THE GREENNESS OF CITIES: CARBON DIOXIDE EMISSIONS AND URBAN DEVELOPMENT

by

Edward L. Glaeser

Harvard University and NBER

And

Matthew E. Kahn[1]

UCLA and NBER

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Abstract

Recent scientific work suggests that carbon dioxide emissions may create significant social harm because of global warming, yet American urban development has been particularly strong in low density areas with very hot summers. In this paper, we attempt to quantify the Carbon Dioxide emissions associated with new construction in different locations in the country. We look at emissions from driving, public transit, home heating, and household electricity usage. We find that the lowest emissions areas are generally in California and that the highest emissions areas are in Texas and Oklahoma. In general, cities have significantly lower emissions than suburban areas. The city-suburb gap is particularly large in older areas, like New York. There is a strong negative associated between emissions and land use regulations, which suggests that the cleanest areas of the country have chosen to restrict new development in their locales and thereby push that development towards places with higher emissions.

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I. Introduction

An increasing scientific consensus agrees that greenhouse gas emissions create significant risks of climate change. While there remains considerable debate about the expected costs of global warming, a wide range of experts believe that it is reasonable to invest billions to reduce the risks of a major change in the earth's environment and that people should be induced to have a smaller carbon footprint. Some of the most important decisions about greenhouse gases concern urban development and transportation. How should we change our living patterns to respond to the threat of global warming?

In Section II of this paper, we review that basic theory of spatial environmental externalities. If emissions are taxed appropriately, then private individuals will make the right decisions about location choices, but when emissions are not taxed, then location decisions will be inefficient. The optimal location-specific tax on building in one place versus another equals the difference in emissions times the gap between the social cost of emissions and the current tax on these emissions. Even if there was an appropriate carbon tax, location decisions might still be off if governments are subsidizing development in high emissions areas or artificially restricting development in low emissions areas.

In Section III of this paper, we measure household carbon dioxide emissions production in 66 major metropolitan areas within the United States. We look at emissions associated with gasoline consumption, public transportation, home heating (fuel oil and natural gas) and electricity usage. No one micro data set provides the information we need to estimate these quantities. As we discuss below, we use data from the National Household Travel Survey to measure gasoline consumption. We use year 2000 household level data from the Census of Population and Housing to measure household electricity, natural gas and fuel oil consumption. To aggregate gasoline, fuel oil and natural gas into a single carbon dioxide emissions index, we use conversion factors. To determine the carbon dioxide impact of electricity consumption in different major cities, we use regional average power plant emissions factors. Regional emissions factors will reflect the fact that some regions' power is generated by dirtier fuels such as coal while other regions rely more on renewables. In addition to establishing a new set of facts concerning average emissions levels, we also see to understand the environmental consequences of new housing. We examine this by studying how average household emissions of carbon dioxide vary across cities and within cities for homes built in the last twenty years.

Overall, our estimates suggest a range of carbon dioxide emissions from about 19 tons per household per year in San Diego and Los Angeles to about 32 tons in Oklahoma City and Memphis. The older cities of the Northeast tend to lie within those extremes. While they drive less, they need large amounts of heating and produce more emissions as a result. For illustrative purposes, we use a social cost figure of 43 dollars per ton of carbon dioxide, which implies that the social cost of a new home in Houston creates $550 dollars more social cost per year than the social cost of a new home in San Francisco.

Across metropolitan areas, we find a weak positive connection between the level of emissions and recent growth when we weigh by initial population size. We find a strong negative correlation between emissions and the level of land use controls. Overall, the places that are the cleanest are also the most restrictive towards new development. As a result of land use regulations in coastal California, new development has moved to the considerable less restrictive, but also much less green areas of the deep south (Glaeser and Tobio, 2007).

We also use our methodology to compare the emissions in central cities and suburbs for each metropolitan area. In general, central city residence is associated with lower levels of emissions, although there are a few places where that fact is reversed. The place with the most extreme emissions difference between central cities and suburbs is New York, where we estimate that suburban development causes more than 300 dollars more damage in carbon dioxide emissions than central city development.

Our location specific estimates provide new insights concerning the environmental costs (based on a carbon dioxide metric) of current land use restrictions. While we recognize that a pure carbon tax will be a more efficient means of addressing this externality than a tax attached to different places, our estimates do suggest that current land use restrictions may be doing exactly the opposite of what a climate change activist may have hoped. Those restrictions, often implemented for local environmental reasons (such as to preserve neighborhood character or to keep down neighborhood traffic), seem to be pushing new development towards the least environmentally friendly urban areas. We now turn to the basic economics of environmental externalities and urban development.

II. Urban Development and Environmental Externalities

This theory section makes three simple points. First, if emissions are actually taxed at the appropriate rate then there is no need for further spatial policy to improve private decisions about location. Second, if emissions are taxed below the optimal level, then it is appropriate to subsidize the areas that have less energy usage and tax the areas with more energy usage. Third, even with an optimal emissions tax, suboptimal public policies, such as zoning or transport subsidies, may still lead to suboptimal locations.

We outline a simple model where location choice interacts with environmental externalities. We assume that there is a fixed population of size N identical individuals that must choose between I communities, labeled 1, 2, 3, .. I. The population of each community is denoted N_i. Individuals choose their communities and their level of energy consumption. We let "E" denote the amount of energy selected by each individual. This energy choice is meant to include household and transportation-related energy use.

Individuals maximize a quasi-linear utility function:
$Y_i - P_i^H - (P_i^E + \mathrm{t})E + \mathrm{t}\hat{E} + V(E; Z_i) - C(\mathrm{N}\hat{E})$, where Y refers to income, P_i^H refers to housing costs that are specific to region i, P_i^E refers to energy costs which are specific to region i, t refers to an energy tax which is initially independent of region, $\hat{E}$ refers to the average energy consumption in the country as a whole, Z_i refers to attributes of the area which individuals treat as exogenous and $\mathrm{C}(\mathrm{N}\ddot{E})$ represents the costs of global energy consumption that may be associated with climate change. To simplify matters, we assume that this environmental cost is separable from the rest of utility.

Income and housing costs are derived from labor markets and housing markets. Specifically, each region has $\mathrm{Q}_\mathrm{i}^\mathrm{F}$ identical employers who earn revenues, denoted f(.), that are increasing and concave in the number of people hired. Each region also has measure one of builders whose costs, denoted k(.), are increasing and convex in the number of buildings produced. The employers and builders are owned equally by all of the people in the country. These assumptions enable us to write that wage income equals $f'\left(\frac{N_i}{Q_i^F}\right)$, the marginal product of labor, and the cost of housing equals $k'\left(\frac{N_i}{Q_i^F}\right)$, the marginal cost of supplying housing. Each person also gets a share of the total earnings of all business spread through the country, or

$$\hat{\pi} = \frac{1}{N}\left(\sum_i Q_i^F\left(f\left(\frac{N_i}{Q_i^F}\right) - \frac{N_i}{Q_i^F} f'\left(\frac{N_i}{Q_i^F}\right)\right) + Q_i^B\left(\frac{N_i}{Q_i^B} k'\left(\frac{N_i}{Q_i^F}\right) - k\left(\frac{N_i}{Q_i^F}\right)\right)\right).$$

Equilibrium is then determined by two optimality conditions. First, individuals must be choosing their private energy consumption to maximize their utility levels which implies that $P_i^E + t = V_1(E_i^*; Z_i)$. The second equilibrium condition is that individuals must be indifferent between the different locations, which means that $f'\left(\frac{N_i}{Q_i^F}\right) - k'\left(\frac{N_i}{Q_i^F}\right) - (t + P_i^E)E_i^* + V(E_i^*; Z_i)$, must be constant across space.

Social optimality requires the optimization of:

$$\sum_i Q_i^F f\left(\frac{N_i}{Q_i^F}\right) - Q_i^B k\left(\frac{N_i}{Q_i^F}\right) + N_i\left(V(E_i; Z_i) - P_i^E E_i - C(N\hat{E})\right) \tag{1}$$

over energy choices and location. This yields first order condition for energy consumption: $P_i^E + NC'(N\hat{E}) = V_1(E_i; Z_i)$, which gives the standard result that the private optimality condition will be equivalent to the social optimality condition if $t = NC'(N\hat{E})$. The first order condition for social optimality locations is that $f'\left(\frac{N_i}{Q_i^F}\right) - k'\left(\frac{N_i}{Q_i^F}\right) + V(E_i; Z_i) - \left(P_i^E + NC'(N\hat{E})\right)E_i$ must be constant across space. This condition is also satisfied if $t = NC'(N\hat{E})$. There is no need for any added spatial policies if energy is properly taxed.

What is the optimal allocation of people across areas if energy is undertaxed? If energy use in an area is independent of the number of people in that area, then the condition for social optimality continues to be that $\mathrm{f}'\left(\frac{\mathrm{N_i}}{\mathrm{Q_i^F}}\right) - \mathrm{k}'\left(\frac{\mathrm{N_i}}{\mathrm{Q_i^F}}\right) + V(E_i;Z_i) - \left(P_i^E + NC'(N\hat{E})\right)E_i$ is equal across space. In the competitive equilibrium, $\mathrm{f}'\left(\frac{\mathrm{N_i}}{\mathrm{Q_i^F}}\right) - \mathrm{k}'\left(\frac{\mathrm{N_i}}{\mathrm{Q_i^F}}\right) - \left(\mathrm{t} + P_i^E\right)E_i^* + V(E_i^*;Z_i)$ is constant across space. If $\mathrm{t} \neq NC'(N\ddot{E})$, then the spatial equilibrium is not Pareto optimal because people don't consider the externalities associated with their energy use when they change locations.

In this case, imposing a location specific tax equal to $E_i^*\left(NC'\left(N\hat{E}\right) - t\right)$ transforms the competitive equilibrium into a second best Pareto optimum. In comparing any two areas, the difference in tax payment for area i versus area j should equal $\left(E_i^* - E_j^*\right)\left(NC'\left(N\hat{E}\right) - t\right)$, the difference in energy usage times the difference between the optimal tax and the current tax. Our primary empirical exercise will be to calculate these quantities for different areas.

We now use the same model to ask when local environmentalism is good environmentalism. We will treat local environmentalism by assuming that a location has imposed a location specific tax, τ_i, on energy usage in that state. We will assume that revenues from this tax are rebated to the residents of the state.

In this case, the first order condition for energy consumption is $P_i^E + t + \tau_i = V_1(E_i^{**}(\tau_i);Z_i)$, which defines a function $E_i^{**}(\tau_i)$, mapping local energy taxes into local energy use. Second order conditions give us that $E_i^{**\prime}(\tau_i) < 0$. Higher taxes will lead to local energy decisions that are better from a global perspective as long as $t + \tau_i < \mathrm{NC}'(\mathrm{N}\ddot{\mathrm{E}})$.

Will a unilateral increase in a local energy tax increase welfare? We ask this relative to a free market setting with no location-specific taxes and where $t < \mathrm{NC}'(\mathrm{N}\ddot{\mathrm{E}})$. We also simplify algebra by reducing the world to only two regions—the region that is raising its local energy tax (denoted region 1), and everywhere else (denoted region 2).

The spatial equilibrium is:

$$(2)\ \mathrm{f}'\left(\frac{\mathrm{N}_1}{\mathrm{Q}_1^{\mathrm{F}}}\right)-\mathrm{k}'\left(\frac{\mathrm{N}_1}{\mathrm{Q}_1^{\mathrm{B}}}\right)-(\mathrm{t}+P_1^E)E_1^{**}(\tau_1)+V(E_1^{**}(\tau_1);Z_1)=$$

$$\mathrm{f}'\left(\frac{\mathrm{N}-\mathrm{N}_1}{\mathrm{Q}_2^{\mathrm{F}}}\right)-\mathrm{k}'\left(\frac{\mathrm{N}-\mathrm{N}_1}{\mathrm{Q}_2^{\mathrm{B}}}\right)-(\mathrm{t}+P_2^E)E_2^{*}+V(E_2^{*};Z_2)$$

Differentiating this with respect to τ_1 yields:

$$\frac{\partial \mathrm{N}_1}{\partial \tau_1}=\frac{E_1^{**\prime}(\tau_1)\left(V_1(E_1^{**}(\tau_1);Z_1)-\left(t+P_1^E\right)E_1^{**}(\tau_1)\right)}{\frac{1}{\mathrm{Q}_2^{\mathrm{B}}}\mathrm{k}''\left(\frac{\mathrm{N}-\mathrm{N}_1}{\mathrm{Q}_2^{\mathrm{B}}}\right)+\frac{1}{\mathrm{Q}_1^{\mathrm{B}}}\mathrm{k}''\left(\frac{\mathrm{N}_1}{\mathrm{Q}_1^{\mathrm{B}}}\right)-\frac{1}{\mathrm{Q}_1^{\mathrm{F}}}\mathrm{f}''\left(\frac{\mathrm{N}_1}{\mathrm{Q}_1^{\mathrm{F}}}\right)-\frac{1}{\mathrm{Q}_2^{\mathrm{F}}}\mathrm{f}''\left(\frac{\mathrm{N}-\mathrm{N}_1}{\mathrm{Q}_2^{\mathrm{F}}}\right)}<0.$$

The energy tax will unambiguously reduce the number of people living in area one. This effect might be quite small, especially if the tax is modest, because the tax impacts migration behavior only by inducing people in area one to consume too little energy relative to the privately optimal level of energy consumption in the absence of this tax.

Returning to the social welfare function, we can now note that the tax in region 1 improves overall social welfare if and only if:

$$(3)\ E_1^{**\prime}(\tau_1)\mathrm{N}_1\left(t+\tau_1-\mathrm{N}C'(N\hat{E})\right)>\frac{\partial \mathrm{N}_1}{\partial \tau_1}(E_1^{**}(\tau_1)-E_2)\left(\mathrm{N}C'\left(N\hat{E}\right)-t\right)$$

If energy usage in region one is greater than energy usage in region two (the rest of the world), then the impact of added energy taxes in that region must have a positive effect on welfare. In that case, the tax is achieving two desirable outcomes. First, it is reducing energy consumption in region one, and making energy consumption in that region closer to the social optimum. Second, it is reducing the number of people living in region one, which is also desirable since region one is a high energy using area.

If region one is using less energy than region two, then the situation is more ambiguous. If the migration margin is very large then it is at least conceivable that this tax will make the energy problem more problematic. The equation certainly implies that imposing a local tax that sets $t+\tau_1=\mathrm{N}C'(N\ddot{E})$ is certainly sub-optimal, since in that case the gains from reducing the tax on the migration margin will exceed the costs of reducing the tax in terms of increased energy usage in region one.

We suspect that in many cases, this is more of an economic curiosity than a real concern. Many energy taxes seem too small to really impact migration behavior, at least if the taxes are rebated to residents in some way. However, environmentally inspired land use restrictions seem more likely to have counterproductive results.

To model these interventions, we assume that location one has imposed a tax on new construction equal to z_1, which is meant to refer to a "zoning tax." With this tax, the first order condition for builders in location one equals $(P_1^H - z_1) = k'(h)$, where h refers to the total number of homes built by an average builder in the area. In equilibrium, h will equal $\frac{N_1}{Q_1^B}$. We assume that this tax is rebated, but if the tax is rebated on a one-for-one basis to the marginal resident of community one, then the tax will have absolutely zero impact. In that case, the tax is essentially being charged to suppliers and returned to consumers and it is a relabeling of prices. We assume, therefore, instead that the tax either goes to infra-marginal residents of the community or that it is shared across both communities.

In this case, the spatial equilibrium is:

$$(4)\quad f'\left(\frac{N_1}{Q_1^F}\right) - k'\left(\frac{N_1}{Q_1^B}\right) - z_1 - (t + P_1^E)E_1^* + V(E_1^*; Z_1) =$$

$$f'\left(\frac{N-N_1}{Q_2^F}\right) - k'\left(\frac{N-N_1}{Q_2^B}\right) - (t + P_2^E)E_2^* + V(E_2^*; Z_2)$$

The impact of increasing the zoning tax will be to reduce the number of people in community one. Specifically, $\frac{\partial N_1}{\partial z_1} = \frac{-1}{\frac{1}{Q_2^B}k''\left(\frac{N-N_1}{Q_2^B}\right) + \frac{1}{Q_1^B}k''\left(\frac{N_1}{Q_1^B}\right) - \frac{1}{Q_1^F}f''\left(\frac{N_1}{Q_1^F}\right) - \frac{1}{Q_2^F}f''\left(\frac{N-N_1}{Q_2^F}\right)} < 0$. This zoning tax has no direct impact on energy usage, but it does reduce the number of people in area one.

The overall impact of this on social welfare is: $\frac{\partial N_1}{\partial z_1}\left((E_2 - E_1)\left(NC'\left(N\hat{E}\right) - t\right) + z_1\right)$

Which is positive so long as $(E_1 - E_2)\left(NC'\left(N\hat{E}\right) - t\right) > z_1$. If the area that is zoning is also the high energy user, then the zoning tax will be efficient, at least until the point where the tax equals the difference in energy usage times the difference between the social cost of energy use and the current tax. However, if the zoning tax is imposed in areas that have particularly low energy use, then it is counter-productive. This motivates our empirical exercise looking at whether areas that are particularly prone to use land use restrictions are also areas that have high levels of energy use.

We now turn to our estimates of the connection between different energy use and location. Our goal is to separate the U.S. across both metropolitan areas and within metropolitan areas. Within metropolitan areas, we will separate living in the urban core, which tends to involve less driving and more living in apartments, from living on the urban edge.

III. Greenhouse Gas Emissions Across Metropolitan Areas

We now turn to estimating the quantity of carbon dioxide emissions that households produce in 66 major metropolitan areas. Our goal is to calculate the marginal impact of an extra household in location j on the total carbon dioxide emissions of that location. This will involve two steps. First, we will calculate a predicted usage of gasoline and electricity. Second, we will convert gas and electric usage into carbon dioxide emissions. The conversion factor for gasoline is uniform across space; the conversion for electricity is not since different regions generate electricity in ways that are more or less clean.

In the model above, the average energy usage in an area also equals the marginal energy created by a new resident. In some cases, like the use of gasoline while driving, the marginal resident will probably use gasoline in more or less the same way as the average resident. In others, like the use of electricity by commuter rail, there may be substantial fixed costs, and the marginal resident may impact energy usage by less than the amount implied by the average resident. In the case of residential electricity, the marginal resident could involve a move to a newer, and less harmful means, of providing electricity. This would also mean that the marginal resident's impact is less than that of the average resident. Nonetheless, data limitations will induce us to use average energy usage. Of course, to the extent that all regions have a similar relationship between marginal and average usage, then the implications of this work for inter city comparisons, may not be terribly effected by our inability to measure true marginal impacts.

We will consider four main sources of carbon dioxide emissions: private within-city transport, public transportation, residential heating (natural gas and fuel oil) and residential electricity. We are not considering the impact of shifting people on the energy emissions associated with moving goods and we are not considering the impact of shifting people on industrial output. The problem of figuring out how the entire transport network will change is beyond the scope of this paper. The problem of figuring out how population change impacts industrial location is also quite hard. Much of modern industry is extremely capital intensive and has low transport costs, and it might not move that much in response to a population shift.

We begin with car and public transportation emissions. We then turn to fuel oil. Both car-based transportation and fuel oil use petroleum and it is easy to convert this energy use into carbon dioxide emissions. We then turn to residential energy usage and commuter rail. These technologies rely on electricity and we will have to convert megawatt hours of usage into carbon dioxide emissions by using information about the carbon dioxide emissions associated with electricity production in different regions of the county.

Car Usage and Emissions

We begin with estimating gasoline usage across metropolitan areas. Our primary data source is the 2001 National Household Transportation Survey (NHTS). This data source contains information on household characteristics and reported annual gasoline consumption. We also have zip code identifiers so that we can use zip code characteristics to predict gasoline usage. We use these zip code identifiers to calculate each household's distance to the metropolitan area's Central Business District.

Our primary approach is to use the NHTS to predict gasoline usage based on individual and zip code level characteristics. We regress:

$$(5)\qquad Gasoline = \sum_j \beta_j Z_k^j + \sum_q \gamma_q X_i^q + \mu_k + \varepsilon_i$$

where Z_k^j refers to the value of zip code characteristic j in zip code k, β_j reflects the impact of those variables, X_i^q refers to the value of individual level q for person i, γ_q is the coefficient on that characteristic and the other two terms are individual level and zip code level error terms. Since there are a significant number of truly extraordinary outliers, and since we are running this regression in levels rather than logs, we top code the top one percent of the sample. The results of this equation are shown in Table 1.

The overall r-squared of the equation is 30 percent. Family size and income strongly increases gas consumption, so it is important to control for these characteristics. Zip code density substantially reduces gasoline usage and so metropolitan area density. Larger distances between people lead to longer drives. We also interact census tract density with region and find that the density-gas consumption relationship is much weaker in the West. Distance to the metropolitan's central business district also increases average gasoline consumption, which is not particularly surprising.

We then take these coefficients and predict gasoline usage for a family with an income of 62,500 dollars and 2.62 members for each census tract located within 66 major metropolitan areas. Specifically, our predicted value for a census tract with characteristics Z_k^j is $\sum_j \beta_j Z_k^j + \sum_q \gamma_q X_{Ave}^q$, where X_{Ave}^q denoted the individual characteristics of a standardized individual. We then form metropolitan area averages by aggregating up from the tract level using the tract's household count as the weights.

These estimates have the advantages of controlling for household level income and size, but they are, of course, imprecise. We are only using two primary characteristics for each tract, its proximity to downtown and its density. As such, there will be an almost automatic relationship between urban sprawl and gasoline usage since gasoline usage decreases with density and increases with distance from downtown. There is a less automatic connection between gasoline consumption and city size, which is shown in Figure 1. On average, a .1 log point increase in city size is associated with a 7.3 gallon reduction in the consumption of gallons of gas.

An alternative approach would be to run regression (5) using metropolitan area fixed effects instead of region fixed effects, and then to use those metropolitan area fixed effects as our measure of gasoline usage. In this case, we would have been restricted to a much smaller number of metropolitan areas since only a few metropolitan areas have more than 50 observations in the sample. The correlation between our measure and the measure estimated using metropolitan area fixed effects is high.

We will be interested in estimating both the average emissions for each household and also the marginal emissions associated with new construction in a particular area. To estimate the marginal emissions, we start with our coefficients shown in Table 1 and then again use them to predict gasoline consumption for each census tract. To calculate marginal emissions for the metropolitan area, we weight census tracts not by current population levels, but instead by the amount of housing built between 1980 and 2000. If the location of housing in the near future looks like the location of housing in the near past, then the location of recent construction gives us some idea about where new homes will go.

On average, the housing built in the last 20 years is associated with 47 more gallons of gas than the total housing stock. As such, we believe that this adjustment makes sense, but it is worth emphasizing that it makes little difference to the cross-metropolitan area rankings. Estimated metropolitan area gasoline consumption using the total population of each census tract or the number of houses built since 1980 yields almost identical estimates. The correlation coefficient between these two measures is .96.

To convert gallons of gasoline into carbon dioxide emissions, we multiply first by 19.564. This is a standard factor used by the Department of Energy (http://www.eia.doe.gov/oiaf/1605/factors.html). We also increase the estimated total emissions by 20 percent to reflect the energy used in refining and distribution. This number is based on an 83 percent energy efficiency figure for gasoline (http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2000_register&docid=00-14446-filed.pdf). Overall, then, each gallon of gasoline is associated with 23.46 pounds of carbon dioxide emissions.

Public Transportation

We now turn to the emissions associated with public transportation. There are no adequate individual surveys that can inform us about energy usage by bus and train commuters. Instead, we turn to aggregate data for each of the nation's public transit systems from http://www.ntdprogram.gov/ntdprogram/. For all of the nation's public transit systems, this data source provides us with information about energy used, which takes the form of gasoline in the case of buses and electricity in the case of rail. The data does not tell us about private forms of public transit, such as private bus lines or the Las Vegas monorail.

For each bus or rail system, the data set provides us with the zip code of their headquarters. We then assign each zip code to the relevant metropolitan area. We then add up all of the gasoline used by bus systems and all of the electricity used by rail systems within each metropolitan area. This provides us with total energy usage by public transit for each metropolitan area.

To convert, energy use into carbon dioxide emissions, we continue to use a factor of 19.546 for gasoline, and again increase that factor by 20 percent to reflect the energy used in refining and distribution. The conversion for electricity is somewhat more difficult, as we use different conversion factors for electricity in different parts of the country. We will discuss those factors later when we discuss our estimates of emissions due to home electricity usage. By combing emissions from gas and emissions from electricity, we estimate a total emissions figure within the metropolitan area. To convert this to a household-level figure, we simply divide by the number of households in the metropolitan area.

While we have some chance of distinguishing marginal from average emissions in the case of car-related gasoline consumption, we have little chance of making such a distinction in the case of public transportation. There are two reasons why the marginal emissions from a new household might not be the same as the average emissions for an existing household. First, the marginal household might be more or less inclined to use public transportation. Second, even if the marginal household uses public transport, we do not know how much extra energy this will entail. Typically, we think of some public transit technologies as having large fixed costs, which could mean that the marginal costs are quite low. However, in some cases, new development may mean that a new bus line is extended to a newer, lower density area, and in this case, the marginal costs might be quite high.

Since we lack the data to make an effective estimate of the marginal effect, we will use the average emissions from public transit throughout this paper. We are not inclined to push too hard on this topic, because in general the emissions from public transit are much lower than the emissions associated with driving. On average, the emissions from private automobiles are fifty times higher than the emissions from driving, so this source of emissions is not terribly crucial for estimates.

Household Heating

We now turn to the emissions from household heating sources: fuel oil and natural gas. Fuel oil is rare in the United States outside of the Northeast, and is an important source of home heating in only a few metropolitan areas. Natural gas is the more common source of home heat. In some areas, electricity also provides heat, but we will deal with electricity in the next section.

For our purposes we need a large representative sample that provides information by metropolitan area on household heating. The Department of Energy's Residential Energy Consumption Survey is too small of a data set to address our needs (http://www.eia.doe.gov/emeu/recs/recs2001/publicuse2001.html). Instead, we use data from the 2000 Census five percent micro-sample (IPUMS). This data set provides information for each household on its expenditure on electricity, natural gas and fuel oil.

The key problem with the IPUMS data is that we are interested in household energy use, not energy spending. Conveniently, the Department of Energy provides data on prices for natural gas (http://www.eia.doe.gov/emeu/states/_seds.html) and fuel oil (http://tonto.eia.doe.gov/dnav/pet/pet_sum_mkt_a_EPD2_PRT_cpgal_a.htm) for the year 2000. These prices are at the state level, so we miss variation in costs within the state. We use these prices to convert household energy expenditure to household energy consumption.

One particular problem with this data is the possibility that energy usage by renters is not reflected in this data because renters are charged for their electricity as part of their rent. Indeed, when we look at the frequency of reported zero expenditure in different metropolitan areas, we find that these tend to be disproportionate among renters and other residents of single family detached houses. In these cases, it is impossible to know whether a zero value for expenditure truly indicates that the household does not consume this particular fuel or whether the household just doesn't pay directly for that energy.

Using our entire IPUMS data, we estimate:

(6) Energy Use=a*Log(Income)+b*Housing Size +c*Age of Head+ MSA Specific Constant

In the case of natural gas in the New York City area, for example, we estimate:

(6') $$Natural\ Gas = \underset{(2.5)}{-138} + \underset{(.21)}{13} * \mathrm{Log(Income)} + \underset{(.15)}{9.8} * \mathrm{Size} + \underset{(.02)}{.81} * \mathrm{Age}$$

Standard errors are in parentheses. There are 104,977 observations and the r-squared is .09. We estimate similar regressions for fuel oil and electricity consumption.

We then use this regression to predict the natural gas and fuel oil consumption for a household with an income of 62,500 dollars and 2.62 members. We are trying to correct for individual characteristics, but we are not trying to correct for housing characteristics. After all, we are not attempting to estimate emissions assuming that people in Houston live in New York City apartment buildings. The buildings of an area are a key component in emissions and we want to include that.

Natural gas consumption is driven primarily by climate. Figure 2 shows the correlation between our estimated natural gas consumption and January temperature. We do not find this -.81 correlation coefficient surprising, but it does suggest that our results are quite reasonable.

For fuel oil and natural gas, there are again conversion factors that enable us to move from energy use to carbon dioxide emissions. In the case of fuel oil the relationship between gallons burned and carbon dioxide emissions is 22.38 pounds of carbon dioxide per gallon of fuel oil. We again increase this number by 20 percent to reflect the energy used in refining and distributing. According to the same source (http://www.eia.doe.gov/oiaf/1605/factors.html), there are 120.59 pounds of carbon dioxide emissions per 1,000 cubic feet of natural gas. In this case, there is much less energy involved in distribution so we use this conversion factor without any adjustment. We combine the emissions from natural gas and fuel oil to form an estimate of total home heating emissions.

To examine the impact of a marginal home, we repeat this procedure using only homes built between 1980 and 2000. Since older homes are less fuel efficient, the average home will overstate true energy use, especially in older areas of the country. We use only homes built within the last 20 years to minimize this effect. In principle, we could have used only homes built in the last five or ten years, but our sample sizes become too small if we limit our samples in this way. We will refer to these estimates as our estimates of marginal heating emissions.

Household Electricity

In the case of electricity consumption, we begin with the same IPUMS-based procedure used for fuel oil and natural gas. We use state-wide price data to convert electricity expenditure into consumption in megawatt hours (http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html.) We then regress this consumption on household characteristics, metropolitan area by metropolitan area. Following this strategy, we predict household annual electricity consumption for each metropolitan area for a standardized household with 2.62 people earning an annual income of $62,500.

In the case of electricity, consumption rises most sharply with July temperatures. Figure 3 shows this relationship. The correlation is relatively strong (.61) but there are some significant outliers in the Pacific Northwest. These places must have either particularly high appliance usage or heavy use of electricity for home heating.

The conversion between energy usage and carbon dioxide emissions is considerably more complicated for electricity than it is for natural gas or fuel oil. If we had a national market for electricity, then it would be appropriate to use a uniform conversion factor, but since electricity markets are regional, we must allow for different conversion factors in different areas of the country. There is considerable heterogeneity in the emissions for megawatt hour of electricity in areas like the Northeast that rely on coal and areas like the West Coast that use more hydroelectric energy.

What is the natural geographic area to use to calculate the emissions related to electricity usage? In principle, one could calculate anything from a national average of emissions per megawatt hour to a block specific figure. Using smaller levels of geography certainly increases the accuracy with which emissions are allocated to electricity usage. However, if electricity is perfectly substitutable between two places, then this precision is somewhat misleading. In the case of perfect substitutability, then the relevant consideration is not the actual greenness of the particular area's supplier, but rather the average emissions of the entire area.

To see this, assume that there are two electricity providers that supply a given region and there are two subareas within that region. Assume that each provider has an identical cost curve, C(E) which is upward sloping and convex. The first provider is a clean provider and creates no emissions for each unit of electricity produced. The second provider is a dirty provider and emits "q" pounds of carbon dioxide for each unit of electricity produced. In equilibrium, the price of electricity will equal C'(E) the margin cost of producing electricity for each of the providers. An increase in demand will impact both providers equally and on average q/2 pounds of carbon dioxide will be emitted for each extra unit of electricity.

What will be the impact on emissions of a new resident in the region that increases electricity consumption by "e" units. The total emissions will increase by qe/2, the average emissions rate. It doesn't matter if this new resident buys disproportionately from the clean or the dirty provider. Since these two providers are perfect substitutes, if the new resident buys from the clean provider, then someone else will be buying from the dirty provider. For this reason, it makes sense to consider the average emissions within the market not the individual emissions of one particular place.

The North American Electric Reliability Corporation (NERC) has divided the U.S. into eight electricity markets. While electricity within these regions is not perfectly fungible and there is some leakage across NERC regions, there is much more substitutability of electricity within NERC regions than across regions. The difficulties involved in transmitting electricity over long distances mean that it is not wildly inappropriate to treat these markets as more or less closed systems. Since electricity in one region cannot readily substitute for electricity in another region, it is reasonably appropriate to treat electricity in each NERC region separately.

Data on NERC region emissions comes from the eGRID, or Emissions & Generation Resource Integrated Database data base (see http://www.epa.gov/cleanenergy/egrid/index.htm). The eGRID data base contains the emissions characteristics of virtually all electric power in the United States and includes emissions and resource mix data for virtually every electricity-generating power plant in the U.S. eGRID uses data from 24 different federal data sources from three different federal agencies: EPA, the Energy Information Administration (EIA), and the Federal Energy Regulatory Commission (FERC). Emissions data from EPA are integrated with generation data from EIA to create the key conversion factor of pounds of carbon dioxide emitted per megawatt hour of electricity produced (lbs/MWh). This conversion factor allows us to compare the environmental attributes of more than 4700 power plants.

Using eGRID, we calculate the emissions for megawatt hour for each of the NERC regions. There is remarkable heterogeneity across these regions. For example, the relatively clean San Francisco NERC generates 1000 pounds of carbon dioxide for each megawatt hour of electricity. The less clean Philadelphia NERC generates 1600 pounds of carbon dioxide for each megawatt hour. Naturally, this reflects the historical mix of power in these areas, which may only imperfectly capture the mix of power sources used to generate new energy in the future.

We then use these conversion factors to turn household electricity usage into carbon dioxide emissions for each metropolitan area. We use the same conversion factor to handle the electricity consumption of commuter rails. To consider the impact of the marginal home, as above, we restrict our IPUMS estimates to homes built only between 1980 and 2000.

Overall Rankings

We finally turn to an overall ranking of metropolitan areas based on carbon dioxide emissions. Table 2 lists the 66 largest metropolitan areas for which we have data. The first column shows our emissions from predicted gasoline consumption within each metropolitan area, which was created by using the coefficients on area level characteristics from NHTS regression, using census tract characteristics to predict gasoline consumption for an average person in that census tract, and then aggregating the census tracts up to form a metropolitan area average.

There is considerable range in the consumption of gasoline at the metropolitan area level. The New York metropolitan area is estimated to use the least gasoline, which reflects its high degree of employment and population concentration and its relatively heavy use of public transportation. Greenville, South Carolina, is estimated to have the most gasoline consumption. The gasoline-related emissions in Greenville are almost twice as high as the gasoline-related emissions in New York City.

The second column reports our results on per household energy emissions due to public transportation. This adds together rail and bus emissions and converts both by appropriate factors to arrive at carbon dioxide emissions. There is, of course, considerable heterogeneity. Per capita emissions from public transportation in New York City are more than 6,000 pounds of carbon dioxide from public transit per capita. Las Vegas has no emissions from public transportation. However, even in New York, these emissions are relatively modest relative to the contributions of cars, which reflects the fact that public transportation generally involves far fewer emissions than automobiles.

The third column gives our results on fuel oil and natural gas. Again, the results show a fair amount of regional disparity. Detroit leads the country in home heating emissions and Boston is a close second. Much of the West has almost no emissions from home heating. In general, places that use fuel oil have much higher emissions than places that use only natural gas, which explains why emissions from this source are much lower in Chicago than in Detroit.

The fourth column shows electricity consumption and the fifth column shows the NERC-based conversion factor for converting electricity into emissions. To calculate electricity related emissions in each area, the fourth and fifth columns need to be multiplied together. We show these columns separately to illustrate the role of electricity usage versus the role of clean electricity production. New Orleans is the leader in electricity usage, while New Yorkers consume the least electricity. San Diego has the second lowest electricity usage in our data.

The sixth column sums together all of the different sources of carbon dioxide emissions. The table is ordered by the amount of these emissions. California cities are blessed with a temperate climate and they use particularly efficient appliances and produce electricity in particularly clean ways. The five cities with the lowest emissions levels are all in California. New York, which has the least amount of driving and particularly low electricity usage, has the sixth highest level of emissions.

The high emissions cities are almost all in the South. These places have large amounts of driving and very high electricity usage. Their electricity usage is also not particularly clean. Texas is particularly well represented among the places with the highest levels of emissions. Oklahoma City has the absolute highest level among our 66 metropolitan areas. Indianapolis is the northernmost place among our ten highest emission metropolitan areas.

New construction in the Northeast is generally between those extremes. These places use moderate amounts of electricity. They drive less than Californians, but use large amounts of fuel oil. The Midwest looks generally similar to the Northeast, but larger amounts of driving push gasoline emissions up.

Finally, in column seven, we multiply total emissions by 43 dollars per ton to find the total emissions-related externality associated with an average home in each location. The 43 dollar number is somewhat arbitrary, and we are using it purely for illustrative purposes. It is conservative relative to the Stern report, which suggests a cost of carbon dioxide that is twice this amount, but it is considerably more aggressive than the numbers used by Nordhaus (2006). Tol (2005) is one meta-study that also suggests that this number may be somewhat too high.

Using this figure, the range of costs associated with each new home goes from 808 dollars in San Diego to more than 1400 dollars in Oklahoma City. This 600 dollar gap is an annual flow, and at a discount rate of 5 percent, this would suggest a tax of 12,000 dollars on every new home in Oklahoma city relative to San Diego, which would mean a 10 percent increase in the cost of housing in Oklahoma. If we used a 30 dollar per ton number for the social cost of carbon dioxide, then the appropriate tax would fall by 30 percent to 837 dollars.

Table 3 shows the results for our estimates of marginal emissions. In this case, we calculate gasoline consumption based on the census tracts where new housing has been built. We calculate housing energy usage using only homes built between 1980 and 2000. The structure of the table is the same, and in the first column we show the results for gasoline consumption.

In every case, the gasoline consumption estimated for tracts with new housing is higher than the gasoline consumption estimated for average housing. The gap is particularly large in older cities like New York and Philadelphia, where much of the new construction has been on the urban fringe. For newer Sunbelt cities, there is no material difference since much of these places has been built in recent decades. While the correction for the location of new housing does increase gasoline-related emissions everywhere, and especially in New York, it does not change the basic ordering of cities. New York is still the lowest gasoline user and Greenville is still the highest. The second column shows public transit related emissions and this is unchanged from Table 2.

In the third column, we show the emissions from home heating sources. In this case, looking at recent homes causes a reduction in estimated emissions by more than 900 pounds of Carbon Dioxide per year. Again, however, the rankings of the metropolitan areas are quite similar. The correlation between marginal and average estimates is more than 98 percent. The fourth column looks at electricity usage considering only recent construction. Again, there is a modest reduction in the amount of electricity usage, but the correlation between average electricity usage and marginal electricity usage is close to 99 percent. Column five continues to show the NERC-based conversion factors which are unchanged.

Column six then shows our total emissions estimates and column seven multiplies those estimates by 43 dollars per ton. The most visible effect of moving to marginal homes is to push the New York area downward, out of the top ten. Now the top ten metropolitan areas with low emissions are all in the far West. Boston also drops somewhat in the rankings.

To get an idea of the correlates of these different sources of emissions, Table 4 regressions emissions from the four different sources on the logarithm of average city income, the logarithm of city population, average January temperature and average July temperature. We also include a measure of the share of city centralization: the share of the population within five miles of the city center.

The first column shows the correlates of private transportation related emissions. Income is uncorrelated with gasoline usage at the metropolitan level. At the individual level, there is a strong connection between gasoline consumption and income, but these estimates are supposed to correct for that relationship and they seem to do that. Larger metropolitan areas have somewhat less driving, which reflects the fact that these cities are somewhat denser. Cities with more concentration of population have less driving. As the share of population within five miles of the city center increases by 10 percent, carbon dioxide emissions from driving decreases by 1300 pounds. Finally, places with warm Januarys have less driving, but places with hot Julys have more driving. These correlations are presumably spurious, and reflect other variables, like the degree of sprawl, associated with these weather variables.

The next regression shows the correlates of public transit emissions. In this case, city population is the only variable that is strongly correlated with emissions. Bigger cities are more likely to have extensive public transit systems. There is also a weak correlation between this outcome and the concentration of population within five miles of the city center.

The third regression looks at the relationship between home heating related emissions and the area-level variables. There is an extraordinarily strong correlation between this variable and January temperature, which was discussed above. July temperatures also weakly increase home heating emissions. None of the other variables are strongly correlated with this outcome variable. The power of temperature to predict home heating emissions explains why the r-square for this regression is higher than for any of the other regressions in this table.

The fourth regression correlates electricity related emissions with our independent variables. Areas that are more geographically concentrated have lower levels of electricity usage and lower emissions. The strongest determinant of home electricity usage in this regression, unsurprisingly, is July temperature. Still, the ability of the weather to explain electricity is weaker than the ability of the weather to explain home heating emissions.

Finally, the fifth regressions look at the correlates of total emissions. In this case, all of the variables except for city income are statistically significant. More populous cities have lower emissions, and this is being driven both by less electricity usage and by less driving. More decentralized cities have higher emissions, and this reflects less electricity and less driving. Places with milder Januarys have lower emissions, which is the result of less use of artificial heat. Places with hotter Julys have higher emissions, which reflects the greater use of electricity.

As such, these regressions suggest that there are several different variables associated with lower levels of emissions at the city level. Older dense cities have lower emissions, but not if they are particularly cold. The temperate Sunbelt uses little electricity, but not the places with particularly hot summers.

One question we can ask is whether there is a connection between low emissions and city growth. Figure 4 shows the correlation between these marginal cost estimates and development in the area since 2000. Our dependent variable is the ratio between average annual housing permits in the area since the year 2000 and the total stock of housing in these places in the year 2000. This measure captures the extent to which the area is building new homes.

The overall relationship is basically flat, which suggests that current development patterns are neutral towards emissions. Unfortunately, that conclusion may be a bit optimistic because the correlation becomes significantly positive if we weight by the initial population of the area. The flat relationship that we see is driven primarily by Las Vegas and

Phoenix, two areas that have high levels of growth and low levels of emissions. Without those areas, the relationship between growth and emissions becomes more strongly positive.

One possible reason for this admittedly weak relationship between new construction and per household emissions is land use regulations. As Figure 5 shows, there is a strong negative association between the Wharton Land Use Regulation Index and carbon dioxide emissions. Places with the least emissions tend also to regulate most heavily. This relationship is strongly statistically significant.

The negative connection between land use regulation and emissions is perhaps unsurprising. Environmentalists have fought both to reduce emissions and to restrict new development. In California, they have been successful in both fights. The result of this combination of activities is that the places with the lowest emissions in the country are also the places that have made it most difficult to build.

IV. Greenhouse Gas Emissions within Metropolitan Areas

In the previous section, we focused on cross-metropolitan area implications of greenhouse gas emissions. We now turn to the implications within metropolitan areas. In particular, we focus on central cities versus suburbs. After all, locating in central cities generally involves far less driving and living in smaller apartments. Since these choices are associated with fewer greenhouse gas emissions, they should also be seen as having fewer negative externalities.

Our approach is again to estimate the average energy consumption associated with locating in different areas, holding an individual's income and size constant, but not controlling for other choices like housing characteristics. Consuming a larger house is a major part of moving to the suburbs for many people, and that should be captured in the environmental impact of suburbanization. We will use the same data sources and the same methodology as above, but we now focus on the differences between central city and suburban locations.

To keep definitions constant across data sources, we use the Census definition of Central City status, which we have for both census tracts and in the IPUMs. We generally exclude those data points that do not provide us with a central city identifier.

To provide estimates of gasoline consumption in central cities and suburbs, we continue to use equation (5) estimated using the National Household Travel Survey. This regression enables us to estimate the level of gasoline usage that a standardized household would purchase in each census tract. We then average all of the predicted gas usage numbers in census tracts that are in Central City PUMAs to form our estimate of Central City gasoline consumption. We do the same thing for Suburban census tracts to form our estimate of Suburban gasoline consumption. We continue to multiply gasoline usage by 23.47 to get total emissions.

As before, we compute gasoline usage for both marginal and average houses. We calculate average household gas consumption by averaging across census tracts using the total number of households in each census tract. We calculate marginal household gas consumption by average across census tracts, weighting them by the number of households built in the last ten years.

In the case of public transportation, we again calculate the total amount of emissions in the metropolitan area. We then allocate those emissions on the basis of public transportation usage. We calculate the total number of households in the central city and suburbs who commute using public transportation. We divide the total public transit emissions by this quantity to find the average public emissions per household that commutes using public transportation. We then multiply this number by the share of households in the suburbs and central city respectively that commute using public transportation to estimate the amount of public transit emissions associated with central city and suburban households.

For fuel oil and natural gas, we continue to use our IPUMS methodology of converting spending into energy use. In this case, the methodology is very dependent on central city and suburban residents facing the same fuel prices. We estimate our regressions separately for each metropolitan area, and in this case we also estimate an indicator variable that takes on a value of one if the household is in the suburbs. This indicator variable provides us with our estimate of how much extra fuel is being consumed in suburban areas. We continue to multiply fuel and gas usage by the standard conversion measures to turn them into emissions.

We use the same procedure for electricity. We regress estimated electricity consumption on personal characteristics and a dummy variable that indicates a suburban location. We use the coefficient on that dummy variable as our estimate of the extra electricity associated with suburban living. We multiply this dummy variable by the NERC factor to calculate the total emissions difference associated with electricity in the central cities and the suburbs.

Just as before, we estimate our IPUMS regressions first for all housing in the metropolitan area and then just for housing built between 1980 and 2000. Again, restricting ourselves to more recent housing eliminates some of the effects that come just from the housing stock. Central cities do tend to have an older housing stock and this will certainly make urban living seem like it is associated with higher levels of emissions.

Our results across all metropolitan areas are shown in Tables 5 and 6. Table 5 shows the results for all housing. Table 6 shows the results when we just look at homes built in the last 20 years. In this case, we only have enough data to estimate results for 48 metropolitan areas. The first column shows the results for gasoline consumption. The city-suburb gap, in Table 5, ranges from 669 pounds of carbon dioxide (about 30 gallons of gas) in Los Angeles to ten times that amount in Philadelphia. Interestingly, there are large gaps in gas emissions both in older cities, where people in the central city take public transportation, and in newer cities, where everyone drives but people in the suburbs just drive much more.

The adjustment to marginal locations in Table 6 makes almost no difference. The average gap increases by 11 gallons, which is relatively modest. The correlation between the marginal and average measures is more than 93 percent.

In the second column of Tables 5 and 6, we turn to public transportation related emissions. Hartford has the largest central city-suburb gap in these emissions (2900 pounds of carbon dioxide), followed by New York. Riverside has almost no gap. Interestingly, while public transportation made little difference to the metropolitan area figures, it does matter here. Since the central city populations tend to be the big users of public transportation and those populations are sometimes much smaller than the overall populations, the emissions that we credit to those people can be reasonably higher. For example, in the case of New York City, more than one-third of the gains in reducing car-related emissions that are associated with central city residents are offset by higher emissions from public transit. This variable is the same in Table 5 and 6.

In the third columns of Table 5 and 6, we turn to heating-related emissions. In this case, there is considerable heterogeneity across metropolitan areas. In New York, central city residents emit more than 6000 pounds of carbon dioxide less than suburbanites. In Detroit, central city residents emit more than 6000 pounds of carbon dioxide more than suburbanites. This is one area where the difference between average and marginal housing is quite significant, since the high levels of emissions in central city Detroit reflect, primarily, the older nature of that housing stock.

In Table 6, we see that when we look only at more recent housing, central city Detroit homes actually create fewer heating related emissions than suburban Detroit homes. There are still some areas, like Rochester, New York, where newer suburban homes have lower emissions than newer central city homes, but, in general, looking only at the more recent homes makes cities look better relative to suburbs along this dimension. We think that this marginal figure provides us with a better guide to the environmental impact of new development.

The fourth column in Table 5 and 6 shows our result for electricity emissions. This column multiplies the NERC factor with the electricity usage gap. Almost everywhere, smaller urban homes mean lower electricity usage. Suburban electricity usage is lower in five cases when we consider average homes, and in eight cases when we look at newer homes. In the case of electricity usage, central cities do not always look better when we switch to newer homes, because while those homes may be more efficient, they are also more likely to have air conditioning.

The fifth columns of Tables 5 and 6 combine the results to show the total emissions gap between central cities and suburbs by metropolitan area. The sixth columns multiply this quantity by 43 dollars to find the total emissions cost. This cost range goes from -88 dollars to 303 dollars in Table 5 and from -22 dollars to 351 dollars in Table 6. New York has the biggest gap between central city and suburbs in both tables, followed by Nashville. When we look at the average house, in Table 5, then Atlanta follows those two. When we look at newer housing in Table 6, then Boston has the third highest gap between central city and suburbs. Table 6 corrects for the heavy fuel oil use of houses in central city Boston.

In Table 5, there are five areas where suburbs have lower emissions than central cities. In Table 6, there are only two such cities: Dayton, Ohio, and Rochester, New York. In these places, suburban homes tend to use much less electricity than urban areas.

Table 7 regresses these differences on the same urban characteristics that we used in Table 4 to explain cross area differences in total carbon dioxide emissions. The dependent variable is the difference in emissions between the suburbs and the central city. The first regression shows that in bigger cities, suburbanites are more likely to drive longer distances relative to central city residents. The suburb-central city driving gap also gets larger in places with warm Julys and shorter in places with warm Januarys.

The second regression shows that the impact of population on emissions is reversed when we look at public transit. In this case, big city residence is particularly likely to be associated with high levels of public transit emissions, which is, after all, what we saw in New York City in Tables 5 and 6. In richer cities, the gap also increases.

In the third regression, we see that the heating gap between central cities and suburbs is larger for bigger, richer and more centralized cities. Interestingly, there is no connection between temperature and the city-suburb heating gap. The fourth regression shows that temperature and income, but not city population or centralization, predict the difference in electricity emissions.

The fifth regression looks at the correlates of the total suburb-city emissions gap. The gap is larger in cities with more income and more people. It is also larger when January temperatures are high and when July temperatures are high.

Lower Levels of Geography

Our procedures cannot provide particularly precise estimates of emissions at finer levels of geography. However, we can use tract data to provide a rough guide to carbon dioxide emissions within geographic sub-areas. We now provide a carbon emissions map for a single metropolitan area: Boston.

As discussed above, we formed our city and suburb measures for energy use based on tract level estimates of gasoline consumption and public transportation emissions. To create our emissions map, we can use those tract level measures directly. These measures essentially use the commuting patterns, density and proximity to downtown to predict energy usage.

To calculate energy usage at the tract level, we have to limit ourselves to structure characteristics that are available at the tract level—specifically the share of respondents in single family detached houses and the average number of rooms per household. To estimate the impact of these variables on energy use, we use the RECS data to calculate the impact of rooms and multi-family dwellings on energy use for the Northeast. We hold individual level income and family size constant. We then predict energy use for a tract based exclusively on its share of households in multi-family dwellings and the number of rooms per household. We use the appropriate NERC-region conversion factor to convert electricity usage into carbon dioxide emissions.

By adding together the gasoline emissions, public transit emissions and home energy emissions, we can find a total emissions level for each tract within greater Boston. We then multiply carbon dioxide emissions by 43 dollars per ton to find total costs due to emissions. Figure 6 gives a map of emissions costs by tract within that area. There is a significant range in those costs from less than 985 dollars per household in the core of urban Boston to 1275 dollars per household within 10 and 12 miles of the city center. The map shows that all of the older cities in greater Boston, including Lawrence and Lowell, are also particularly likely to have lower carbon dioxide emissions costs.

The map gives us a better idea of the places where high emissions development replaces low emissions development. Within greater Boston that replacement occurs between five and ten miles of the city center. It is in this area that single family units replace multi-family units and that public transportation is replaced by driving longer distances. Those are the key variables, in this exercise, that are predicted higher levels of emissions in less central locales.

V. Conclusion

If carbon dioxide emissions are taxed appropriately, then individuals will make appropriate decisions about their locations without any further government interventions. However, if we believe that current carbon taxes, which are essentially zero, do not charge people for the full use of their energy consumption, then location decisions will fail to internalize environmental costs. In this paper, we attempted to quantify the externalities associated with different location choices by estimating the carbon dioxide emitted by households in different places.

We estimate that a range of costs per household from 830 dollars per year in San Diego, California, to almost 1500 dollars per year in Oklahoma City. Across areas, emissions are positively associated with July temperature, negatively associated with January temperature, and negatively associated with both city population and centralization. New York has the biggest central city-suburb gap: 350 dollars. Rochester, New York, has the smallest gap: -22 dollars.

Our work has some profound limitations. We have little confidence in the 43 dollar per ton number. Our estimates are based on regressions that can provide only a very imperfect estimate of gasoline usage or electricity consumption in particular areas. We restricted ourselves to household energy use and did nothing to consider the impact of carbon dioxide in the workplace. All of these facts suggest that this is at best a first step at estimating the carbon dioxide emissions associated with homes in different areas.

That being said, this paper does provide what we consider to be reasonable estimates of the emissions-related externalities associated with homes built in different areas. There are however, two reasons why we would be skeptical about actually using these numbers as the basis for a tax on development in Oklahoma or a subsidy for development in San Diego. First, these results are just too preliminary. Second, there are surely much better ways, like a direct carbon tax, to get people to internalize the social costs of their actions. Perhaps, the clearest public policy-related conclusion that comes out of this analysis is that current land use controls operate in a way that maximizes, rather than minimizes, carbon dioxide emissions.

Table 1:
Gallons of Gasoline Consumed Per Year

	Household's Annual Total Gasoline Consumption (Gallons)
MidWest Dummy	90.3877
	(195.164)
South Dummy	58.2290
	(160.4072)
West Dummy	-421.0394
	(101.966)
Log(Zip Code Distance to CBD)	62.8384
	(11.7195)
Log(Census Tract Density)	-115.5208
	(6.6531)
Log(Metropolitan Area Density)	-38.9251
	(18.4743)
Log(Census Tract Density)*MidWest	2.1369
	(22.3581)
Log(Census Tract Density)*South	6.9970
	(19.5603)
Log(Census Tract Density)*West	60.7966
	(11.9206)
Log(household income)	315.8490
	(17.969)
household size	167.9646
	(5.8041)
Constant	-1816.9110
	(255.2391)
Observations	11728
R2	0.30

Notes:

(1) The data source is the 2001 NHTS.

(2) The unit of analysis is a household.

(3) A dummy variable indicating that the head of household's age is missing is included.

(4) Top 1% set as topcode

(5) Standard errors are clustered by metropolitan area

Table 2:
Annual CO_2 Output Emissions

MSA	Emissions from Driving (Lbs of CO2)	Emissions from Public Transportation (Lbs of CO2)	Emissions from Home Heating (Lbs of CO2)	Electricity (Megawatt Hrs)	NERC	Carbon Dioxide Emissions Cost ($ per Year)
San Diego, CA	23,833	689	6,105	7.35	1,007	808
San Francisco, CA	23,123	1,675	7,074	6.92	1,007	813
Los Angeles-Long Beach, CA	22,631	1,062	6,695	8.42	1,007	820
San Jose, CA	22,908	2,058	6,958	7.81	1,007	826
Sacramento, CA	24,606	458	7,154	9.52	1,007	893
New York, NY	17,196	6,386	11,936	7.19	1,400	893
Riverside-San Bernardino, CA	25,444	42	6,897	9.58	1,007	903
Tucson, AZ	25,323	616	5,060	12.84	1,007	936
Fresno, CA	24,728	951	8,018	11.03	1,007	949
Las Vegas, NV	23,345	0	7,004	13.86	1,007	953
Phoenix-Mesa, AZ	24,810	75	2,810	16.96	1,007	961
Albuquerque, NM	24,349	648	11,961	9.49	1,007	992
Buffalo	23,553	1,124	13,918	7.49	1,185	1,006
Portland-Vancouver, OR	25,039	2,098	5,696	15.16	1,007	1,006
Rochester, NY	24,883	902	12,636	7.82	1,185	1,013
Providence, RI	22,737	1,273	14,852	7.86	1,185	1,019
Denver, CO	24,619	1,374	11,595	10.65	1,007	1,021
Salt Lake City-Ogden, UT	24,667	3,104	12,258	10.72	1,007	1,048
Boston, MA	22,700	2,276	15,754	8.34	1,185	1,058
Syracuse, NY	25,816	574	13,075	8.71	1,185	1,063
Albany-Schenectady-Troy, NY	25,891	1,054	13,174	8.81	1,185	1,073
Fort Lauderdale, FL	24,414	1,124	574	17.17	1,427	1,074
Hartford, CT	24,638	1,539	14,599	8.58	1,185	1,075
Seattle-Bellevue-Everett, WA	24,485	5,948	6,481	17.09	1,007	1,087
Miami, FL	23,177	4,689	892	17.58	1,427	1,092
Tacoma, WA	25,310	430	5,620	19.84	1,007	1,098
Sarasota	27,048	510	594	16.37	1,427	1,101
West Palm Beach-Boca Raton, FL	26,482	616	745	17.72	1,427	1,135
Tampa-St. Petersburg-Clearwater, FL	27,220	742	740	17.72	1,427	1,151
Milwaukee-Waukesha, WI	25,433	1,291	11,614	9.94	1,614	1,152
Chicago, IL	23,522	5,221	12,341	10.12	1,614	1,163
Washington, DC	24,992	4,729	5,968	14.34	1,543	1,180
Baltimore, MD	25,632	2,135	5,785	14.38	1,614	1,192
Pittsburgh, PA	24,815	2,093	13,269	10.22	1,614	1,192
Columbus, OH	27,208	278	10,421	10.99	1,614	1,193
Orlando, FL	27,049	1,361	829	19.06	1,427	1,195
San Antonio, TX	26,297	1,929	4,203	16.24	1,555	1,213
Cleveland-Lorain-Elyria, OH	25,781	1,733	12,102	11.32	1,614	1,222
Norfolk-Virginia Beach-Newport News, VA	26,071	1,078	5,560	17.05	1,472	1,228

Table 2:
Annual CO_2 Output Emissions

MSA	Emissions from Driving (Lbs of CO2)	Emissions from Public Transportation (Lbs of CO2)	Emissions from Home Heating (Lbs of CO2)	Electricity (Megawatt Hrs)	NERC	Carbon Dioxide Emissions Cost ($ per Year)
Akron, OH	27,473	768	11,404	11.55	1,614	1,243
Minneapolis-St. Paul, MN	26,532	143	12,244	10.46	1,819	1,244
Philadelphia, PA	21,807	3,993	14,108	12.78	1,614	1,248
Cincinnati, OH	27,178	770	9,732	13.50	1,543	1,248
Grand Rapids-Muskegon-Holland, MI	28,115	572	16,216	8.44	1,614	1,251
St. Louis, MO	27,217	1,267	9,413	14.47	1,472	1,256
Greensboro--Winston Salem--High Point, NC	30,383	216	4,804	15.73	1,472	1,256
Richmond-Petersburg, VA	28,254	771	4,417	17.65	1,472	1,268
New Orleans, LA	24,032	663	5,225	20.03	1,472	1,268
Charlotte-Gastonia-Rock Hill, NC	30,033	1,084	5,906	15.44	1,472	1,270
Raleigh-Durham-Chapel Hill, NC	29,477	495	6,056	15.94	1,472	1,273
Scranton--Wilkes-Barre--Hazleton, PA	27,082	282	14,728	10.72	1,614	1,273
Dayton-Springfield, OH	27,732	986	9,386	13.47	1,614	1,274
Detroit, MI	26,391	889	17,872	9.60	1,614	1,292
Tulsa, OK	28,600	353	8,994	14.71	1,561	1,305
Greenville-Spartanburg-Anderson, SC	31,503	130	5,020	16.41	1,472	1,306
Austin-San Marcos, TX	27,489	1,595	4,972	17.87	1,555	1,308
Atlanta, GA	28,487	1,121	9,425	15.45	1,472	1,313
Kansas City, MO	27,848	643	10,885	14.27	1,561	1,317
Louisville, KY	27,567	884	9,156	15.76	1,543	1,320
Indianapolis, IN	28,280	534	11,187	13.71	1,614	1,329
Dallas, TX	26,205	1,723	6,128	18.66	1,555	1,332
Houston, TX	26,294	1,447	5,255	19.29	1,555	1,334
Nashville, TN	29,953	473	6,722	18.58	1,472	1,381
Birmingham, AL	30,218	227	7,999	17.70	1,472	1,384
Memphis, TN	27,647	1,073	8,574	19.73	1,472	1,412
Oklahoma City, OK	27,981	332	8,784	17.64	1,649	1,419

Table 3:
Marginal Effect: Annual CO_2 Output Emissions

MSA	**Emissions from Driving (Lbs of CO2)**	**Emissions from Public Transportation (Lbs of CO2)**	**Emissions from Home Heating (Lbs of CO2)**	**Electricity (Megawatt Hrs)**	**NERC**	**Carbon Dioxide Emissions Cost ($ per Year)**
San Diego, CA	24,295	689	6,106	7.45	1,007	830
Los Angeles-Long Beach, CA	22,904	1,062	6,035	8.54	1,007	830
San Francisco, CA	23,881	1,675	5,882	7.38	1,007	836
San Jose, CA	23,142	2,058	6,219	7.82	1,007	845
Sacramento, CA	24,932	458	6,861	9.74	1,007	904
Riverside-San Bernardino, CA	25,846	42	6,806	9.55	1,007	910
Fresno, CA	24,700	951	7,722	10.90	1,007	954
Las Vegas, NV-AZ	23,795	0	7,498	13.26	1,007	960
Tucson, AZ	26,135	616	4,507	13.35	1,007	961
Phoenix-Mesa, AZ	25,434	75	2,225	17.26	1,007	970
Albuquerque, NM	24,873	648	11,907	9.49	1,007	1,010
Rochester, NY	25,923	902	10,935	8.02	1,185	1,016
New York, NY	19,486	6,386	11,112	8.18	1,400	1,041
Buffalo	25,533	1,124	12,174	8.15	1,185	1,043
Providence, RI	24,652	1,273	12,825	8.44	1,185	1,048
Portland-Vancouver, OR-WA	25,612	2,098	6,210	14.74	1,007	1,048
Denver, CO	25,245	1,374	11,384	10.85	1,007	1,052
Syracuse, NY	26,636	574	11,986	9.42	1,185	1,083
Tacoma, WA	25,966	430	5,572	18.67	1,007	1,091
Albany-Schenectady-Troy, NY	27,600	1,054	11,321	9.36	1,185	1,098
Hartford, CT	26,051	1,539	12,576	9.30	1,185	1,101
Fort Lauderdale, FL	25,010	1,124	372	17.41	1,427	1,104
Salt Lake City-Ogden, UT	25,380	3,104	11,920	11.10	1,007	1,109
Boston, MA	25,056	2,276	13,121	9.67	1,185	1,116
Sarasota	28,123	510	638	16.50	1,427	1,136
West Palm Beach-Boca Raton, FL	27,002	616	608	18.05	1,427	1,161
Tampa-St. Petersburg-Clearwater, FL	27,935	742	734	17.42	1,427	1,167
Miami, FL	24,044	4,689	661	17.45	1,427	1,167
Milwaukee-Waukesha, WI	27,018	1,291	9,516	10.43	1,614	1,175
Seattle-Bellevue-Everett, WA	24,945	5,948	6,806	17.02	1,007	1,179
Columbus, OH	28,521	278	9,467	11.18	1,614	1,211
Orlando, FL	27,903	1,361	773	18.65	1,427	1,218
Pittsburgh, PA	27,057	2,093	10,548	10.91	1,614	1,232
Chicago, IL	25,059	5,221	10,960	10.40	1,614	1,248
Minneapolis-St. Paul, MN-WI	28,148	143	11,085	10.43	1,819	1,254
Greensboro--Winston Salem--High Point, N	30,551	216	4,298	15.86	1,472	1,256
Grand Rapids-Muskegon-Holland, MI	29,256	572	15,297	8.29	1,614	1,258
Norfolk-Virginia Beach-Newport News, VA-	26,656	1,078	5,476	17.43	1,472	1,266
Raleigh-Durham-Chapel Hill, NC	29,524	495	5,599	15.86	1,472	1,268

Table 3:

Marginal Effect: Annual CO $_2$ Output Emissions

MSA	Emissions from Driving (Lbs of CO2)	Emissions from Public Transportation (Lbs of CO2)	Emissions from Home Heating (Lbs of CO2)	Electricity (Megawatt Hrs)	NERC	Carbon Dioxide Emissions Cost ($ per Year)
San Antonio, TX	27,868	1,929	2,844	16.96	1,555	1,269
Cincinnati, OH-KY-IN	28,436	770	7,385	14.65	1,543	1,273
Baltimore, MD	27,386	2,135	3,672	16.29	1,614	1,279
Charlotte-Gastonia-Rock Hill, NC-SC	30,260	1,084	5,348	15.51	1,472	1,280
Dayton-Springfield, OH	28,485	986	7,922	13.94	1,614	1,288
Akron, OH	29,471	768	10,579	11.92	1,614	1,291
St. Louis, MO-IL	28,802	1,267	7,574	15.25	1,472	1,292
New Orleans, LA	25,195	663	3,202	21.21	1,472	1,296
Greenville-Spartanburg-Anderson, SC	31,705	130	4,193	16.59	1,472	1,300
Cleveland-Lorain-Elyria, OH	28,293	1,733	10,535	12.53	1,614	1,307
Washington, DC-MD-VA-WV	26,529	4,729	5,144	15.85	1,543	1,309
Richmond-Petersburg, VA	28,616	771	3,868	18.78	1,472	1,309
Scranton--Wilkes-Barre--Hazleton, PA	29,087	282	11,277	12.60	1,614	1,311
Tulsa, OK	29,943	353	8,376	14.99	1,561	1,335
Indianapolis, IN	29,311	534	9,541	14.16	1,614	1,338
Kansas City, MO-KS	29,243	643	9,600	14.60	1,561	1,339
Detroit, MI	28,455	889	16,928	10.00	1,614	1,342
Austin-San Marcos, TX	28,794	1,595	4,707	17.65	1,555	1,345
Philadelphia, PA-NJ	24,412	3,993	11,084	14.39	1,614	1,348
Atlanta, GA	29,252	1,121	9,065	15.82	1,472	1,349
Louisville, KY-IN	29,292	884	7,558	16.45	1,543	1,357
Dallas, TX	27,185	1,723	5,346	19.36	1,555	1,384
Houston, TX	27,243	1,447	5,006	19.73	1,555	1,384
Birmingham, AL	31,612	227	6,386	18.36	1,472	1,403
Nashville, TN	31,067	473	7,006	18.17	1,472	1,404
Memphis, TN-AR-MS	28,612	1,073	8,367	20.24	1,472	1,459
Oklahoma City, OK	30,410	332	8,419	18.17	1,649	1,486

Table 4:
Regression Table

	(1) **Emissions from Driving**	(2) **Emissions from Public Transportation**	(3) **Emissions from Home Heating**	(4) **Emissions from Electricity**	(5) **Total Emissions**
Log (Income)	1463.8	1122.7	-2798.8	3868.8	3656.5
	(1948.492)	(1351.195)	(2493.818)	(6711.231)	(7166.566)
Log (population)	-2542.8	1193.3	1147.2	-2849.2	-3051.4
	(411.3692)	(285.2667)	(526.4994)	(1416.887)	(1513.019)
Share of Employment within 5 Miles of the City Center	-13114.6	2587.1	4540.6	-24407.4	-30394.3
	(2436.412)	(1689.546)	(3118.292)	(8391.782)	(8961.138)
January Temperature	-68.8	-3.7	-211.7	-34.5	-318.9
	(17.0132)	(11.7979)	(21.7746)	(58.5988)	(62.5745)
July Temperature	106.4	-11.4	-97.9	624.5	621.6
	(38.6662)	(26.8133)	(49.4877)	(133.1787)	(142.2145)
Constant	44881.7	-27650.6	36511.3	-23569.4	30173.0
	(20102.67)	(13940.33)	(25728.82)	(69240.05)	(73937.77)
Number of Observations	66	66	66	66.00	66
R^2	0.56	0.38	0.72	0.41	0.44

Notes:

(1) Dependent variables are the total pounds of CO_2 emissions from the listed source.

(2) The dependent variables are the marginal emissions, that is, emissions calculated for housing built between 1980 and 2000.

(3) Sample size is 66 MSAs.

Table 5:
City-Suburb Differences in CO_2 Output Emissions

MSA	City-Suburb Difference in Emissions from Driving (Lbs of CO2)	City-Suburb Difference in Emissions from Public Transportation (Lbs of CO2)	City-Suburb Difference in Emissions from Home Heating (Lbs of CO2)	City-Suburb Difference in Electricity (Lbs of CO2)	City-Suburb Difference in Carbon Dioxide Emissions ($ per Year)
New York, NY	6,172	-2,367	6,521	3,756	303
Nashville, TN	7,765	-649	527	3,776	245
Atlanta, GA	6,375	-1,242	35	5,074	220
Boston, MA	6,573	-1,091	3,423	1,069	214
Philadelphia, PA	6,836	-2,286	256	3,798	185
Washington, DC	5,330	-2,280	80	5,264	180
Houston, TX	2,760	-561	675	4,464	158
Dallas, TX	4,061	-986	-346	4,447	154
Tulsa, OK	4,944	-161	-34	2,323	152
Raleigh-Durham-Chapel Hill, NC	2,838	-182	-1,399	5,526	146
San Francisco, CA	3,969	-939	1,726	1,835	142
Hartford, CT	5,350	-2,905	2,836	1,285	141
Minneapolis-St. Paul, MN	5,195	-105	-1,320	2,116	127
Memphis, TN	3,554	-423	27	2,232	116
Cincinnati, OH	2,793	-383	-2,516	5,452	115
Baltimore, MD	6,167	-1,647	-3,580	4,040	107
Portland-Vancouver, OR	2,818	-553	-106	2,661	104
Seattle-Bellevue-Everett, WA	2,707	-2,608	848	3,679	99
San Antonio, TX	3,694	-388	-811	2,108	99
Charlotte-Gastonia-Rock Hill, NC	2,913	-604	-189	2,345	96
Richmond-Petersburg, VA	4,420	-995	-3,950	4,800	92
Norfolk-Virginia Beach-Newport News, VA	3,028	-295	-156	1,697	92
Syracuse, NY	1,983	-204	234	1,630	78
Austin-San Marcos, TX	4,087	-784	-450	706	77
Milwaukee-Waukesha, WI	4,467	-860	-1,743	1,442	71
Sacramento, CA	2,029	-101	219	1,136	71
Providence, RI	4,344	-982	-568	438	69
Phoenix-Mesa, AZ	3,409	-94	-1,526	1,140	63
Akron, OH	3,555	-369	-1,153	630	57
Greensboro--Winston Salem--High Point, NC	1,571	-60	-3,056	4,153	56

Table 5:
City-Suburb Differences in CO_2 Output Emissions

MSA	City-Suburb Difference in Emissions from Driving (Lbs of CO2)	City-Suburb Difference in Emissions from Public Transportation (Lbs of CO2)	City-Suburb Difference in Emissions from Home Heating (Lbs of CO2)	City-Suburb Difference in Electricity (Lbs of CO2)	City-Suburb Difference in Carbon Dioxide Emissions ($ per Year)
Denver, CO	2,339	-641	-93	672	49
Oklahoma City, OK	851	-115	0	1,163	41
Chicago, IL	5,479	-2,624	-2,449	1,374	38
Fresno, CA	1,278	-92	130	369	36
Cleveland-Lorain-Elyria, OH	4,139	-1,002	-3,812	2,299	35
New Orleans, LA	3,315	-474	-1,848	614	35
Kansas City, MO	2,669	-542	-1,800	1,176	32
St. Louis, MO	4,153	-1,378	-3,671	1,867	21
Riverside-San Bernardino, CA	1,087	-8	555	-807	18
Grand Rapids-Muskegon-Holland, MI	1,444	-183	-1,847	1,215	14
Buffalo, NY	4,199	-813	-3,513	652	11
Tampa-St. Petersburg-Clearwater, FL	2,974	-560	-752	-1,297	8
Tacoma, WA	2,855	-134	-690	-1,812	5
Dayton-Springfield, OH	2,725	-527	-3,321	831	-6
Rochester, NY	2,508	-554	-2,697	369	-8
Pittsburgh, PA	5,707	-1,819	-4,573	60	-13
Los Angeles-Long Beach, CA	669	-229	-382	-1,733	-36
Detroit, MI	4,368	-1,214	-6,702	-540	-88

Table 6:
Marginal Effect: City-Suburb Differences in CO_2 Output Emissions

MSA	**City-Suburb Difference in Emissions from Driving (Lbs of CO2)**	**City-Suburb Difference in Emissions from Public Transportation (Lbs of CO2)**	**City-Suburb Difference in Emissions from Home Heating (Lbs of CO2)**	**City-Suburb Difference in Electricity (Lbs of CO2)**	**City-Suburb Difference in Carbon Dioxide Emissions ($ per Year)**
New York, NY	7,105	-2,367	5,953	5,637	351
Nashville, TN	8,002	-649	1,700	4,416	290
Boston, MA	7,197	-1,091	5,863	158	261
Minneapolis-St. Paul, MN	5,934	-105	2,661	2,539	237
Washington, DC	6,128	-2,280	2,176	4,518	227
Cincinnati, OH	4,255	-383	-204	6,427	217
Atlanta, GA	6,587	-1,242	1,324	3,136	211
Philadelphia, PA	7,030	-2,286	1,221	3,519	204
Houston, TX	2,846	-561	1,597	5,379	199
Hartford, CT	6,814	-2,905	2,762	2,314	193
San Francisco, CA	5,087	-939	2,852	1,723	188
Baltimore, MD	7,266	-1,647	-1,831	4,185	171
Dallas, TX	4,404	-986	1,023	3,138	163
Tulsa, OK	4,518	-161	1,226	1,001	142
Richmond-Petersburg, VA	5,387	-995	-2,020	4,195	141
Raleigh-Durham-Chapel Hill, NC	2,137	-182	-1,260	5,834	140
Pittsburgh, PA	7,283	-1,819	-567	1,396	135
Chicago, IL	7,341	-2,624	496	1,055	135
St. Louis, MO	6,200	-1,378	-2,030	3,190	129
Cleveland-Lorain-Elyria, OH	4,477	-1,002	-1,747	3,960	122
Syracuse, NY	742	-204	3,966	999	118
Providence, RI	5,637	-982	541	291	118
Milwaukee-Waukesha, WI	5,337	-860	-70	956	115
Memphis, TN	3,137	-423	1,542	994	113
Phoenix-Mesa, AZ	3,199	-94	1,053	1,037	112
Detroit, MI	6,180	-1,214	220	-297	105
Sacramento, CA	2,692	-101	1,634	599	104
Buffalo	4,686	-813	-370	1,092	99
Greensboro--Winston Salem--High Point, NC	1,922	-60	-2,626	5,207	96
Seattle-Bellevue-Everett, WA	2,681	-2,608	1,356	2,860	92

Table 6:
Marginal Effect: City-Suburb Differences in CO_2 Output Emissions

MSA	**City-Suburb Difference in Emissions from Driving (Lbs of CO2)**	**City-Suburb Difference in Emissions from Public Transportation (Lbs of CO2)**	**City-Suburb Difference in Emissions from Home Heating (Lbs of CO2)**	**City-Suburb Difference in Electricity (Lbs of CO2)**	**City-Suburb Difference in Carbon Dioxide Emissions ($ per Year)**
Charlotte-Gastonia-Rock Hill, NC	2,476	-604	887	1,373	89
Norfolk-Virginia Beach-Newport News, VA	2,344	-295	1,103	905	87
San Antonio, TX	2,865	-388	-379	1,570	79
Portland-Vancouver, OR	2,121	-553	505	1,186	70
Denver, CO	2,018	-641	1,436	223	65
Austin-San Marcos, TX	3,093	-784	-41	618	62
Grand Rapids-Muskegon-Holland, MI	1,191	-183	1,009	751	60
Kansas City, MO-KS	2,875	-542	-797	1,198	59
New Orleans, LA	4,086	-474	-526	-410	58
Tacoma, WA	2,615	-134	243	-685	44
Oklahoma City, OK	291	-115	281	1,525	43
Tampa-St. Petersburg-Clearwater, FL	3,712	-560	-201	-976	42
Akron, OH	2,118	-369	1,204	-1,341	35
Riverside-San Bernardino, CA	1,077	-8	924	-976	22
Los Angeles-Long Beach, CA	1,171	-229	550	-726	16
Fresno, CA	758	-92	24	-81	13
Dayton-Springfield, OH	2,295	-527	-1,918	34	-2
Rochester, NY	1,816	-554	-1,943	-356	-22

Table 7:
Regression Table

	(1) **City-Suburb Difference in Emissions from Driving**	**(2)** **City-Suburb Difference in Emissions from Public Transportation**	**(3)** **City-Suburb Difference in Emissions from Home Heating**	**(4)** **City-Suburb Difference in Electricity**	**(5)** **City-Suburb Difference in Carbon Dioxide Emissions Cost**
Log (Income)	3730.0	-1894.5	4444.1	6792.3	13071.9
	(2667.864)	(924.2144)	(2363.929)	(2796.077)	(4267.31)
Log (population)	1324.1	-478.4	1058.1	-259.4	1644.3
	(501.6394)	(173.7803)	(444.4904)	(525.7472)	(802.3837)
Share of Employment within 5 Miles of the City Center	3172.0	-1911.3	8058.5	-3641.8	5677.4
	(3335.318)	(1155.437)	(2955.344)	(3495.608)	(5334.919)
January Temperature	-79.0	17.3	12.0	-49.5	-99.2
	(25.1982)	(8.7293)	(22.3275)	(26.4092)	(40.3052)
July Temperature	89.8	-6.8	9.9	107.6	200.5
	(48.7722)	(16.8959)	(43.2158)	(51.1161)	(78.0122)
Constant	-60848.1	27215.1	-66438.2	-74732.5	-174803.7
	(27497.93)	(9525.964)	(24365.24)	(28819.43)	(43983.56)
Number of Observations	48	48	48	48.00	48
R^2	0.41	0.44	0.34	0.27	0.48

Notes:

(1) Dependent variables are the suburb-city difference of total pounds of CO_2 emissions from the listed source.

(2) The dependent variables are the marginal emissions, that is, emissions calculated for housing built between 1980 and 2000.

(3) Sample size is 48 MSAs.

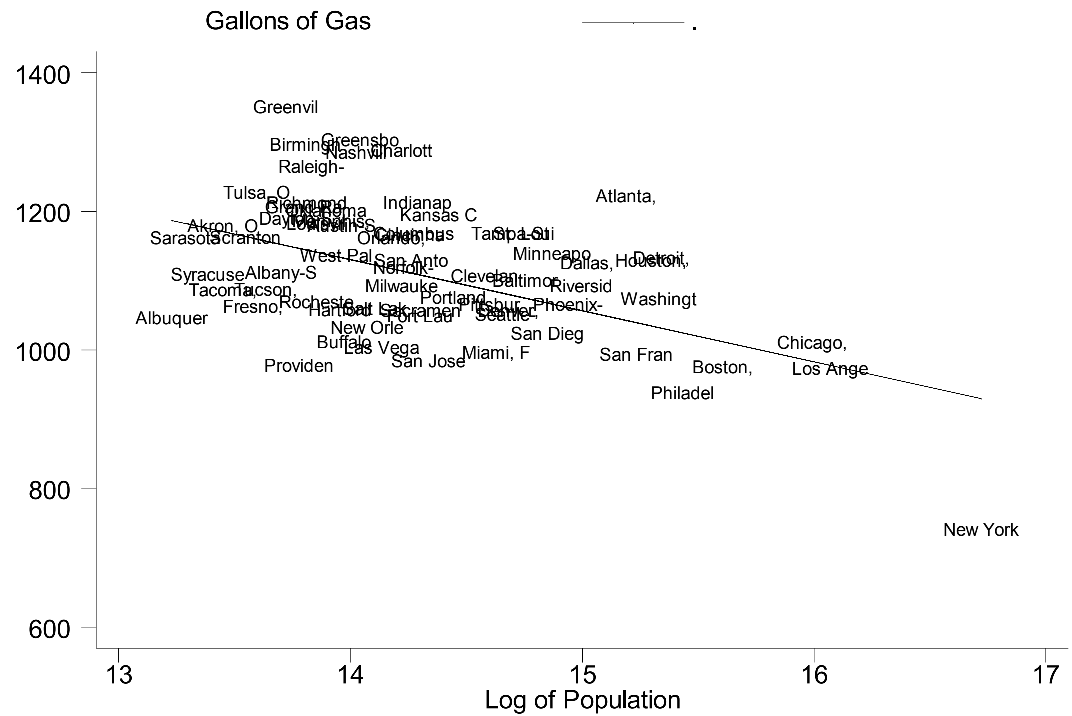

Figure 1: Gas Consumption and City Size

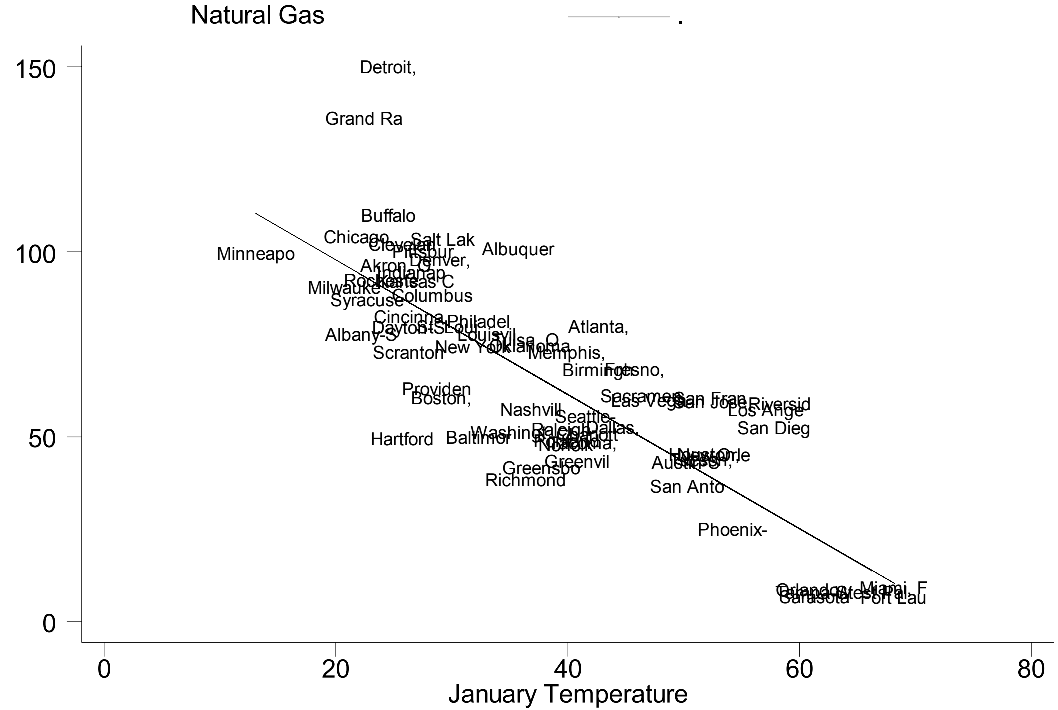

Figure 2: Natural Gas and January Temperature

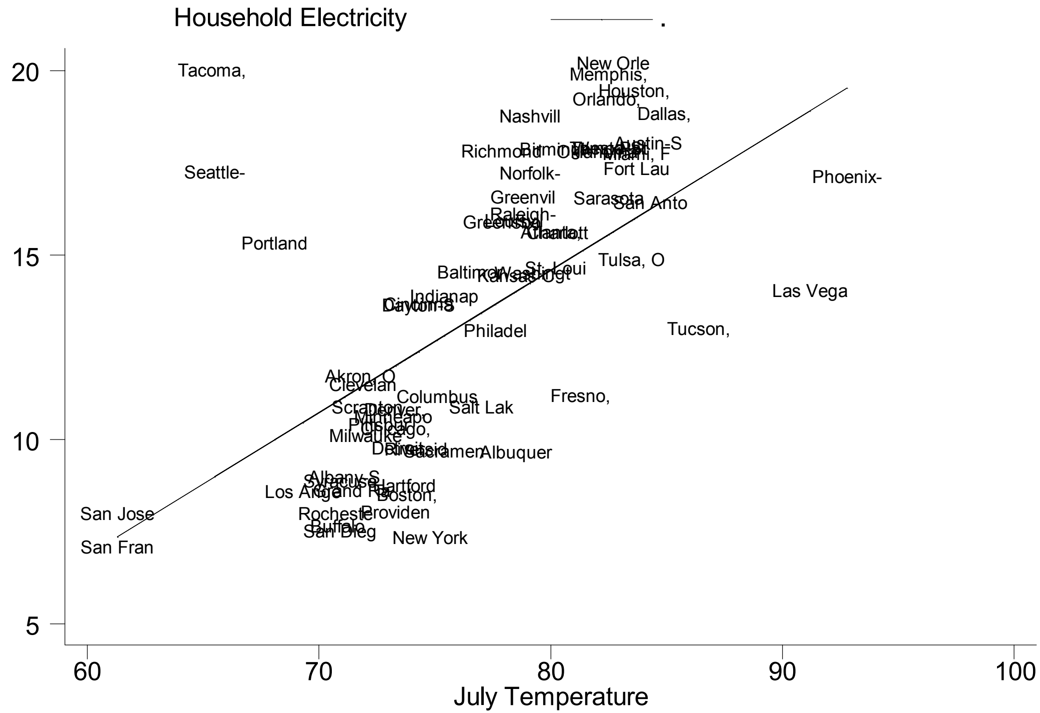

Figure 3: Electricity Use and July Temperature

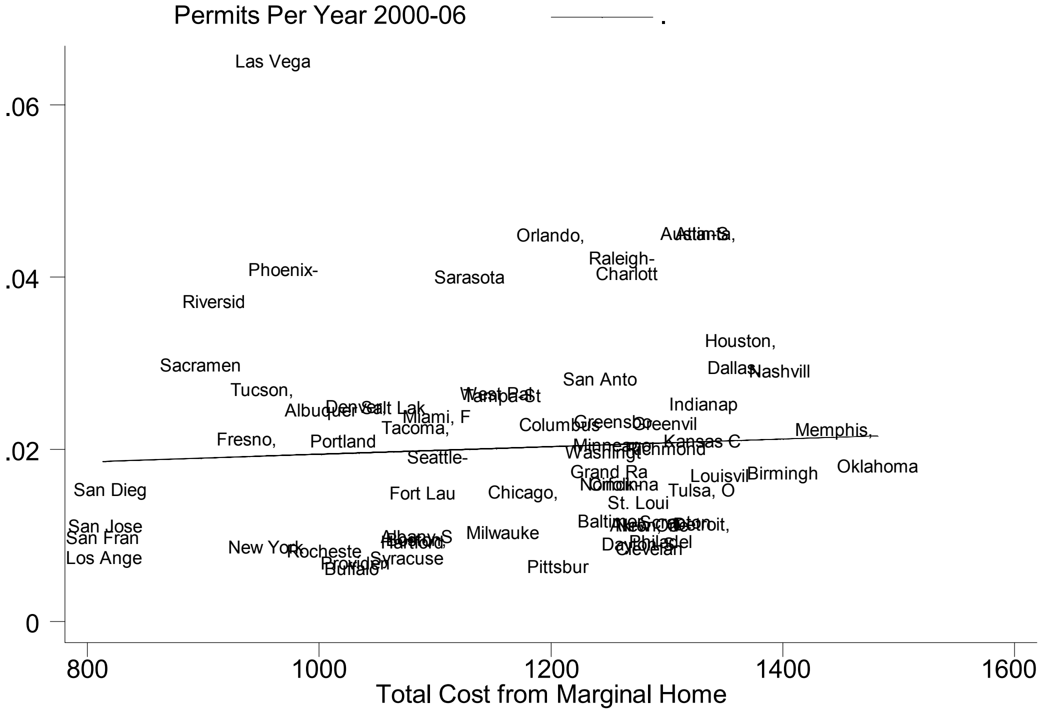

Figure 4: Total Emissions Costs and Growth

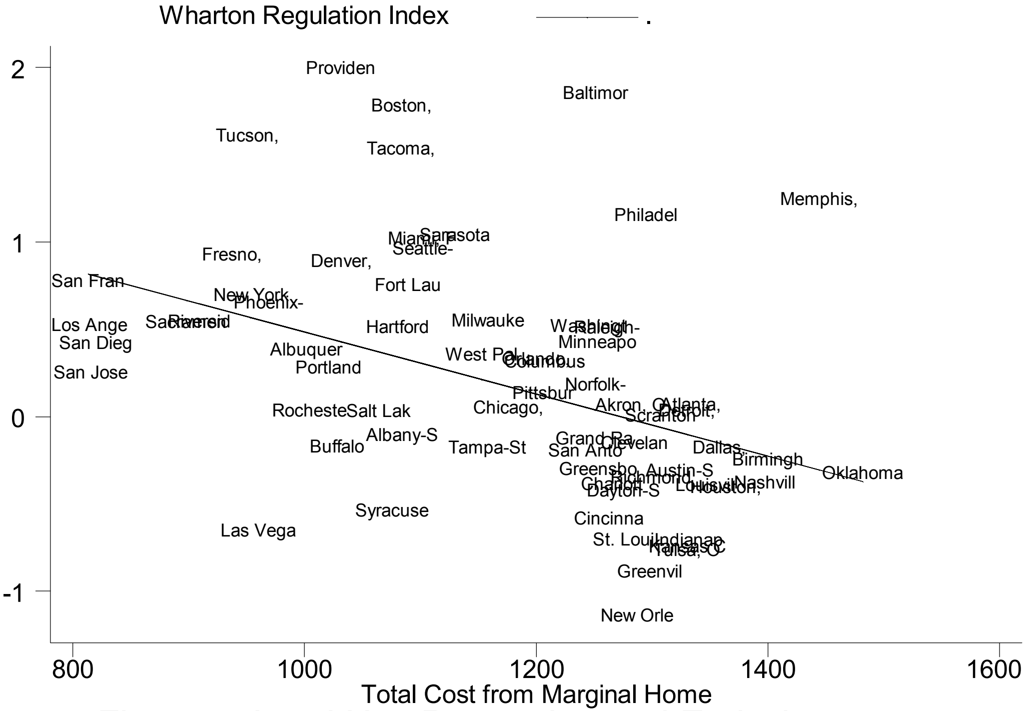

Figure 5: Land Use Regualtion and Emissions

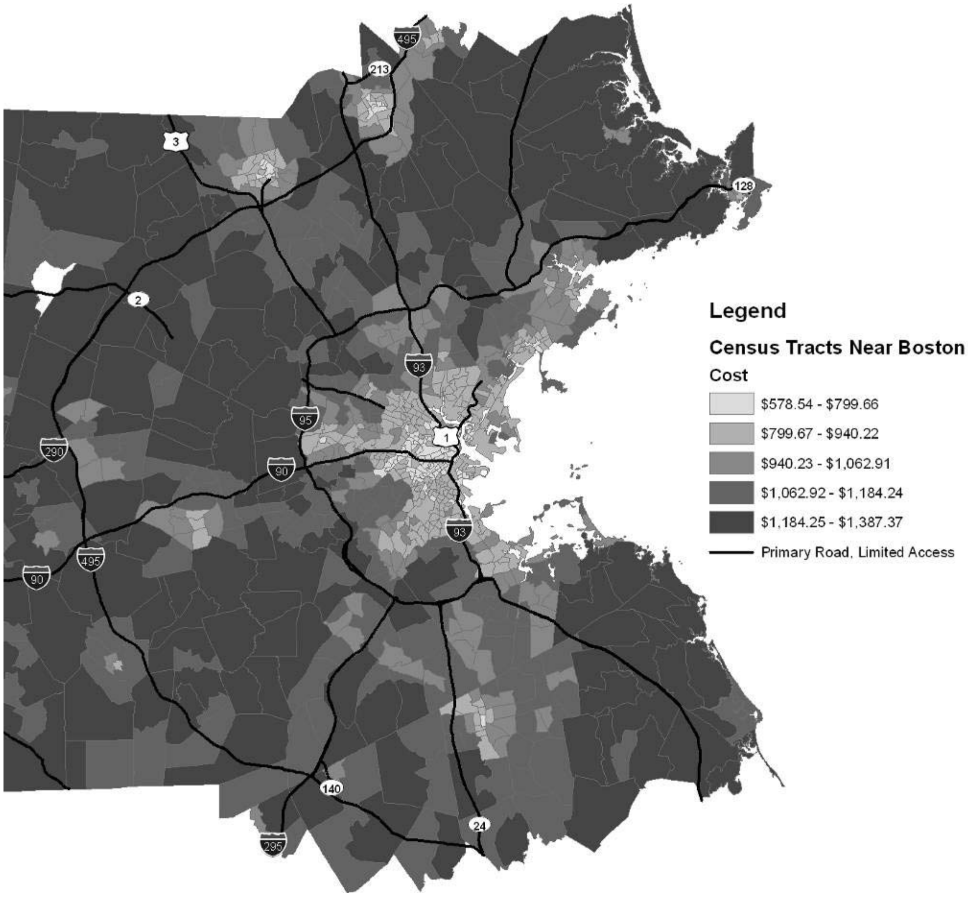

Figure 6: Emissions Costs Within Greater Boston