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POLICY BRIEFS

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The Greenness of Cities

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Introduction

Over the past 50 years, automobile-oriented suburbs have grown much more quickly than denser urban areas, and over the past six years, the four fastest growing American metropolitan areas have been Atlanta, Dallas, Houston and Phoenix—all hot places that use an impressive amount of electricity to create a pleasant year-round climate. Cars and air conditioners both lead to significant emissions of carbon dioxide, which an increasing body of evidence has linked to potentially dangerous climate change. If this evidence is correct, then there are serious social costs associated with new forms of development that tend to be extremely energy intensive.

This policy brief summarizes a long, forthcoming research report, which has found that:

- Per capita emissions generally are lowest in Western metropolitan areas and highest in Southern ones. Metropolitan areas in the Northeast and Midwest fall in between these two extremes.
- All told, if the social cost of one ton of carbon dioxide emissions is \$43, then the annual environmental damage associated with an additional home in greater Houston is more than \$500 greater than the damage for a new home in greater San Francisco.
- Residents of older, denser cities such as New York and Boston emit significantly less carbon dioxide than suburbanites in those regions. The annual environmental emissions damage associated with an average suburban home in greater Boston is about \$200 more than the damage associated with an average home in the city of Boston. By contrast, emissions are actually lower in suburban Los Angeles than they are in the central cities of that metropolitan area.
- While per-capita emissions rise as you move away from the urban core in Boston, they level off once you are more than 10 miles from downtown.

These findings do not imply that there is one right form of urban development. However, they do suggest that low-density development, particularly in the South, is associated with far more carbon dioxide emissions than higher density construction. If, as a society, we are seeking to reduce our carbon emissions, then it might make sense for us to consider steps that would

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make it relatively more attractive to build up areas with a lower carbon footprint and less attractive to build more homes in places where emission rates are particularly high.

Measuring Greenhouse Gas Emissions

Low-density development, particulary in the South, is associated with far more carbon dioxide emissions than higher density construction.

We now turn to the measurement of carbon dioxide emissions across space. We will attempt to estimate the carbon emissions of a standardized household with average earnings of $62,000 in 2000 and 2.62 members. As such, our estimates will not reflect the different tendency of richer or poorer people to live in different locales. Our estimates will, however, reflect the tendency of people in different locales to own larger homes or more cars. We are, after all, interested in capturing the tendency of people who live in the suburbs to own bigger homes.

Technically, if we are interested in estimating the environmental impact of new construction in different areas, then we should be concerned with the emissions of the average new home, rather than the average existing home. In the longer research report on which this policy brief is based, we do more to consider the likely differences between the average new home and the average existing home in a given area. Here, we focus on average existing homes, since that involves the least guesswork. The decision to use the existing stock will tend to make cities look worse relative to suburbs, since cities generally have an older housing stock.

Another limitation of this brief is that we only consider the carbon dioxide emissions associated with personal transportation and household energy use. We do not consider energy use at work. This omission will understate the true emissions consequences of development, and we hope that future research will undertake the extremely difficult task of estimating workplace-related emissions for different places.

We begin with gasoline usage across metropolitan areas. We use National Household Travel Survey (NHTS) for 2001, which contains information on gasoline usage associated with travel by private automobile, family characteristics, and zip code characteristics. (See http://nhts.ornl.gov/index.shtml) We use this data to estimate the statistical relationship between gasoline consumption and both family and area characteristics, which in turn allows us to predict gasoline use for a standardized household in any area of the country.

We use census tract information to estimate gasoline use for every area of the country, and in particular, every census tract within greater Boston. Essentially, we are multiplying the statistical effect that density and distance to downtown have on gasoline usage in the NHTS with the average density and distance to the downtown in an area. To form our metropolitan area-wide estimates, we then average across all of the census tracts in the area.

To move from gasoline usage to carbon dioxide emissions, we start with a conversion factor of 19.56 pounds of carbon dioxide per gallon of gas used, which is a standard figure (http://www.eia.doe.gov/oiaf/1605/factors.html). We also add 20 percent to this amount, which reflects the energy used in refining and distribution (http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2000_register&docid=00-14446-filed.pdf). Together these imply that each gallon of gas used by the consumer is associated with 23.47 pounds of carbon dioxide emissions.

While public transportation creates far less emissions per capita than driving, it is necessary for us to also consider those emissions. We start with aggregate 2006 data for each of the nation's public transit systems (from http://www.ntdprogram.gov/ntdprogram), which provides us with energy use for each transit system. We then aggregate buses and rail systems separately to the metropolitan area level. To find total emissions for buses, we again multiply gallons used by 23.47 pounds to arrive at an emissions estimate. For rail systems that use electricity, we use regional conversion factors discussed below.

To form our metropolitan area average carbon dioxide emissions, we simply divide the total emissions from public transit in the metropolitan area by the number of households in the area. When we distinguish between city and suburban energy usage, we allocate public transit energy usage so that central city usage per household is formed by multiplying total emissions from public transit by the census share of central city residents that use public transit and then dividing by the estimated number of users in the area. We use similar formulas to calculate the public transit energy usage for suburbs and for each geographic subarea.

To estimate the energy usage associated with household electricity and fuel consumption, we use the 2000 Individual Public Use Microsample (IPUMS), which is a five percent sample of the U.S. population in that year. While more recent data would be desirable, there is no equivalently large data set that is usable for more recent years. This data source provides us with information on spending on electricity, fuel oil and natural gas. In all cases, we convert spending on these forms of energy into actual energy usage, by using state level price indices for the year 2000. (State average residential electricity prices and the fuel oil prices are taken from Energy Information Administration data online, respectively, at http://www.eia.doe.gov/emeu/states/_seds.html and http://tonto.eia.doe.gov/dnav/pet/pet_sum_mkt_a_EPD2_PRT_cpgal_a.htm.). We do not have price data that can distinguish city and suburban costs, and this is a shortcoming of our methodology.

After making these adjustments, we estimate the average energy usage for a standardized person in each metropolitan area, holding individual characteristics such as income and age constant. We then use this regression to calculate the difference between central city and suburban energy usage for each metropolitan area. Our procedure attempts to correct for household size and income levels in different areas, but it does not correct for housing attributes. Correcting for household characteristics is important if we want to estimate how much the same household would emit in different places. We choose not to correct for housing characteristics because the choice of housing unit will be different in different places, and this is one of the important ways in which locations interact with carbon dioxide emissions. We would not want to investigate suburban emissions assuming, counterfactually, that suburbanites all live in high-rise apartments.

It might make sense for us to consider steps that would make it relatively more attractive to build up areas with a lower carbon footprint.

To calculate household energy usage at even smaller levels of geography, we are forced to use a much coarser procedure. In this case, we focus on those variables, such as share of households living in single-family detached dwellings, that are available at the census tract level. We estimate the impact of these variables in each region and then use those coefficients to predict the energy usage in each census tract.

Our final step is to convert energy usage into carbon dioxide emissions. In the case of fuel oil and natural gas, we use national conversion factors of 22.38 pounds of carbon dioxide emissions per gallon of fuel oil and 120.59 pounds of carbon dioxide emissions per 1,000 cubic feet of natural gas. (See http://www.eia.doe.gov/oiaf/1605/factors.html) We also adjust fuel oil emissions upward to correct for the emissions during the refining process. In the case of electricity, the conversion process is more complex. In principle, one could use a conversion factor based on everything from a national number, which would badly understate local heterogeneity in electricity emissions, to a number based on the actual electricity source of each locality.

We use conversion factors based on the North American Electric Reliability Corporation (NERC) regions. There are eight such regions within the country, and they differ significantly in their use of relatively clean energy sources, such as hydroelectric power, and relatively dirty sources, such as coal. Moving electricity across these regions is difficult because of the limitations of the electricity grid. However, moving electricity within these regions is much easier. As such, we treat these regions as essentially closed units.

While it might be appealing to give a particular place more credit for buying particularly clean energy from within their region, we should recognize that if one part of a NERC region buys more clean energy, then given a fixed nature of the energy stock within the region, other areas will buy less clean energy. We do not mean to imply that buying cleaner energy is not a good thing, because, in the long run, added demand for cleaner energy will induce producers to shift to cleaner sources. However, in the short, if one part of a NERC region uses cleaner energy, then another uses dirtier energy. As a result, we will use NERC region-wide conversion factors to estimate the carbon impact of energy usage for areas within those regions (taken from http://www.epa.gov/cleanenergy/egrid/index.htm).

By adding together emissions from household energy use and transportation, we can estimate total carbon dioxide emissions for each metropolitan area, and for central cities and suburbs separately within each metropolitan area. To find the climate change related damage from different types of development, we must then convert these figures into dollars of damage. While there have been many attempts to quantify the social cost of a ton of carbon dioxide emissions, there is no clear consensus on the right number. We use $43 per ton of carbon dioxide, which is significantly above some estimates (e.g., Tol, 2005) and is significantly below other estimates (e.g., Stern, 2007). We will use this number, but with little confidence. Of course, adjusting for different costs is quite straightforward, since our costs can simply be multiplied up or down to accommodate any desired cost figure.

Metropolitan Area Differences in Greenhouse Gas Emissions

We now turn to our findings on difference in greenhouse gas emissions across metropolitan areas. We have estimated these costs separately for 66 different large metropolitan areas, which we define using standard census definitions. We list these estimates for the 10 largest metropolitan areas in the country in Table 1, ranked by population living within 30 miles of their central business districts. The table has seven columns. In the first column, we list the per household carbon dioxide emissions from driving estimated for each metropolitan area. Unsurprisingly, the New York City metropolitan area has the lowest per household driving-related emissions because it has the highest use of public transportation. In contrast, Atlanta and Detroit have particularly high per household gas consumption and driving-related emissions.

The second column looks at carbon dioxide emissions associated with public transportation. New York, Chicago and Washington, D.C., have the greatest per household emissions from this source. However, even in these places, emissions from public transport are a small fraction of per household emissions from private driving. For example, in Chicago and Washington, per household emissions from private cars are more than ten times the emissions from public transport.

The third column shows the annual per household carbon dioxide emissions associated with natural gas and fuel oil, two key home heating technologies. Not surprisingly, emissions are greatest in colder areas of the country. Because fuel oil generates more carbon dioxide than natural gas, places that rely on fuel oil for home heating, such as Boston and New York, have higher per household emissions than colder places like Chicago that rely more heavily on natural gas for home heating.

The fourth column turns to electricity consumption in megawatt hours. San Francisco is the lowest electricity user, which reflects the strong regulatory effort that California has made to encourage energy-efficient appliances as well as the fact that the region's temperate climate requires less air conditioning. Boston and New York are also relatively light users of electricity. By contrast, the hot, humid metropolitan areas in Texas are at the high end of electricity use.

The fifth column gives the NERC conversion factor for these different metropolitan areas. Here the difference is completely regional and it reflects only the technologies used by different areas. The West is much cleaner than the rest of the country, and the Northeast is

Table 1: Annual CO_2 Output Emissions

MSA Name	Emissions from Driving (Lbs. of CO_2)	Emissions from Public Transportation (Lbs of CO_2)	Emissions from Home Heating (Lbs of CO_2)	Electricity (Megawatt Hours)	NERC Factor	CO_2 Emissions Cost ($ per Year)	Rank Out of 66 Areas
New York, NY	17,196	2,328	11,936	7.2	1,400	$893	6
Los Angeles - Long Beach, CA	22,631	350	6,695	8.4	1,007	$820	3
Chicago, IL	23,522	1882	12,341	10.1	1,614	$1,163	31
Boston, MA	22,700	870	15,754	8.3	1,185	$1,058	19
Philadelphia, PA	21,807	1499	14,108	12.8	1,614	$1,248	42
Detroit, MI	26,391	338	17,872	9.6	1,614	$1,292	53
Washington, DC	24,992	1778	5,968	14.3	1,543	$1,180	32
Houston, TX	26,294	506	5,255	19.3	1,555	$1,334	62
San Francisco, CA	23,123	631	7,074	6.9	1,007	$813	2
Atlanta, GA	28,487	411	9,425	15.5	1,472	$1,313	57

far less clean, because of its dependence on coal. The other areas are between these two extremes. It is worth emphasizing that figures reflect current technologies, and could change significantly if, for example, Texas switched to heavier use of wind power or the Northeast engaged in more sequestration of carbon dioxide emissions from coal plants.

The sixth column provides our total estimate of costs associated with carbon dioxide emissions for each metropolitan area. As mentioned above, we use a cost figure of $43 per ton. As discussed previously, we view this figure as purely illustrative. The costs will scale up or down depending on the cost per ton. With this cost figure, the range for these 10 metropolitan areas goes from $813 per household in greater San Francisco to $1,334 per household in greater Houston. Northeast metropolitan areas, such as greater Boston, are neither particularly clean nor particularly dirty. They are cleaner than greater Houston because they have less driving and electricity. They are dirtier than San Francisco because of greater fuel oil consumption and heavy emissions levels from power plants.

The difference in costs between metropolitan areas is an estimate of the benefits of having new households in San Francisco rather than in Houston, assuming, of course, that the energy consumption associated with a new household is the same as the energy consumption of an average current household.

To put these figures in a broader national perspective, the seventh column shows the rank for each metropolitan area relative to our larger sample of 66 metropolitan areas. Note that these 10 large areas almost completely span the sample. San Francisco is not only the cleanest area among the 10 biggest metropolitan areas, but is also the second cleanest area among the 66 total areas. Houston is not only the dirtiest among our 10 areas, but also among the five dirtiest overall. Boston is in the middle of both groups.

One interesting question is whether the country is moving towards places that are greener or towards places that emit more carbon dioxide. Figure 1 shows the correlation between housing supply growth since 2000 relative to the stock of housing in 2000 and our estimate of per household environmental damage. Overall, there is a modest and statistically insignificant positive correlation between growth and the damage per household. The relationship would be significantly stronger if it were not for two outliers—Las Vegas and Phoenix—that have relatively low levels of emissions and extremely high growth rates. These places are relatively clean because their electricity is produced with relatively low levels of emissions, and their car usage is moderate. Otherwise, the fastest growing places in the country have tended to be in the areas with particularly high carbon dioxide emissions.

Why are these energy intensive areas growing so quickly? Glaeser and Tobio (2008) argue that the rise of the Sunbelt areas has much to do with housing supply elasticity, and that reflects, at least in part, land use regulations. Figure 2 shows the correlation between environmental damage and the Wharton Land Use Index. That index, described and compiled by Gyourko, Saiz and Summers (2008), measures the difficulties involved in permitting new projects. Overall, we find a striking negative correlation between estimated emissions and the Wharton index. Places with more emissions are more permissive towards new construction, and this probably explains why they grow more.

In a sense, this correlation is unsurprising. The environmental movement includes both a push to limit development and a movement to make energy less harmful. Californians have embraced both elements of environmentalism. The sad impact of that, however, is that while California has become the least emissions-intensive area of the country, that state has also reduced its growth. As a result, fewer

Figure 1: Correlations Between CO_2 Emissions and Growth in Housing Supply, by Region

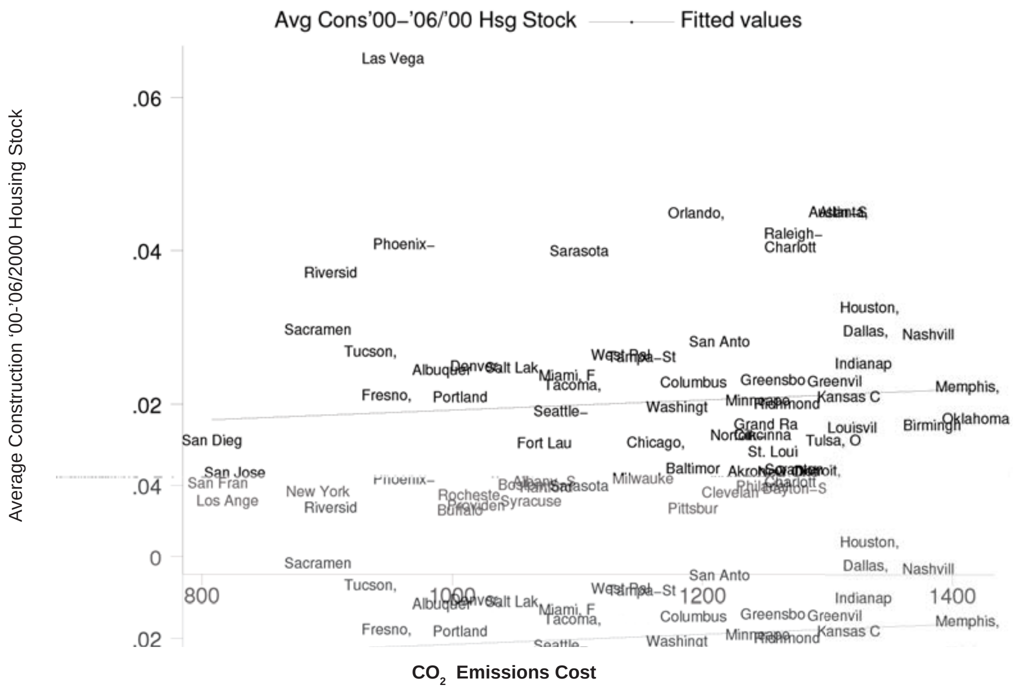
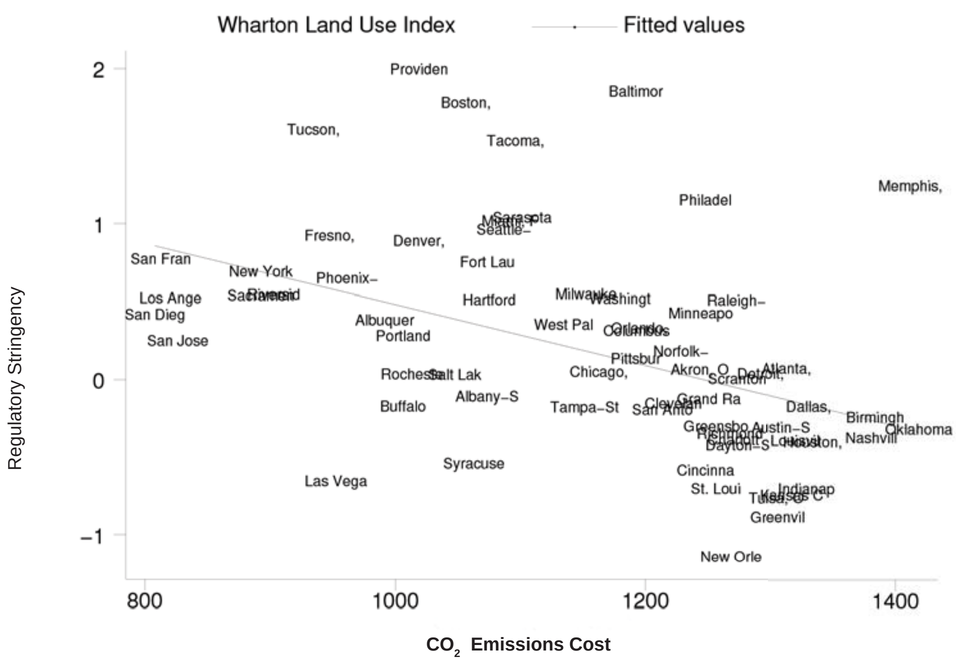


Figure 2: Correlations Between CO_2 Emissions and Wharton Land Use Index, by Region



new households are locating in that energy-conserving state and more households are locating in places that are far less environmentally friendly.

City-Suburb Differences

We now turn to our within-city estimates. To form central city and suburban energy

Table 2: Suburb-City Difference in CO_2 Emissions

MSA Name	Suburb-City Difference in Driving Emissions (Lbs. of CO2)	Suburb-City Difference in Public Transit Emissions (Lbs of CO_2)	Suburb-City Difference in Home Heating Emissions (Lbs of CO_2)	Suburb-City Difference in Household Electicity (Megawatt Hours)	Suburb-City Difference in Cost of CO_2 Emissions	Rank Out of 48 Areas
NewYork, NY	6,172	-2367	6521	2.68	$303	1
Los Angeles - Long Beach, CA	669	-229	-382	-1.72	($36)	47
Chicago, IL	5,479	-2.624	-2,449	0.85	$38	33
Boston, MA	6,573	-1,091	3423	0.90	$214	4
Philadelphia, PA	6,836	-2,286	256	2.35	$185	5
Detroit, MI	4,368	-1,214	-6,702	-0.33	($88)	48
Washington, DC	5,330	-2,280	80	3.41	$180	6
Houston, TX	2,760	-561	675	2.87	$158	7
San Francisco, CA	3,969	-939	1,726	1.82	$142	11
Atlanta, GA	6,375	-1,242	35	3.45	$220	3

estimates on household consumption, we have estimated a separate central city effect in the census-based regressions. This effect holds the impact of metropolitan area and individual characteristics constant, and separately estimates an impact on energy usage for central city and suburban residents. The census central city variable includes not only the primary city within each metropolitan area, but also other areas that qualify as highly urban. For example, within the greater Boston region, Boston qualifies as a central city, but so does Cambridge.

We estimate gasoline usage for each tract using the NHTS estimates described above. We then average across all central city and suburban tracts in each metropolitan area. To allocate public transit energy use, we follow the procedure described above that allocates these emissions on the basis of total population and share of the population that uses public transportation.

Because the central-city status is not well identified for all 66 metropolitan areas in our larger sample, we have calculated the differences in carbon emissions between central cities and suburbs for only 48 of the 66 metropolitan areas. Table 2 presents results for the largest metropolitan areas just like Table 1. The table follows the basic format of Table 1, but instead of reporting regionwide energy use, we report the differences in various forms of energy use between each area's central city residents and suburbanites.

In the first column we show the per-household gap in driving-related emissions between central city and suburban residents in ten metropolitan areas. As expected, older metropolitan areas with dense city centers are particularly likely to see less driving in their urban core. Boston and Philadelphia have the largest gaps between central city and suburban gasoline consumption, not only among these areas, but also across the entire sample of 48 metropolitan areas. By contrast, Los Angeles, where densities do not change significantly between the city and the suburbs, is a dramatic outlier with almost no gap in driving-related emissions between the region's central cities and its suburbs.

In the second column, we show differences in emissions associated with public transportation. These gaps go in the opposite direction of private gasoline consumption, which is unsurprising since central-city residents are much more likely to use public transportation. As before, however, we stress that generally there are far less emissions associated with public transit so that the city-suburb differences in emissions from public transit do not come close to offsetting the city-suburb differences in emissions from driving. For example, in Boston, the emissions gap from driving cars is more than five times the emissions gap from public transportation.

In the third column, we look at city-suburb differences in fuel oil and natural gas used to heat homes. In regions that rely heavily on fuel oil, such as greater Boston and New York, there were particularly large differences between emissions from smaller urban homes and larger suburban ones. Conversely, natural gas consumption was often higher in urban areas. This gap primarily reflects the tendency of suburban homes to be newer. This is a variable where our decision to show results for all housing, instead of housing built within the last ten or twenty years, understates any emissions advantages from urban development.

In the fourth column, we show the differences in electricity usage between central cities and suburbs. These differences are never huge, but they tend to be largest in warmer areas that rely heavily on air conditioning, like Washington, DC and Houston. In contrast, electricity usage is relatively low in greater Boston, and so is the difference between central city and suburban electricity usage. In some areas, such as Los Angeles, electricity usage is actually higher in the region's central cities, probably because of the older housing stock.

The fifth column combines all of the emissions differences between the central city and suburbs across all sources. As before, we convert into tons of carbon dioxide and multiply by $43. In eight out of the ten areas, the emissions costs are higher in suburbs than in central cities. Among those cities where emissions were higher in the suburbs, the costs were generally moderate, between $142 and $220 per year. Only Detroit had an emissions reduction associated with suburban development of more than $40 per year. The high level of emissions in Detroit's central city reflects largely its older housing stock, which is a particularly heavy user of natural gas.

Cold places that rely on fuel oil for home heating, such as Boston and New York, have higher per household emissions than cold places like Chicago that rely more heavily on natural gas.

The sixth column shows the rank of these differences across the entire 48-city sample. For example, Boston has the second largest gap between central cities and suburbs in the entire 48-city sample. Detroit had the least energy use in the suburbs relative to the central city areas in the entire sample. Overall, three-quarters of the metropolitan areas had lower levels of emissions in central cities.

Tract-Level Variation Within Boston

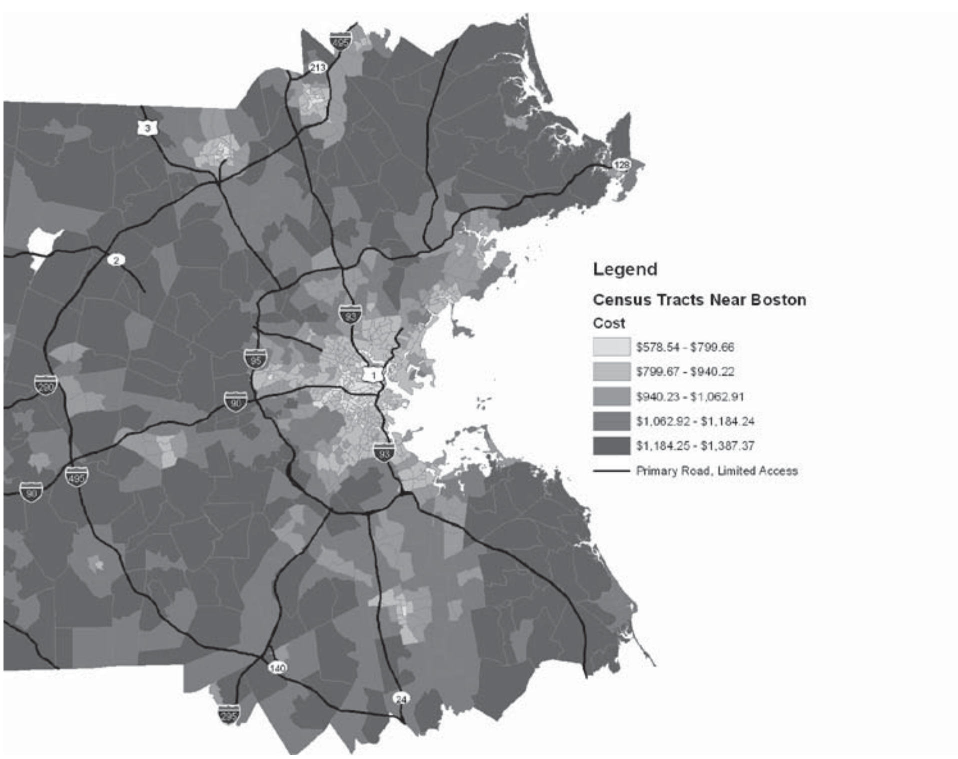
We finally turn to our lowest level of geography, the census tract, to get a better sense of finer differences within the metropolitan area. To form census tract estimates of gasoline usage, we run NHTS gasoline consumption regressions for the Northeast region of the country. We include individual and zip code level characteristics, which will enable us to predict gasoline consumption based on density and distance to the city center. We then use those coefficients to estimate gasoline usage for each census tract in greater Boston. To estimate public transit energy usage, we take total public transit energy expenditures and allocate them across census tracts based on the number of people in each census tract that commute using public transit.

Our most difficult step is to allocate energy usage based on household consumption. Our basic approach is to use tract level housing characteristics, in particular, share of the tract living in single-family detached housing to form a predicted level of household energy consumption using coefficients estimated from individual level census regressions. Adding together the energy predicted from household and transportation sources gives us a total emissions figure for each census tract. As before, we multiply tons of carbon dioxide emissions by $43 to create our measure of total environmental damage per area.

Figure 3 shows a map of greater Boston showing the emissions-related damage for the entire region. The map shows that the region's principle cities, mainly Boston but also Lawrence and Lowell, are estimated to have significantly lower levels of environmental damage than suburban areas. While the average tract within three miles of the Boston city center does $985 of emissions-related harm per year, the average tract between 10 and 12 miles of the city center does $1,275 of emissions-related harm per year.

The gradient of environmental damage is also quite interesting. The big dropoff occurs between five and ten miles from the city center. In those middle areas, people switch from using public transportation to driving more. This is also the area where people switch from living

Figure 3: Emissions-Related Costs in Greater Boston, by Census Tract



in multi-family dwellings to living in larger single-family detached dwellings.

We should stress that these are both estimates and averages. A number of strong assumptions were needed to make these maps and many of them may be problematic. Moreover, these area-wide averages mask the considerable variation within each area. There are certainly plenty of people who live in large homes and drive close to the city center, while there are people who live in apartments and take public transit further away.

Nevertheless, it is not obvious that our approximations are particularly biased in one way or another. For example, we are not including the tendency of suburbanites to live in bigger homes, conditional upon living in a single-family detached home. This omission means that these estimates would tend to underestimate the environmental damage associated with suburban living. Conversely, we are not including the fact that some newer suburban homes may be better insulated and have more energy-efficient appliances, which would work in the opposite direction. It would be a mistake to make environmental policy without much more information, but we do believe that this is a reasonable first step at attempting to catalog the geography of carbon dioxide emissions.

Conclusion

In this policy brief, we give estimates of carbon dioxide across metropolitan areas and between central cities and suburbs within metropolitan areas. We found considerably heterogeneity across metropolitan areas. Greater Boston, like much of the Northeast, falls between the extremes of California and Texas. Bostonians drive less than residents in either of those places, which would make greater Boston greener than those places. However, Bostonians also use a great deal of fuel oil and electricity generated by coal-powered plants, which leads the region to emit more carbon dioxide and therefore, appear to be less green than some places where people drive more.

Boston, like many other areas, has a significant difference in energy-related emissions between its central city and its suburbs. Suburbanites drive extensively and also use a great deal of household energy. Central city residents are especially likely to drive less, much more so than residents of central cities in the Sunbelt. This means that the gains from supporting urban development are much higher in greater Boston and other Northeast metropolitan areas, at least in comparison to many of the Sunbelt's urban areas.

This work is far too preliminary to be a sound basis for particular policies. However, it does emphasize the contradictions of current American land-use policies. Local land-use restrictions cannot stop development in the nation as a whole. They simply have the ability to move development from one area to another. Our current land-use restrictions tend to stop development in those areas, like California, that are environmentally friendly and encourage it in areas, like Texas, where households produce more carbon dioxide. Within metropolitan areas, land use restrictions often push development out towards the urban fringe where energy use is highest. Our results do suggest that it makes sense to look for policies that would encourage building in more environmentally friendly cities and discourage it in areas that have the greatest carbon dioxide emissions.

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