U.S. Internal Migration Networks, Energy Use, and Emissions

Cody Karl Reinhardt
Georgia State University

Abstract

This paper studies migration patterns in the U.S. and the relationship between migration patterns and energy use and carbon emissions. The paper uses a two-city model of energy use and household migration to analyze emission implications from city level green policies. Per-household emissions are calculated for the largest 49 MSA's in the U.S. and data on migration patterns used to assign substitute locations to migrating households. Detail is given to ranking cities in carbon contributions from migration as well as changes to migration and carbon contributions over time. Results show large differences in net carbon emissions from migration, which has implications for a wide range of policies affecting migration decisions. The MSA's which are the most carbon-reducing in migration are also those with the strictest land use regulations, and new regulations suggest this pattern will continue. Several cities with strong impacts on national carbon emissions are given detailed analysis: Atlanta, Washington D.C., San Antonio, and Los Angeles.

1. Introduction

Climate change as a result of carbon emissions is a highly studied and broad topic in the economics literature. As noted in Glaeser and Kahn

(2010), a significant proportion of US carbon emissions come from household energy use, and urban structure plays a prominent role in how much energy households consume. Mangum (2017) and Glaeser and Kahn (2010) have shown that cities vary greatly in per household levels of emissions, with the high-emission U.S. cities having nearly twice the per-household emissions as the low-emission cities. Glaeser and Kahn examine differences in urban structure and both within city and between city variation in household energy use. This paper extends this literature by using historic internal migration data to examine the role migration plays in the total emissions for the U.S. Given the plethora of local policies on housing and zoning, and the popularity of local green regulations, it is highly unlikely that emissions will be optimally taxed. As noted by Glaeser and Kahn, even a perfectly calibrated Piguvian carbon tax is not sufficient for optimal location decisions in the presence of local policies or incentives which restrict development in green areas and subsidized development in less green areas. In reality, the U.S. has many such policies and incentives. According to Glaeser, "By restricting new development, the cleanest areas are pushing development to areas of higher emissions." (Glaeser and Kahn pp.1) So migration will play a key role in how optimal emission decisions are made from a country perspective, because how the population is distributed and moving among the cities of various emissions levels affects the total country level of emissions. As household migrate between cities, they change their housing consumption, carbon content of electricity and heating, and driving patterns as they change locations. Any local policies directly or indirectly taxing carbon emissions would have to consider the potential migration effects on emissions an how movement of households to and from their neighbors contributes to the national carbon account. Policies in all of the cities are important, as well as a city's location in the sense of it's largest migration neighbors. While Mangum (2017) considers simulations of national level policies, this paper focuses on local policies with migration effects following historic migration patterns. The purpose of this paper is to examine the role migration plays in the total carbon emissions in the U.S. This paper extends a two-city model first developed in Glaeser and Kahn (2008). It does this by using city pairs constructed from data on MSA emissions and MSA-to-MSA migration data. This will represent the migration effect of the MSA by weighting its migrants with the per-household emissions of their destination MSA. Each MSA will thus have different migration effects, for both out- and in- migration, due to their place in the migration network and the greenness of substitute cities in their part of the network. The paper proceeds as follows. Section 2 presents the two-city model and the generation process for the representative migration city. Section 3 describes the data used in the paper. Section 4 details the results and implications. Section 5 concludes and discusses opportunities for further research.

2. The Two-City Model

This section expands on the two-region model presented in Glaeser and Kahn (2008). The original model is introduced and then expanded by considering the changes on energy use. The model contains two regions (which will be defined as cities in this paper) where individuals are free to move between them to maximize utility. They maximize utility by choosing location and energy service consumption. The individual wishes to live in the location where they can get the most utility from energy service consumption, which depends on the price of energy services and that location's utility function with respect to energy. For example, heating and cooling expenses can be expensive in an area with a very mild climate and total energy service consumption could be lower and yield a higher total utility. With income and total population being held constant, the model shows that the distribution of population between regions with different energy prices, energy uses, and external costs of energy service consumption affects total utility. New zoning or tax policies cause a movement between cities as well as a change in energy service consumption within.

The two regions are expanded from abstract areas to constructed empirical areas using migration data to represent the migration effect of a city. The model is presented and then followed by the representative migration city construction. The two-city model begins with individuals maximizing a quasi-linear utility function $Y_i - P_i^H - (P_i^E + t)E_i + t\hat{E} + V_i(E_i; X_i) - C(N\hat{E})$ where Y_i is income, $P_i^H$and P_i^E are prices of housing and energy services for city i; t is an energy use tax; E is energy use in city i; $\hat{E}$ is the national average energy consumption; $V_i(.;.)$ is a function for city-specific benefits from energy services; X_i is a vector of exogenous attributes for location i; $C(N\hat{E})$ is the external cost of energy use by the whole country, which can be thought of as the national contribution to climate change; and N is population. Note that in modeling energy services, I am looking at the cost of, e.g., maintaining a given temperature in the home, which will be a function of energy prices but also house size, weather, and so forth. Finally, note that the tax is revenue neutral, since individuals are receiving a lump sum rebate of $t\hat{E}$. Next, each city i has Q_i^F identical employers, with revenues $f(.)$ increasing and concave in the the number of people hired. Each city has builders Q_i^B, with costs $k(.)$ increasing and convex in buildings constructed. Now wage income is $f'(\frac{N_i}{Q_i^F})$, or the marginal revenue product of labor (MPL), and housing cost is $k'(\frac{N_i}{Q_i^B})$, the marginal cost of supplying housing. Individuals hold equal rights to all business profits. The two equilibrium conditions are as follows: individuals choose privately optimal energy consumption E_i^* to maximize their utility, so $P_i^E + t = V_1(E_i^*; X_i)$, with $V_1(E_i^*; X_i)$ being the first derivative of $V(.;.)$ with respect to E. The next condition is a locational equilibrium, so $f'(\frac{N_i}{Q_i^F}) - k'(\frac{N_i}{Q_i^B}) - (t + P_i^E)E_i^* + V(E_i^*; Z_i)$ must be equal for all cities. Individuals in this model are identical, and the social welfare function used is additive:

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

So this yields two first order conditions. The first, for energy consumption, is

$$P_i^E E_i - NC^{'}(N\hat{E}) = V_1(E_i; X_i) \tag{2}$$

so that the private optimality condition is socially optimal at a tax of $t = NC^{'}(N\hat{E})$. For the last unit of energy service consumption, the price of energy services plus the optimal tax equals the marginal benefit for the city of that unit of energy services.

The first order condition for location decisions is that

$$f'(\frac{N_i}{Q_i^F}) - k'(\frac{N_i}{Q_i^B}) + V(E_i^*; X_i) - E_i(P_i^E + NC^{'}(N\hat{E})) \tag{3}$$

is constant over space. Income plus the benefits from energy services, minus the cost of energy (both price cost and external cost) and cost of housing must be equal for all locations. This gives a locational equilibrium and there is no arbitrage opportunity from changing location.

Consider the case of environmentally inspired land use restrictions. A location can impose a zoning tax z_i on new construction. Builders in location 1 now have a first order condition $P_1^H = z_1 + k'(\frac{N_1}{Q_1^B})$. Assume that the tax is returned to inframarginal residents to be revenue neutral. Here, Glaeser and Kahn (2008) assume that zoning can affect population sizes but not energy use or energy prices. However, as noted in Mangum (2017), zoning regulations affect the patterns of energy consumption which lead to observed cases of low-emission and high-emission cities, and are not merely an impediment to the movement of households. The effect of zoning on patterns of energy use in City 1 will be modeled though the cost of energy services, P_1^E. Zoning increases the cost of energy related services, P_1^E. Height restrictions, for example, decrease the ratio of interior living space to exterior building space, known in the literature as the floor-area-ratio (FAR), lowering heating and cooling efficiency and making it more expensive to achieve the same level of energy services E_1; it has been shown that such restrictions are welfare decreasing for the urban resident (Bertaud and Brueckner 2005). Any zoning which reduces density, such as a minimum lot size, green belt, or height restriction (such as a limit on the FAR) means that the network for electricity must consist of a higher ratio of infrastructure (such as wires and cables) to buildings they service. Electricity transfer over such infrastructure is less than perfect, so increasing this ratio increases costs of providing any level of electricity. Thus $\frac{\partial P_1^E}{\partial z_1} > 0$. However, it is also possible that added green space reduces cooling costs and that zoning decreases dwelling unit size, which would have the opposite effect.

The zoning tax reduces the number of people in location 1. Starting with the locational equilibrium condition for two cities 1 and 2 after adding the zoning cost for city 1,

$$f'\frac{(N_1}{(Q_1^F})-(k'(\frac{N_1}{Q_1^B})+z_1)-(t+P_1^E)E_1^*+V(E_1^*;X_1)=$$
$$f'(\frac{N_2}{Q_2^F})-k'(\frac{N_2}{Q_2^B})-(t+P_2^E)E_2^*+V(E_2^*;X_2).$$

It is possible to differentiate this condition with respect to zoning z_1:

$$\frac{\partial}{\partial z_1}\Bigg[f'(\frac{N_1}{Q_1^F})-(k'(\frac{N_1}{Q_1^B})+z_1)-(t+P_1^E)E_1^*+V(E_1^*;X_1)=$$
$$f'(\frac{N_2}{Q_2^F})-k'(\frac{N_2}{Q_2^B})-(t+P_2^E)E_2^*+V(E_2^*;X_2).\Bigg]$$

which yields the expression:

$$(\frac{1}{Q_1^F})f''(\frac{N_1}{Q_1^F})(\frac{\partial N_1}{\partial z_1})-(\frac{1}{Q_1^B})k''(\frac{N_1}{Q_1^B})(\frac{\partial N_1}{\partial z_1})-1-t(\frac{\partial E_1^*}{\partial z_1})-(\frac{\partial P_1^E}{\partial z_1})E_1^*-(\frac{\partial E_1^*}{\partial z_1})P_1^E+$$
$$(\frac{\partial E_1^*}{\partial z_1})V_1(E_1^*;X_1)=(\frac{1}{Q_2^F})f''(\frac{N_2}{Q_2^F})(\frac{\partial N_2}{\partial z_1})-(\frac{1}{Q_2^B})k''(\frac{N_2}{Q_2^B})(\frac{\partial N_2}{\partial z_1})$$

First, note that with only two cities, $\frac{\partial N_2}{\partial z_1}=-\frac{\partial N_1}{\partial z_1}$. Population gained by city 2 is population lost by city 1 and vice versa. Secondly, recall the private energy optimization $P_i^E+t=V_1(E_i^*;Z_i)$; this cancels terms and leaves the equation ready to be solved for $\frac{\partial N_1}{\partial z_1}$

$$(\frac{1}{Q_1^F})f''(\frac{N_1}{Q_1^F})(\frac{\partial N_1}{\partial z_1})-(\frac{1}{Q_1^B})k''(\frac{N_1}{Q_1^B})(\frac{\partial N_1}{\partial z_1})-1-(\frac{\partial P_1^E}{\partial z_1})E_1^*=$$
$$(-\frac{1}{Q_2^F})f''(\frac{N_2}{Q_2^F})(\frac{\partial N_1}{\partial z_1})+(\frac{1}{Q_2^B})k''(\frac{N_2}{Q_2^B})(\frac{\partial N_1}{\partial z_1})$$

And thus the resulting equation for $\frac{\partial N_1}{\partial z_1}$ is:

$$\frac{\partial N_1}{\partial z_1}=\frac{-1-(\frac{\partial P_1^E}{\partial z1})E_1^*}{(\frac{1}{Q_1^B})k''(\frac{N_1}{Q_1^B})+(\frac{1}{Q_2^B})k''(\frac{N_2}{Q_2^B})-(\frac{1}{Q_1^F})f''(\frac{N_1}{Q_1^F})-(\frac{1}{Q_2^F})f''(\frac{N_2}{Q_2^F})}<0. \quad (4)$$

Zoning regulations increase the price of energy services and will cause additional reduction in population 1 relative to a model where zoning has no impact on the price of energy services. The impact from the zoning migration effect on welfare is $((E_2 - E_1)(NC^{'}(N\hat{E}) - t) + z_1)(\frac{\partial N_1}{\partial z_1})$. $(E_2 - E_1)$ is the change in energy consumption from the household moving from city 1 to city 2. $(NC^{'}(N\hat{E}) - t)$ is the external cost of energy use in the zoned city, net of energy taxes. This is positive as long as $(E_1 - E_2)(NC^{'}(N\hat{E}) - t) > z_1$. This effect is welfare improving if 1) city 1 was the high energy use city $((E_1 - E_2) > 0)$ and 2) z_1 is smaller than the difference in energy use times the difference in between social cost of energy use and the energy tax. This is to say that the zoning tax should not be greater than the external cost of energy consumption net of taxes. Assuming energy taxes which are smaller than external cost of energy $((NC^{'}(N\hat{E}) - t) > 0)$, if city 1 is the low-energy city $((E_1 - E_2) < 0)$ then z_1 must be welfare reducing. In other words, if zoning taxes are imposed on low energy use city, they will be counterproductive: they force population away from low energy-use areas and into high energy-use areas. Next consider the effect of a zoning tax on energy services E_1.

Energy service can be broken down into two main types: in-home energy and gasoline from driving. Thus E_1 can be represented as a function: $E_1 = f(Heating(p_h(z_1), p_e, Z_1), Electricity(p_h(z_1), p_e, Z_1), Driving(p_h(z_1), p_e, Z_1$. Z_1 is a vector of city characteristics such as climate. In-home energy services are comprised of heating and electricity, both of which depend on the price of housing, the price of energy services, and city characteristics. Driving depends on price of housing, the price of energy services, and city characteristics. The primary interest for energy is the relationship between per-household energy services and zoning. Thus $\frac{\partial E_1}{\partial z_1}$ depends on zoning's effect on heating, electricity, and driving through price of housing. $\frac{\partial p_h}{\partial z_1}$ is positive; as zoning regulations increase, housing prices increase. And for heating and electricity, $\frac{\partial Heating(.)}{\partial z_1}$ and $\frac{\partial Electricty(.)}{\partial z_1}$ are negative because of two effects: higher housing prices lead to smaller houses built and consumed, reducing energy consumption in-home, because smaller houses will require less energy to heat and cool and use less electricity. Zoning increases the price of energy services P_1^E, reducing quantity demanded of these services. Smaller houses built increases density and reduces average commute distance, reducing driving. Price of energy services includes gasoline and other transport related expenditures, and thus reduces consumption of these services via driving. Finally, simulations of zoning regulations on energy use in Mangum (2017) show a negative correlation at the national level for both in-home energy use and for driving. Thus $\frac{\partial E_1}{\partial z_1}$ is negative. When zoning z_1 is changed, there are effects on the extensive $\frac{\partial N_1}{\partial z_1}$ and intensive $\frac{\partial E_1}{\partial z_1}$ margins. As noted in Mangum(2017), any simulation of national policy necessarily involves changes on both margins. What this means is that high-emission cities will have two carbon-reducing effects from increased zoning: shifting population to cleaner cities (carbon decreasing) and lowering per-household carbon use within the city (carbon decreasing.) However, low-emission cities will have opposing effects from zoning: they can trade higher per-household energy use for more population by decreasing zoning, or trade lower per-household energy use for lower population by increasing zoning. The effect of zoning policies on energy use can be written as:

$$\frac{\partial (NE)}{\partial z_1} = \frac{\partial N_1}{\partial z_1}[E_1 - E_2] + \frac{\partial E_1}{\partial z_1}N_1. \tag{5}$$

The first half is the effect of migration on total energy use; this comes from multiplying the number of people who move out of city 1, $\frac{\partial N_1}{\partial z_1}$, by the energy use differential between city 1 and city 2, $[E_1 - E_2]$. The second half is the effect of zoning policies on per-household energy use within city 1, $\frac{\partial E_1}{\partial z_1}$, times the population of city 1 N_1. Thus equation (5) captures the tradeoffs mentioned above when considering zoning policies and energy use.

Whereas Glaeser and Kahn (2010) consider the carbon intensity of living in arbitrarily compared cities, and whereas Mangum (2017) estimates an equilibrium model without regards to observed patterns of inter-city substitution, I propose to calibrate the carbon intensity of a city's relevant substitutes using the matrix of intercity migration patterns. Thus to expand the two-city model, and to quantify the counterproductive effects described in the two-city model, pairs will be constructed for an MSA and its representative migration city. Two types of representative cities are constructed for each MSA: one representing the target of that MSA's out-migration, and one representing the origin of that MSA's in-migration. The representative out-migration city is a migration-weighted city using all of the cities which receive migration from the MSA. This represents the yearly flow carbon footprint of all migrants moving out of MSA i at year t. For each MSA_k which receives migrants from MSA_i, the percent of out-migration of MSA_i which goes to MSA_k is multiplied by the per-household emissions for MSA_k. This is done for multiple years t. So for $MSA_{i,t}$, the representative out-migration city $R_{i,t}$ is defined:

$$R_{i,t} = \sum_k \frac{Migration_t \; MSA_i \; to \; MSA_k}{\sum_l Migration_t \; MSA_i \; to \; MSA_l} * Emissions(MSA_{k,t}) \forall l \neq i, k \neq i. \tag{6}$$

The representative out-migration city does not include the people who do not move ($k \neq i$ and $l \neq i$). For each $MSA_{i,t}$, the net effect on national emissions from out-migration is:

$$(Emissions(MSA_{i,t}) - Emissions(R_{i,t})) * \sum_k Migration_t(MSA_i to MSA_k)$$
$$for\ k \neq i,$$

which is the difference in emissions per household between the MSA and its representative out-migration city times the number of households which migrated out of that MSA. A second set of representative migration cities is also constructed for in-migration. This represents the yearly flow carbon footprint of all migrants who move to MSA_i at year t. For MSA_i, the representative in-migration city R^{IN} it is defined:

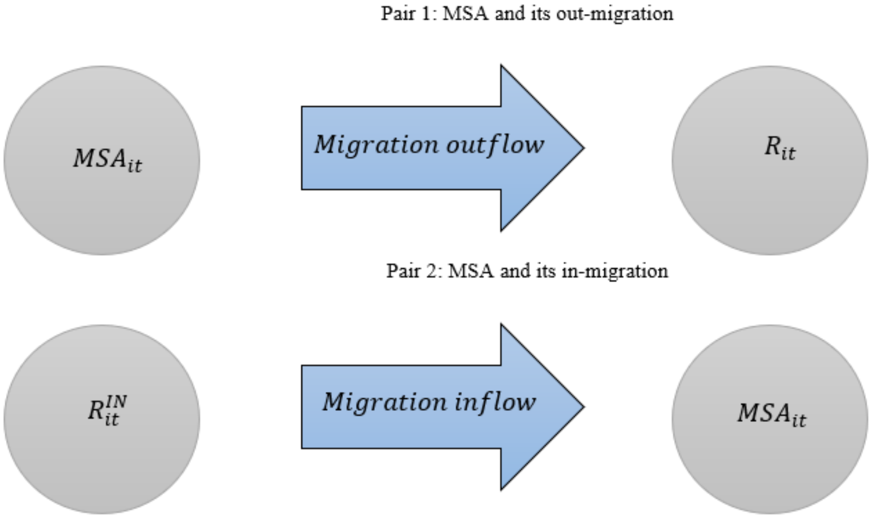
$$R^{IN}_{i,t} = \sum_k \frac{Migration_t\ MSA_k\ to\ MSA_i}{\sum_l Migration_t\ MSA_l\ to\ MSA_i} * Emissions(MSA_{k,t}), \forall l \neq i, k \neq i. \tag{7}$$

The net effect on national emissions from in-migration is:

$$(Emissions(R^{IN}_{i,t}) - Emissions(MSA_{i,t})) * \sum_k Migration_t MSA_k to MSA_i$$
$$for\ k \neq i,$$

which is the difference in emissions per household between the representative in-migration city and the MSA times the number of households which migrated into that MSA. There are two possible pairs of cities to use the two-city model for. These two pairs will be analyzed to show the impact on national emissions from migration to and from major metro areas in the US.They can be seen in Figure 1.

Figure 1: Representative Migration Cities



3. Data

This section describes the data used in this paper. Migration data comes from the IRS tax returns data. These are reported to the IRS as a change in household address from year to year on the head of household tax return. This data has both to and from city, and so gives flows for every county-to-county pair in the US. These counties are aggregated up to the MSA level so that moves in the data represent changes in labor markets rather than local moves. Data for all MSA pairs in the US exists, though only those MSAs with adequate emissions data are included in the analysis. As better emissions data becomes available, more MSAs can be added to the migration network data. These data are a panel of one-way flows for years 1991-2010. Data on energy use closely follows the methodology of Glaeser and Kahn (2010) and Mangum (2017). The goal of this data is to assign per household carbon emissions to each MSA in the analysis for each year in the time horizon. Data for gasoline use comes from the National Highway Transportation Survey (NHTS), which has 5 waves from 1983 until 2009. Total gallons per household are calculated in the same way as Mangum (2017) by regressing gas usage on location and time dummy variables, and then scaled for city household size and proportion of households with personal vehicles obtained from public use census files. This is to be able to use the average driving emissions of the city household rather than the NHTS household. In-home energy use comes from the Residential Energy Consumption Survey (RECS). The energy sources used are fuel oil, natural gas, and electricity. The RECS has seven waves from 1987-2009. Geographic data is relatively limited, including census subregion and metro status. Older homes are known to have higher energy use than newer homes, so the average energy use tends to be higher than the marginal new home energy use. However, newer homes are more often built in the suburbs and are associated with higher gasoline consumption (Glaeser and Kahn 2010). It is possible to distinguish between average energy use and marginal energy use by restricting the sample to homes built in the last 20 years for marginal energy use.

With energy usage data assigned, it is now necessary to standardize energy use in terms of carbon emissions. Glaeser and Kahn (2010) assign 23.46 pounds per gallon of gasoline, 120.6 pounds per 1000 cubic feet of natural gas, and 26.86 per gallon for fuel oil. Carbon content for electricity is determined by state using the North American Electric Reliability Corporation (NERC) carbon content per kilowatt hour. Now each MSA has a household level average annual carbon emission for each year in the time horizon. For a summary of assigned household carbon emissions at the MSA level over time, see Figure 18 in the Appendix.

Data for the Wharton Regulation Index is published online by the authors of Gyourko, Saiz, and Summers (2008). This data is used as an indicator of strictness of housing regulations. This analysis is limited to more recent years by the time limitations of the Wharton Index.

4. Results

This section details the estimates and results for the representative migration cities. The 49 largest U.S. MSA's have their average household carbon content, representative migration city, and total carbon content from migration calculated for the years 1992, 2000, and 2008. All estimates use the top 49 largest metropolitan areas in the US. These are the cities which have the best available data for emissions at the household and individual level. First, all representative migration cities are calculated by taking the shares of out-migration and multiplying by household level emissions. Figure 11 in the appendix details the findings for 2008. Each MSA is identified by numeric MSA code and name. The second column is the population rank of the MSA. Within the sample of cities, they are ranked on average population between 1990 and 2010. The fourth column is the carbon emissions per household of the MSA (origin city). This is for the city listed in the same row. A household is calculated using a representative number of household members which is constant for all MSAs. The fifth column is the total number of households moving out of the MSA for 2008. Note that these only include moves within the sample of MSAs. The sixth column is the per-household carbon of the representative out-migration city (i.e. the aggregate substitute to which migrants from the city are going to). For an out-migrant from the row MSA chosen at random, this is the average new carbon per household of the destination. For comparison, the seventh column shows the per-household difference in carbon emissions between the representative out-migration city and the MSA (Rep MSA.) A positive number indicates that the MSA has a lower carbon per household emission, and thus each out migrant on net will add to national carbon emissions. The last column is the total carbon footprint for migration out of the MSA in millions of pounds, and the table is sorted by this value. The average net carbon from out-migration is weighted by that MSA's out migration to return a total carbon footprint for all out migration for that year. Positive numbers show that out-migration (caused by policy or any other reason) increases national carbon emissions, and negative numbers show that out migration is instead carbon reducing. The magnitudes are related to the total migration flows and the other MSAs to which these flows are sent to; some specific cases are discussed later. In Tables 2 and 3, this same layout is repeated for years 2000 and 1992 to see how metropolitan areas and their representative migration cities change over time. Note that carbon emissions for these calculations are in terms of annual emissions added: a result of 10 million pounds means that the migrants from that year add 10 million pounds of carbon to the national emissions *every year*.

What the tables show is that the MSAs with the largest footprint for out-migration are those cities with relatively low household level emissions for their region and large total outflows. Los Angeles is at the top of the table for all three years, and for 2008 households leaving LA added over 700 million pounds of carbon emissions per year to the national footprint. New York City and Philadelphia in the northeast, Chicago in the Midwest, Miami in the Southeast, and Seattle in the Northwest all have similar roles in the regions, though have a much smaller outflow and a lower household emissions differential with their representative out-migration cities, and thus a lower footprint. This is not always the case, however, and the migration network plays a large role in carbon footprint from migration. For example, Miami is ranked 5th in carbon footprint from out migration at 177 million annual pounds per year, despite having almost identical household emissions as Salt Lake City, which is ranked 19th in this table and is carbon saving in out-migration. Also notable is that NYC started off in the middle of the pack in 1992, almost carbon neutral, but has risen to the second highest footprint for leavers at over 477 million pounds of carbon in 2008.

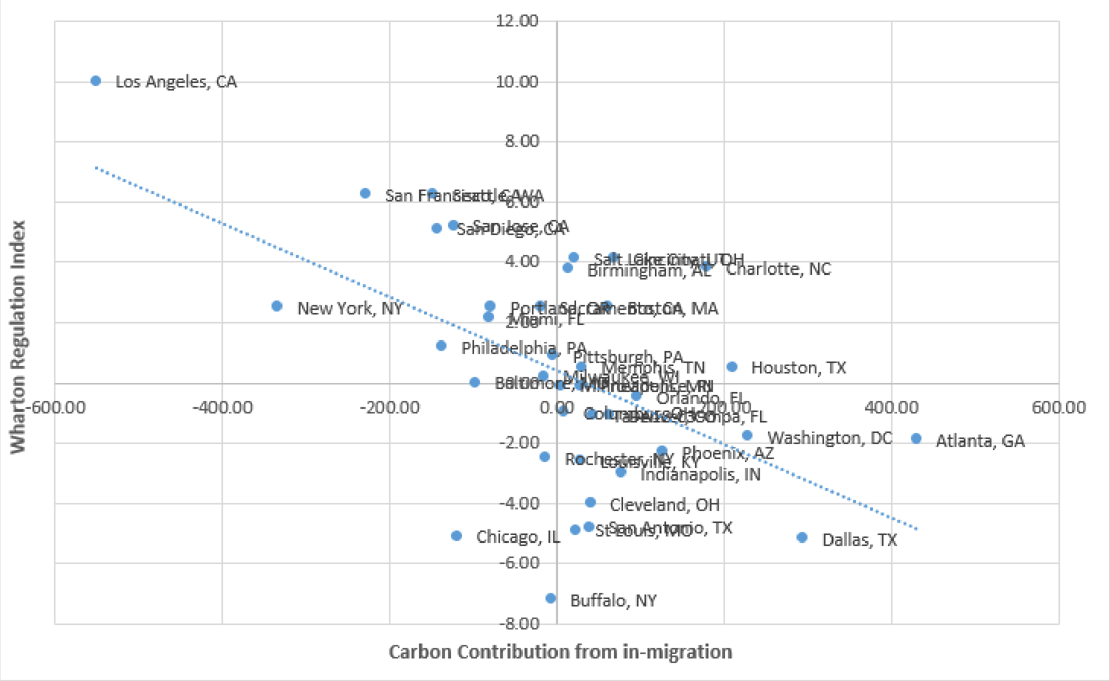
The bottom of the table, occupied by those cities most carbon-saving in out-migration, is occupied primarily by MSAs in the south. Atlanta, Washington DC, Houston, and Dallas are all near the bottom, and thus are carbon-saving from their out-migration. Oklahoma City, Boston, and Las Vegas are also notable examples from other regions, though to a lesser extent. Again it is interesting to see the role of the migration network at play. Washington DC is a close second in terms of carbon saving from out-migration, coming in at a 230 million annual pounds per year reduction, even though it has lower per household emissions than San Antonio, which is essentially carbon neutral in out-migration. Boston is an interesting case because most of its representative out-migration city is New York City, and so becomes grouped as a high-emission city due to its proximity and migration flow relationship with one of the lowest-emission cities.

Next are the results for representative in-migration cities. This represents the emissions for migrants to a city. High-emission cities have a high in-migration footprint. The same tables are constructed for 2008, 2000, and 1992. Southern MSAs dominate the top of the list. The magnitudes have changed but the regional pattern remains similar. Again NYC goes from being an average footprint city in 1992 to a low-emission city in 2008.

Two-City Model

Attention is now turned to the two-city model. MSAs with the highest addition to the carbon footprint, either with a low carbon footprint for leavers or a high carbon footprint for newcomers, are ones which would want the highest housing regulations, all else equal, if the goal is reducing the overall carbon footprint of the US. This would provide the most incentive for households to migrate away from these high emissions MSAs and provide disincentives for migrants to move to these MSAs. There can also be gains from the intensive margin, as stricter zoning can reduce carbon emissions within the city. Unfortunately, according the Wharton Regulation Index, the reality is almost exactly the opposite. LA, which has far and away both the highest contribution to carbon footprint from out-migration and highest carbon footprint savings from in-migration, is the city with far and away the highest Wharton index value, meaning it is the strictest on new housing development. San Francisco, San Diego, Seattle, San Jose, NYC and Miami are all near the top of the regulation list and the top in terms of their contribution from out-migration to carbon footprint and savings from in-migration. Those MSAs which are the most carbon-saving from out-migration and carbon-costing from in-migration (standing to reduce emissions the most on the extensive margin), Atlanta, Dallas, Washington DC, and Oklahoma City, are at the very bottom of the Wharton index, meaning they are the most friendly towards new housing development. This confirms the conjecture of Glaeser and Kahn (2010). Regression results for Figure 2 are shown in Figure 17 in the appendix.

Figure 2: Wharton Regulation Index and Carbon from In-Migration



Next special attention is paid to both high-emission and low-emission cities. The high-emission cities to be examined are Atlanta, Washington DC, and San Antonio. These three are selected to show the differing influences of migration flows and within-city carbon emissions on total footprints. In-migration is considered for these cities. Los Angles is selected as the low-emission city. Out-migration is considered for LA.

Atlanta, Georgia

Atlanta is a prototypical high-emission city by the known factors which increase per-household carbon emissions: It is located in the south, people spend a lot of time driving, and people live in large houses. As noted in Mangum (2017), Atlanta is near the top of MSAs in terms of carbon from in home sources and from driving. In terms of migration flows, Atlanta was near the top of the list in total households migrating to it (nearly 42,000 in 2008). All of these factors combine to make Atlanta the dirtiest MSA in the country in 2008 in terms of carbon emissions from in-migration. Note that when discussing migration for a particular MSA, only the migration to and from the top 49 MSAs are considered as a base. 10% of Atlanta's in-migrants means 10% of the total in-migrants from the 48 other MSAs used for the sample. For most cities in the sample, the top 48 other MSA's constitute nearly all of the migration flows. Where are the households moving to Atlanta coming from? For 2008, about 17% of Atlanta's in-migrants in the city sample come from New York City, and about 14% come from Miami. After these two, no other MSAs represent more than 5% of Atlanta's in-migrants. The difference in annual household carbon emissions for Atlanta and NYC is over 15,000 pounds per year; in other words, Atlanta households emit 50% more carbon than NYC households. The difference in annual household carbon emissions for Atlanta and Miami is over 12,000 pounds per year; households in Atlanta emit around 36% more carbon than households in Miami. Accounting for just over 30% of Atlanta's in-migrants, NYC and Miami account for over 40% of its carbon emissions from in-migration. So over 160 million pounds of annual carbon emissions was added by movers from Miami and NYC to Atlanta in 2008. Los Angeles, with one of the lowest carbon emissions per household, accounts for around 5% of Atlanta's in-migration (1,900 households in 2008). L.A. accounts for over 10% of the carbon contribution from Atlanta's in-migration. The per-household carbon emissions in Atlanta is 93% higher than in L.A., a gap of around 22,000 pounds per year. If L.A. were to send a similar amount of households to Atlanta as NYC does, this would mean an additional 5,000 households moving from L.A. to Atlanta and would increase national annual carbon emissions by 110 million pounds. Figure 3 details Atlanta's in-migration in households for 2008, while Figure 4 details Atlanta's in-migration carbon contributions for 2008. Atlanta's carbon contributions from in-migration for 2000 and 1992 can be found in the appendix.

Figure 3: Atlanta Representative In-Migration City 2008

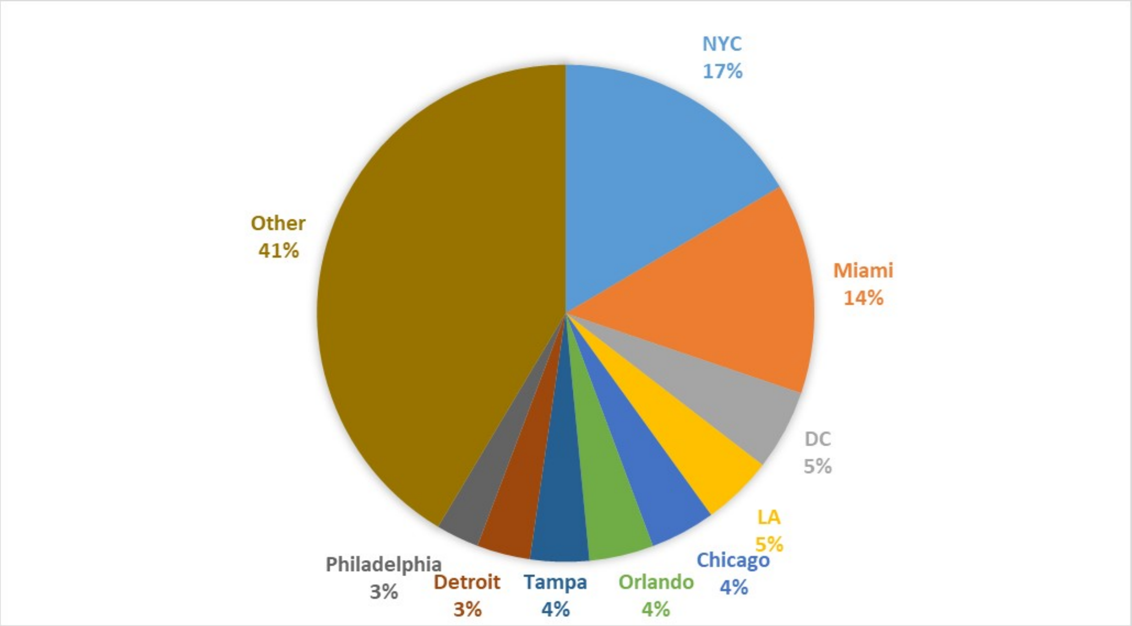
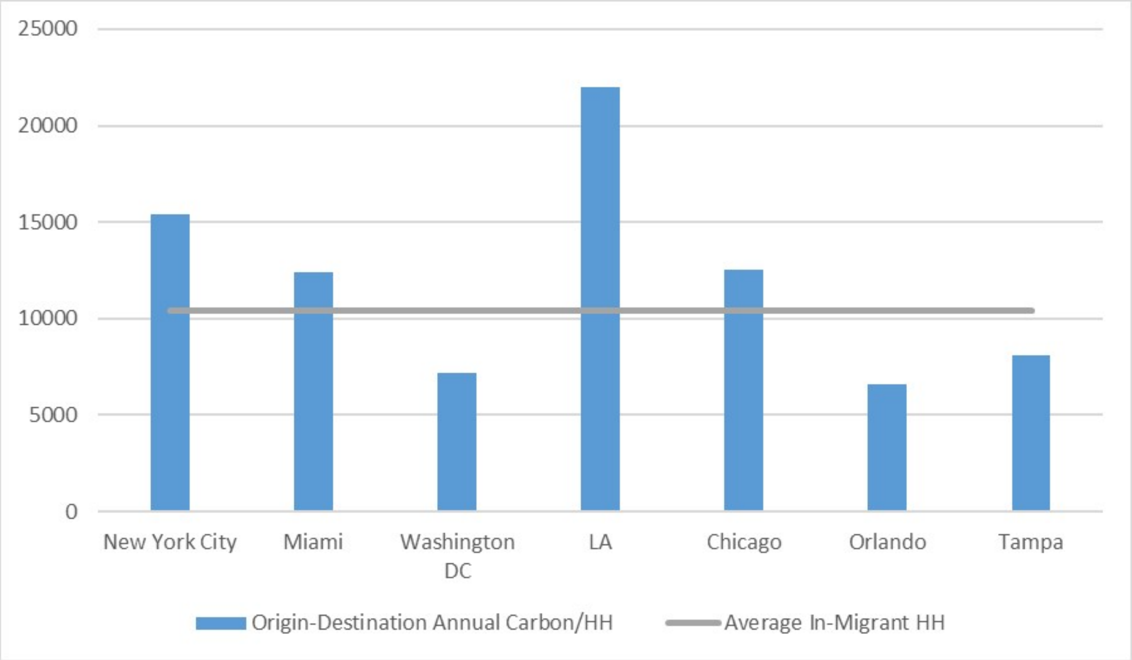


Figure 4: Atlanta In-Migration Carbon Differentials, 2008



Washington, D.C.

Washington DC has consistently contributed one of the highest carbon totals from in-migration, despite being significantly cleaner in terms of carbon emissions per-household than other cities near the top of in-migration footprint. In 2008 DC had a per household carbon emission of 38,375 pounds. By comparison, Atlanta had a per-household carbon emission of over 45,500 pounds, and Dallas, Houston, Charlotte, and Austin, all cities near the top of in-migration carbon footprint, all had per-household emissions between 42,000 and 45,000 pounds per year. Despite being lower emission than these cities, Washington DC has a large in-carbon footprint because of its migration network, as shown in Figures 5 and 6. The biggest migration senders to DC are Baltimore and NYC, and they have significantly lower emissions per household (32,227 and 30,157 respectively.) This means that these two channels of migration contribute more than half of DC's in-migration carbon footprint, adding 120 million pounds of carbon per year in 2008. Washington DC's carbon contributions from in-migration for 2000 and 1992 can be found in the appendix.

Figure 5: Washington D.C. Representative In-Migration City 2008

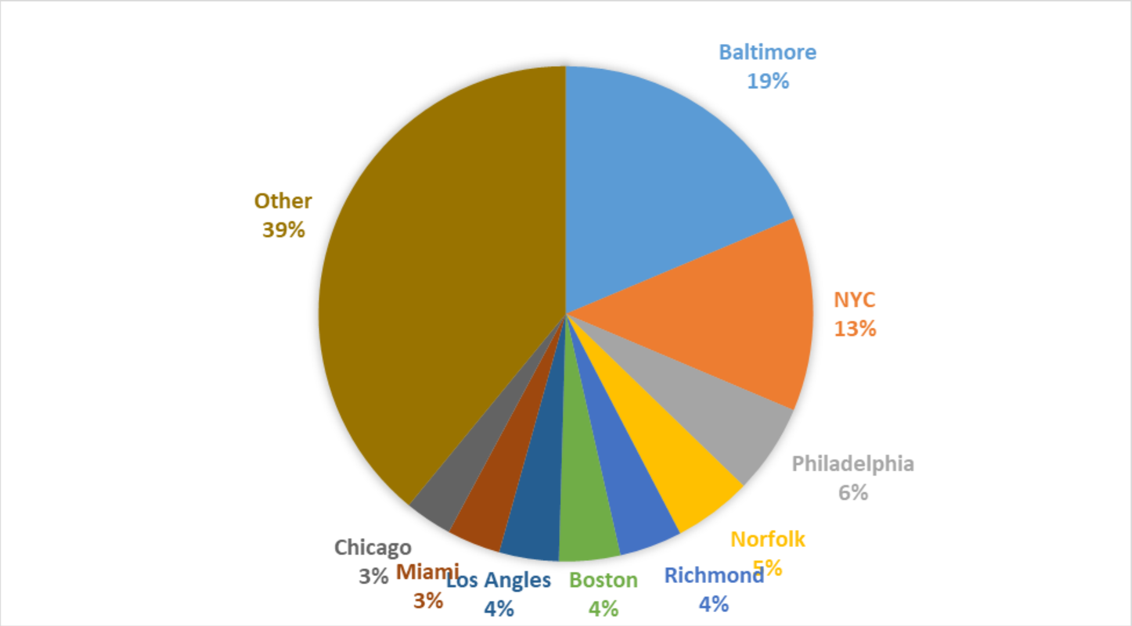
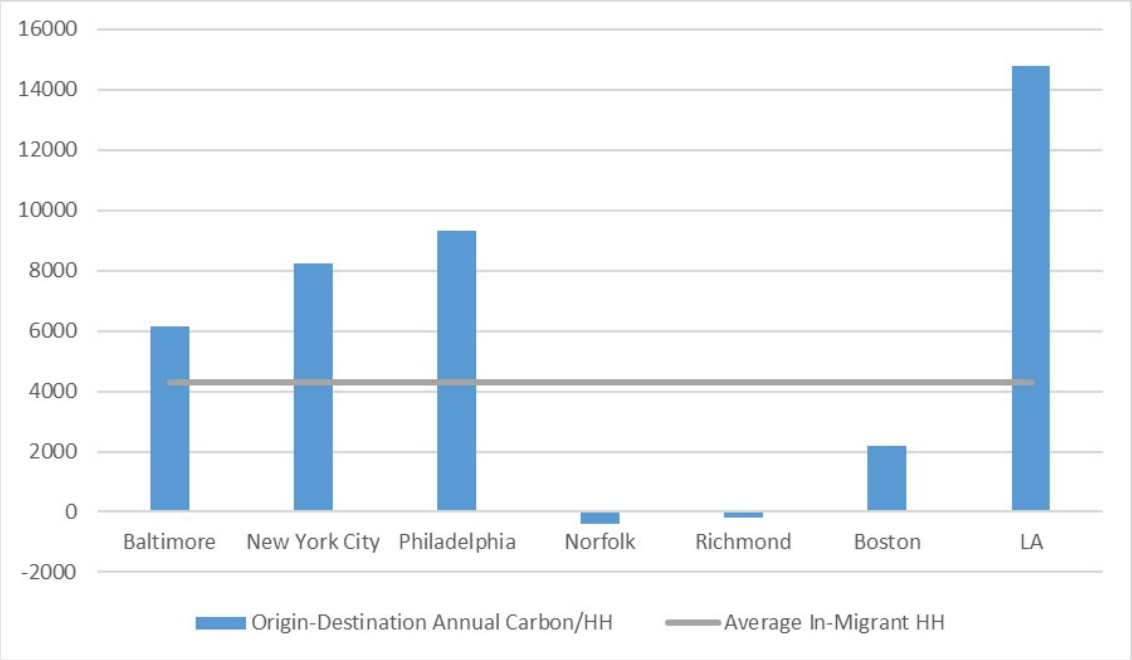


Figure 6: Washington DC In-Migration Carbon Differentials, 2008



San Antonio, TX

San Antonio is an interesting city and another example of the importance of the interplay between migration network and per-household emissions. In 2008, San Antonio had a per-household emission of 39,994 pounds per year; this is higher than that of Washington DC. However, the carbon footprint of in-migration in San Antonio was only 40 million pounds per year, or about 17% of the footprint from in-migration for Washington DC. Its top 3 migration senders, Austin, Houston, and Dallas (see Figure 7) are all higher than San Antonio in per-household emissions. The in-carbon footprint for these cities is -25 million pounds per year for 2008. Relative to its Texas neighbors, San Antonio is a low-emission city, and so is actually carbon-reducing for these migrants. However, the carbon footprint for movers from Los Angeles to San Antonio is around 21 million pounds per year, or over half of the total net footprint for San Antonio's in-movers. Riverside and San Diego are also large contributors to the in-migration footprint, 9 million pounds per year and 6 million pounds per year respectively, despite only being 3% each of the total in-movers to San Antonio. San Antonio's carbon contributions from in-migration for 2000 and 1992 can be found in the appendix.

Figure 7: San Antonio Representative In-Migration City 2008

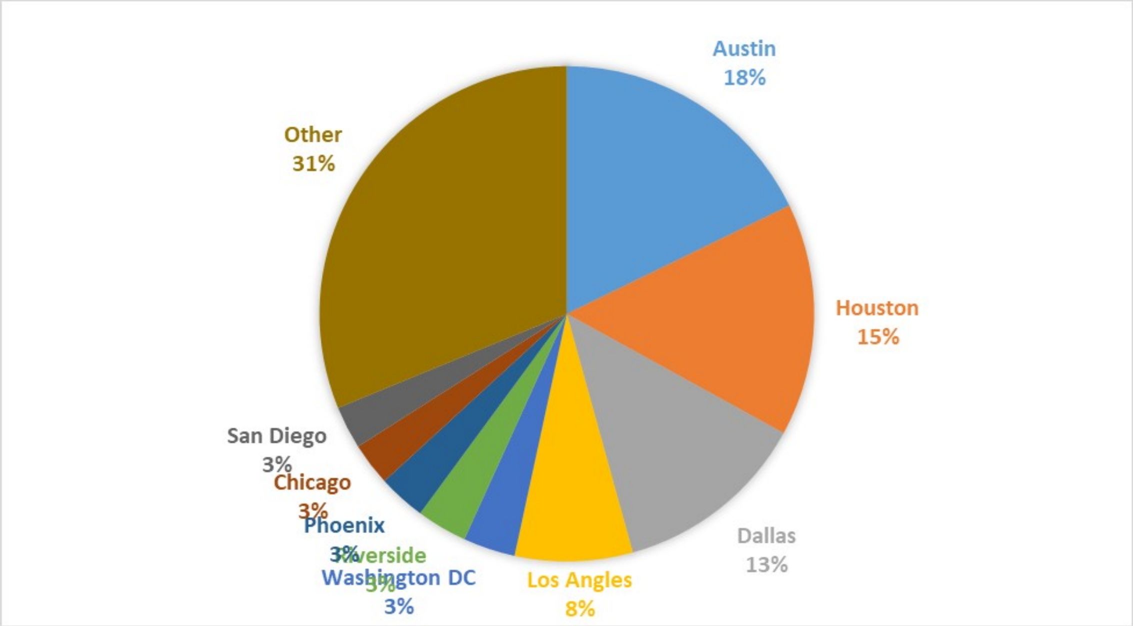
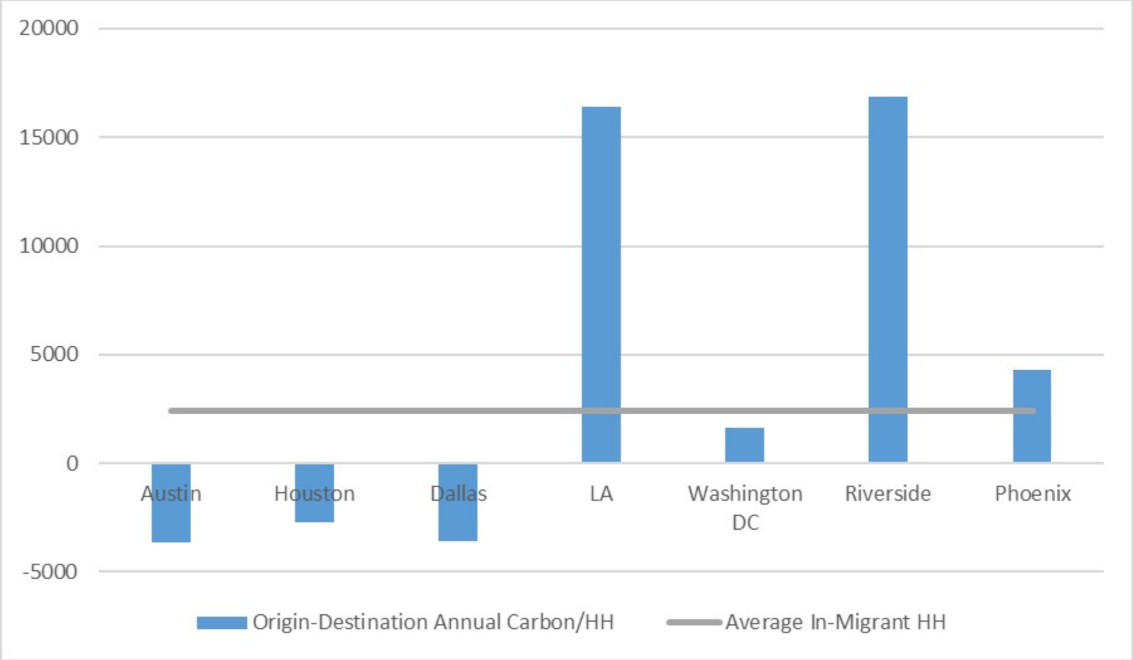


Figure 8: San Antonio In-Migration Carbon Differentials, 2008



Los Angeles, California

L.A. is a low-emission city and contributes to carbon emissions through out-migration. Thus the representative out-migration city will be used for L.A. In 2008, L.A. had a per-household emission of 23,590 pounds per year, one of the lowest in the country. Homes in Los Angeles don't require much cooling and heating, and the sources of electricity and heating are low carbon in California. Each year 100,000 households migrate out of L.A., and the destination cities have on average 6400 pounds per ear higher emissions per household. The total annual carbon increase from out-migration for L.A. in 2008 was over 700 million pounds. Almost half of the out-migrants are to other cities in California, mostly Riverside, San Diego, and San Francisco. Only a small part of the total carbon footprint comes from these cities. Destinations which receive a smaller portion of the out-migrants from L.A., such as Las Vegas, Phoenix, and Dallas, and Atlanta as we say previously, all have very large carbon footprints. A small percent of L.A.'s migration is still a very large number of households, and the increase in carbon emissions can be nearly double.

Figure 9: L.A. Out-Migration City 2008

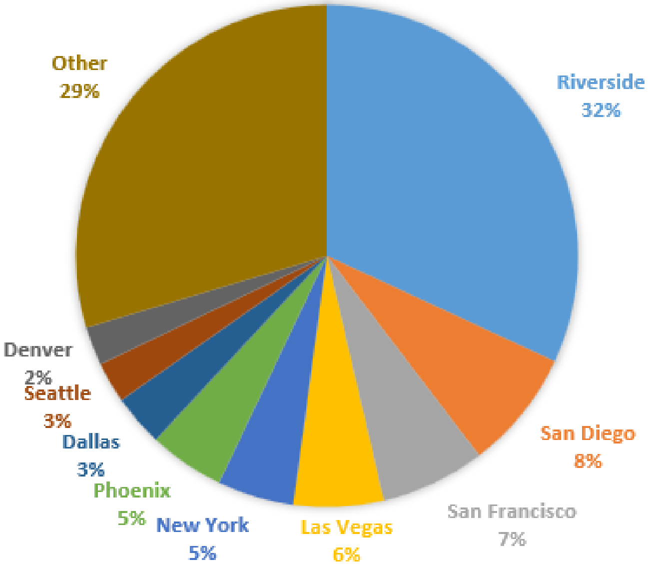
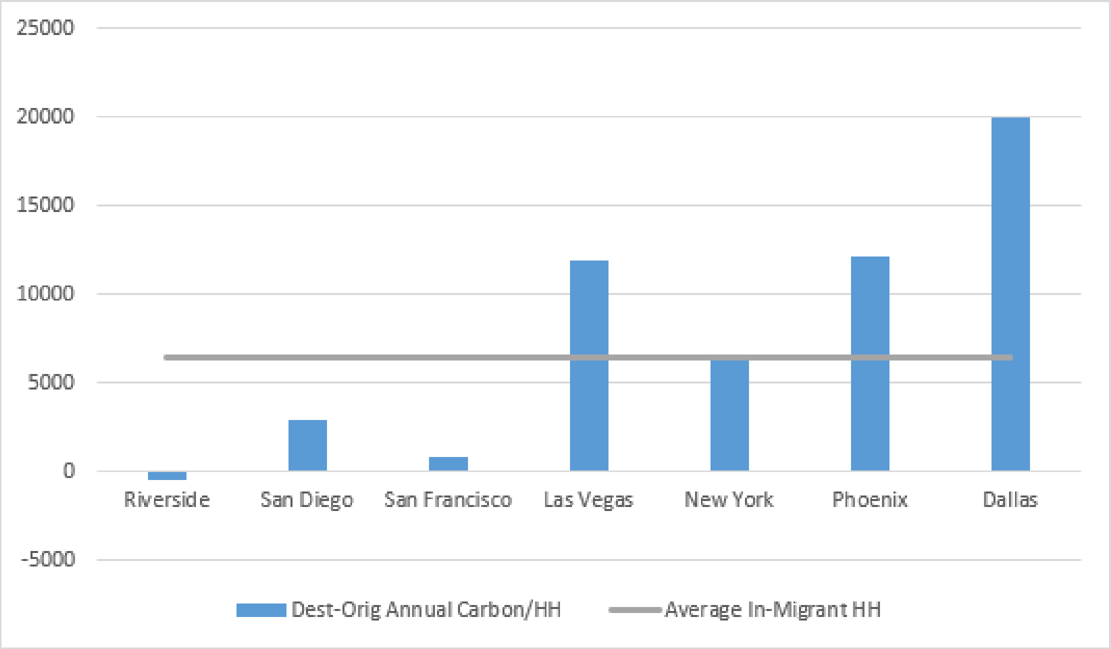


Figure 10: L.A. Out-Migration Carbon Differentials, 2008

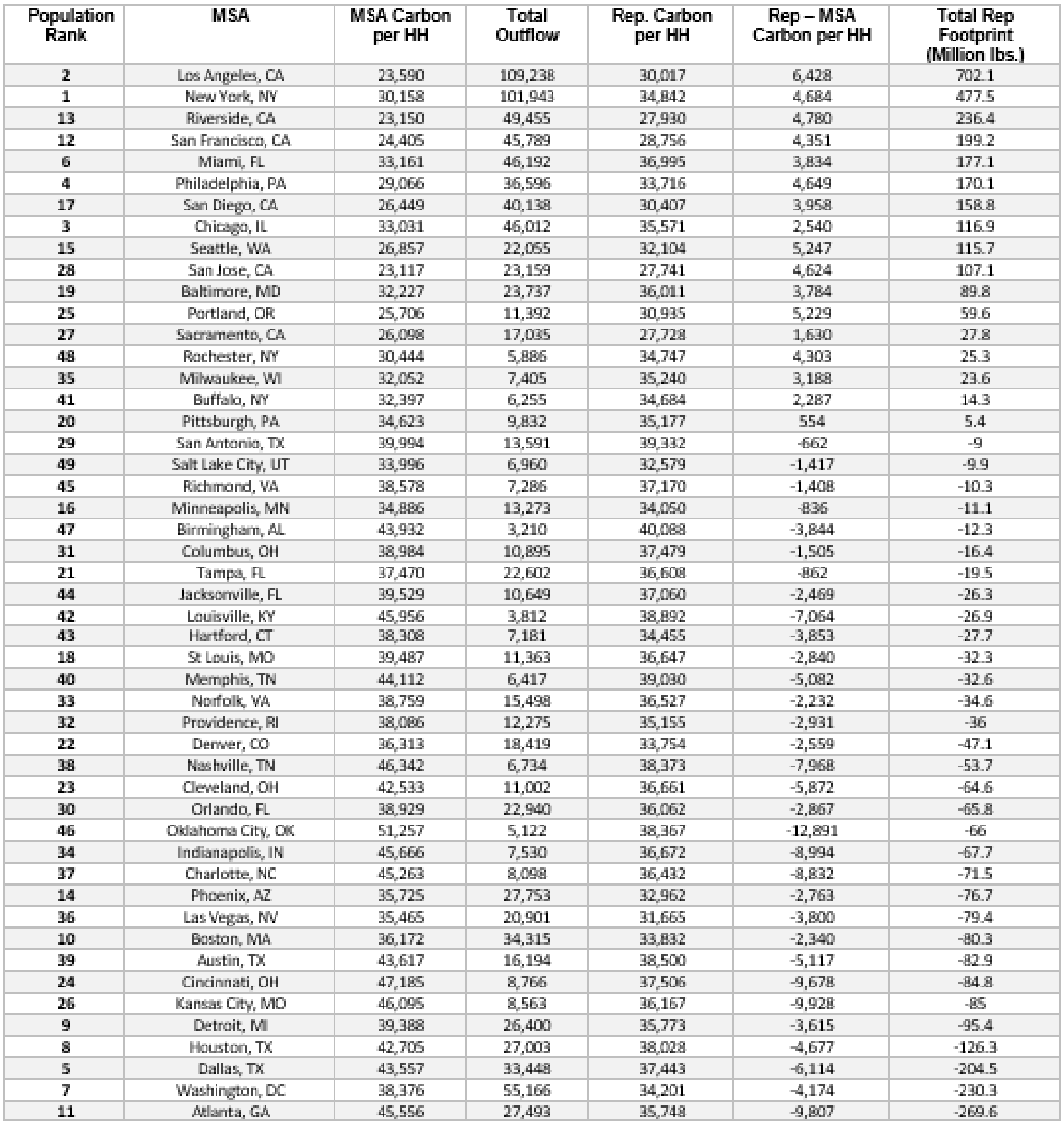


5. Conclusion

This paper investigates the relationship between the intercity migration network in the US and carbon emissions at the household level. It's not simply the case that some cities are cleaner than others in emissions, but as people move from city to city, they affect the overall carbon output of the country. Thus is it important to know not only the emissions levels of cities, but also their relative position in the migration network and the carbon emissions associated with migration. Certain cities, notably Atlanta and Washington, DC are in a position where they receive many migrants from other cities and have a high per-household emissions factor, and thus growth in these cities increases total carbon output. Certain cities in a large part of the migration network can vastly improve the national carbon footprint by attracting people to migrate there from higher emission cities. Los Angeles, Chicago, and New York City are particularly striking examples of this phenomena, together reducing the annual national carbon footprint by nearly one billion tons per year from in-migration. When it comes to policies which can affect internal migration, we see from analysis using the Wharton Regulation Index that current housing policies greatly add to national carbon emissions on the extensive margin, since the places which are most carbon-saving as destinations are those more heavily regulated than the cities which are most carbon-saving as origins of movers. In the attempts to reduce total national carbon footprint, the ultimate way to reduce the consequences from climate change, it is clear that policies must be aimed at both the household emissions margin and the migration flow margin. Attempting to tax or regulate cities such as New York City or Los Angeles will cause a substantial increase in total national carbon from migration sources. In 2018, a new regulation was passed in California which requires new homes to be constructed with solar panels, with an increased construction cost z_1 estimated between $8,000 to $12,000 per house (Penn 2018). It was passed by unanimous vote by the California Energy Commission with wide public approval. While sure to provide some energy savings from solar energy, the increase to an already regulated and expensive housing market is sure to have trade-offs not considered by the commission. The gains come in an area which has the best climate and thus lowest need for in-home energy, and replaces energy generated from among the lowest carbon-heavy sources in the country. The increase in housing costs are sure to drive would-be movers and some current residents to migrate elsewhere, and migrating out of California cities will increase the national carbon footprint substantially. Local policies passed on their green merit can in fact not be green at all, and understanding these trade-offs in terms of energy use and migration flows is the key to evaluating such policies now and in the future.

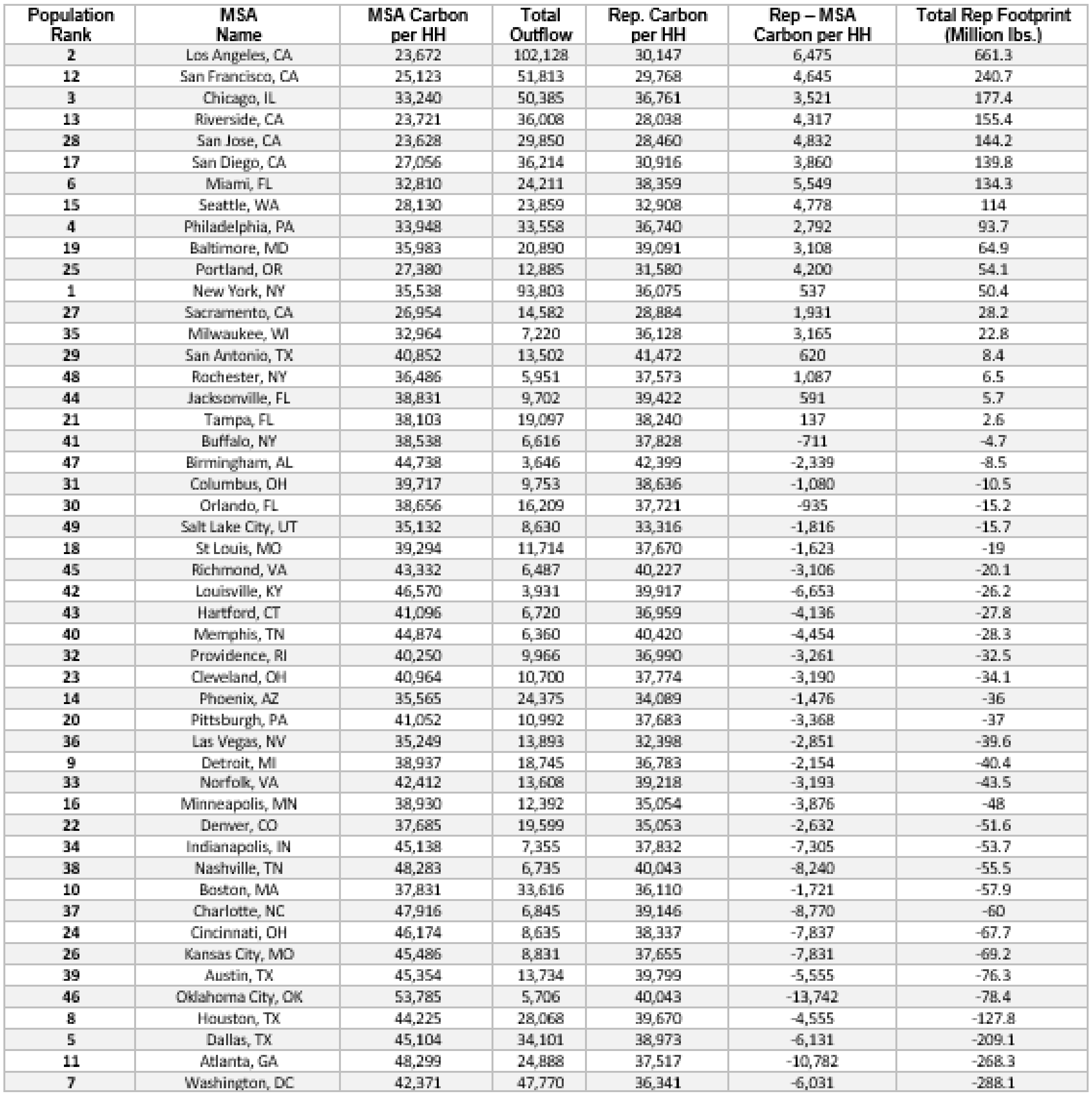
Appendix

Figure 11: Representative Cities 2008



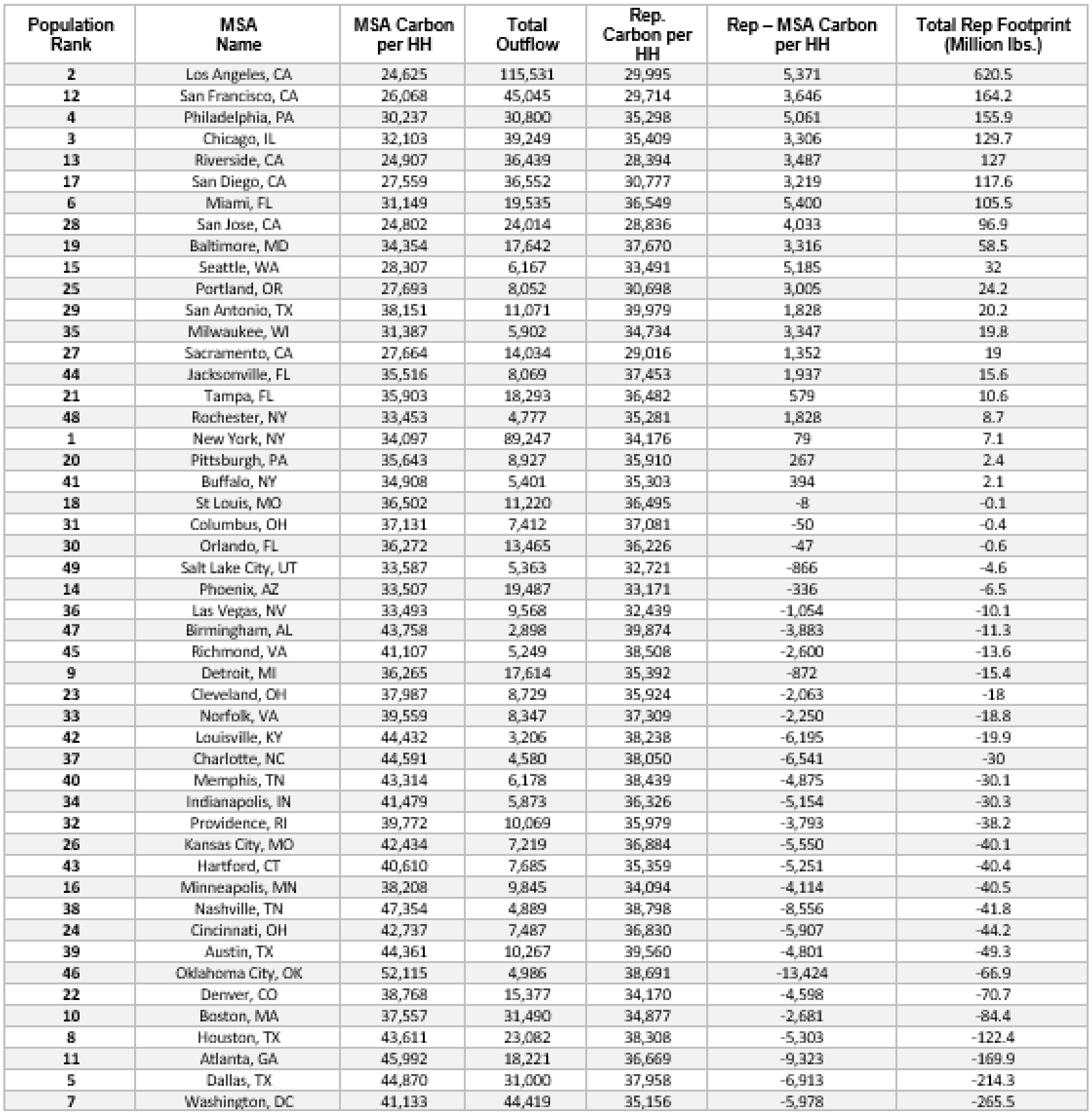
Population Rank	MSA	MSA Carbon per HH	Total Outflow	Rep. Carbon per HH	Rep – MSA Carbon per HH	Total Rep Footprint (Million lbs.)
2	Los Angeles, CA	23,590	109,238	30,017	6,428	702.1
1	New York, NY	30,158	101,943	34,842	4,684	477.5
13	Riverside, CA	23,150	49,455	27,930	4,780	236.4
12	San Francisco, CA	24,405	45,789	28,756	4,351	199.2
6	Miami, FL	33,161	46,192	36,995	3,834	177.1
4	Philadelphia, PA	29,066	36,596	33,716	4,649	170.1
17	San Diego, CA	26,449	40,138	30,407	3,958	158.8
3	Chicago, IL	33,031	46,012	35,571	2,540	116.9
15	Seattle, WA	26,857	22,055	32,104	5,247	115.7
28	San Jose, CA	23,117	23,159	27,741	4,624	107.1
19	Baltimore, MD	32,227	23,737	36,011	3,784	89.8
25	Portland, OR	25,706	11,392	30,935	5,229	59.6
27	Sacramento, CA	26,098	17,035	27,728	1,630	27.8
48	Rochester, NY	30,444	5,886	34,747	4,303	25.3
35	Milwaukee, WI	32,052	7,405	35,240	3,188	23.6
41	Buffalo, NY	32,397	6,255	34,684	2,287	14.3
20	Pittsburgh, PA	34,623	9,832	35,177	554	5.4
29	San Antonio, TX	39,994	13,591	39,332	-662	-9
49	Salt Lake City, UT	33,996	6,960	32,579	-1,417	-9.9
45	Richmond, VA	38,578	7,286	37,170	-1,408	-10.3
16	Minneapolis, MN	34,886	13,273	34,050	-836	-11.1
47	Birmingham, AL	43,932	3,210	40,088	-3,844	-12.3
31	Columbus, OH	38,984	10,895	37,479	-1,505	-16.4
21	Tampa, FL	37,470	22,602	36,608	-862	-19.5
44	Jacksonville, FL	39,529	10,649	37,060	-2,469	-26.3
42	Louisville, KY	45,956	3,812	38,892	-7,064	-26.9
43	Hartford, CT	38,308	7,181	34,455	-3,853	-27.7
18	St Louis, MO	39,487	11,363	36,647	-2,840	-32.3
40	Memphis, TN	44,112	6,417	39,030	-5,082	-32.6
33	Norfolk, VA	38,759	15,498	36,527	-2,232	-34.6
32	Providence, RI	38,086	12,275	35,155	-2,931	-36
22	Denver, CO	36,313	18,419	33,754	-2,559	-47.1
38	Nashville, TN	46,342	6,734	38,373	-7,968	-53.7
23	Cleveland, OH	42,533	11,002	36,661	-5,872	-64.6
30	Orlando, FL	38,929	22,940	36,062	-2,867	-65.8
46	Oklahoma City, OK	51,257	5,122	38,367	-12,891	-66
34	Indianapolis, IN	45,666	7,530	36,672	-8,994	-67.7
37	Charlotte, NC	45,263	8,098	36,432	-8,832	-71.5
14	Phoenix, AZ	35,725	27,753	32,962	-2,763	-76.7
36	Las Vegas, NV	35,465	20,901	31,665	-3,800	-79.4
10	Boston, MA	36,172	34,315	33,832	-2,340	-80.3
39	Austin, TX	43,617	16,194	38,500	-5,117	-82.9
24	Cincinnati, OH	47,185	8,766	37,506	-9,678	-84.8
26	Kansas City, MO	46,095	8,563	36,167	-9,928	-85
9	Detroit, MI	39,388	26,400	35,773	-3,615	-95.4
8	Houston, TX	42,705	27,003	38,028	-4,677	-126.3
5	Dallas, TX	43,557	33,448	37,443	-6,114	-204.5
7	Washington, DC	38,376	55,166	34,201	-4,174	-230.3
11	Atlanta, GA	45,556	27,493	35,748	-9,807	-269.6

Figure 12: Representative Cities 2000



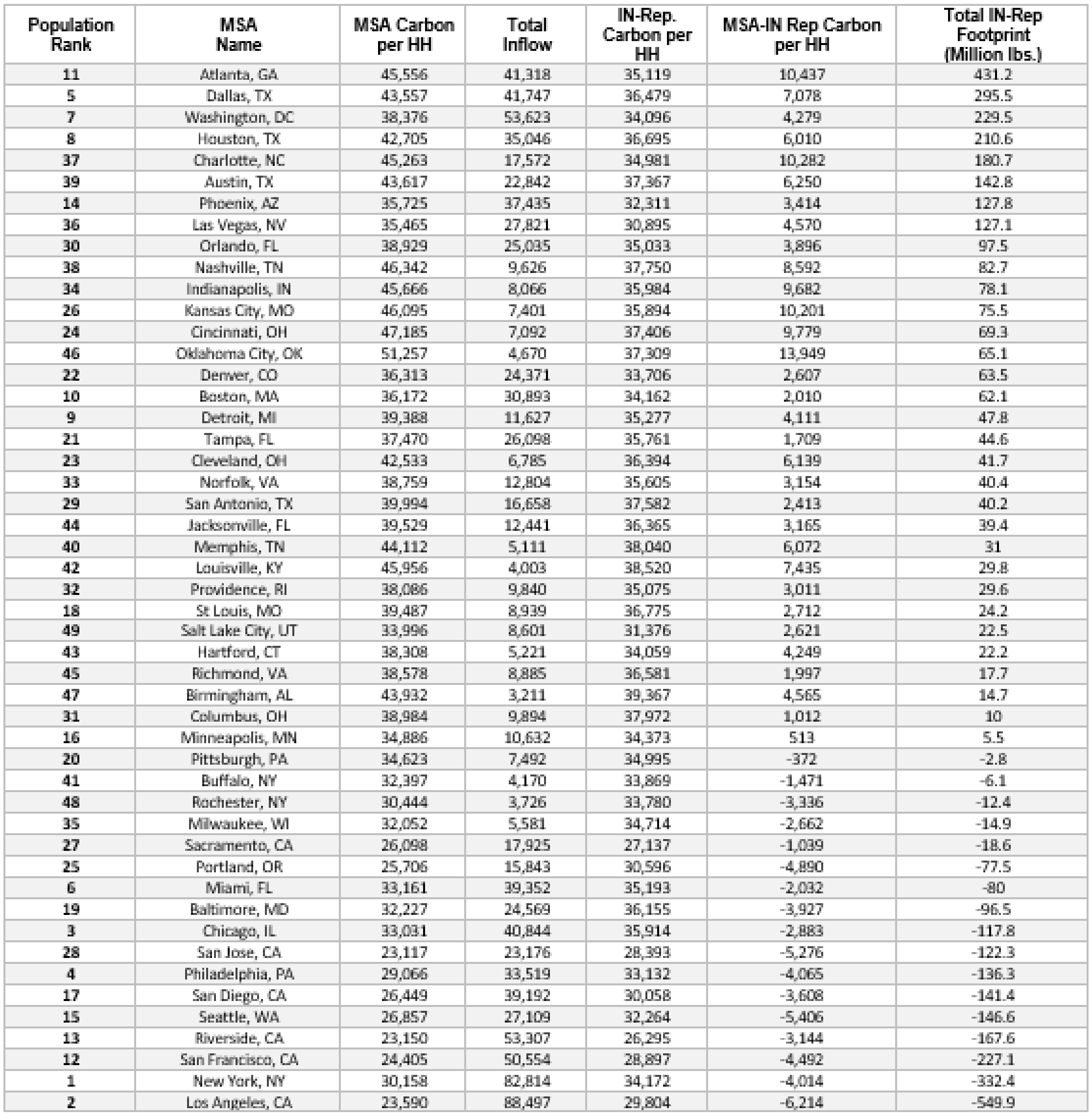
Population Rank	MSA Name	MSA Carbon per HH	Total Outflow	Rep. Carbon per HH	Rep – MSA Carbon per HH	Total Rep Footprint (Million lbs.)
2	Los Angeles, CA	23,672	102,128	30,147	6,475	661.3
12	San Francisco, CA	25,123	51,813	29,768	4,645	240.7
3	Chicago, IL	33,240	50,385	36,761	3,521	177.4
13	Riverside, CA	23,721	36,008	28,038	4,317	155.4
28	San Jose, CA	23,628	29,850	28,460	4,832	144.2
17	San Diego, CA	27,056	36,214	30,916	3,860	139.8
6	Miami, FL	32,810	24,211	38,359	5,549	134.3
15	Seattle, WA	28,130	23,859	32,908	4,778	114
4	Philadelphia, PA	33,948	33,558	36,740	2,792	93.7
19	Baltimore, MD	35,983	20,890	39,091	3,108	64.9
25	Portland, OR	27,380	12,885	31,580	4,200	54.1
1	New York, NY	35,538	93,803	36,075	537	50.4
27	Sacramento, CA	26,954	14,582	28,884	1,931	28.2
35	Milwaukee, WI	32,964	7,220	36,128	3,165	22.8
29	San Antonio, TX	40,852	13,502	41,472	620	8.4
48	Rochester, NY	36,486	5,951	37,573	1,087	6.5
44	Jacksonville, FL	38,831	9,702	39,422	591	5.7
21	Tampa, FL	38,103	19,097	38,240	137	2.6
41	Buffalo, NY	38,538	6,616	37,828	-711	-4.7
47	Birmingham, AL	44,738	3,646	42,399	-2,339	-8.5
31	Columbus, OH	39,717	9,753	38,636	-1,080	-10.5
30	Orlando, FL	38,656	16,209	37,721	-935	-15.2
49	Salt Lake City, UT	35,132	8,630	33,316	-1,816	-15.7
18	St Louis, MO	39,294	11,714	37,670	-1,623	-19
45	Richmond, VA	43,332	6,487	40,227	-3,106	-20.1
42	Louisville, KY	46,570	3,931	39,917	-6,653	-26.2
43	Hartford, CT	41,096	6,720	36,959	-4,136	-27.8
40	Memphis, TN	44,874	6,360	40,420	-4,454	-28.3
32	Providence, RI	40,250	9,966	36,990	-3,261	-32.5
23	Cleveland, OH	40,964	10,700	37,774	-3,190	-34.1
14	Phoenix, AZ	35,565	24,375	34,089	-1,476	-36
20	Pittsburgh, PA	41,052	10,992	37,683	-3,368	-37
36	Las Vegas, NV	35,249	13,893	32,398	-2,851	-39.6
9	Detroit, MI	38,937	18,745	36,783	-2,154	-40.4
33	Norfolk, VA	42,412	13,608	39,218	-3,193	-43.5
16	Minneapolis, MN	38,930	12,392	35,054	-3,876	-48
22	Denver, CO	37,685	19,599	35,053	-2,632	-51.6
34	Indianapolis, IN	45,138	7,355	37,832	-7,305	-53.7
38	Nashville, TN	48,283	6,735	40,043	-8,240	-55.5
10	Boston, MA	37,831	33,616	36,110	-1,721	-57.9
37	Charlotte, NC	47,916	6,845	39,146	-8,770	-60
24	Cincinnati, OH	46,174	8,635	38,337	-7,837	-67.7
26	Kansas City, MO	45,486	8,831	37,655	-7,831	-69.2
39	Austin, TX	45,354	13,734	39,799	-5,555	-76.3
46	Oklahoma City, OK	53,785	5,706	40,043	-13,742	-78.4
8	Houston, TX	44,225	28,068	39,670	-4,555	-127.8
5	Dallas, TX	45,104	34,101	38,973	-6,131	-209.1
11	Atlanta, GA	48,299	24,888	37,517	-10,782	-268.3
7	Washington, DC	42,371	47,770	36,341	-6,031	-288.1

Figure 13: Representative Cities 1992



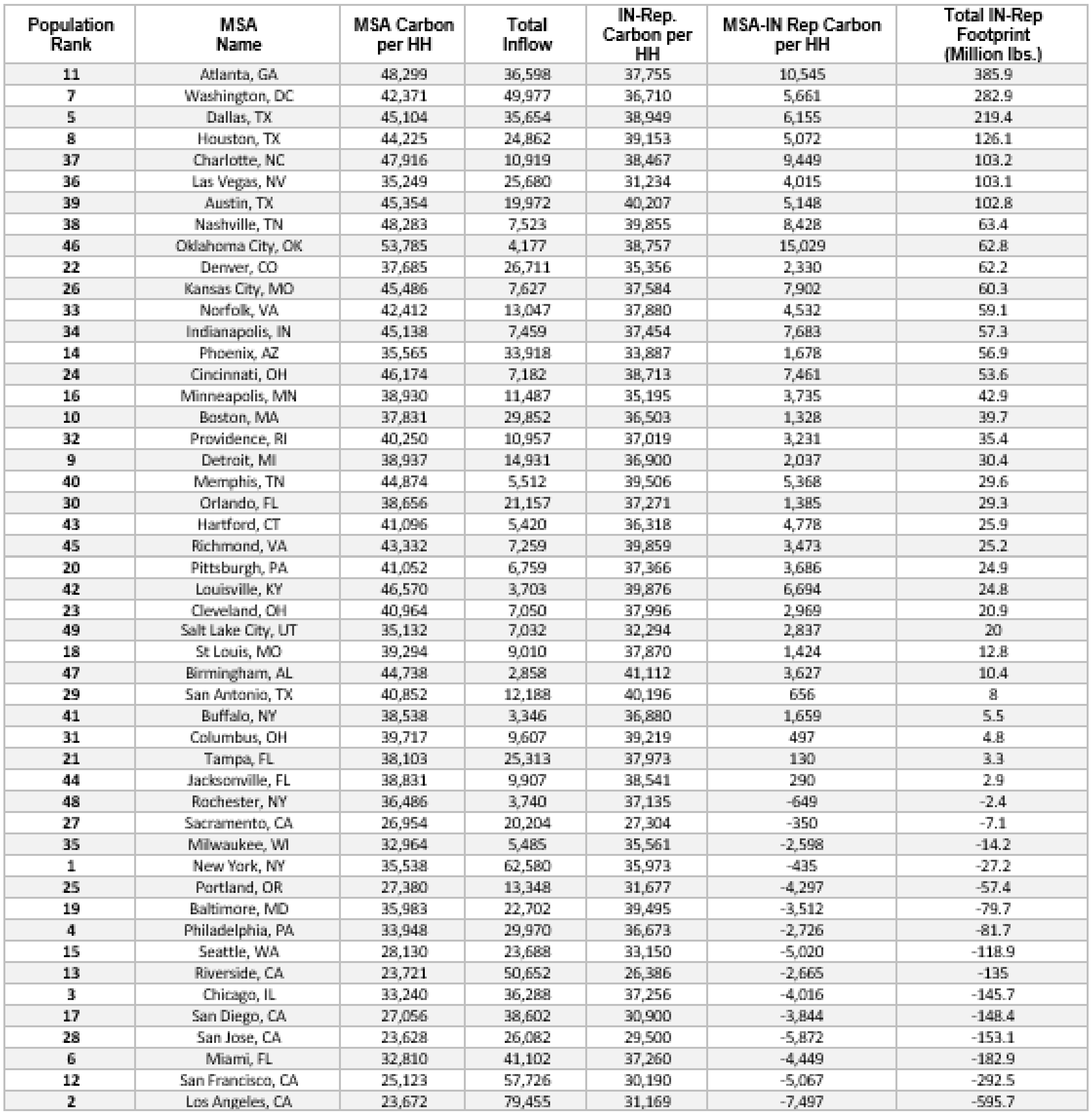
Population Rank	MSA Name	MSA Carbon per HH	Total Outflow	Rep. Carbon per HH	Rep – MSA Carbon per HH	Total Rep Footprint (Million lbs.)
2	Los Angeles, CA	24,625	115,531	29,995	5,371	620.5
12	San Francisco, CA	26,068	45,045	29,714	3,646	164.2
4	Philadelphia, PA	30,237	30,800	35,298	5,061	155.9
3	Chicago, IL	32,103	39,249	35,409	3,306	129.7
13	Riverside, CA	24,907	36,439	28,394	3,487	127
17	San Diego, CA	27,559	36,552	30,777	3,219	117.6
6	Miami, FL	31,149	19,535	36,549	5,400	105.5
28	San Jose, CA	24,802	24,014	28,836	4,033	96.9
19	Baltimore, MD	34,354	17,642	37,670	3,316	58.5
15	Seattle, WA	28,307	6,167	33,491	5,185	32
25	Portland, OR	27,693	8,052	30,698	3,005	24.2
29	San Antonio, TX	38,151	11,071	39,979	1,828	20.2
35	Milwaukee, WI	31,387	5,902	34,734	3,347	19.8
27	Sacramento, CA	27,664	14,034	29,016	1,352	19
44	Jacksonville, FL	35,516	8,069	37,453	1,937	15.6
21	Tampa, FL	35,903	18,293	36,482	579	10.6
48	Rochester, NY	33,453	4,777	35,281	1,828	8.7
1	New York, NY	34,097	89,247	34,176	79	7.1
20	Pittsburgh, PA	35,643	8,927	35,910	267	2.4
41	Buffalo, NY	34,908	5,401	35,303	394	2.1
18	St Louis, MO	36,502	11,220	36,495	-8	-0.1
31	Columbus, OH	37,131	7,412	37,081	-50	-0.4
30	Orlando, FL	36,272	13,465	36,226	-47	-0.6
49	Salt Lake City, UT	33,587	5,363	32,721	-866	-4.6
14	Phoenix, AZ	33,507	19,487	33,171	-336	-6.5
36	Las Vegas, NV	33,493	9,568	32,439	-1,054	-10.1
47	Birmingham, AL	43,758	2,898	39,874	-3,883	-11.3
45	Richmond, VA	41,107	5,249	38,508	-2,600	-13.6
9	Detroit, MI	36,265	17,614	35,392	-872	-15.4
23	Cleveland, OH	37,987	8,729	35,924	-2,063	-18
33	Norfolk, VA	39,559	8,347	37,309	-2,250	-18.8
42	Louisville, KY	44,432	3,206	38,238	-6,195	-19.9
37	Charlotte, NC	44,591	4,580	38,050	-6,541	-30
40	Memphis, TN	43,314	6,178	38,439	-4,875	-30.1
34	Indianapolis, IN	41,479	5,873	36,326	-5,154	-30.3
32	Providence, RI	39,772	10,069	35,979	-3,793	-38.2
26	Kansas City, MO	42,434	7,219	36,884	-5,550	-40.1
43	Hartford, CT	40,610	7,685	35,359	-5,251	-40.4
16	Minneapolis, MN	38,208	9,845	34,094	-4,114	-40.5
38	Nashville, TN	47,354	4,889	38,798	-8,556	-41.8
24	Cincinnati, OH	42,737	7,487	36,830	-5,907	-44.2
39	Austin, TX	44,361	10,267	39,560	-4,801	-49.3
46	Oklahoma City, OK	52,115	4,986	38,691	-13,424	-66.9
22	Denver, CO	38,768	15,377	34,170	-4,598	-70.7
10	Boston, MA	37,557	31,490	34,877	-2,681	-84.4
8	Houston, TX	43,611	23,082	38,308	-5,303	-122.4
11	Atlanta, GA	45,992	18,221	36,669	-9,323	-169.9
5	Dallas, TX	44,870	31,000	37,958	-6,913	-214.3
7	Washington, DC	41,133	44,419	35,156	-5,978	-265.5

Figure 14: In-Representative Cities 2008



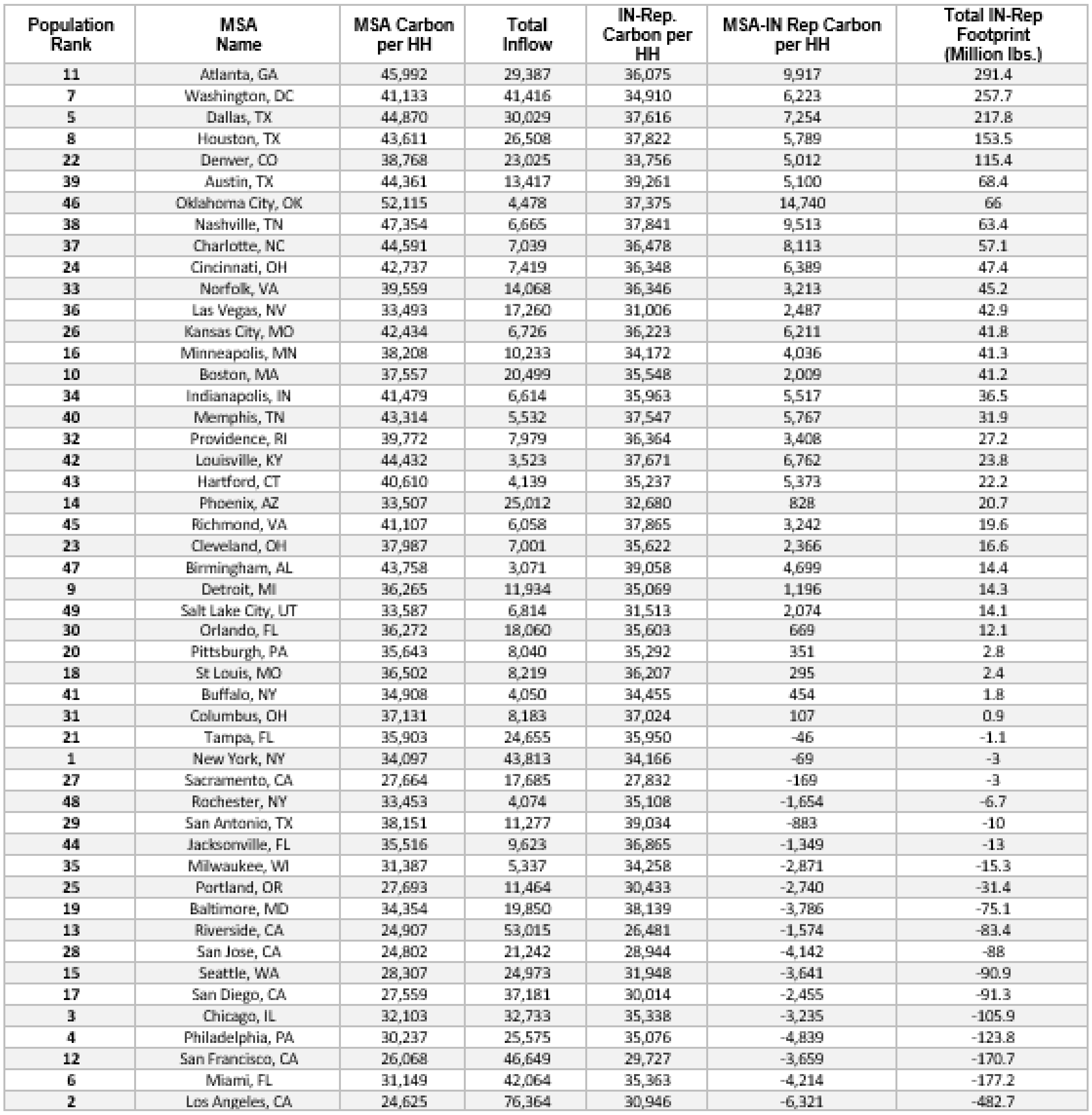
Population Rank	MSA Name	MSA Carbon per HH	Total Inflow	IN-Rep. Carbon per HH	MSA-IN Rep Carbon per HH	Total IN-Rep Footprint (Million lbs.)
11	Atlanta, GA	45,556	41,318	35,119	10,437	431.2
5	Dallas, TX	43,557	41,747	36,479	7,078	295.5
7	Washington, DC	38,376	53,623	34,096	4,279	229.5
8	Houston, TX	42,705	35,046	36,695	6,010	210.6
37	Charlotte, NC	45,263	17,572	34,981	10,282	180.7
39	Austin, TX	43,617	22,842	37,367	6,250	142.8
14	Phoenix, AZ	35,725	37,435	32,311	3,414	127.8
36	Las Vegas, NV	35,465	27,821	30,895	4,570	127.1
30	Orlando, FL	38,929	25,035	35,033	3,896	97.5
38	Nashville, TN	46,342	9,626	37,750	8,592	82.7
34	Indianapolis, IN	45,666	8,066	35,984	9,682	78.1
26	Kansas City, MO	46,095	7,401	35,894	10,201	75.5
24	Cincinnati, OH	47,185	7,092	37,406	9,779	69.3
46	Oklahoma City, OK	51,257	4,670	37,309	13,949	65.1
22	Denver, CO	36,313	24,371	33,706	2,607	63.5
10	Boston, MA	36,172	30,893	34,162	2,010	62.1
9	Detroit, MI	39,388	11,627	35,277	4,111	47.8
21	Tampa, FL	37,470	26,098	35,761	1,709	44.6
23	Cleveland, OH	42,533	6,785	36,394	6,139	41.7
33	Norfolk, VA	38,759	12,804	35,605	3,154	40.4
29	San Antonio, TX	39,994	16,658	37,582	2,413	40.2
44	Jacksonville, FL	39,529	12,441	36,365	3,165	39.4
40	Memphis, TN	44,112	5,111	38,040	6,072	31
42	Louisville, KY	45,956	4,003	38,520	7,435	29.8
32	Providence, RI	38,086	9,840	35,075	3,011	29.6
18	St Louis, MO	39,487	8,939	36,775	2,712	24.2
49	Salt Lake City, UT	33,996	8,601	31,376	2,621	22.5
43	Hartford, CT	38,308	5,221	34,059	4,249	22.2
45	Richmond, VA	38,578	8,885	36,581	1,997	17.7
47	Birmingham, AL	43,932	3,211	39,367	4,565	14.7
31	Columbus, OH	38,984	9,894	37,972	1,012	10
16	Minneapolis, MN	34,886	10,632	34,373	513	5.5
20	Pittsburgh, PA	34,623	7,492	34,995	-372	-2.8
41	Buffalo, NY	32,397	4,170	33,869	-1,471	-6.1
48	Rochester, NY	30,444	3,726	33,780	-3,336	-12.4
35	Milwaukee, WI	32,052	5,581	34,714	-2,662	-14.9
27	Sacramento, CA	26,098	17,925	27,137	-1,039	-18.6
25	Portland, OR	25,706	15,843	30,596	-4,890	-77.5
6	Miami, FL	33,161	39,352	35,193	-2,032	-80
19	Baltimore, MD	32,227	24,569	36,155	-3,927	-96.5
3	Chicago, IL	33,031	40,844	35,914	-2,883	-117.8
28	San Jose, CA	23,117	23,176	28,393	-5,276	-122.3
4	Philadelphia, PA	29,066	33,519	33,132	-4,065	-136.3
17	San Diego, CA	26,449	39,192	30,058	-3,608	-141.4
15	Seattle, WA	26,857	27,109	32,264	-5,406	-146.6
13	Riverside, CA	23,150	53,307	26,295	-3,144	-167.6
12	San Francisco, CA	24,405	50,554	28,897	-4,492	-227.1
1	New York, NY	30,158	82,814	34,172	-4,014	-332.4
2	Los Angeles, CA	23,590	88,497	29,804	-6,214	-549.9

Figure 15: In-Representative Cities 2000



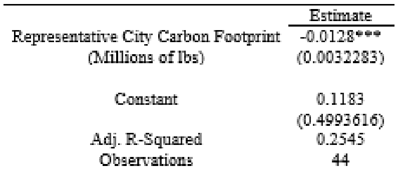
Population Rank	MSA Name	MSA Carbon per HH	Total Inflow	IN-Rep. Carbon per HH	MSA-IN Rep Carbon per HH	Total IN-Rep Footprint (Million lbs.)
11	Atlanta, GA	48,299	36,598	37,755	10,545	385.9
7	Washington, DC	42,371	49,977	36,710	5,661	282.9
5	Dallas, TX	45,104	35,654	38,949	6,155	219.4
8	Houston, TX	44,225	24,862	39,153	5,072	126.1
37	Charlotte, NC	47,916	10,919	38,467	9,449	103.2
36	Las Vegas, NV	35,249	25,680	31,234	4,015	103.1
39	Austin, TX	45,354	19,972	40,207	5,148	102.8
38	Nashville, TN	48,283	7,523	39,855	8,428	63.4
46	Oklahoma City, OK	53,785	4,177	38,757	15,029	62.8
22	Denver, CO	37,685	26,711	35,356	2,330	62.2
26	Kansas City, MO	45,486	7,627	37,584	7,902	60.3
33	Norfolk, VA	42,412	13,047	37,880	4,532	59.1
34	Indianapolis, IN	45,138	7,459	37,454	7,683	57.3
14	Phoenix, AZ	35,565	33,918	33,887	1,678	56.9
24	Cincinnati, OH	46,174	7,182	38,713	7,461	53.6
16	Minneapolis, MN	38,930	11,487	35,195	3,735	42.9
10	Boston, MA	37,831	29,852	36,503	1,328	39.7
32	Providence, RI	40,250	10,957	37,019	3,231	35.4
9	Detroit, MI	38,937	14,931	36,900	2,037	30.4
40	Memphis, TN	44,874	5,512	39,506	5,368	29.6
30	Orlando, FL	38,656	21,157	37,271	1,385	29.3
43	Hartford, CT	41,096	5,420	36,318	4,778	25.9
45	Richmond, VA	43,332	7,259	39,859	3,473	25.2
20	Pittsburgh, PA	41,052	6,759	37,366	3,686	24.9
42	Louisville, KY	46,570	3,703	39,876	6,694	24.8
23	Cleveland, OH	40,964	7,050	37,996	2,969	20.9
49	Salt Lake City, UT	35,132	7,032	32,294	2,837	20
18	St Louis, MO	39,294	9,010	37,870	1,424	12.8
47	Birmingham, AL	44,738	2,858	41,112	3,627	10.4
29	San Antonio, TX	40,852	12,188	40,196	656	8
41	Buffalo, NY	38,538	3,346	36,880	1,659	5.5
31	Columbus, OH	39,717	9,607	39,219	497	4.8
21	Tampa, FL	38,103	25,313	37,973	130	3.3
44	Jacksonville, FL	38,831	9,907	38,541	290	2.9
48	Rochester, NY	36,486	3,740	37,135	-649	-2.4
27	Sacramento, CA	26,954	20,204	27,304	-350	-7.1
35	Milwaukee, WI	32,964	5,485	35,561	-2,598	-14.2
1	New York, NY	35,538	62,580	35,973	-435	-27.2
25	Portland, OR	27,380	13,348	31,677	-4,297	-57.4
19	Baltimore, MD	35,983	22,702	39,495	-3,512	-79.7
4	Philadelphia, PA	33,948	29,970	36,673	-2,726	-81.7
15	Seattle, WA	28,130	23,688	33,150	-5,020	-118.9
13	Riverside, CA	23,721	50,652	26,386	-2,665	-135
3	Chicago, IL	33,240	36,288	37,256	-4,016	-145.7
17	San Diego, CA	27,056	38,602	30,900	-3,844	-148.4
28	San Jose, CA	23,628	26,082	29,500	-5,872	-153.1
6	Miami, FL	32,810	41,102	37,260	-4,449	-182.9
12	San Francisco, CA	25,123	57,726	30,190	-5,067	-292.5
2	Los Angeles, CA	23,672	79,455	31,169	-7,497	-595.7

Figure 16: In-Representative Cities 1992



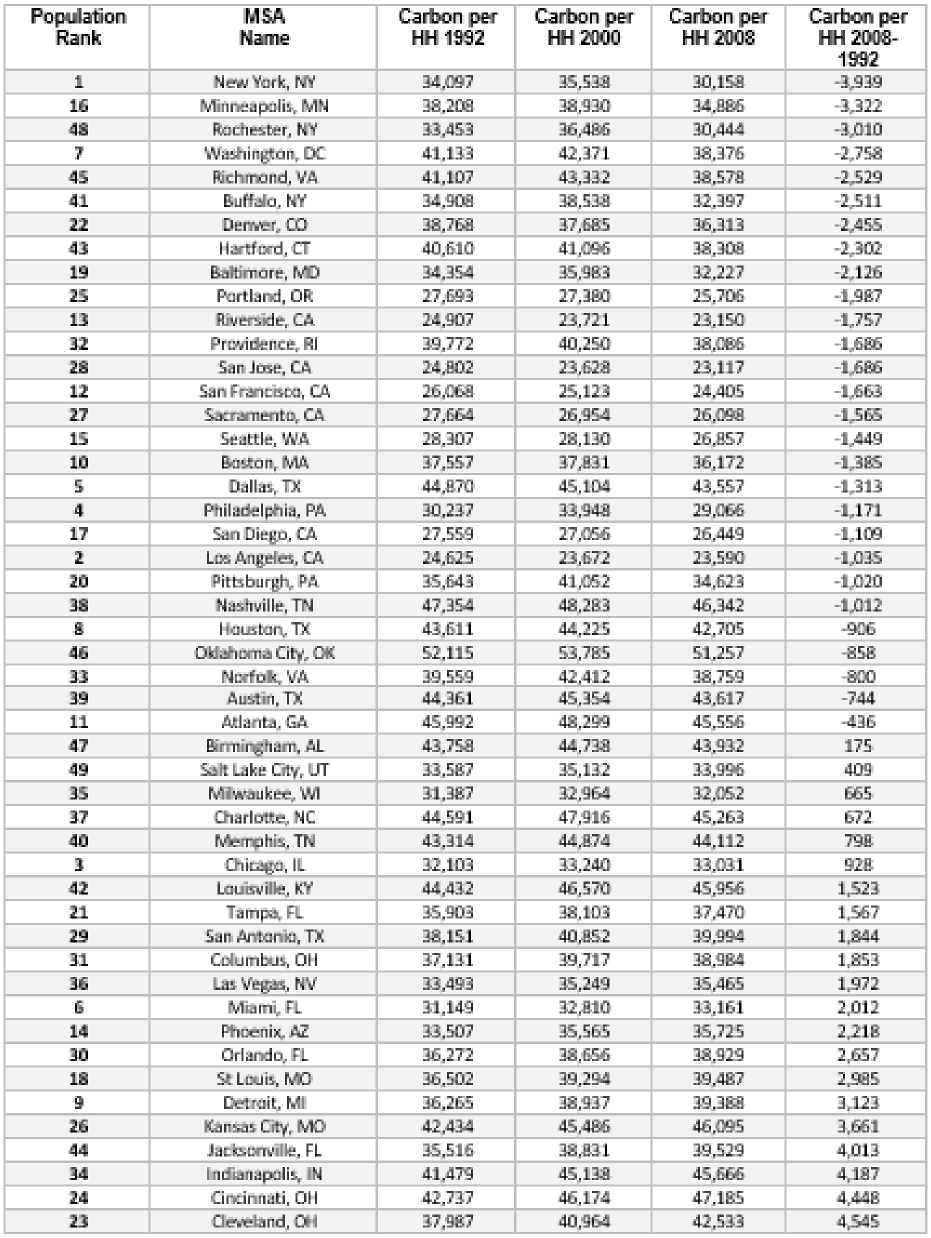
Population Rank	MSA Name	MSA Carbon per HH	Total Inflow	IN-Rep. Carbon per HH	MSA-IN Rep Carbon per HH	Total IN-Rep Footprint (Million lbs.)
11	Atlanta, GA	45,992	29,387	36,075	9,917	291.4
7	Washington, DC	41,133	41,416	34,910	6,223	257.7
5	Dallas, TX	44,870	30,029	37,616	7,254	217.8
8	Houston, TX	43,611	26,508	37,822	5,789	153.5
22	Denver, CO	38,768	23,025	33,756	5,012	115.4
39	Austin, TX	44,361	13,417	39,261	5,100	68.4
46	Oklahoma City, OK	52,115	4,478	37,375	14,740	66
38	Nashville, TN	47,354	6,665	37,841	9,513	63.4
37	Charlotte, NC	44,591	7,039	36,478	8,113	57.1
24	Cincinnati, OH	42,737	7,419	36,348	6,389	47.4
33	Norfolk, VA	39,559	14,068	36,346	3,213	45.2
36	Las Vegas, NV	33,493	17,260	31,006	2,487	42.9
26	Kansas City, MO	42,434	6,726	36,223	6,211	41.8
16	Minneapolis, MN	38,208	10,233	34,172	4,036	41.3
10	Boston, MA	37,557	20,499	35,548	2,009	41.2
34	Indianapolis, IN	41,479	6,614	35,963	5,517	36.5
40	Memphis, TN	43,314	5,532	37,547	5,767	31.9
32	Providence, RI	39,772	7,979	36,364	3,408	27.2
42	Louisville, KY	44,432	3,523	37,671	6,762	23.8
43	Hartford, CT	40,610	4,139	35,237	5,373	22.2
14	Phoenix, AZ	33,507	25,012	32,680	828	20.7
45	Richmond, VA	41,107	6,058	37,865	3,242	19.6
23	Cleveland, OH	37,987	7,001	35,622	2,366	16.6
47	Birmingham, AL	43,758	3,071	39,058	4,699	14.4
9	Detroit, MI	36,265	11,934	35,069	1,196	14.3
49	Salt Lake City, UT	33,587	6,814	31,513	2,074	14.1
30	Orlando, FL	36,272	18,060	35,603	669	12.1
20	Pittsburgh, PA	35,643	8,040	35,292	351	2.8
18	St Louis, MO	36,502	8,219	36,207	295	2.4
41	Buffalo, NY	34,908	4,050	34,455	454	1.8
31	Columbus, OH	37,131	8,183	37,024	107	0.9
21	Tampa, FL	35,903	24,655	35,950	-46	-1.1
1	New York, NY	34,097	43,813	34,166	-69	-3
27	Sacramento, CA	27,664	17,685	27,832	-169	-3
48	Rochester, NY	33,453	4,074	35,108	-1,654	-6.7
29	San Antonio, TX	38,151	11,277	39,034	-883	-10
44	Jacksonville, FL	35,516	9,623	36,865	-1,349	-13
35	Milwaukee, WI	31,387	5,337	34,258	-2,871	-15.3
25	Portland, OR	27,693	11,464	30,433	-2,740	-31.4
19	Baltimore, MD	34,354	19,850	38,139	-3,786	-75.1
13	Riverside, CA	24,907	53,015	26,481	-1,574	-83.4
28	San Jose, CA	24,802	21,242	28,944	-4,142	-88
15	Seattle, WA	28,307	24,973	31,948	-3,641	-90.9
17	San Diego, CA	27,559	37,181	30,014	-2,455	-91.3
3	Chicago, IL	32,103	32,733	35,338	-3,235	-105.9
4	Philadelphia, PA	30,237	25,575	35,076	-4,839	-123.8
12	San Francisco, CA	26,068	46,649	29,727	-3,659	-170.7
6	Miami, FL	31,149	42,064	35,363	-4,214	-177.2
2	Los Angeles, CA	24,625	76,364	30,946	-6,321	-482.7

Figure 17: Regression Results for Wharton Regulation Index



	Estimate
Representative City Carbon Footprint	-0.0128***
(Millions of lbs)	(0.0032283)
Constant	0.1183
	(0.4993616)
Adj. R-Squared	0.2545
Observations	44

Figure 18: Summary of Assigned Carbon Per Household



Population Rank	MSA Name	Carbon per HH 1992	Carbon per HH 2000	Carbon per HH 2008	Carbon per HH 2008-1992
1	New York, NY	34,097	35,538	30,158	-3,939
16	Minneapolis, MN	38,208	38,930	34,886	-3,322
48	Rochester, NY	33,453	36,486	30,444	-3,010
7	Washington, DC	41,133	42,371	38,376	-2,758
45	Richmond, VA	41,107	43,332	38,578	-2,529
41	Buffalo, NY	34,908	38,538	32,397	-2,511
22	Denver, CO	38,768	37,685	36,313	-2,455
43	Hartford, CT	40,610	41,096	38,308	-2,302
19	Baltimore, MD	34,354	35,983	32,227	-2,126
25	Portland, OR	27,693	27,380	25,706	-1,987
13	Riverside, CA	24,907	23,721	23,150	-1,757
32	Providence, RI	39,772	40,250	38,086	-1,686
28	San Jose, CA	24,802	23,628	23,117	-1,686
12	San Francisco, CA	26,068	25,123	24,405	-1,663
27	Sacramento, CA	27,664	26,954	26,098	-1,565
15	Seattle, WA	28,307	28,130	26,857	-1,449
10	Boston, MA	37,557	37,831	36,172	-1,385
5	Dallas, TX	44,870	45,104	43,557	-1,313
4	Philadelphia, PA	30,237	33,948	29,066	-1,171
17	San Diego, CA	27,559	27,056	26,449	-1,109
2	Los Angeles, CA	24,625	23,672	23,590	-1,035
20	Pittsburgh, PA	35,643	41,052	34,623	-1,020
38	Nashville, TN	47,354	48,283	46,342	-1,012
8	Houston, TX	43,611	44,225	42,705	-906
46	Oklahoma City, OK	52,115	53,785	51,257	-858
33	Norfolk, VA	39,559	42,412	38,759	-800
39	Austin, TX	44,361	45,354	43,617	-744
11	Atlanta, GA	45,992	48,299	45,556	-436
47	Birmingham, AL	43,758	44,738	43,932	175
49	Salt Lake City, UT	33,587	35,132	33,996	409
35	Milwaukee, WI	31,387	32,964	32,052	665
37	Charlotte, NC	44,591	47,916	45,263	672
40	Memphis, TN	43,314	44,874	44,112	798
3	Chicago, IL	32,103	33,240	33,031	928
42	Louisville, KY	44,432	46,570	45,956	1,523
21	Tampa, FL	35,903	38,103	37,470	1,567
29	San Antonio, TX	38,151	40,852	39,994	1,844
31	Columbus, OH	37,131	39,717	38,984	1,853
36	Las Vegas, NV	33,493	35,249	35,465	1,972
6	Miami, FL	31,149	32,810	33,161	2,012
14	Phoenix, AZ	33,507	35,565	35,725	2,218
30	Orlando, FL	36,272	38,656	38,929	2,657
18	St Louis, MO	36,502	39,294	39,487	2,985
9	Detroit, MI	36,265	38,937	39,388	3,123
26	Kansas City, MO	42,434	45,486	46,095	3,661
44	Jacksonville, FL	35,516	38,831	39,529	4,013
34	Indianapolis, IN	41,479	45,138	45,666	4,187
24	Cincinnati, OH	42,737	46,174	47,185	4,448
23	Cleveland, OH	37,987	40,964	42,533	4,545

Figure 19: Washington D.C. In-Representative Carbon Differential, 2000

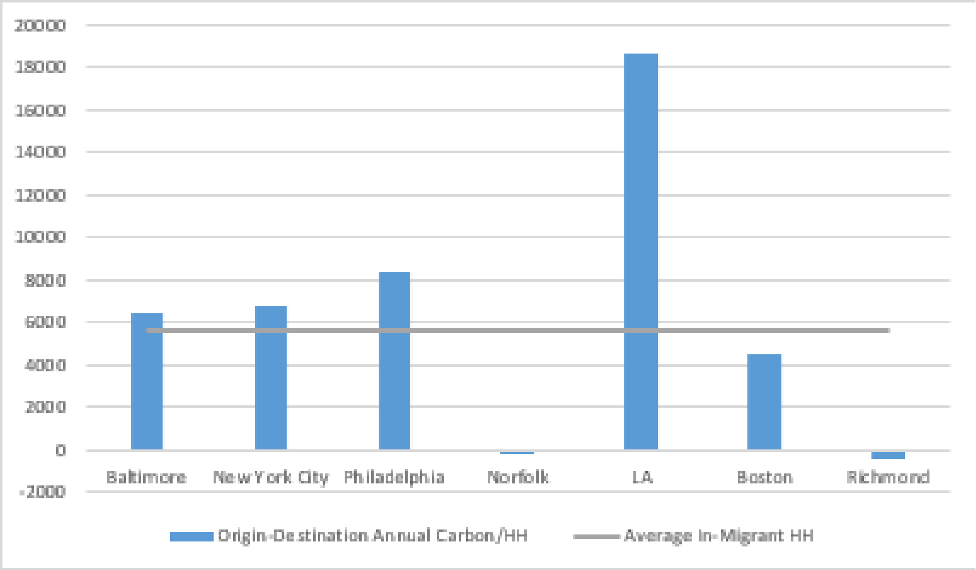


Figure 20: Washington D.C. In-Representative Carbon Differential, 1992

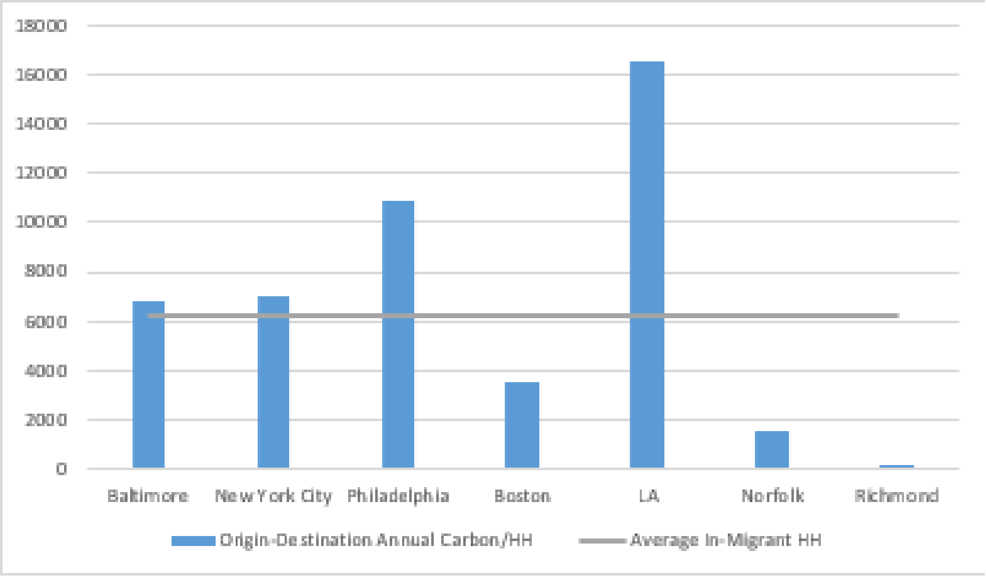


Figure 21: San Antonio In-Representative Carbon Differential, 2000

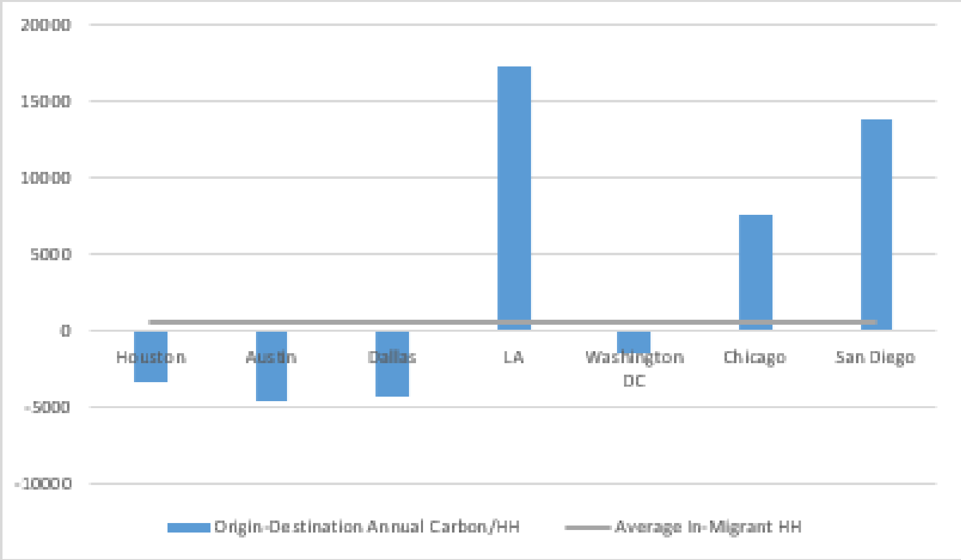


Figure 22: San Antonio In-Representative Carbon Differential, 1992

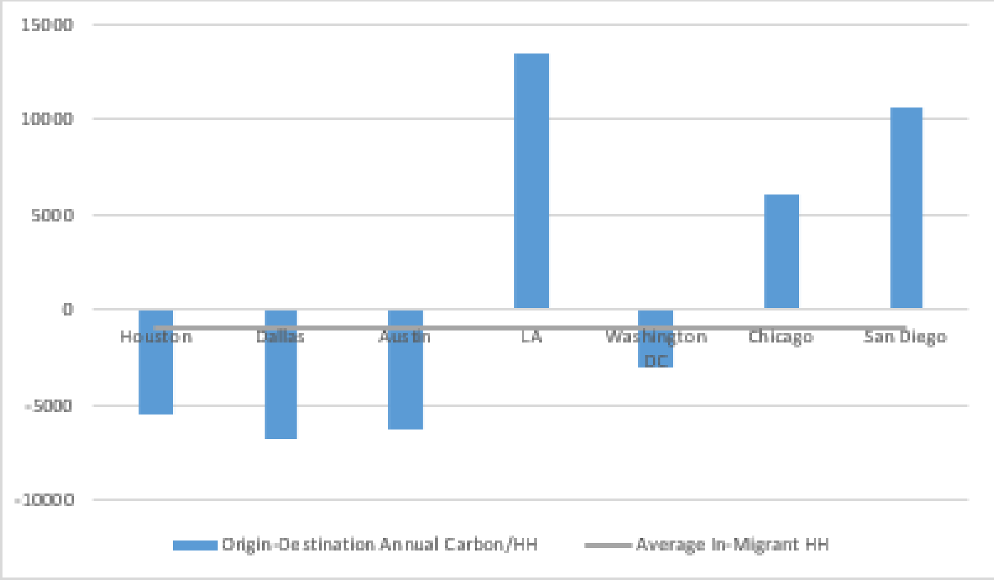


Figure 23: Atlanta In-Representative Carbon Differential, 2000

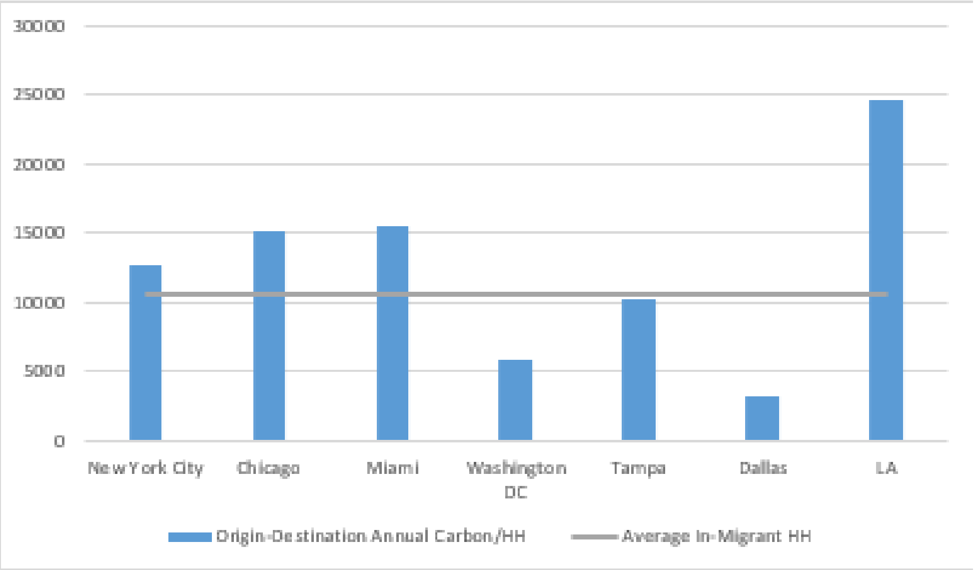
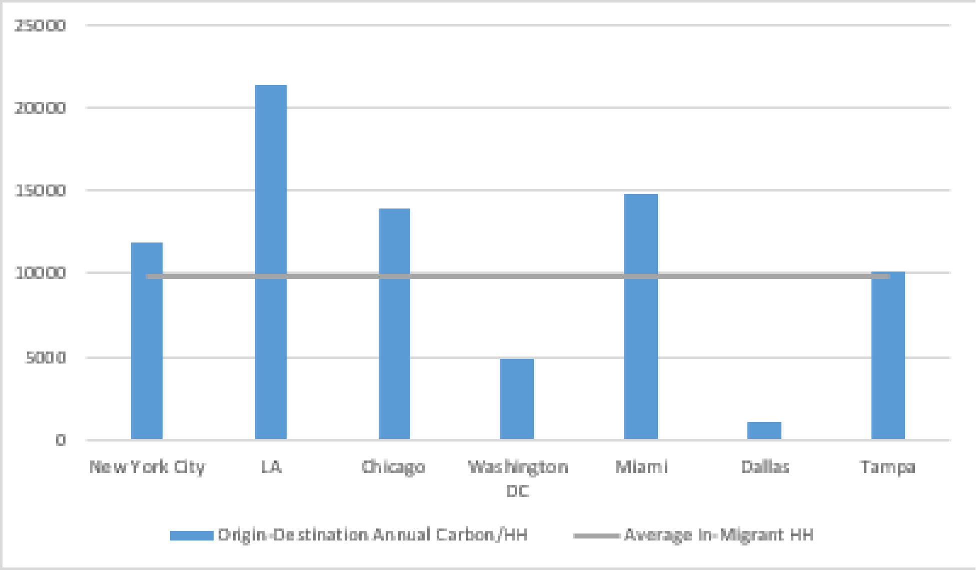


Figure 24: Atlanta In-Representative Carbon Differential, 1992



References

Bertaud, Alain, and Jan K. Brueckner. “Analyzing Building-Height Restrictions: Predicted Impacts and Welfare Costs.” *Regional Science and Urban Economics*, vol. 35, no. 2, 2005, pp. 109125., doi:10.1016/j.regsciurbeco.2004.02.004.

Glaeser, Edward, and Matthew Kahn. “The Greenness of Cities: Carbon Dioxide Emissions and Urban Development.” 2008, doi:10.3386/w14238.

Glaeser, Edward L., and Matthew E. Kahn. “The Greenness of Cities: Carbon Dioxide Emissions and Urban Development.” *Journal of Urban Economics*, vol. 67, no. 3, 2010, pp. 404418., doi:10.1016/j.jue.2009.11.006.

Gyourko, Joseph, et al. “A New Measure of the Local Regulatory Environment for Housing Markets: The Wharton Residential Land Use Regulatory Index.” *Urban Studies*, vol. 45, no. 3, 2008, pp. 693729., doi:10.1177/0042098007087341.

Mangum, Kyle. “The Role of Housing in Carbon Emissions.” *SSRN Electronic Journal*, 2017, doi:10.2139/ssrn.2957749.

Penn, Ivan. “California Will Require Solar Power For New Homes.” *The New York Times* [New York City], May 10 2018: Pages B1