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

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ABSTRACT

This paper studies internal migration patterns in the U.S. and the relationship between these migration patterns and household level energy use and carbon emissions. The paper uses a two-city model of energy use and migration to analyze emission implications from city level green policies. With recent policy emphasis on energy use and emissions, particularly with gasoline and natural gas, these policies have the potential for a rebound effect due to migration when prices increase in low-emission areas. The effect of total emissions can be increasing under such conditions.

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I. 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. Geography of metro areas in the U.S. have a great impact on potential environmental regulations and improvements (Brown et al., 2009). 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. 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 priced. As noted by Glaeser and Kahn (2010), even an otherwise 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, 2010). Kahn (2011) suggests that political landscapes can also affect restrictions on new housing construction; as this paper will show, this would affect migration and emissions as well. 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 and 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 its largest migration neighbors. 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 to take advantage of data on MSA-level emissions and MSA-to-MSA migration. 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 presents a two-city model and the generation process for the representative migration city.

II. THE TWO-CITY MODEL

This section expands on the two-region model presented in Glaeser and Kahn (2010). 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

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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, southern California with a very mild climate could have higher per-unit energy costs than in Dallas, Texas, but California residents could get a higher utility from these services while using a lower quantity of them, because they have smaller homes to heat and cool. 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 data comes from the IRS report of changes to address in tax return filings. These data don't cover every move (such as twice in the same tax year) but do cover a large majority of the U.S. population.

First the model is introduced, then equilibrium conditions derived. Next the zoning tax is added, and finally the representative migration city construction.

A. Model Introduction

The two-city model begins with individuals maximizing a quasi-linear utility function:

$$Y_i - P_i^H - (P_i^E + t)E_i + t\hat{E} + V_i(E_i; X_i) - C(N\hat{E}) \tag{1}$$

where Y_i is income, P_i^H and P_iE 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; $C(NE^{\wedge})$ 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 $Q^F{}_i$ 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 equally share profits from building.

B. Equilibrium Conditions

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 $f'\left(\frac{N_i}{Q_i^F}\right) - k'\left(\frac{N_i}{Q_i^B}\right) - (t + P_i^E)E_i^* + V_1(E_i^*; X_i)$ must be equal for all cities.

Individuals in this model are identical, and the social welfare function used is additive:

$$\sum_i Q_i^F f\left(\frac{N_i}{Q_i^F}\right) - Q_i^B k\left(\frac{N_i}{Q_i^B}\right) + N_i(V(E_i;X_i) - P_i^E E_i - C(N\hat{E})) \tag{2}$$

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

$$P_i^E E_i - NC'(N\hat{E}) = V_1(E_i^*;X_i) \tag{3}$$

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

$$f'\left(\frac{N_i}{Q_i^F}\right) - k'\left(\frac{N_i}{Q_i^B}\right) + V(E_i^*;X_i) - E_i\left(P_i^E + NC'(N\hat{E})\right) \tag{4}$$

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.

C. Zoning Tax

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 $P_1^H = z_1 + k'(\frac{N_1}{Q_1^B})$. Tax revenue is returned to inframarginal residents so as 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, 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; Borck and Brueckner, 2018). 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. In the same way, the fuel requirements for transportation would be higher. Thus $\frac{\partial P_1^E}{\partial z_1} > 0$.

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

$$f'\left(\frac{N_1}{Q_1^F}\right)-\left(k'\left(\frac{N_1}{Q_1^B}\right)+z_1\right)-(t+P_1^E)E_1^* \ +V(E_1^*;X_1)=f'\left(\frac{N_2}{Q_2^F}\right)-k'\left(\frac{N_2}{Q_2^B}\right)- \\ (t+P_2^E)E_2^* \ +V(E_2^*;X_2) \tag{5}$$

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

$$\frac{\partial}{\partial z_1}[f'\left(\frac{N_1}{Q_1^F}\right)-\left(k'\left(\frac{N_1}{Q_1^B}\right)+z_1\right)-(t+P_1^E)E_1^* \ +V(E_1^*;X_1)=f'\left(\frac{N_2}{Q_2^F}\right)- \\ k'\left(\frac{N_2}{Q_2^B}\right)-(t+P_2^E)E_2^* \ +V(E_2^*;X_2)] \tag{6}$$

which yields the expression:

$$\left(\frac{1}{Q_1^F}\right)f''\left(\frac{N_1}{Q_1^F}\right)\left(\frac{\partial N_1}{\partial z_1}\right)-\left(\frac{1}{Q_1^B}\right)k''\left(\frac{N_1}{Q_1^B}\right)\left(\frac{\partial N_1}{\partial z_1}\right)-1-t\left(\frac{\partial E_1^*}{\partial z_1}\right)-\left(\frac{\partial P_1^E}{\partial z_1}\right)E_1^*- \\ \left(\frac{\partial E_1^*}{\partial z_1}\right)P_1^E+\left(\frac{\partial E_1^*}{\partial z_1}\right)V_1(E_1^*;X_1)=\left(\frac{1}{Q_2^F}\right)f''\left(\frac{N_2}{Q_2^F}\right)\left(\frac{\partial N_2}{\partial z_1}\right)-\left(\frac{1}{Q_2^B}\right)k''\left(\frac{N_2}{Q_2^B}\right)\left(\frac{\partial N_2}{\partial z_1}\right) \tag{7}$$

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 $P_i^E+t = V_1(E_i^*;X_i)$; this cancels terms and leaves the equation ready to be solved for $\frac{\partial N_1}{\partial z_1}$:

$$\left(\frac{1}{Q_1^F}\right)f''\left(\frac{N_1}{Q_1^F}\right)\left(\frac{\partial N_1}{\partial z_1}\right)-\left(\frac{1}{Q_1^B}\right)k''\left(\frac{N_1}{Q_1^B}\right)\left(\frac{\partial N_1}{\partial z_1}\right)-1-\left(\frac{\partial P_1^E}{\partial z_1}\right)E_1^*= \\ -\left(\frac{1}{Q_2^F}\right)f''\left(\frac{N_2}{Q_2^F}\right)\left(\frac{\partial N_1}{\partial z_1}\right)+\left(\frac{1}{Q_2^B}\right)k''\left(\frac{N_2}{Q_2^B}\right)\left(\frac{\partial N_1}{\partial z_1}\right) \tag{8}$$

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

$$\frac{\partial N_1}{\partial z_1}=\frac{-1-\left(\frac{\partial P_1^E}{\partial z_1}\right)E_1^*}{\left(\frac{1}{Q_1^B}\right)k''\left(\frac{N_1}{Q_1^B}\right)+\left(\frac{1}{Q_2^B}\right)k''\left(\frac{N_2}{Q_2^B}\right)-\left(\frac{1}{Q_1^F}\right)f''\left(\frac{N_1}{Q_1^F}\right)-\left(\frac{1}{Q_2^F}\right)f''\left(\frac{N_2}{Q_2^F}\right)}<0 \tag{9}$$

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. This means the rebound effect of such regulations on total energy use will be greater. The impact from the zoning migration effect on welfare is $((E_1-E_2)\left(NC'\left(N\hat{E}\right)-t\right)+z_1)(\frac{\partial N_1}{\partial z_1})$. (E_1-E_2) is the change in energy consumption from the household moving from city 1 to city 2. $\left(NC'\left(N\hat{E}\right)-t\right)$ is the external cost of energy use in the zoned city, net of energy taxes. This is positive as long as $(E_1-E_2)\left(NC'\left(N\hat{E}\right)-t\right)>z_1$.

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 $\left(NC'\left(N\hat{E}\right) - t\right) > 0$, 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:

$$E_1 = f(Heating(p_h(z_1), p_e, Z_1), Electricity(p_h(z_1), p_e, Z_1) \\ , Driving(p_h(z_1), p_e, Z_1)) \tag{10}$$

The variable 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. $\frac{\partial E_1}{\partial z_1}$ 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 $\frac{\partial Electricity(.)}{\partial z_1}$ 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:

$$\frac{\partial (NE)}{\partial z_1} = \frac{\partial N_1}{\partial z_1}[E_1 - E_2] + \frac{\partial E_1}{\partial z_1} N_1 \tag{11}$$

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 (6) captures the tradeoffs mentioned above when considering zoning policies and energy use.

D. Representative City Construction

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, pairs can be constructed for an MSA and its representative migration city. Two types of representative cities can be 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:

$$R_{i,t} = \sum\nolimits_k \frac{Migration_t\ MSA_i\ to\ MSA_k}{\sum_l Migration_t\ MSA_i\ to\ MSA_l} * Emissions\left(MSA_{k,t}\right) \forall l \neq i, k \neq i \qquad (12)$$

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

$$\begin{gathered}\left(Emissions\left(MSA_{i,t}\right) - Emissions\left(R_{k,t}\right)\right) * \\ \sum\nolimits_k Migration_t\left(MSA_i\ to\ MSA_k\right)\ for\ k \neq i\end{gathered} \qquad (13)$$

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 can also be 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:

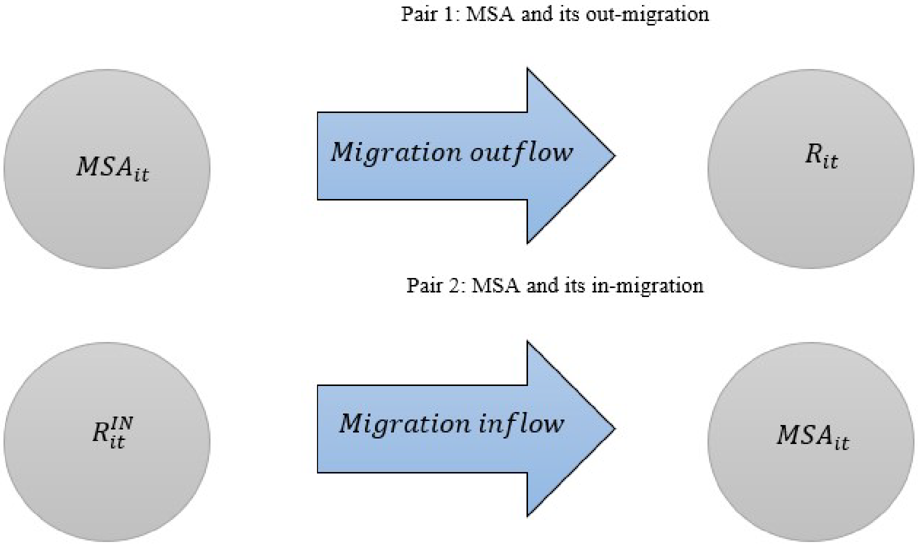
$$R^{IN}_{i,t} = \sum\nolimits_k \frac{Migration_t\ MSA_k\ to\ MSA_i}{\sum_l Migration_t\ MSA_l\ to\ MSA_i} * Emissions\left(MSA_{k,t}\right) \forall l \neq i, k \neq i \qquad (14)$$

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

$$\left(Emissions\left(R_{i,t}^{IN}\right) - Emissions\left(MSA_{i,t}\right)\right) * \sum_k Migration_t(MSA_k \; to \; MSA_i) \; for \; k \neq i \tag{15}$$

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 can 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



Notes: The first pair represents out-migration, the households leaving a given MSA. The second pair represents in-migrations, the households entering a given MSA.

III. CONCLUSION

This paper investigates the relationship between the intercity migration 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 study 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. When it comes to policies which can affect internal migration, current housing policies have the potential to 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, policies should be aimed at both the household emissions margin and the migration flow margin. Attempting to tax or regulate cities with low energy consumption, 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 also 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 (Glaeser and Kahn, 2010). 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.

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