results, we followed several data rules. First, we top coded the top one percent of the sample for the dependent variable. We also restricted the sample to households whose head is between the ages of 18 and 65, and for whom we have complete demographic and geographic data. As mentioned above, we restricted our sample to households living within 35 miles of each MSA's central business district (CBD).[14] These data rules yield a sample that includes 65,955 households.[15] The specific variables we use to estimate equation (1) are listed in Table 11 below. Summary statistics for these variables are presented in Table 12.

Table 11. Variable Descriptions, Baseline Model

Variable Name	Description
GHG	Gallons of gasoline consumed annually by household* 20.98
HHSIZE	Number of individuals living in household
HHR_AGE	Age of survey respondent
MIDWEST	Dummy variable equal to one if in Midwest region
SOUTH	Dummy variable equal to one if in South region
WEST	Dummy variable equal to one if in West region
LNDISTANCE	The log of the distance to the CBD (in kilometers)
LNDENSITY	The log of the density of household's tract; pop per sq mile
LNMSADENSITY	The log of the density of household's MSA; pop per sq mile
MIDDENSITY	An interaction variable: MIDWEST*LNDENSITY
SOUTHDENSITY	An interaction variable: SOUTH*LNDENSITY
WESTDENSITY	An interaction variable: WEST*LNDENSITY
HHFAMINC1	Household family income < $5,000
HHFAMINC2	Household family income between $5,000–$9,999
HHFAMINC3	Household family income between $10,000–$14,999
HHFAMINC4	Household family income between $15,000–$19,999
HHFAMINC5	Household family income between $20,000–$24,999
HHFAMINC6	Household family income between $25,000–$29,999
HHFAMINC7	Household family income between $30,000–$34,999
HHFAMINC8	Household family income between $35,000–$39,999
HHFAMINC9	Household family income between $40,000–$44,999
HHFAMINC10	Household family income between $45,000–$49,999
HHFAMINC11	Household family income between $50,000–$54,999
HHFAMINC12	Household family income between $55,000–$59,999
HHFAMINC13	Household family income between $60,000–$64,999
HHFAMINC14	Household family income between $65,000–$69,999
HHFAMINC15	Household family income between $70,000–$74,999
HHFAMINC16	Household family income between $75,000–$79,999
HHFAMINC17	Household family income between $80,000–$99,999
HHFAMINC18	Household family income > $100,000

The location of each MSA's CBD was obtained by recording the geocode returned when entering the central city name in Google Earth. Although this method of identifying CBDs places considerable trust in Google's potentially ad hoc definitions of central places, we found them to be quite reasonable in all cases—for example, this procedure identifies the CBD as Broadway and Chambers for New York; First and Main for Los Angeles; Jackson and Federal for Chicago; and Market and Van Ness for San Francisco. Even if these locations were off by up to a mile or so, further refinements would not improve much, as we define "downtown" as the area within five miles of the CBD.

Table 12. Summary Statistics, Baseline Model

Variable	Obs	Mean	Std. Dev.	Min	Max
GHG	70,800.00	25,660.00	16,224.00	20.98	90,885.00
HHSIZE	73,869.00	2.67	1.32	1.00	13.00
HHR_AGE	73,869.00	49.48	10.91	18.00	65.00
MIDWEST	73,869.00	0.10	0.30	0.00	1.00
SOUTH	73,869.00	0.52	0.50	0.00	1.00
WEST	73,869.00	0.24	0.43	0.00	1.00
LNDISTANCE	73,869.00	2.72	0.88	-3.57	4.03
LNDENSITY	73,015.00	7.28	1.66	-4.85	12.23
LNMSADENSITY	73,869.00	6.35	1.12	2.65	8.70
MIDDENSITY	73,015.00	0.69	2.14	-1.80	11.02
SOUTHDENSITY	73,015.00	3.64	3.66	-4.22	10.96
WESTDENSITY	73,015.00	1.98	3.54	-4.49	11.57
HHFAMINC1	69,502.00	0.02	0.12	0.00	1.00
HHFAMINC2	69,502.00	0.03	0.16	0.00	1.00
HHFAMINC3	69,502.00	0.03	0.18	0.00	1.00
HHFAMINC4	69,502.00	0.04	0.19	0.00	1.00
HHFAMINC5	69,502.00	0.03	0.17	0.00	1.00
HHFAMINC6	69,502.00	0.05	0.21	0.00	1.00
HHFAMINC7	69,502.00	0.03	0.18	0.00	1.00
HHFAMINC8	69,502.00	0.05	0.22	0.00	1.00
HHFAMINC9	69,502.00	0.03	0.17	0.00	1.00
HHFAMINC10	69,502.00	0.06	0.23	0.00	1.00
HHFAMINC11	69,502.00	0.03	0.17	0.00	1.00
HHFAMINC12	69,502.00	0.06	0.23	0.00	1.00
HHFAMINC13	69,502.00	0.03	0.16	0.00	1.00
HHFAMINC14	69,502.00	0.05	0.22	0.00	1.00
HHFAMINC15	69,502.00	0.03	0.16	0.00	1.00
HHFAMINC16	69,502.00	0.05	0.23	0.00	1.00
HHFAMINC17	69,502.00	0.12	0.32	0.00	1.00
HHFAMINC18	69,502.00	0.27	0.45	0.00	1.00

The results from estimating equation (1) are reported in the first column of Table 13. This table does not report the income fixed effects; they were monotonically increasing with income. The standard errors are clustered by MSA.

Table 13. Household GHG Emissions from Driving

Variables	GHG
HHSIZE	3,899.00***
	(82.58)
HHR_AGE	54.78***
	(7.52)
MIDWEST	3,688.00***
	(1,382.00)
SOUTH	4,181.00***
	(1,396.00)
WEST	-1,521.00
	(1,591.00)
LNDISTANCE	1,228.00***
	(144.20)
LNDENSITY	-1,484.00***
	(186.00)
LNMSADENSITY	-1,041.00***
	(177.60)
MIDDENSITY	-132.30
	(209.00)
SOUTHDENSITY	-8.52
	(209.10)
WESTDENSITY	588.90**
	(228.90)
Constant	13,341.00***
	(1,489.00)
Observations	65,955
R-squared	0.24
Income Fixed-effects?	Yes

*Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

As seen in Table 13, the overall R-squared is 24%. Family size and income strongly increase GHG emissions and as such they are important control variables. The land-use variables all have the predicted signs. Population density, whether at the tract or MSA level, reduces GHG production. More distance to the MSA's center[16] is associated with higher average gasoline consumption. We also interact tract density with region dummies and find that the density-gas consumption relationship is weaker in the West.

These estimates indicate that a 1% increase in LNDISTANCE is associated with a 12.28 pound increase in annual household CO2 emissions (.01 times 1,228), and a 1% reduction in LNDENSITY is associated with a 14.84 pound increase in annual household CO2 emissions (.01 times 1,484). A 1% decrease in population density in every census tract is associated with a 25.25-pound increase in annual household CO2 emissions (.01 times 1,484 plus 1,041, the coefficient on LNMSADENSITY). Finally, a 1% decrease in "compactness"—by which we mean a one percent increase in LNDISTANCE and a one percent decrease in density in each census tract—is associated with a 37.53-pound increase in CO2 emissions per household per year. These estimates can be immediately useful for policymakers who are trying to estimate the cost and benefits of various GHG reduction policies. Estimates from the cost-benefit analysis literature suggest that each ton of CO2 emitted generates $35 in social damages.[17]

We will now use these estimates to illustrate the environmental impact of changing a household's location within an MSA. As shown in Table 12, the average household in our sample had 2.67 members, the average respondent was 49 years old, and the median value of household family income was $67,500. We will use these values to create a standardized household. We also use data from a specific MSA to make the calculation concrete. In 2010, the average person in the Atlanta, Georgia MSA lived 30 kilometers from downtown, and at population density of 630 people per square mile. To predict what GHG emissions would be if we placed our standardized household in an Atlanta Census tract with 630 people per square mile, we use the relevant estimated coefficients from above (and the unreported coefficient on HHFAMINC14 of 2,674) and find that predicted GHG emission equal 41,225 plus 1,228 times LNDISTANCE, minus 1,475 times LNDENSITY, minus 1,041 times LNMSADENSITY. The natural log of Atlanta's MSA population density of 630 is 6.45, and the natural log of the distance the average person in Atlanta lives from downtown, 30, is 3.4. We predict this household produces 41,225 + 1,228 x 3.4–1,475 x 6.45–1,041 x .45 = 35,418 pounds of CO2, resulting from burning 1,688 gallons of gasoline.

Now assume we move this individual to a new home, in a Census tract that is one mile from downtown Atlanta that has a population density of 6,000 people per square mile in 2010 (such a location did exist in Atlanta in that year). Now, given the natural log of 1 is zero, and the natural log of 6,000 is 8.7, our prediction is that this household will produce 41,225 + 1,228 x 0 – 1,475 x 8.7 – 1,041 x .45 = 27,924 pounds of CO2 per year, resulting from consuming 1330 gallons of gasoline. By moving this household to a new neighborhood, which is near downtown and has a moderately high population density (in 2010, 25% of Census tracts in U.S. metropolitan areas had population densities higher than 6,000 people per square mile), the model predicts that the household will consume 358 less gallons of gasoline, and will therefore produce 7,500 fewer pounds, or nearly four tons, of CO2.

Alternatively, we can imagine a policy that affects the entire Atlanta MSA. Imagine a policy that increases the population density of every Census tract in Atlanta by 1%. The model predicts such a change would result in a reduction of 25 pounds of CO2 per household per year. Because there are over two million households in the Atlanta MSA, our model predicts such a policy would result in a 50-million-pound (25-thousand-ton) reduction in CO2, resulting from a reduction in gasoline consumption of 2.38 million gallons.

Using the $35 per ton social cost figure for CO2 emissions mentioned above, the social value of such a policy would be $875,000 (25,000 x $35) per year.[18]

These correlations are suggestive about the role that land-use policy plays in encouraging less driving. If households were randomly assigned to homes, then OLS estimates of equation (1) would be of immediate use to policy makers in determining how urban policies affect an important part of the household carbon footprint. But, we know that households self-select where they want to live. Those who do not like driving are likely to self-select and choose to live in the high-density areas, close to the center city, and close to subway stations. This means that OLS estimates are likely to overstate the true causal effect of how a random household's transit behavior would change if it was randomly assigned to a new urbanist location. Given the possibility of sample selection bias, the estimates reported above should be viewed as an upper bound of the effect of changing land-use patterns on GHG emissions.

In an attempt to get a handle on the true causal impact of urban form on driving behavior, we have completed some preliminary analysis using instrumental variables techniques. Our approach was to look only at the subsample of our data that consisted of two-child households. We then generated an indicator variable if the gender of the children was the same, the idea being that it will be easier for children in these households to share a bedroom, and thus this indicator would serve as an instrument for density. Our other instrument was a count of the number of school-age children in the household, again to proxy for density, the idea being that households with school-age children are less likely to live at higher density because of the belief that urban schools are worse than suburban schools. Although we were not entirely satisfied with our analysis, and in particular were concerned that our instruments may be weak, we nonetheless did not find evidence of a self-selection bias.[19]

VIBRANCY AND GHG PRODUCTION

Having established that urban form is correlated with emissions from driving, we now turn to the hypothesis that metropolitan areas with more vibrant urban cores produce fewer GHG emissions. We are not aware of previous studies that have directly addressed our main question of interest—namely whether more vibrant urban areas have smaller carbon footprints—although some studies in the planning literature have explored the related question of whether mixed use correlates with less driving and other outcomes.[20] Reduced vehicle emissions in vibrant areas could come about for at least two reasons. First, if people live closer to downtown in areas with vibrant urban cores, then sprawl would be less in these cities, and as our estimates presented in Table 13 above show, this means GHG emissions per household would be smaller. We directly address this possibility in Section 3, where we explore whether urban sprawl is faster in places with less vibrant downtowns.

Second, there could be a pure effect of vibrancy in reducing GHG emissions; for example, regardless of land-use patterns, in safer areas with bustling commercial activity, people will be encouraged to get out of their cars, walk more, and perhaps use public transit. Because the models we estimate below will control for land-use characteristics, the hypothesis tests we carry out in the remainder of this section may be interpreted as a test of this second possible effect of vibrancy, though we recognize these tests may be picking up some of the indirect effect of vibrancy.

How should one measure downtown vibrancy? Clearly, vibrancy is a multidimensional concept. Edward Glaeser and his coauthors[21] argue that there are four critical urban amenities: 1) a rich variety of services and consumer goods, such as restaurants and theaters; 2) aesthetics and physical settings, such as architectural beauty; 3) good public services, especially schools and safety, and 4) speed, enabled by transportation infrastructure. As a general statement, we consider a downtown area vibrant if it is an area where people want to be. If a downtown has a large number of jobs, people will want to be there. However, there are many Central Business Districts (CBDs) in U.S. cities that are largely empty after 5 p.m. Therefore, in addition to jobs and other production-based vibrancy measures, we will also consider consumption-based vibrancy measures.

Measuring quality of life is a topic of intense interest in the urban economics literature.[22] Economists infer that an area has high quality of life if it offers relatively low wages and yet local real estate prices are high. This theory of compensating differentials infers that non-market quality of life must be high in such areas otherwise people would migrate away from them.

With respect to the urban planning literature, perhaps the best-known work on quality of life is by Richard Florida who posits that an educated population is a major driver of urban renewal.[23] Other work in this literature deals with strategies for downtown revitalization. For example, Robertson[24] "…describes and evaluates contemporary policy on downtown redevelopment in the United States, in…seven widely-used strategies of planning and design: pedestrianization, indoor shopping centers, historic preservation, waterfront development, office development, special activity generators [e.g. sports stadiums, convention centers], and transportation enhancement." Downtown revitalization has been the subject of scores of articles and dozens of books.[25]

One take away from this planning literature is that planners are mainly focused on how to revitalize a downtown area, and not as much on why having a revitalized downtown might be good. Economists, on the other hand, have focused on why vibrancy and quality of life matter—mainly because it attracts people and jobs—but the various metropolitan-area measures they have constructed are not appropriate for measuring vibrancy at the downtown level.

Because we were not able to find studies that used vibrancy measures that would be useful for our purposes, we have collected our own, which we now describe. We employ eleven vibrancy measures in an attempt to capture different aspects of downtown vibrancy. These are listed in Table 14 and described in detail below. We include some vibrancy measures that relate to jobs to capture production-oriented vibrancy, some related to consumer services (for example, restaurants) to capture consumption-oriented vibrancy, and some related to crime to capture public service and environmental amenities. However, many of these variables are correlated with one another, likely because they measure different aspects of the same underlying variable. For example, the correlation between the restaurant measure and the bar, hotel, and live-music measures range from 0.72 to 0.90. Therefore, our approach was to estimate separate models for each vibrancy measure rather than including them all in a single specification.

Before presenting our regression results, here we describe our vibrancy measures in detail. Our first vibrancy measure is the fraction of the downtown population with college degrees. We calculated this measure using tract-level data from the 2000 Census. Here, as with the other "downtown" variables, we define downtown as the area within five miles of the CBD. This is a revealed preference measure of the desirability of the center city because the college-educated could afford to live anywhere in the metro area. In addition, high human capital areas are pleasant to live in because they are more likely to be free of social problems and offer better schools.

Our next two vibrancy measures capture different aspects of downtown employment. We look at overall jobs downtown, both as a fraction of all MSA jobs, and also in terms of growth in jobs downtown. This data comes from the 2005 Zip Code Business Patterns (ZBP).[26] We describe in more detail the data sources for all of these measures in a Data Appendix.

The fourth vibrancy measure is the average central city murder rate between 2000 and 2005. Unfortunately, we were unable to obtain data at a more geographically refined level such as the downtown. A smaller value of these measures corresponds to a more vibrant downtown. We use the murder rate because there is likely to be less measurement error for murders compared to other crimes (because other crimes are less likely to be reported to the police), as well as the fact that murders are high-profile events that are widely publicized in the media, and hence more likely to influence public perceptions of safety. The fifth vibrancy measure is growth in the murder rate. We calculated the average murder rate in the 1990s (we had four years of data, 1992, and 1997-1999), and calculated the percentage of change between the average murder rate in the 1990s and the 2000-2005 period.

Our sixth vibrancy measure is growth in the downtown population from 2000 to 2010. We used Census tract data to calculate the population living within five miles of the CBD. This is a catchall measure that tries to capture the extent to which people want to be downtown regularly, overnight.

The last five vibrancy measures all deal with various establishments that provide consumer-oriented and cultural services. The first of these is a measure of the number of restaurants downtown per capita. Data on the number of restaurants comes from the ZBP data for 2005. After calculating the number of restaurants within five miles of the CBD, we divide by the total number of workers downtown (divided by one-hundred thousand) to get a per capita measure.[27] We also collected data on the number of hotels downtown, which might be a proxy for the number of leisure visits,[28] as well as the number of live music performers, museums and bars, again, all within five miles of the CBD, and all on a per capita basis. Table 14 below provides brief descriptions of the eleven vibrancy measures, while Table 15 shows the summary statistics for our vibrancy measures over each of the 366 MSAs in our study.[29]

Table 14. Vibrancy Measure Descriptions

Variable	Description
COLLEGE	percent of downtown residents with college degree
JOBS_DWNTWN_05	percent of MSA jobs downtown
JOB_GRWTH_DWNTWN	growth in jobs downtown, 2000-2005
MURDER	average murder rate, 2000-2005
MURDER_GRWTH	growth in average murder rate, 1990s-2005
DWNTWN_POP_GRWTH	growth in downtown population, 2000-2010
LIVE_MUSIC	live-music performers per 100,000, downtown
MUSEUM	number of museums per 100,000, downtown
HOTEL	number of hotels per 100,000, downtown
BAR	number of bars per 100,000, downtown
RESTAURANT	number of restaurants per 100,000, downtown

Table 15. Vibrancy Measures, Summary Statistics

Variable	Obs	Median	Mean	Std. Dev	Min	Max
COLLEGE	366	0.218	0.241	0.101	0.081	0.661
JOBS_DWNTWN_05	366	0.6	0.580	0.222	0.039	0.998
JOB_GRWTH_DWNTWN	366	0.064	0.090	0.152	-0.559	1.102
MURDER	362	5.88	8.250	7.991	0	61.101
MURDER_GRWTH	359	-0.093	0.064	0.654	-1	3.745
DWNTWN_POP_GRWTH	366	0.008	0.026	0.222	-0.272	3.361
LIVE_MUSIC	366	1.58	3.781	7.390	0	90.854
MUSEUM	366	2.9	6.225	12.583	0	167.879
HOTEL	366	25.25	56.248	99.169	0	1,159.901
BAR	366	24.78	66.929	142.180	0	1,846.670
RESTAURANT	366	112.69	211.895	360.531	0	4,101.077

In Table 16, we re-estimate our baseline model in separate specifications with the eleven vibrancy measures mentioned above. In each column, the specification is exactly the same as we reported in Table 12 above, except that we replace MSA density with one of the vibrancy measures.

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Table 16. Household GHG Production, Land-Use Patterns, and Downtown Vibrancy

Variables	GHG	GHG	GHG	GHG	GHG	GHG	GHG	GHG	GHG	GHG	GHG
COLLEGE	-8,090***										
	(1554)										
JOBS_ DWNTWN		-2,094**									
		(874)									
JOB_GRWTH_ DWNTWN			2,724**								
			(1246)								
MURDER				-19.67							
				(31.20)							
MURDER_ GRWTH					640.0**						
					(304.60)						
DWNTWN_ POP_GRWTH						-1,007					
						(633.60)					
LIVE_MUSIC							-26.32***				
							(7.81)				
MUSEUM								5.092			
								(8.85)			
HOTEL									1.343		
									(3.41)		
BAR										0.631	
										(0.49)	
RESTAURANT											-0.0335
											(0.56)

Table 16. Household GHG Production, Land-Use Patterns, and Downtown Vibrancy (continued)

Variables	GHG	GHG	GHG	GHG	GHG	GHG	GHG	GHG	GHG	GHG	GHG
HHSIZE	3,876***	3,901***	3,896***	3,901***	3,904***	3,905***	3,902***	3,903***	3,902***	3,903***	3,903***
	(82.82)	(83.80)	(83.29)	(83.43)	(83.66)	(83.59)	(83.83)	(83.77)	(83.77)	(83.78)	(83.82)
HHR_AGE	52.65***	54.61***	54.75***	54.56***	54.46***	54.89***	54.44***	54.68***	54.67***	54.68***	54.64***
	(7.39)	(7.59)	(7.58)	(7.58)	(7.52)	(7.58)	(7.58)	(7.58)	(7.58)	(7.58)	(7.58)
MIDWEST	2,772**	2,744	2,657	2,669	2,926*	2,914*	2,530	2,997*	2,893*	2,959*	2,810
	(1408.00)	(1792.00)	(1711.00)	(1758.00)	(1578.00)	(1686.00)	(1696.00)	(1722.00)	(1713.00)	(1720.00)	(1721.00)
SOUTH	3,320**	3,441*	3,147*	3,238*	3,631**	3,460**	2,895*	3,484**	3,430**	3,499**	3,277*
	(1381.00)	(1767.00)	(1719.00)	(1755.00)	(1557.00)	(1662.00)	(1684.00)	(1703.00)	(1690.00)	(1702.00)	(1702.00)
WEST	-2,661*	-1,950	-2,910*	-2,355	-1,994	-2,189	-2,743	-2,096	-2,122	-2,093	-2,312
	(1446.00)	(1853.00)	(1735.00)	(1804.00)	(1635.00)	(1749.00)	(1753.00)	(1776.00)	(1766.00)	(1771.00)	(1783.00)
LNDISTANCE	591.6***	763.1***	623.7***	607.5***	619.0***	550.1***	529.8***	593.2***	602.0***	594.9***	568.5***
	(109.70)	(148.60)	(127.30)	(140.90)	(120.90)	(121.60)	(119.50)	(119.90)	(127.20)	(121.10)	(122.60)
LNDENSITY	-1,972***	-1,943***	-2,023***	-2,026***	-1,983***	-2,027***	-2,083***	-2,011***	-2,008***	-2,011***	-2,036***
	(202.00)	(278.20)	(267.60)	(278.90)	(234.00)	(258.90)	(261.30)	(264.30)	(267.30)	(262.60)	(268.10)
MIDDENSITY	14.31	80.59	85.84	98.05	61.16	60.3	105	61.17	68.93	63.84	77.37
	(229.50)	(291.40)	(286.60)	(290.70)	(261.80)	(278.80)	(282.00)	(284.20)	(284.60)	(282.90)	(286.00)

*Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Of these eleven vibrancy measures, four are significant at the five percent level or better, and of the expected sign. Metropolitan areas with a more educated downtown population, a higher fraction of jobs downtown, and more live music performers per capita downtown are associated with fewer GHG emissions. Metropolitan areas in which the center city has experienced an increase in the murder rate (a decrease in vibrancy) are associated with higher GHG emissions.

The estimated coefficient on job growth downtown, however, was contrary to our expectations. This variable is positive and significant, indicating that areas with higher job growth are associated with higher GHG emissions. One possible reason for this, as we documented in Section 1, are MSAs where a larger fraction of the population commutes by driving alone were more likely to grow. Therefore, it could be that this particular vibrancy measure is correlated with overall growth, and we know from Section 1 that these areas are likely to be car cities—cities where many drive to work alone.

With the exception of job growth downtown, on the whole, we feel that our results lend support to our hypothesis that vibrant cities are also green cities. A one standard deviation increase in vibrancy leads to a decrease in GHG emissions on the order of 817 pounds for COLLEGE, 1,579 pounds for JOBS_DWNTWN, 418 pounds for MURDER_GRWTH, and 195 pounds for LIVE_MUSIC. Compared to the 1,166 pounds decrease, which was associated with a one standard deviation increase in MSA density in Table 13, holding tract-level density constant we see that vibrancy as defined here can be at least as important as land-use in reducing driving and GHG emissions.

The next sub-subsection [looks like just a subsection to me. ~FC] looks further at the effect of vibrancy, and tests for an interaction between urban form, vibrancy, and GHG production.

THE INTERACTION OF URBAN FORM AND VIBRANCY ON GHG PRODUCTION

In this final subsection, we look at whether urban form has a stronger effect on GHG emissions in more vibrant areas. It is possible that the effect of urban form is more pronounced in vibrant areas. Consider a household living close to the city center in an area where the downtown lacks vibrancy. This person will have to travel for work, chores, and entertainment, much like someone who lives far from the city center. This is to say that distance from the CBD will not have as great an effect on a household's GHG emissions. Formally, the estimated coefficient on LNDISTANCE may be positive, but it will not be large.

Now contrast the household described above with a household living at the same distance from the city center, but in an area with a vibrant downtown. This person will be able to find employment, entertainment, and safety near their home, so they will not need to drive as much. A household living far from the city center, however, will still likely travel far distances, whether they drive to the city center or seek opportunities elsewhere. In this case, distance from the CBD will have a great effect on a household's GHG emissions, and the estimated coefficient on distance will be large.[30]

To explore the interaction between distance and vibrancy, we stratify the sample into eleven vibrant and non-vibrant subsamples for each of our individual vibrancy measures. An MSA is classified as vibrant if it has a level of vibrancy (for the particular measure under consideration) that is above the sample median; an MSA is classified as non-vibrant if it has a level of vibrancy below the sample median.[31] (We report the above median values in Table 15). Our prediction here is simply that the estimated coefficient on the distance variable will be larger when estimated with the vibrant subsample. To give an idea of which MSAs are vibrant according to our measures, Dallas, Detroit, Phoenix, and Riverside were four MSAs that were in the bottom quartile for four or more of the five establishment-based vibrancy measures (they were classified as non-vibrant based on the industry-based measures), and Honolulu, Madison, San Francisco, and Syracuse were four MSAs that were in the top quartile for four or more of the five establishment-based vibrancy measures (they are vibrant).

In Table 17 below, we report the coefficient estimate on LNDISTANCE for both subsamples, as well as an indicator for statistically different coefficient estimates.[32] The results reported in Table 17 reveal that the effect of distance is indeed greater in more vibrant metropolitan areas. In four of the eleven stratifications, the effect of distance was statistically different across the two subsamples, and in each of these four cases, the effect of distance was larger in the vibrant subsample. We take this as strong evidence that vibrancy matters, and that the effect of land-use and vibrancy interact in predictable ways.

Table 17. Estimated Coefficient on LNDISTANCE, Stratifying by Vibrancy Measures

Stratified by	Vibrant subsample	Nonvibrant subsample	* if coefficient estimates differ statistically
COLLEGE	1,492	713	*
JOBS_DWNTWN	1,396	999	
JOB_GRWTH_DWNTWN	1,093	1,339	
MURDER	1,020	1,372	
MURDER_GRWTH	1,532	796	*
DWNTWN_POP_GRWTH	1,496	745	*
LIVE_MUSIC	1,596	1,028	*
MUSEUM	1,218	1,291	
HOTEL	1,014	1,380	
BAR	1,052	1,284	
RESTAURANT	1,152	1,379	

The estimated coefficient on LNDISTANCE was about twice as large in the vibrant sub–sample when stratifying by COLLEGE, MURDER_GRWTH, DWNTWN_POP_GRWTH, while the estimated coefficient on LNDISTANCE was about 50% larger when stratifying by LIVE_MUSIC. In each of these cases, the coefficient estimates were statistically different.

III. MACRO-LEVEL STUDY OF GHG PRODUCTION

Unlike the previous section, where the unit of analysis in our data was the individual household, in this section we zoom out and explore the effect of urban form and vibrancy on average gasoline consumption using MSA level data. The fact that our dependent variable comes from a completely different source serves as a robustness check on our results. Also, while micro data is generally preferable, the data we analyze in this chapter has at least one advantage over the NHTS, in that it is more nationally representative.[33]

This section differs from the previous section in at least one other major way, as here we focus explicitly on explaining changes in land-use patterns. Specifically, we explore whether metropolitan areas that had vibrant downtowns in 2000 experienced less sprawl over the 2000-2010 period. If so, then this points to an important indirect effect of vibrancy on GHG production; namely, vibrancy leads to more compact urban forms, which in turn leads to less GHG production.

Reliable measures of gasoline consumption from which we could construct GHG emissions estimates at the metropolitan area are notoriously difficult to obtain. However, we were able to obtain data on vehicle miles traveled (VMT) for 408 urbanized areas (UAs).[34] To obtain metropolitan statistical area (MSA) estimates, we first matched each urbanized area to a principle city. We then matched each principle city to a county,[35] and finally, we matched each county to an MSA (as MSAs are comprised of counties.) Some MSAs were matched with more than one UA, and so we aggregated data from the multiple UAs together to form MSA level estimates.

The VMT data comes from the Federal Highway Administration's 2008 Highway Statistics publication.[36] They provide data on daily vehicle miles traveled, as well as population and land area for each UA. Therefore, although our method of translating urbanized areas into metropolitan statistical areas means the boundaries will not perfectly coincide, the fact that the VMT, population, and land area data all come from the same source, and that we will be interested in the per capita (or more precisely, per household) measures, means any inconsistencies should not lead to large measurement error bias. We created estimates of annual household miles traveled by multiplying the available data on daily vehicle miles traveled by 365 to get an annual measure, and then again times 2.67 (the size of the average household in 2005), to arrive at a household level measure comparable to the measure used in the previous section.

We considered further adjusting this annual household VMT data for differences in vehicle gas mileage efficiency across metropolitan areas. However, and to our surprise, analysis of the 2009 NHTS data showed that there is extremely little variation in gas mileage across MSAs. Most parts of the county have vehicle efficiency of about twenty miles per gallon. In rural areas (those not in metropolitan statistical areas) gas mileage is on average 19.59, and in metropolitan areas it is only slightly better, at 20.37. One might think that the urban-suburban difference might be larger, and that we could therefore estimate average gas mileage based on the urban form of metropolitan areas. However, looking at households within metropolitan areas (and using the same data rules from Section 2), those who live within five miles of the city center have cars with efficiency of 20.99 miles per gallon (MPG) on average, while households who live less than five miles from the CBD have nearly the same average mileage, at 20.94. We also estimated multiple regression models of MPG, and while it is possible to find statistically significant relationships, the magnitude of our independent variables was very small. Moreover, in our multiple regression modeling attempts, the R2 was never larger than 0.05.[37]

As discussed in the previous section, using standard conversion factors, consuming a gallon of gasoline produces 19.56 pounds of CO2 directly. The conversion factor we used was 7% larger to account for the indirect emissions associated with producing gasoline. Consider that the average fuel efficiency in our sample of households in metropolitan areas is 20.98 MPG. The models presented below are models of vehicle miles traveled. We decided not to adjust VMT for fuel efficiency, nor do we convert the mileage estimates into pounds of carbon dioxide. If we had used a conversion factor of 20.98, the same conversion factor we used in Section 2, it would amount to using the conventional rule-of-thumb that one mile traveled generates one pound of CO2. Considering the numbers in the most recent data available, it turns out that this rule of thumb provides nearly as much accuracy as can be bought. Our choice of conversion factors was somewhat influenced by the desire to make our results in this and the previous section comparable, but we did not have to adjust them much to get this comparability.[38]

At first glance, the data appear to correspond well to our expectations. Looking at the 86 metro areas that had a population of 500,000 or more in the year 2000 for which Highway Statistics reports data, Houston, Texas was nearly highest in terms of average household VMT (80 out of 86) at 31,932 miles (or equivalently, pounds of CO2). Near the top of the list was the New York metro area (which was third lowest out of 86), whose households on average drove 15,586 miles annually. San Francisco and San Jose were ninth and 14th respectively, at 19,230 and 19,703 miles. Houston residents drive, on average, exactly twice as much as residents in the New York MSA. The difference of 16,000 miles created an additional eight tons of CO2. Economists have estimated the social cost of a ton of CO2 is about $35. Therefore, each Houston household generates on average $280 more in environmental damage from increased CO2 from driving per year than the average New York household.

The remainder of this section analyzes this data more carefully, and is divided into two subsections. The first subsection estimates the macro-equivalent land-use-GHG models from section two. We show that the average person in more compact MSAs drives less and therefore produces fewer GHG emissions. The second subsection explores the role of vibrancy, and we again document some significant correlations between the vibrancy measures and lower GHG emissions. The concluding subsection contains some interesting and, we think, important results. There, we document that cities with vibrant downtowns experienced less sprawl over the 2000-2010 period. This leads us to conclude that one of the main ways in which promoting vibrancy can lower GHG emissions is through its effect on land-use patterns.

GHG EMISSIONS AS A FUNCTION OF URBAN FORM

In this section, using OLS, we estimate a model of the form

$$VMT_k = \beta_0 + \sum_j \beta_j X_{kj} + \varepsilon_k$$

where VMT_k refers to the vehicle miles traveled for the average household in MSA k, X_{kj} refers to the value of characteristic j in MSA k the β's are parameters to be estimated, and ε_k is the error term. As we stressed above, the variable VMT_k can be thought of as the amount of CO2 produced by the average household from driving, annually, in pounds. Table 18 below contains variable descriptions, and Table 19 shows the summary statistics for our data. Due to the fact that the Highway Statistics data does not report VMT for all urbanized areas, we were only able to calculate estimates for 312 of our 366 MSAs. The average GHG emissions in this data, 23,194 pounds, constructed from Highway Statistics data, are remarkably similar to the 25,660 pounds we calculated using the NHTS data.

Table 18. Variable Descriptions

Variable	Description
VMT	Average household vehicle miles traveled
LNINC	Natural log of per capita income
LNPOP	Natural log of MSA population
AGE	Median age
WEST	Dummy variable equal to one if in West region
SOUTH	Dummy variable equal to one if in West region
MIDWEST	Dummy variable equal to one if in West region
LNDENSITY	Natural log of MSA population density
LNAVGDIST	Natural log of distance the average MSA resident lives from downtown

Table 19. Summary Statistics, MSA-level GHG Model

Variable	Obs	Mean	Std. Dev.	Min	Max
VMT	312.00	23,193.68	5,838.64	3,927.15	46,994.96
LNINC	312.00	10.33	0.19	9.61	11.12
LNPOP	312.00	12.38	1.23	10.49	16.74
AGE	312.00	38.65	1.48	32.71	41.29
WEST	312.00	0.23	0.42	0.00	1.00
SOUTH	312.00	0.38	0.49	0.00	1.00
MIDWEST	312.00	0.25	0.44	0.00	1.00
LNDENSITY	312.00	7.22	0.53	4.62	8.68
LNAVGDIST	312.00	2.69	0.33	1.40	3.53

The regional dummy variables in Table 18 are self-explanatory. The income variable, which is the log of per capita income, is from 2005, and is from the City and County Data Book. This source is also where the age measure comes from. In order to be consistent with our micro-level model from the previous section, we calculated and used the average age of the 16-65 age subset of the population for this measure. The population and density measures, also in logs, are from the Highway Statistics data, as discussed above. Finally, average distance measures the distance the average person lives from the city center. It was calculated using 2010 Census tract relationship files.[39]

Table 20 shows the results of our macro-level GHG model. We specified our model so that the estimates could be viewed as the macro-counterpart to the micro models from the previous section. The dependent variable is the number of miles traveled by the average household (or as above, the number of pounds of CO2 produced by the average household.) We estimate a baseline specification without urban form variables, then include each urban form variable separately, and finally together, to demonstrate the relative explanatory power of each urban form variable.

Table 20. MSA-level Average VMT and Urban Form

Variables	VMT	VMT	VMT	VMT
LNINC	3,535*	4,312**	4,167**	4,842***
	(2,004)	(1,764)	(1,963)	(1,726)
LNPOP	8.866	897.0***	-786.5**	154
	(279.10)	(278.50)	(394.80)	(392.60)
AGE	731.8***	617.2***	506.8**	421.9*
	(211.60)	(216.00)	(215.60)	(215.20)
WEST	-1,180	317.7	-805.7	589.3
	(877.20)	(857.70)	(870.10)	(853.70)
SOUTH	5,845***	5,404***	5,512***	5,126***
	(781.50)	(670.20)	(790.20)	(705.60)
MIDWEST	1,880**	2,521***	2,499***	3,044***
	(853.40)	(763.40)	(873.50)	(807.50)
LNDENSITY		-4,648***		-4,458***
		(1,046)		(1,017.00)
LNAVGDIST			5,054***	4,490***
			(1,450)	(1,373)
Constant	-44,192**	-25,539	-45,866**	-27,789
	(19,657)	(18,493)	(19,308)	(18,272)
Observations	312	312	312	312
R-squared	0.276	0.392	0.322	0.428

*Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

The results presented in column five of Table 20 show that a one percent increase in MSA-level density is associated with a 45-pound annual reduction in per-household CO2 emissions (-4,458 x .01). In addition, a one-percent decrease in average distance is also associated with a 45-pound reduction in per-household CO2 emissions (4,490 x -.01). If we consider the effect of an urban form that is one percent “more compact,” as we did in Section 2 (and by which we mean a one percent increase in density, and a one percent decrease in average distance), we find that the model predicts average annual household CO2 emissions are lower by 90 pounds. In contrast, in Section 2 we found that a similar, one percent change in “compactness” would cause CO2 emissions to fall by 37.53 pounds per household per year. These estimates suggest that the effect of urban form on GHG emissions is about two-and-a-half times larger than what we found in Section 2.

Another finding from Table 20 is that each urban form variable contributes explanatory power to the model, and each seems to be capturing different aspects of urban form. The LNDENSITY variable causes the R-squared to rise by eleven percent and the LNAVGDIST variable causes the R-squared to rise by about five percent. Together, these variables cause the R-squared to rise by 15 percent, compared to the baseline model in column two.

VIBRANCY AND GHG PRODUCTION

We now move to the question of how well our vibrancy measures predict GHG emissions at the level of the metropolitan area. Table 21 contains the summary statistics for those 312 MSAs for which we have data. All variables are the same as described in Table 14, but we report summary statistics again due to the change in sample size.

Table 21. Summary Statistics, MSA-level Vibrancy

Variable	Obs	Mean	Std. Dev.	Min	Max
COLLEGE	312	0.24	0.10	0.10	0.66
JOBS_DWNTWN	312	0.59	0.22	0.07	1.00
JOB_GRWTH_ DWNTWN	312	0.09	0.15	-0.56	1.10
MURDER	309	8.83	8.33	0	61.10
MURDER_GRWTH	308	0.08	0.65	-1.00	3.75
DWNTWN_POP_ GRWTH	312	0.01	0.14	-0.27	0.93
LIVE_MUSIC	312	3.93	7.74	0	90.85
MUSEUM	312	5.92	12.89	0	167.88
HOTEL	312	52.56	83.92	0	914.87
BAR	312	62.34	133.53	0	1,846.67
RESTAURANT	312	197.18	311.70	0	2,967.90

Table 22 below shows our estimates of our macro-level vibrancy model where the dependent variable is VMT from the Highway Statistics data.

Table 22. Highway Statistics Data and Vibrancy

Variables	VMT	VMT	VMT	VMT	VMT	VMT	VMT	VMT	VMT	VMT	VMT
COLLEGE	6,493*										
	(3,778.0)										
JOBS_ DWNTWN		3,176									
		(1,944.0)									
JOB_GRWTH_ DWNTWN			604.1								
			(2,586.0)								
MURDER				84.02*							
				(49.4)							
MURDER_ GRWTH					156						
					(613.2)						
DWNTWN_ POP_GRWTH						2,929					
						(2,199.0)					
LIVE_MUSIC							-69.85*				
							(38.6)				
MUSEUM								-36.06*			
								(21.2)			
HOTEL									-9.017***		
									(3.2)		
BAR										-5.327	
										(3.2)	
RESTAURANT											-2.267**
											(0.9)

Table 22. Highway Statistics Data and Vibrancy (continued)

Variables	VMT	VMT	VMT	VMT	VMT	VMT	VMT	VMT	VMT	VMT	VMT
LNINC	1,452	3,352*	3,518*	4,230**	3,686*	3,316*	3,952*	3,487*	3,614*	3,300	3,563*
	(2,437)	(2,027)	(2,004)	(2,049)	(2,018)	(1,997)	(2,021)	(2,010)	(2,007)	(2,001)	(2,009)
LNPOP	102.9	-215.8	15.36	-243.7	0.859	38.13	-81.95	-78.41	-219.6	-114.1	-179.5
	(292.9)	(349.1)	(284.5)	(291.7)	(268.6)	(281.4)	(291.9)	(290.4)	(308.2)	(293.3)	(303.6)
AGE	1,018***	741.4***	739.0***	642.3***	732.2***	773.3***	628.3***	720.3***	721.3***	732.4***	673.7***
	(290.7)	(206.0)	(213.8)	(218.6)	(214.7)	(210.0)	(231.8)	(212.5)	(207.2)	(207.0)	(214.5)
WEST	-1,074	-1,477*	-1,249	-741.7	-1,056	-1,333	-1,411	-1,452	-1,287	-1,552*	-1,575*
	(880.6)	(871.8)	(962.0)	(918.0)	(894.7)	(884.5)	(890.9)	(899.7)	(874.2)	(877.3)	(885.9)
SOUTH	5,840***	5,618***	5,806***	5,843***	6,036***	5,752***	5,668***	5,593***	5,838***	5,406***	5,516***
	(784.8)	(789.6)	(810.2)	(771.2)	(797.0)	(793.2)	(795.4)	(808.8)	(780.5)	(803.4)	(797.4)
MIDWEST	2,027**	1,926**	1,889**	1,955**	1,940**	1,988**	1,800**	1,722**	1,938**	1,858**	1,674**
	(867.2)	(836.4)	(853.7)	(843.1)	(882.8)	(841.8)	(848.4)	(857.6)	(849.4)	(860.2)	(847.1)
Constant	-36,517*	-41,610**	-44,396**	-45,613**	-45,748**	-43,894**	-42,959**	-41,754**	-41,282**	-39,665**	-39,188**
	(20,049)	(20,030)	(19,728)	(20,294)	(19,840)	(19,547)	(19,746)	(19,910)	(19,671)	(19,786)	(19,893)
Observations	312	312	312	309	308	312	312	312	312	312	312
R-squared	0.283	0.286	0.276	0.287	0.279	0.28	0.283	0.281	0.29	0.289	0.288

*Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

The main finding from this table is that two of the vibrancy measures—per capita hotels downtown, and per captita restaurants downtown—are statistically significant at the five-percent level. A one standard deviation increase in HOTEL is associated with a 747-pound reduction in GHG emissions, and a one standard deviation increase in RESTAURANT is associated with a 707-pound reduction in emissions. Compared to the micro estimates from Section 2, where we found a one standard deviation increase in LIVE_MUSIC was associated with a 195-pound reduction in emissions, the results here suggest a larger impact of industry-based vibrancy measures.

The average household drives less in metropolitan areas with more restaurants and hotels downtown, presumably because these areas are more vibrant. Recall that our motivation for using hotels as a measure of vibrancy is that people want to visit vibrant places, hence the need for hotels—these results shouldn't be interpreted as saying that putting more hotels in a place that lacks vibrancy will lower driving. Instead, if policy makers can somehow foster a vibrant downtown where people want to be, one result will be less GHG emissions from driving.

THE EFFECT OF VIBRANCY: A CLOSER LOOK

In the introduction, we mentioned the following statistic: The average person who lived in a metropolitan area lived 9.8 miles from the City Center in 1970 and this distance grew to 13.2 miles by the year 2000. Over this period of time, the definitions of MSAs changed; therefore, these figures would be slightly different when calculated based on more recent MSA definitions. Using the 2006 definitions of MSAs, we find that the average person who lived in one of the 88 MSAs that had a population greater than 500,000 in the year 2000 lived 11.9 miles from the city center in 2000, and this distance grew to 12.4 miles in the year 2010. This was a four percent increase over the decade.[40]

Although this average distance continues to grow, it actually fell in a few metropolitan areas over the most recent time period, and it remained nearly constant in many others areas. What determines changes in sprawl, and what can cities due to reverse the trend towards greater sprawl? We now approach these questions by exploring the determinants of percentage changes in this average distance variable, and in particular, we ask whether downtown vibrancy is associated with less sprawl.

We estimate, using ordinary least-squares (OLS), a model of the form:

$$\frac{avgdist10_k - avgdist00_k}{avgdist00_k} = \beta_0 + \sum_j \beta_j X_{kj} + \varepsilon_k$$

Where $avgdist10_k$ is the distance the average person in MSA k lived from downtown in 2010, $avgdist00_k$ is this distance the in 2000, X_{kj} is a variable that measures the value of characteristic j for MSA k and the β's are parameters to be estimated. For independent variables, we are mainly interested in the effect of vibrancy on rates of sprawl, but it seems likely that if the population of a metropolitan area as a whole grows, a disproportionate amount of these new residents will choose to live farther from the city center, and this would serve to increase our dependent variable. Because MSA population growth is likely to increase average distance, we include it as a control variable. In addition to MSA population growth over the 2000 to 2010 period, we also include four vibrancy measures:[41] percent of downtown population with a college degree in 2000, the percent of MSA jobs downtown in 2000, the average murder rate in the 1990s,[42] and the number of restaurants per capita downtown in 2000. Table 23 below contains summary statistics for these variables for all 366 MSAs that were defined in 2006.

Table 23. Summary Statistics, Sprawl and Vibrancy

Variable	Obs	Mean	Std. Dev	Min	Max
CHNG_AVGDIST	366.00	0.05	0.06	-0.28	0.37
MSA_GRWTH	366.00	0.11	0.11	-0.11	0.92
COLLEGE	366.00	0.24	0.10	0.08	0.66
JOBS_DWNTWN_00	366.00	0.56	0.22	0.05	1.00
MURDER_90s	364.00	8.81	8.15	0.00	57.07
RESTAURANT_00	366.00	224.98	115.24	78.60	1,246.88

We will also analyze a subsample of the data containing only the largest MSAs, which had a population of at least 500,000 in the year 2000. Summary statistics for these 88 MSAs are presented in Table 24 below.

Table 24. Summary Statistics, Sprawl and Vibrancy (MSA Pop > 500k)

Variable	Obs	Mean	Std. Dev	Min	Max
CHNG_AVGDIST	88	0.04	0.04	-0.05	0.15
MSA_GRWTH	88	0.12	0.11	-0.11	0.42
COLLEGE	88	0.25	0.09	0.11	0.50
JOBS_DWNTWN_00	88	0.71	0.12	0.28	0.99
MURDER_90s	88	15.35	10.96	1.86	57.07
RESTAURANT_00	88	173.23	36.61	101.63	309.67

Table 25 presents the results of our ordinary least squares regressions using all 366 MSAs. We present six specifications, one containing only the MSA growth control, four containing this control plus one of the vibrancy measures, and finally, a specification containing the MSA growth control and all four vibrancy measures. In column six of Table 25 we see that two vibrancy measures are significant determinants of sprawl over the 2000-2010 period, including percent college downtown and percent jobs downtown. Larger values of these variables are associated with less sprawl over this period. However, the R2 is rather low, at 0.054.

In Table 26, we estimate identical specifications as in Table 25, but using data from only the largest MSAs. The justification for looking at only large MSAs is that they should be more comparable.

In column six of Table 26 below, we see that four vibrancy measures, along with MSA growth over the 2000-2010 time period, explain 33% of the variation in sprawl, as measured by the change over the 2000-2010 period in the distance the average household lives from the city center. Three of the vibrancy measures are statistically significant at the 5% level: the percentage of jobs downtown, the murder rate, and the number of restaurants per capita. These results provide strong evidence for our indirect causal story—that a vibrant city center encourages more people to live closer to downtown, and this in turn lowers a city's carbon footprint.[43]

Evaluated at the sample means, our model predicts that the distance the average household lives from downtown increases 4.3 percent over the 2000-2010 period. However, consider an MSA that grew by an average amount, but which has vibrancy levels (for all four variables included in the tables above) that are one standard deviation above the mean. The estimates from Table 26 predict that such an MSA would have a sprawl rate of only slightly over half (0.57) of one percent. Thus, the model predicts that sprawl is more than seven times faster in non-vibrant places.

What about a direct effect of vibrancy? The results presented in Table 16 and Table 22 above indicate that, holding a household's tract density and distance to the CBD constant, the vibrancy of the downtown has a separate, or pure effect on driving. This is not a definitive test, however, as it could be that vibrancy is causing MSA density, which also predicted GHG emissions in Table 13. Rather, we take this as suggestive evidence of a direct effect of vibrancy on travel behavior and GHG emissions. On the other hand, we consider our evidence of an indirect effect of vibrancy, presented here, to be rather robust.

The question of the direct versus indirect effect of vibrancy on lowering GHG emissions requires further investigation, but we have presented strong evidence in this section that there is an important indirect effect of sprawl; namely, encouraging households to live closer to the city center enables less driving and, hence, lower GHG emissions.

Table 25. Urban Sprawl and Vibrancy

Variables	CHNG_AVGDIST	CHNG_AVGDIST	CHNG_AVGDIST	CHNG_AVGDIST	CHNG_AVGDIST	CHNG_AVGDIST
MSA_GRWTH	0.0431	0.0531	0.0495	0.0697*	0.0433	0.0912**
	(0.03)	(0.04)	(0.04)	(0.04)	(0.03)	(0.04)
COLLEGE		-0.0755**				-0.0663**
		(0.03)				(0.03)
JOBS_DWNTWN_00			-0.0329*			-0.0468**
			(0.02)			(0.02)
MURDER_90s				0.000543*		0.000712*
				(0.00)		(0.00)
RESTAURANT_00					-2.62E-05	-2.74E-05
					(0.00)	(0.00)
Constant	0.0432***	0.0602***	0.0609***	0.0351***	0.0490***	0.0796***
	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Observations	366	366	366	364	366	364
R-squared	0.005	0.02	0.019	0.016	0.008	0.054

*Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Table 26. Urban Sprawl and Vibrancy (MSA Pop > 500k in 2000)

Variables	CHNG_AVGDIST	CHNG_AVGDIST	CHNG_AVGDIST	CHNG_AVGDIST	CHNG_AVGDIST	CHNG_AVGDIST
MSA_GRWTH	0.120**	0.123**	0.119**	0.155***	0.116**	0.141***
	(0.05)	(0.05)	(0.05)	(0.04)	(0.05)	(0.04)
COLLEGE		-0.0298				-0.0472
		(0.04)				(0.04)
JOBS_DWNTWN_00			-0.00989			-0.0702**
			(0.04)			(0.03)
MURDER_90s				0.00133***		0.00114***
				(0.00)		(0.00)
RESTAURANT_00					-0.000370***	-0.000330***
					(0.00)	(0.00)
Constant	0.0288***	0.0359***	0.036	0.00414	0.0935***	0.127***
	(0.01)	(0.01)	(0.03)	(0.01)	(0.02)	(0.03)
Observations	88	88	88	88	88	88
R-squared	0.104	0.108	0.105	0.229	0.219	0.327

*Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

IV. HOUSEHOLD PUBLIC TRANSIT USE

In this subsection, we ask nearly the same questions we posed in Section 2; however, rather than examining the role of urban form and vibrancy on driving and GHG emissions, we explore the effect of these variables on public transit use. This analysis is important in gaining a deeper understanding of the role of urban form on reducing driving. Do people in more compact cities drive less because they travel less? Or, do they travel the same amount as people in more sprawling cities, but they substitute driving for other forms of transportation? If they are using other forms of transportation, are they taking public transit, walking, riding a bike? Although we are by no means able to provide a complete set of answers to all these questions, stating them at the outset makes obvious the need for this and the next section on public transit use.

There are several reasons we might expect urban form to have a strong affect on public transit use, and indeed, perhaps a stronger affect than on driving behavior. Take, for example, distance. In most cities, public transit systems are focused on bringing people downtown, and most of the connections are made downtown. This is in part due to the logistics of public transit systems, and in part due to transit's historical legacy. Therefore, someone who lives close to downtown may find public transit much more convenient than someone who lives far from downtown. As a result, we expect the relationship between distance and public transit use to be stronger than the relationship between distance and driving.

Similar reasoning holds for why we might expect the effect of density on public transit use to be especially strong. In most cities, the best and most frequent public transit lines are usually located in the densest parts of town, in order to attract the highest possible ridership. Again, we expect the relationship between density and public transit use to be very strong.

In the first subsection, we estimate a modified version of our baseline urban form-transportation model. We look at all households in metropolitan areas, but also the subset of households who live in metro areas with rail systems, and we are therefore able to explore the effect of household proximity to rail transit stops. In the second subsection we explore the role of vibrancy.

PUBLIC TRANSIT USE AS A FUNCTION OF URBAN FORM

Our first analysis of public transit involves estimating a slightly modified version of the baseline model from Section 2. There are two modifications here: 1) the dependent variable is an indicator variable equal to one if someone in the household used public transit in the last month, and 2) we include as an independent variable an indicator equal to one if the household's metropolitan area has some form of rail transit.[44] Because the dependent variable is binary, we estimate both linear probability and Probit models to compare the effect of model selection. We will also analyze a subsample of cities with rail transit infrastructure, and estimate the impact of proximity to rail stations on public transit use.

We maintain the use of the household as our unit of analysis, and we construct the dependent variable so that it is equal to one if at least one member of the household used public transit in the last month. Using the same data rules from Section 2, the 2009 NHTS contains data for 73,869 households, and 19.67 percent of these households had at least one member who used public transit in the last month. Of these households, the average number of trips taken by all members was 2.91. Eighty percent of these households did not use public transit in the last month, 90% used transit less than six times, 95% used transit less than 20 times, and 99% used transit less than 60 times in the last month. Almost 19% of our sample (14,031 households) lived in MSAs with rail infrastructure, and public transit use was substantially higher in these areas. In MSAs with rail infrastructure, over 41 percent of households used public transit at least once in the last month, versus 14.58 percent in cities without rail infrastructure.

In Table 27 we present the estimates of the baseline transit model. Households are ten to 12.7 percent more likely to use public transit if they live in cities with rail infrastructure, given the estimates of the Probit and linear probability models, respectively (we report marginal effects for the Probit estimates). For the most part, the estimates do not differ much between the two models. Most of the urban form variables are significant and predictable. A ten percent increase in LNDISTANCE is associated with an increase in a household's probability of transit use by 0.55% (10 x .0555 = 0.55); a ten percent increase in LNDENSITY is associated with a 0.45% increase, and a ten percent increase in the density of every tract in an MSA is associated with a 1% increase (10 x .0455 + .055).

Table 27. Household Public Transit Use

Variables	PTUSED (OLS)	PTUSED (Probit)
RAIL	0.127***	0.102**
	(0.04)	(0.04)
HHSIZE	0.0168***	0.0170***
	(0.00)	(0.00)
HHR_AGE	-0.00135***	-0.00142***
	(0.00)	(0.00)
REGIONMIDWEST	0.201*	0.0571
	(0.10)	(0.10)
REGIONSOUTH	0.165	0.000875
	(0.10)	(0.09)
REGIONWEST	0.126	0.0794
	(0.12)	(0.11)
LNDISTANCE	-0.0555***	-0.0530***
	(0.01)	(0.01)
LNDENSITY	0.0455***	0.0311***
	(0.02)	(0.01)
LNMSADENSITY	0.0545***	0.0530***
	(0.01)	(0.01)
MIDDENSITY	-0.0454***	-0.0221*
	(0.02)	(0.01)
SOUTHDENSITY	-0.0413**	-0.0158
	(0.02)	(0.01)
WESTDENSITY	-0.0307	-0.02
	(0.02)	(0.01)
Constant	-0.258**	
	(0.11)	
Observations	68,685	68,685
R-squared	0.138	
Income fixed effects?	Yes	Yes

*Robust standard errors in parentheses; column two reports marginal effects, *** p<0.01, ** p<0.05, * p<0.1*

Linear probability models can be difficult to interpret. To make this more concrete, consider a household with average values of HHSIZE, HHR_AGE, a median level of income ($67,500), who lives in a Census tract in the Northeast with average values of LNDISTANCE, LNDENSITY, and in an MSA with average values of LNMSADENSITY and without rail infrastructure. Our estimates predict that this household has a 25% chance of having used transit in the last month (using the methodology described in Section 2, and given the unreported coefficient on HHFAMINC14 was 0.0061583). Now assume we move this household from their current home, 15 kilometers from the city center to a new Census tract that is one kilometer from the city center (LNDISTANCE falls from 2.72 to zero). The model predicts this household is now 40.4% likely to use transit (25 + 2.72 x .0555 = 40.4). If this new tract has a population density of 6,000 people per square mile (up from 1,450 in the old tract), our transit use prediction rises to 47%.

In Table 28 we examine a subset of cities that have rail infrastructure. We drop the rail dummy, but add a variable (LNRAILDISTANCE) that measures a household's distance in kilometers to the nearest rail transit stop for stations that were built as of the year 2000.[45] An important finding from Table 28 is that, when looking at cities with rail systems and including the LNRAILDISTANCE variable, the effects of the other urban form variables are highly muted. In the linear probability model, the estimated coefficient on LNDISTANCE falls by almost half compared to the estimate from Table 27, and the standard errors rise by so much that the estimate is no longer statistically significant. Similarly, the effect of tract-level density falls by about 25% and is no longer statistically significant. These comparisons actually understate the magnitude that including LNRAILDISTANCE reduces the effect of the other neighborhood urban form variables, because the estimates reported in Table 27 were obtained using households who live in MSAs with and without rail systems. When we estimated the same specification as in Table 27 but using only the subsample of households who live in MSAs with rail systems, the coefficient estimates on the urban form variables were about twice as large as in Table 27.

Table 28. Household Public Transit Use, Select Rail Cities

Variables	PTUSED	PTUSED
HHSIZE	0.0220***	0.0245***
	(0.00)	(0.00)
HHR_AGE	-0.00190***	-0.00216***
	(0.00)	(0.00)
REGIONMIDWEST	-0.0418	0.0641
	(0.20)	(0.24)
REGIONSOUTH	0.0684	0.177
	(0.14)	(0.15)
REGIONWEST	0.0842	0.222**
	(0.11)	(0.10)
LNDISTANCE	-0.0285	-0.0321
	(0.02)	(0.02)
LNDENSITY	0.0350*	0.0525***
	(0.02)	(0.02)
LNRAILDISTANCE	-0.0702***	-0.0754***
	(0.02)	(0.02)
LNMSADENSITY	0.0730**	0.0783**
	(0.03)	(0.03)
MIDDENSITY	-0.00344	-0.0166
	(0.02)	(0.03)
SOUTHDENSITY	-0.024	-0.0381**
	(0.02)	(0.02)
WESTDENSITY	-0.0269*	-0.0446***
	(0.01)	(0.01)
Constant	-0.169	
	(0.29)	
Observations	18,532	18,532
R-squared	0.152	
Income fixed effects?	Yes	Yes

*Robust standard errors in parentheses ; *** p<0.01, ** p<0.05, * p<0.1*

Of course, rail transit stops are usually built in dense areas, so teasing out the pure effect of each variable is not as straightforward as the discussion above might suggest. But several facts are apparent from the analysis presented so far in this section. First, urban form is certainly important for understanding public transit use. Second, proximity to rail has a larger impact on the probability of transit use.

Finally, we briefly consider the effect of income on public transit use. Although we included but did not report income fixed effects, one noteworthy finding revealed by these income fixed effects is that, controlling for everything reported in Table 27, although the estimate of the fixed income effect is largest for the lowest income group (the coefficient on HHFAMINC1 was .1733), the fixed-effect estimate for the other income groups falls only over the next eleven income groups (the coefficient on HHFAMINC11 was -.0141176, and the coefficient on HHFAMINC12 was just slightly negative). We observed a U-shaped relationship between income and household public transit use. The likelihood of using public transit is roughly equal for households from the highest and fourth lowest income groups, and the coefficient on HHFAMINC18 (the highest income group) was .0614.

VIBRANCY AND PUBLIC TRANSIT USE

In this subsection, we again re-estimate a model from Section 2—the vibrancy model. As above, we modify this model slightly by using our measure of household public transit use as a dependent variable, and by including the dummy indicating the household's MSA has rail infrastructure. Given the estimates above did not appear to be sensitive to model specification, we estimate only linear probability models for ease of exposition.

All of the vibrancy measures are the same as in Section 2, and because the sample we analyze here is also very similar, we do not report summary statistics. Table 29 reports the results from our regressions. Three variables, COLLEGE, MURDER_GRWTH, and LIVE_MUSIC are statistically significant and as expected. An increase in the percentage of the downtown population with a college degree from the mean of 0.24 by one standard deviation would increase the probability of household public transit use by slightly more than five percent. Likewise, a city that lowers its murder growth rate by one standard deviation will see household public transit use increase by 3.05 percent. A city that increases its number of live music performers per capita by one standard deviation will see public transit use rise by 1.08 percent.

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Table 29. Household Public Transit Use and Downtown Vibrancy

Variables	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED
COLLEGE	0.529***										
	(0.08)										
JOBS_DWNTWN		0.0707*									
		(0.04)									
JOB_GRWTH_ DWNTWN			-0.131*								
			(0.07)								
MURDER				0.00155							
				(0.00)							
MURDER_ GRWTH					-0.0467***						
					(0.02)						
DWNTWN_ POP_GRWTH						0.0159					
						(0.03)					
LIVE_MUSIC							0.00147***				
							(0.00)				
MUSEUM								-0.000116			
								(0.00)			
HOTEL									-1.30E-05		
									(0.00)		
BAR										-4.18e-05*	
										(0.00)	
RESTAURANT											8.41E-06
											(0.00)

Table 29. Household Public Transit Use and Downtown Vibrancy (continued)

Variables	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED	PTUSED
HHSIZE	0.0183***	0.0166***	0.0168***	0.0167***	0.0164***	0.0165***	0.0166***	0.0165***	0.0165***	0.0165***	0.0165***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
RAIL	0.164***	0.169***	0.169***	0.169***	0.167***	0.173***	0.174***	0.173***	0.173***	0.172***	0.174***
	(0.03)	(0.05)	(0.04)	(0.04)	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
HHR_AGE	-0.0012***	-0.00136***	-0.00137***	-0.00136***	-0.0013***	-0.0013***	-0.0013***	-0.0013***	-0.0013***	-0.0013***	-0.0013***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
REGIONMID-WEST	0.235**	0.240**	0.245**	0.251**	0.227**	0.234**	0.250**	0.232**	0.235**	0.227**	0.240**
	(0.10)	(0.12)	(0.12)	(0.12)	(0.11)	(0.12)	(0.11)	(0.11)	(0.12)	(0.11)	(0.11)
REGIONSOUTH	0.195**	0.199*	0.210*	0.209*	0.176*	0.199*	0.222**	0.197*	0.200*	0.188*	0.207*
	(0.09)	(0.12)	(0.11)	(0.12)	(0.10)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)	(0.11)
REGIONWEST	0.182*	0.153	0.194	0.17	0.139	0.161	0.186	0.158	0.161	0.15	0.169
	(0.09)	(0.12)	(0.12)	(0.12)	(0.11)	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)	(0.12)
LNDISTANCE	-0.0270***	-0.0324***	-0.0285***	-0.0287***	-0.0292***	-0.0262***	-0.0243***	-0.0270***	-0.0268***	-0.0279***	-0.0257***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
LNDENSITY	0.0646***	0.0664***	0.0689***	0.0690***	0.0655***	0.0687***	0.0711***	0.0682***	0.0685***	0.0674***	0.0695***
	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
MIDDENSITY	-0.0487***	-0.0538***	-0.0540***	-0.0555***	-0.0521***	-0.0529***	-0.0544***	-0.0528***	-0.0530***	-0.0524***	-0.0535***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
SOUTHDENSITY	-0.0427***	-0.0476**	-0.0473**	-0.0484**	-0.0444**	-0.0464**	-0.0484***	-0.0464**	-0.0466**	-0.0457**	-0.0472**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
WESTDENSITY	-0.0303*	-0.0345*	-0.0372*	-0.0354*	-0.0326*	-0.0345*	-0.0367*	-0.0343*	-0.0345*	-0.0336*	-0.0353*
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Constant	-0.308***	-0.176	-0.157	-0.177	-0.134	-0.167	-0.203*	-0.16	-0.164	-0.147	-0.178
	(0.09)	(0.12)	(0.12)	(0.12)	(0.10)	(0.12)	(0.11)	(0.12)	(0.12)	(0.12)	(0.12)
Observations	68,685	68,685	68,685	68,685	68,685	68,685	68,685	68,685	68,685	68,685	68,685
R-squared	0.146	0.131	0.131	0.13	0.132	0.13	0.131	0.13	0.13	0.13	0.13

*Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

THE INTERACTION OF URBAN FORM AND VIBRANCY ON PUBLIC TRANSIT USE

We now analyze the effect of downtown vibrancy on the distance-transit use connection. We have re-estimated the model presented in Table 27, while stratifying the sample according to whether the respondent's MSA was above or below the median value for each vibrancy indicator. Median vibrancy values were reported in Table 15. The results of this analysis are presented below in Table 30.

Table 30. Estimated Coefficient on Lndistance, Stratifying By Vibrancy Measures

Stratified by	Vibrant subsample	Non-vibrant subsample	* if coefficient estimates differ statistically
COLLEGE	-0.0594	-0.0427	
JOBS_DWNTWN	-0.0674	-0.0363	*
JOB_GRWTH_DWNTWN	-0.0524	-0.0589	
MURDER	-0.0356	-0.0648	*
MURDER_GRWTH	-0.0688	-0.0368	*
DWNTWN_POP_GRWTH	-0.0575	-0.0443	
LIVE_MUSIC	-0.0512	-0.0574	
MUSEUM	-0.0361	-0.0673	*
HOTEL	-0.0342	-0.0681	*
BAR	-0.0413	-0.0616	
RESTAURANT	-0.0331	-0.0687	*

Table 30 reports some surprising findings. As expected, the effect of distance is statistically greater[46] in MSAs with vibrant downtowns when stratifying by JOBS_DWNTWN and MURDER_GRWTH. However, it is, surprisingly, statistically greater in areas with non-vibrant downtowns when we stratify by MURDER, as well as by three industry-based measures: MUSEUM, HOTEL and RESTAURANT.

A possible explanation for these findings may be found in the concept of "reverse commuting." In vibrant downtowns, particularly those with many consumer-oriented services and quality of life amenities, it is possible that households choose to live downtown and then commute to suburban jobs. We will say more about strategies to further explore these surprising results in the conclusion.

V. MACRO-LEVEL STUDY OF PUBLIC TRANSIT USE

The previous section used micro data to analyze the connections between urban form, downtown vibrancy, and household public transit use. In this section, we again turn to macro level data in an attempt to verify our results for public transit use.

The National Transit Database (NTD) is our main source for aggregate data on public transit use. "The NTD was established by Congress to be the Nation's primary source for information and statistics on the transit systems of the United States."[47] As with the Highway Statistics data used in Section 3, the unit of observation in the NTD data is the urbanized area. And again, as the unit of analysis in this report is the MSA, we matched urbanized areas to MSAs using the same procedure as explained in Section 3—urbanized areas were matched to principle cities, principle cities to counties, and finally counties to MSAs.

We use the NTD as the source of our dependent variable, which is the natural log of total annual passenger miles traveled (PMT). We estimate the same model as in Section 3, except that there the dependent variable was VMT and it was in household averages. The analysis in Section 3 was in household averages to facilitate comparability with the results from Section 2. However, because the models in Section 4 were linear probability models, it is not clear it is possible to make the analysis in the present section comparable. And because PMT values run into the millions, logarithmic transformation makes the most sense. Beyond PMT, the other variables in the analyses below are the same measures used in Section 3.

This section consists of two subsections. The first contains an analysis of the effect of urban form on public transit use. We find that two measures of urban form—the same density and distance measures used in Section 3—are also statistically significant determinants of public transit use. The second subsection contains an analysis of the effect of downtown vibrancy on public transit use. We find mixed results—COLLEGE, MUSEUM, and BAR were as expected, however JOBS_DWNTWN, JOB_GRWTH_DWNTWN and DWNTWN_POP_GWTH were not. These unexpected findings again force us to reconsider our theory as well as our empirical techniques.

PUBLIC TRANSIT USE AS A FUNCTION OF URBAN FORM

We refer to the dependent variable as LNPMT, which is the natural log of total passenger miles traveled over all seventeen modes of service for which the NTD collected data in 2008.[48] The other variables are the same measures used in Section 3, except that LNDENSITY is constructed using the 2010 MSA population and land area from the Census, and the LNPOP variable is from the 2010 Census.

Table 31. Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
LNPMT	293.000	16.276	1.916	11.974	23.802
LNINC	293.000	10.342	0.181	9.607	11.116
LNPOP	293.000	12.858	1.090	11.231	16.755
AGE	293.000	38.603	1.473	32.705	41.287
WEST	293.000	0.225	0.418	0.000	1.000
SOUTH	293.000	0.358	0.480	0.000	1.000
MIDWEST	293.000	0.283	0.451	0.000	1.000
LNDENSITY	293.000	5.324	0.930	1.977	7.941
LNAVGDIST	293.000	2.696	0.322	1.884	3.530

We also ran the regression reported below in terms of average passenger miles per household for greater comparability to Section 3, and the coefficient estimates for the urban form variables are qualitatively similar whether we use averages or logs. Unlike in Section 3, the LNPOP variable is positive and significant in the average PMT specification. This suggests there are economies of scale in public transit. Given the differences in transit ridership levels across MSAs, and the fact that using average PMT does not buy us anything in terms of greater comparability with the public transit results obtained using the micro data, the log form seems preferable.

Table 32 below reports the public transit regression results obtained using the macro data described above. Both of our urban form variables are significant and expected. In order to illustrate the explanatory power of each variable, we estimate four separate models: one with no urban form variables, one with the density measure only, one with the distance measure only, and finally a model with both urban form variables.

Table 32. Aggregate Public Transit Use in 2008, All Modes

Variables	LNPMT	LNPMT	LNPMT	LNPMT
LNINC	1.091***	1.025**	0.984**	0.946**
	(0.417)	(0.417)	(0.426)	(0.426)
LNPOP	1.487***	1.368***	1.661***	1.548***
	(0.056)	(0.070)	(0.077)	(0.096)
AGE	-0.164***	-0.172***	-0.129***	-0.140***
	(0.038)	(0.039)	(0.039)	(0.041)
WEST	0.134	0.345**	0.0931	0.261
	(0.161)	(0.167)	(0.159)	(0.171)
SOUTH	-0.530***	-0.443***	-0.467***	-0.408***
	(0.144)	(0.150)	(0.143)	(0.147)
MIDWEST	-0.315**	-0.258*	-0.373***	-0.323**
	(0.132)	(0.137)	(0.131)	(0.137)
LNDENSITY		0.223***		0.172**
		(0.082)		(0.085)
LNAVGDIST			-0.849***	-0.749***
			(0.236)	(0.243)
Constant	-7.569*	-6.286	-7.720*	-6.713
	(4.062)	(4.126)	(4.095)	(4.161)
Observations	293	293	293	293
R-squared	0.814	0.819	0.822	0.825

*Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Contrary to our findings from Section 3, distance seems to be more important than density in that it raises R^2 by a larger amount; however, neither urban form variable contributes very much explanatory power to the baseline model presented in the first column. The magnitude of the coefficient estimates also suggests that distance is more important than density in increasing public transit use—a ten percent increase in density is associated with 1.7 percent more public transit use, and a ten percent decrease in the distance the average resident lives from downtown is associated with 7.49 percent more public transit use (looking at the coefficient estimates in the final column; recall in log-log specifications, coefficient estimates can be directly interpreted as elasticities.) In the final column, which includes both the density and distance measures, we see that the estimated coefficient on each variable is not much smaller compared to the estimated coefficients in the specifications where they were included individually, suggesting they are largely capturing different aspects of the urban form.

VIBRANCY AND PUBLIC TRANSIT USE

We now turn to the effect of vibrancy on MSA-level public transit use. We re-estimate the modes from Section 3, only as above, the dependent variable is the natural log of PMT.

Table 33. Summary Statistics, Vibrancy Measures

Variable	Obs	Mean	Std. Dev.	Min	Max
COLLEGE	293.000	0.246	0.102	0.099	0.659
JOBS_DWNTWN	293.000	0.591	0.213	0.039	0.998
JOB_GRWTH_DWNTWN	293.000	0.084	0.140	-0.377	1.102
MURDER	291.000	8.513	8.151	0.000	61.101
MURDER_GRWTH	290.000	0.064	0.646	-1.000	3.745
DWNTWN_POP_GRWTH	293.000	0.015	0.128	-0.272	0.926
LIVE_MUSIC	293.000	4.036	7.812	0.000	90.854
MUSEUM	293.000	6.101	13.156	0.000	167.879
HOTEL	293.000	50.596	91.843	0.000	1,159.901
BAR	293.000	70.685	152.797	0.000	1,846.670
RESTAURANT	293.000	203.173	369.873	0.000	4,101.077

The vibrancy measures are the same as in our earlier analysis; however, because the samples differ from those in previous sections, we report summary statistics for those MSAs that were used in this analysis. Below, Table 34 reports the results. The estimated coefficients on COLLEGE, MUSEUM, BAR were as expected, however JOBS_DWNTWN, JOB_GRWTH_DWNTWN and DWNTWN_POP_GWTH were not.

What could be behind these mixed findings? One possibility is that population growth was higher in places with less public transit use—which we know to be the case from the analysis presented in Section 1—and, therefore, it is possible that the growth variables happen to be negatively correlated with public transit use, though growth is not causing lower public transit use. So two of the unexpected findings may be understandable, but what is going on with JOBSDWNTWN? The answer is not immediately apparent.

We will consider this further, and present some ideas in the conclusion, where we discuss steps for future analysis.

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Table 34. NTD Data and Vibrancy

Variables	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT
COLLEGE	1.383**										
	(0.6)										
JOBS_DWNTWN		-0.549**									
		(0.3)									
JOB_GRWTH_ DWNTWN			-1.12***								
			(0.4)								
MURDER				0.00255							
				(0.0)							
MURDER_GRWTH					-0.0707						
					(0.1)						
DWNTWN_POP_ GRWTH						-1.16***					
						(0.4)					
LIVE_MUSIC							0.0114*				
							(0.0)				
MUSEUM								0.0103***			
								(0.0)			
HOTEL									0.000709		
									(0.0)		
BAR										0.000653***	
										(0.0)	
RESTAURANT											0.000281*
											(0.0)

Table 34. NTD Data and Vibrancy (continued)

Variables	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT	LNPMT
LNINC	1.110***	1.110***	1.095***	1.102**	1.090***	1.194***	1.019**	1.106***	1.060**	1.091***	1.054**
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
LNPOP	1.502***	1.538***	1.474***	1.478***	1.478***	1.470***	1.507***	1.522***	1.509***	1.513***	1.518***
	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
AGE	-0.102**	-0.162***	-0.17***	-0.17***	-0.16***	-0.18***	-0.15***	-0.16***	-0.16***	-0.16***	-0.15***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
WEST	0	0.182	0.285*	0.142	0	0	0	0	0	0.186	0.19
	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)
SOUTH	-0.525***	-0.488***	-0.46***	-0.53***	-0.55***	-0.49***	-0.49***	-0.45***	-0.52***	-0.48***	-0.48***
	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
MIDWEST	-0.276**	-0.309**	-0.34***	-0.316**	-0.339**	-0.36***	-0.291**	-0.251*	-0.319**	-0.310**	-0.285**
	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
Constant	-6.351	-8.191**	-6.988*	-7.478*	-7.672*	-7.640*	-7.884*	-8.556**	-7.845*	-8.117**	-8.298**
	(3.96)	(4.07)	(3.89)	(4.06)	(4.11)	(4.05)	(4.07)	(4.01)	(4.06)	(4.08)	(4.08)
Observations	293	293	293	291	290	293	293	293	293	293	293
R-squared	0.817	0.816	0.819	0.814	0.815	0.819	0.816	0.818	0.815	0.816	0.816

*Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

CONCLUSION: SUMMARY AND POLICY RECOMMENDATIONS

This report has used several different data sets to investigate one core research question: all else equal, is the per-capita transportation carbon footprint of a metropolitan area smaller if its center city is more vibrant? To test this hypothesis, we have defined "vibrancy" based on a downtown's share of residents who are college graduates, the center city crime rate, the number of cultural and consumer-oriented establishments downtown, and the share of the metropolitan area's jobs and population growth downtown.

Using micro data from the recently released 2009 National Household Transportation Survey, and macro data from Highway Statistics and the National Transit Database, we find robust evidence that, in fact, our vibrancy indicators are associated with a smaller carbon footprint. It is important to note that many of these results are holding constant "traditional urban form" indicators such as the distance from the city center and the population density at which the household lives. We have augmented the traditional model of transportation and land-use to include quantifiable measures of quality of life. We recognize that "quality of life" can be an ambiguous, hard to pin down concept, but we have sought out objective indicators that we believe correlate with what most people seek out in center cities in terms of employment and leisure opportunities. We welcome future studies that use better data to augment the set of vibrancy indicators.

Based on our empirical proxies, we find that in those metropolitan areas whose center cities are graded as "more vibrant," people live closer to the city center, and are driving less and commuting more using public transit. Our strongest evidence concerns the effect of vibrancy on driving, but given that public transit is a system focused on taking people downtown, it makes sense that people are walking and using this infrastructure more in those areas where living and working downtown is more desirable.

IMPLICATIONS FOR URBAN POLICY

Starting in the early 1990s, U.S. cities have enjoyed a sharp reduction in crime. As center city crime and downtown pollution has declined, major center cities ranging from New York City, to Chicago, to Boston, to Los Angeles have enjoyed a renaissance. Demographic changes are such that many young adults and older adults whose children have moved away are actively seeking out center city living. It is important that policy encourages, or at least does not discourage, this trend.

At the end of Section 1, we discussed how an unintended consequence of various federal policies—principally, the home mortgage interest deduction—has been a flight from cities to the suburbs. If federal policy makers rethink this and other federal housing policies, the result would be higher demand for low-carbon urban living. It is clear to us that federal home ownership policy plays an important role in reinvigorating our cities; however, in the paragraphs that follow, we turn our attention to policy options for local governments.

While urban economists continue to debate how much of the suburbanization trend in the 1960s and 1970s was "flight from blight," it is clear that many people are now willing to live at higher density.[49] With this reversal in mind, our policy suggestions focus on the goal of increasing center city vibrancy in order to reduce the GHG emissions associated with transportation. We have three suggestions in this regard; cities should:

1. Rethink current land-use regulations,

2. Continue investments to reduce center city crime, and

3. Increase local public school quality.

These three policy proposals seek to further enhance the quality of life in downtown areas. Current land-use regulations—for example, building height and density limits—make housing more expensive in many U.S. cities, and this causes individuals and households to seek cheaper housing at the urban fringe where their carbon footprint will be larger. A recent Urban Land Institute report recognized this point, noting, “Some of the biggest impacts on [reducing GHG emissions from driving] can be achieved through changes to local land development policies. Many communities have not overhauled their zoning and subdivision ordinances since they were created in the 1950s or 1960s, when they were designed to separate land-uses, maintain low densities and large setbacks, ensure plentiful parking, keep streets wide, and save money by limiting sidewalks.”[50] A smaller population will also support fewer restaurants and entertainment options—in short making the city less vibrant. Thus one way local policy could lessen a city’s carbon footprint by fostering a more vibrant downtown is to remove regulations that raise the cost of new construction in established communities. Recent efforts by state governments that encourage cities to permit larger multi-family buildings, such as California’s SB 375, are steps in the right direction.

Falling crime will attract skilled workers and the establishments that cater to them to locate in the center city. Unfortunately, we are not aware of any guaranteed recipes for fighting crime, and we are undecided on which tactical measures cities should follow. For example, the policing literature has suggested both “centralized” paradigms—like New York City’s Compstat program—as well as “decentralized” paradigms—such as community policing—and we think both approaches have merit. But regardless of the tactics city leaders choose to follow, keeping the city center as free of crime as possible should be a top priority.

A remaining challenge is local public schools. Our analysis did not directly analyze any public schooling variable—the fraction of a downtown’s population who are college graduates comes the closest—but this reflects the difficulty of obtaining data on public school quality. It certainly does not reflect the fact that we believe public school quality is unimportant. Many young families with school age children seek out suburban locations because the local schools are of higher quality. Some of these households would remain downtown if they had more choice over schooling options. An unintended consequence of such households remaining in the center city is that their carbon footprint would be smaller.

Like our attitude towards policing tactics, we are undecided about strategies to improve public schools. Both liberal and conservative policies offer promise for improving schooling. As a liberal example, if the U.S. adopted a system of centralized schooling, either at the state or federal level, there would be less reason for households to flee cities with poor-quality school districts. As an example of a conservative policy, if school districts adopted a system of school vouchers that provided more options for downtown parents, competition might force urban schools to improve.

FURTHER ANALYSIS

We conclude this chapter and this report by pointing out the limitations of our analysis, and suggest profitable directions for future research. We have already suggested some ways to improve future analyses. For example, in Section 2, we pointed out that more work is needed to respond to skeptics who argue the correlations we find in the data greatly exaggerate the causal effect of land-use on transportation behavior. We agree that our econometric approach is open to self-selection criticisms, however, we doubt how large of a bias there is in actuality. Introspection tells us that the relationship is at least partly causal; however, solid econometric work that directly deals with this issue is needed.

In Section 3 and Section 5, we only utilized Highway Statistics and NTD data for one year. It is worth trying to get more years of data and carrying out an analysis using panel data. Likewise, our sprawl regressions in Section 3 only looked at the changes in sprawl from 2000 to 2010. Although many of our variables are not available before 1994, and the industry classifications do not match perfectly before 1998, it should be possible to carry out a panel data analysis using data from 1990 to 2010 to look at changes in sprawl over a longer time frame.

There is room for improvement with respect to our analysis of public transit. Our approach largely mimicked our analysis of driving, although we did include different variables; however, more thought on model specification is probably warranted. Perhaps incorrectly specified models are the reason for our surprising results in the subsection, “The interaction between urban form and vibrancy on public transit use.” For example, although we control for income, perhaps we need to control for poverty status.

It is also possible that our analysis of public transit needs to be fundamentally rethought. Future work may need to consider a multinomial approach that accounts for walking and biking, as well as transit. Edward Glaeser highlights the importance of walking, and offers other policy recommendations that are in line with our own:[51]

> *Older cities can’t count on either higher gas prices or a sudden disgust with the automobile to bring more Americans back to downtown living. But they can make city life more attractive by speeding the trips of their own residents. Urban bus commutes can be improved, as they have been in London and Singapore, by charging congestion fees that reduce the numbers of drivers on city streets. Even more important, new compact high-rise development can provide the one commute that is even faster than a twenty-four minute drive: a fifteen-minute walk. In many cities, like New York, once-poor neighborhoods, like Tribeca, that can offer fast commutes on foot to core business districts have come back, spurred by the same increasing value of time that pushed Americans out of public transit into cars. Cities can compete, but they need radical new designs that offer affordable housing and quicker commutes.*

In the year 2000, nearly six million people typically completed the journey to work via public transit, but more than three million walked. And in most MSAs, walking is a much more common mode of commuting than taking public transit. Looking at all 366 MSAs, from Abilene to Yuma, the average percentage of commuters walking to work is 2.9, versus only 1.6 taking public transit. In 85% of MSAs, walking is a more widely used method of getting to work than public transit. This suggests that the best way to get people out of the car may be by encouraging walking. The results of our analysis suggest that fostering a vibrant urban environment is an important ingredient in encouraging walking and thus lowering GHG production from transportation.

APPENDIX A: DATA NOTES

SECTION ONE NOTES

We obtained a list of MSAs used in the original analysis from Jesse Shapiro. It turns out that this list is essentially the 1999 definitions with the following exceptions: all MSAs in Puerto Rico were removed, as were Auburn and Corvalis. Finally, New Haven was placed into its own unique MSA. These changes resulted in the same set of 275 MSAs as used in the original study. Almost all of the data analyzed in this section was accessed through the American Fact Finder, which contains Census data from 2000 and 2010. The only exceptions are land area data, which we obtained from the 2000 and 2010 Gazetteer, and climate data, which came from the 2007 City and County Data Book.

CRIME DATA NOTES

We obtained crime data from the U.S. Department of Housing and Urban Development's State of the Cities Data Systems (SOCDS). "This system provides crime data from a database derived from FBI crime data. It contains crime rates for metropolitan central/principal cities and metropolitan suburban places for 1992 and 1997–2008." http://socds.huduser.org/FBI/FBI_Home.htm As mentioned in the text, our variable MURDER is the average murder rate (murders per 100,000 residents) for the years 2000 through 2005. For the analysis presented in Section 3, the variable MURDER_90s is the average murder rate for the years 1992, and 1997-1999.

ZIP CODE NOTES

We started with 42,865 zip codes, with geocode information, provided by ESRI. Then we dropped 17209 non-metro zip codes. Then we matched these remaining zip codes with data from ZBP. Finally, we dropped ESRI codes from 1 to 501, since ZBP never reports data for these. The list below details the NAICS categories we used to calculate our five establishment-based measures:

711130	Musical groups and artists
712110	Museums
721110	Hotels (except casino hotels) and motels
722110	Full-service restaurants
722410	Drinking places (alcoholic beverages)

In a few cases there were no zip codes within five miles of an MSA. In these cases, we used the single zip code with the smallest distance the CBD to calculate the downtown measures.

ABBREVIATIONS AND ACRONYMS

CBD	Central Business District
CO2	Carbon Dioxide
ESRI	Environmental Systems Research Institute
GHG	Greenhouse Gas
MPG	Miles per Gallon
MSA	Metropolitan Statistical Area
NHTS	National Household Travel Survey
NTD	National Transit Database
OLS	Ordinary Least Squares
PMT	Passenger Miles Traveled
UA	Urbanized Area
VMT	Vehicle Miles Traveled
ZBP	Zip Code Business Patterns

ENDNOTES

1. Edward Glaeser and Jesse Shapiro, "Urban Growth in the 1990s: Is City Living Back?" Journal of Regional Science 43 (2003): 139-165.

2. The same result obtains when stratifying by downtown population growth as well.

3. The results from Section 1 offer a possible explanation for this, as "driving cities" were by and large the ones that grew. Thus, population growth downtown may not have caused increased household emissions, but households may have moved to areas where emissions were already high.

4. Peter Katz, ed., The New Urbanism: Toward an Architecture of Community (New York: McGraw-Hill, 1994).

5. Edward Glaeser, Triumph of the City (New York: Penguin Press, 2011), 194-195.

6. Edward Glaeser and Joseph Gyourko, Rethinking Federal Housing Policy (Washington D.C.: The AEI Press, 2008).

7. Reid Ewing and Robert Cervero, "Travel and the built environment: A synthesis," Transportation Research Record, 1780 (2001): 87-114. Reid Ewing and Robert Cervero, "Travel and the built environment: A meta-analysis." Journal of the American Planning Association, 76(2010): 265-294.

8. A recent report, funded by the U.S. Department of Energy, "aimed at establishing the scientific basis for and making appropriate judgments about the relationships among development patterns, VMT, and energy consumption…" A committee of experts commissioned five papers that explore various aspects of the study charge. Transportation Research Board Special Report 298, Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO2 Emissions, http://onlinepubs.trb.org/Onlinepubs/sr/sr298.pdf (Accessed August 18, 2011).

9. U.S. Department of Transportation, Federal Highway Administration, "National Household Travel Survey," http://nhts.ornl.gov (Accessed August 18, 2011).

10. In Section 4, we will estimate a linear probability model that is identical to (1), but with a dependent variable that equals one if at least one member of the household used public transit in the last month.

11. The U.S. Energy Information Administration provides gasoline consumption estimates to the NHTS, who in turn provide the estimates in their public-use data sets. These gasoline estimates take into account vehicle miles traveled, the type and age of the vehicle. Detailed information on how the EIA calculates this gasoline consumption estimate can be found in Tom Leckey and Mark Schipper, "Extending NHTS to Produce Energy-Related Transportation Statistics," (paper presented at the TRB

Workshop Using National Household Travel Survey Data for Transportation Decision Making, Washington, D.C., June 6, 2011) http://onlinepubs.trb.org/onlinepubs/conferences/2011/NHTS1/Leckey.pdf (Accessed August 18, 2011).

12. U.S. Energy Information Administration, "Voluntary Reporting of Greenhouse Gases Program, Table 2: Carbon Dioxide Emission Factors for Transportation Fuels," http://www.eia.gov/oiaf/1605/coefficients.html (Accessed August 18, 2011).

13. "Petroleum refining and distribution efficiency = 0.83," U.S. Government Printing Office, Federal Register, Volume 65, Number 113, June 12, 2000, Rules and Regulations, Department of Energy, Office of Energy Efficiency and Renewable Energy, p. 36,987, http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2000_register&docid=00-14446-filed.pdf (Accessed August 18, 2011). Therefore, 20.98 is conservative and likely understates the actual emissions associated with a gallon of gasoline. We decided to sacrifice accuracy for comparability, as our factor of choice facilitates comparing the results here to those we will present in Section 3.

14. MSA definitions change roughly annually. Throughout the remainder of this report, we use the 2006 definitions and the principle cities identified by the Census. U.S. Census Bureau, "Metropolitan and Micropolitan Statistical Areas," http://www.census.gov/population/www/metroareas/metrodef.html (Accessed August 18, 2011).

15. Following near identical data rules, Glaeser and Kahn, using the 2001 NHTS, obtained a sample size of only 11,728. Other differences between their approach and ours are that we were able to obtain tract-level geocodes for respondents while they only had zip code level geographic data. We also used more recent MSA definitions (see the note above). Edward Glaeser and Matthew Kahn, "The Greenness of Cities: Carbon Dioxide Emissions and Urban Development," Journal of Urban Economics, 67 (2010): 404–418.

16. Geocodes for census tracts were obtained from the Census, U.S. Census Bureau, "U.S. Gazetteer: 2010, 2000 and 1990," http://www.census.gov/geo/www/gazetteer/gazette.html (Accessed August 18, 2011). Distance calculations are based on the spherical law of cosines.

17. See Hanley and Barbier, pp. 144-145 for alternative estimates. Nick Hanley and Edward Barbier, Pricing Nature: Cost-Benefit Analysis and Environmental Policy, (Northampton: Edward Elgar, 2009).

18. These estimates refer only to the social costs of CO2 resulting from household vehicle emissions. They do not, for example, include any benefits related to particulate matter reductions that may improve public health. A full cost-benefit analysis would need to compare all the benefits of reduced vehicle emissions, with all potential costs of a more compact urban form. This is beyond the scope of the current project.

19. In this sense, our results, which we do not report here, were similar to those found by Grazi et al. Fabio Grazi, Jeroen C.J.M. van den Bergh, and Jos N. van Ommeren. "An

empirical analysis of urban form, transport, and global warming," The Energy Journal 29(2008): 97-122.

20. Reid Ewing, Rolf Pendall and Don Chen, "Measuring Sprawl and Its Transportation Impacts," Transportation Research Record: Journal of the Transportation Research Board 1831 (2003): 175-183.

21. Edward Glaeser, Jed Kolko, and Albert Saiz, "Consumer city," Journal of Economic Geography 1 (2001): 27-50.

22. The foundations of this literature include Rosen (1979), Roback (1982), Gyourko and Tracy (1991), and Kahn (1995). Chen and Rosenthal (2008) contain references to more recent studies in this quality of life literature. Sherwin Rosen, "Wage-based indexes of urban quality of life," In: Mieszkowski, P., Straszheim, M. (Eds.), Current Issues in Urban Economics. (Baltimore: Johns Hopkins Univ. Press, 1979.) Jennifer Roback, "Wages, rents, and the quality of life," Journal of Political Economy 90 (1982): 257–278. Joseph Gyourko and Joseph Tracy, "The structure of local public finance and the quality of life," Journal of Political Economy 99 (1991): 774–806. Matthew Kahn, "A revealed preference approach to ranking city quality of life," Journal of Urban Economics 38 (1995): 221–235. Yong Chen and Stuart Rosenthal, "Local amenities and life-cycle migration: Do people move for jobs or fun?" Journal of Urban Economics 64 (2008): 519–537.

23. Richard Florida, The Rise of the Creative Class, (New York: Basic Books, 2002). Richard Florida, Cities and the Creative Class (London: Routledge, 2004). Richard Florida, The Flight of the Creative Class (New York: Collins, 2005).

24. Kent Robertson, "Downtown redevelopment strategies in the United States: An end-of-the-century assessment," Journal of the American Planning Association 61 (1995): 429-437.

25. Including Hinshaw (2007), Gratz and Mintz (1998), Herzog (2006), and Dawkins and Nelson (2003). Mark Hinshaw, True Urbanism: Living In and Near the Center. (Chicago: APA Planners Press, 2007). Lawrence Herzog, Return to the Center: Culture, Public Space, and City-Building in a Global Era. (Austin: University of Texas Press, 2007). Roberta Gratz and Norman Mintz, Cities Back from the Edge: New Life for Downtown. (New York: John Wiley and Sons, 1998). Casey Dawkins and Arthur Nelson, "State growth management programs and central-city revitalization," Journal of the American Planning Association 69 (2003): 381-396.

26. Zip code geocodes were obtained from the ESRI Data and Maps CD.

27. For example, in Abilene there were 21 restaurants and 40,659 workers downtown in 2005. Thus, 21/.40659=51.65, which is the value of RESTAURANT for Abilene. We believe that the number of restaurants, and other establishments discussed below, must be reported on per capita basis to purge the more direct correlation with

population. We use downtown workers as a proxy for downtown population because of the difficulty of obtaining reliable population estimates for non-census years.

28. Carlino and Saiz (2010) find that "Population and employment growth in the 1990s was about 2 percent higher in an MSA with twice as many leisure visits." Gerald Carlino and Albert Saiz, "Beautiful City: Leisure Amenities and Urban Growth," working paper, University of Pennsylvania, 2008, http://real.wharton.upenn.edu/~saiz/BEAUTIFUL%20CITY.pdf (Accessed August 18, 2011). We don't really think of our hotels measure as consumer service, but we think it should be correlated with aspects of the downtown environment, such as architectural interest, and so on, which make people want to visit.

29. Crime data was not available for all central cities in our sample.

30. The issue of reverse commuting could invalidate these hypotheses. Reverse commuting occurs when people live in vibrant downtown areas for consumption benefits, but then commute to suburban jobs. Therefore, we might expect the effect of distance on driving to be strongest when we stratify by the jobs downtown vibrancy measure, and other vibrancy measures that mainly have to do with production. Another possibility that would invalidate our hypothesis would be if suburban households have access to nearby suburban jobs and amenities, though it is unlikely, even in such a case, that they would be walking to them.

31. Except in the cases of the murder rate and murder rate growth, where an MSA is vibrant if its value is below the median.

32. Our procedure for determining whether coefficients were statistically different involved estimating a fully interacted model, and then conducting a t-test on the estimated interacted distance coefficient. Specifically, we generated a dummy variable equal to one if the respondent's MSA had a vibrancy value that indicated it has a vibrant downtown (for each of the eleven measures). Then, we interacted this dummy with each of the variables in our baseline model. Our interaction specification includes all the variables reported in Table 13, plus all of the interaction variables generated in this manner. If the p-value on the interacted LNDISTANCE variable was less than 0.05, we conclude the two subsamples have statistically different coefficients. For more on this procedure, see William Gould, "Computing the Chow Statistic," www.stata.com/support/faqs/stat/chow.html (Accessed August 18, 2011).

33. While the NHTS is a nationwide survey, there are a few MSAs for which it does not contain any respondents, and there are quite a few MSAs for which the number of respondents is small. However, one concern we have is that the macro data may be biased by inter-city and freight transport, whereas we are interested in intra-city household urban transportation.

34. Metropolitan statistical areas are our preferred unit of analysis, both conceptually, as well as practically—our vibrancy measures are all at the MSA level. Urbanized areas do not correspond perfectly to metropolitan statistical areas. "The United States

Census Bureau defines an 'urbanized area' as the densely settled 'central place(s)' in an urban area plus the less densely settled 'urban fringe' that surround them. An urbanized area (UA) must consist of at least 50,000 people and is built up from the Census Blocks (and not incorporated cities) that contain at least 1,000 people per square mile and surround the chosen central place(s)…" (p. 440) Robert Wassmer and Michelle Baass, "Does a more centralized urban form raise housing prices?" Journal of Policy Analysis and Management 25 (2006): 439-462.

35. We matched UAs to their central cities using information provided by the U.S. Census. U.S. Census Bureau, "UA Central Places and UC Central Places for Census 2000," www.census.gov/geo/www/ua/ctrlplace.html (Accessed August 18, 2011).We then matched central cities to counties with data from the 2007 City and County Data Book, file C-1. U.S. Census Bureau, County and City Data Book: 2007, http://www.census.gov/statab/ccdb/ccdbstcounty.html (Accessed August 18, 2011). Some city borders extend over multiple counties. In these cases, we matched the central city with whichever county name came first in alphabetical order.

36. U.S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information. Highway Statistics Series, www.fhwa.dot.gov/policyinformation/statistics.cfm (Accessed August 18, 2011).

37. The model we estimated was identical to the specification reported in Table 12, except we used MPG as a dependent variable. The results showed that gas mileage increases with income, and decreases with household size and respondent age. Gas mileage also increases with MSA density and density measured at the tract level, except in the northeast, where tract-level density was associated with lower mileage. However, while all of these results were statistically significant at the 5% level, the size of the estimated coefficients were all very small, and the R2 was 0.024. The only possible exception to small magnitudes may be the difference between the highest and lowest income groups, where the highest income group had a gas mileage of approximately three miles per gallon higher than the lowest income group.

38. In short, say X is a member of an average household. If X drives 20.98 miles, he burns one gallon of gasoline. Burning one gallon of gasoline produces 20.98 pounds of CO2. Hence, one mile of driving produces one pound of CO2.

39. U.S. Census Bureau, "2010 Census Tract Relationship Files," www.census.gov/geo/www/2010census/tract_rel/tract_rel.html (Accessed August 18, 2011). Specifically, this variable is calculated by taking, for each census tract in a metropolitan area within 35 miles of the CBD, the number of residents times the tract's distance to the city center. Then, we sum up these weighted distances, and divide by the total population.

40. This would appear to represent a slowing of sprawl compared to the rates seen over the 1970-2000 period. Unfortunately, due to the different definitions and samples of MSAs used in calculating these statistics, we do no suggest using these figures to compare sprawl rates over time.

41. We excluded downtown population growth both because this is relatively highly correlated with MSA population growth, and because this has an almost direct correlation with our dependent variable, given the way it is calculated (which we described in Subsection 3.2).

42. Previous work has explored the effect of crime on urban sprawl, including Cullen and Levitt (1999) and Ellen and O'Regan (2010), though their findings are mixed. Julie Berry Cullen and Steven Levitt, "Crime, Urban Flight, And The Consequences For Cities," The Review of Economics and Statistics, 81 (1999): 159-169. Ingrid Gould Ellen and Katherine O'Regan, "Crime and urban flight revisited: The effect of the 1990s drop in crime on cities," Journal of Urban Economics 68 (2010): 247–259.

43. We also estimated specifications using BARS, HOTEL, LIVE_MUSIC and MUSEUMS as the industry-based independent variable, rather than RESTRAURANT. In the full data with all 366 MSAs, all of these variables were negative and significant at the 5% level. In the subsample of MSAs with a 2000 population greater than 500,000, LIVE_MUSIC and MUSEUMS were negative and significant at the 5% level, but the other two were not significant.

44. We used data from the 2009 NHTS to determine which cities had rail infrastructure.

45. This data comes from Baum-Snow and Kahn (2005), and covers the Atlanta, Baltimore, Boston, Buffalo, Chicago, Cleveland, Dallas, Denver, Los Angeles, Miami, New York, Philadelphia, Pittsburgh, Portland, Sacramento, St. Louis, Salt Lake city, San Diego, San Francisco, San Jose and Washington, D.C. metropolitan statistical areas. Nathaniel Baum-Snow and Matthew Kahn, "Effects of urban rail transit expansions: Evidence from sixteen cities, 1970–2000." In G. Burtless & J. R. Pack (Eds.), Brookings-Wharton Papers on Urban Affairs, Washington D.C.: Brookings, 2005.

46. Greater in magnitude, but smaller, or "more negative" mathematically.

47. From the NTD's 2010 Annual Reporting Manual, page 2. U.S. Department of Transportation, Federal Transit Administration, National Transit Database, 2010 Annual Reporting Manual, www.ntdprogram.gov/ntdprogram/pubs/ARM/2010/pdf/2010_annual_Manual_Complete.pdf (Accessed August 18, 2011).

48. We use 2008 because it was the same year as the Highway Statistics data we analyzed in Section 3. We have tried specifications with only bus miles and the results do not differ dramatically. NTD's complete list of modes can be found in: U.S. Department of Transportation, Federal Transit Administration, National Transit Database, 2010 Monthly Reporting Manual, www.ntdprogram.gov/ntdprogram/pubs/MonthlyRidership/2010/html/ridership.htm (Accessed August 18, 2011).

49. Peter Mieszkowski and Edwin Mills, "The causes of metropolitan suburbanization," Journal of Economic Perspectives 7 (1993): 135-147.

50. Reid Ewing, Keith Bartholomew, Steve Winkelman, Jerry Walters and Don Chen, Growing Cooler: Evidence on Urban Development and Climate Change, (Washington, D.C.: The Urban Land Institute), 151.

51. Edward Glaeser, Triumph of the City, (New York: Penguin Press, 2011), 179-180.

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