Local Development and Global Warming: A Socio-Demographic Analysis of Spatial Inequalities in Carbon Appropriation within the United States*

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ABSTRACT

This study examines an overlooked dynamic in sociological research on greenhouse gas emissions: how local areas appropriate the global carbon cycle for use and exchange purposes as they develop. Drawing on theories of place and space, we hypothesize that development differentially drives and spatially decouples use- and exchange-oriented emissions at the local level. To test our hypotheses, we integrate longitudinal, county-level data on residential and industrial emissions from the Vulcan Project with demographic, economic and environmental data from the U.S. Census Bureau and National Land Change Database. Results from spatial regression models indicate that alongside innovations and efficiencies capable of reducing environmentally harmful effects of development comes a spatial disarticulation between carbon-intensive production and consumption *within* as well as across societies. Implications for existing theory, methods and policy are discussed.

KEYWORDS: Carbon Emissions; Local Development; Environment; Political Economy

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1. INTRODUCTION

For most of human history, social activities that degraded the environment did so locally. With the rise of modern cities, industrial combustion, and capitalist economies, this arrangement changed, and the environmental impacts of local life became increasingly global in scale. Nowhere is this historic shift more evident than in releases of carbon dioxide (CO_2) to the atmosphere (Clark and York 2005, 2008; Gonzalez 2009; Grimm et al. 2008; Jorgenson and Clark 2012). To better understand this type of socio-environmental interaction, the present study takes a closer look at the relationship between local development and carbon emissions within the United States – the second largest producer of greenhouse gases on Earth (U.S. Energy Information Administration 2013). The aim is to illuminate the spatial contours of this socio-environmental interaction and what they reveal about the social bases of global environmental change now taking place at and from the local level within advanced market societies.

Although most sociological research on carbon emissions has focused on national-level statistics (e.g., Grimes and Kentor 2003; Jorgenson 2007; Satterthwaite 2009; York et al. 2003), it is useful to consider local links between development and emissions for a number of reasons. One is the simple fact that nearly all carbon is emitted locally – i.e., from a particular location in time and space. So it makes empirical sense to examine contributing factors *within* as well as across societies, especially those characterized by significant social inequality. This argument is particularly pertinent in the United States, where nearly half of all counties emit more carbon waste than many less developed nations (Satterthwaite 2009). Another reason to focus on local drivers of emissions involves policy. To date, the United States has delegated primary responsibility for carbon mitigation to local, state and regional initiatives – e.g., the Regional Greenhouse Gas Initiative and the Mayors Climate Protection Agreement (Lutsey and Sperling 2008). This approach means that effective policies must cultivate better understanding of local variation in sources as well as amounts of carbon released into the atmosphere. Otherwise, successful strategies deployed in one type of area may be inappropriately applied to other types of areas, leading to frustration, failure, or indifference.

A final reason to investigate local drivers of emissions is theoretical. Moving down in scale – from national to local – allows us to assess the relevance of sociological theories of place and space for understanding how societies organize their ongoing appropriation of the global carbon cycle. These theories begin with political economy's intractable tension between the social production of use and exchange values in advanced market societies. They then point to how more affluent areas strive to resolve some of this tension through reductions in the latter, shifting how carbon is released locally over time. From this modified framework, we advance and test several hypotheses using county-level data from the 2001 and 2006 waves of the Vulcan Project (Gurney et al. 2009). This dataset includes direct monitoring data from a wide array of governmental sources, allowing us to conduct one of the most thorough, locally comparative studies of CO_2 output to date.

Results indicate that the United States is now shifting carbon-intensive industrial production from faster to slower developing areas, with areas of rising affluence showing no sign of reducing carbon-intensive residential consumption. The implication is that as advanced market societies develop, they re-organize where carbon is appropriated for different purposes, further complicating local solutions to global warming.

2. SOCIAL APPROPRIATION OF THE CARBON CYCLE

Sociological research emphasizes that carbon emissions are best understood as part of a global carbon cycle, which refers to the circulation of carbon through living organisms and non-living matter in support of Earth's biosphere (Clark and York 2005). The connection of human societies to this cycle is as old as our species. Before written records, humans appropriated carbon in the form of fire for cooking, foraging and agricultural practices, tapping energy stored in renewable carbon resources, such as wood (Bowman et al. 2009). Thereafter, humans extended appropriation of the carbon cycle into non-renewable resources, such as coal, petroleum and natural gas for an expanding array of activities – from making salt to heating homes to smelting metals. These activities increased human production and trade capacities but remained for centuries small in scale and oriented mostly towards local use (Ponting 2007).

Over the past century and a half, however, these social connections to the carbon cycle have shifted dramatically in scale and purpose, rendering environmental consequences of local activities increasingly global (Foster 1994). To explain this development, scholars now emphasize two anthropogenic drivers. One is the rise of industrial combustion, which has greatly increased the use of fossil fuels to power a growing number of human activities (Rockström et al. 2009). The other is the expansion of capitalism, which has harnessed the power of industrial combustion to the production of commodities for expanding market exchange and capital accumulation (Foster, Clark and York 2010).

In environmental sociology, the latter development is commonly associated with Schnaiberg's (1980) treadmill of production theory. This theory contends that capitalism and the environment are in inherent conflict because of the former's intrinsic drive to increase profits through heightened use of natural resources. Theories of ecological modernization contest this claim, arguing instead that advanced market societies will improve resource efficiency through social and technological innovations that are now in process (e.g., Mol 1997). Efforts to resolve this debate empirically have focused on national-level data and uncovered support for each side, pointing to different outcomes in different socio-spatial contexts (Jorgenson and Clark 2012). This complexity is now pushing scholars to develop middle-range theories that better account for variation in carbon-related activities within, as well as across, societies.

One example of this new line of research is Shwom's (2011) study of subnational variation in the implementation of new policies for energy-efficient appliances. Another is Zahran and colleagues' (2008) study of inter-metropolitan variation in local support for climate protection campaigns (see also Dietz et al. 2007; Krause 2010). In the present study, we advance a related but distinct line of research. Instead of focusing on variation in local support for specific policies and programs, we return to classic political economy to highlight tensions between the social production of use and exchange values for which carbon is appropriated. Below, we review this tension and its role in prominent theories of place and space. We then use these theories to generate middle-range hypotheses for empirical investigation.

3. SOCIAL PRODUCTION OF VALUE, PLACES & SPACE

Classic political economy contends that the aim of any society is to produce use values in the form of goods and services that members can consume to satisfy culturally accepted needs and wants.

However, in market societies – especially advanced capitalist ones – people don't just produce things for their own use; they also produce commodities for market exchange. These commodities are socially complex because they embody both exchange values for those who produce and sell them for profit *and* use values for those who eventually buy and consume them for their own satisfaction (Foster 2011). A core claim of political economy is that this complexity generates social tensions that increase as market-based societies develop and become more production, or exchange, oriented. Drawing from Marx's (1857-61/[1973]) arguments in *Grundrisse*, Harvey (1982: 80-81) describes this transition as one from "consumptive production" to "productive consumption." In both cases, nature (including labor power) is consumed, or appropriated, to produce things but under different prevailing logics: primarily for use versus primarily for profit. According to the political economy of place, tensions between the two become evident not only in the social production of things but also in the social production of places.

3.1 *Political Economy of Place-Making*

In a prominent version of the political economy of place, Logan and Molotch (2007) explain that tensions between use and exchange values influence how areas develop (see also Molotch 1976). They begin with the proposition that local development reflects the socio-cultural context in which it occurs. In the United States, this context treats land as a commodity, and as such, all settled areas – like any commodity – have a dual nature. On the one hand, they offer use values to local residents who use the area to live, form meaningful relationships, and forge deep attachments to place. On the other hand, they also offer exchange values to those who own the land and generate profits through rents, leases and sales in the real estate market. This duality of place produces political tension between actors primarily interested in maximizing local use values, or quality of life, and those primarily interested in maximizing local exchange values, or land-based profits, even if this pursuit means degrading local use values.

Logan and Molotch (2007) point out that these two sides tend to be unequal. Large land owners, developers and others who seek to raise exchange values of local lands by attracting new businesses and residents tend to be politically organized and powerful. Homeowners, neighborhood associations, and other civic actors who might challenge them – say, over increased traffic congestion, pollution, and loss of green space – tend to be less so. Land-based elites are presumed to use this advantage to capture local officials who steer government towards intensifying local land uses, which raise land-based profits. Logan and Molotch call these local coalitions “growth machines,” which compete against one another for development at the same time that they work to contain local political tensions that can arise from their own success. What this political economy of place-making means for local carbon appropriation remains a subject of implicit debate.

On the one hand, theories of ecological modernization draw on case studies of innovative companies, industries and areas to argue that local development is becoming less carbon (and thus globally) intensive with time (Grossman and Krueger 1995; Huber 2009; Mol, Spaargaren and Sonnenfeld 2009). This trend is argued to be especially evident in (ever) more affluent areas of more developed societies for a couple of reasons. On the “use side” of the carbon cycle, residents of these areas have more financial, political and cultural resources to protect local use values, even as development continues. It is presumed that residents use these resources to buy new energy-saving appliances, drive more fuel-efficient vehicles, preserve local green space, and generally adopt “sustainable lifestyles” that become a growing part of both local and individual identities (Spaargaren and Van Vliet 2000). These lifestyle choices then act as a type of informal environmental management as local citizen-consumers strive to give material form to their new identities, or narratives of self, by reducing local and global environmental degradation. Some scholars even argue that these social practices coincide with increased consumption of high-culture in the form of museums or natural amenities, which require fewer material resources to sustain than other forms of mass consumption because they are less oriented toward the accumulation of stuff (Owen 2009).

On the "exchange" side of the carbon cycle, theories of ecological modernization contend that these new reflexive politics pressure local economic actors to develop new technologies and production practices that promote "delinking [local] economic growth from natural resource inputs and outputs of emissions and wastes" (Mol 1997, p.141). Examples include efforts by industrial ecologists to convert wastes from one industrial sector into resources for another, as well as the development and adoption of new carbon-efficient tools, such as nanotechnologies that turn window panes into photovoltaic panels to convert solar energy into electricity; piezoelectric floor tiles that convert energy from human foot traffic into power for nearby businesses; and installation systems that store ambient heat during warmer months to heat buildings during cooler months (c.f., Sassen and Dotan 2010). The underlying argument is that local development – particularly the kind that raises incomes and empowers citizen-consumers – encourages an increasingly integrated set of practices that lower local carbon emissions, foster new markets, and promote further investment in cleaner production and consumption practices.

In these ways, local development – although politically contentious – is working to decouple itself from global warming through reductions in both use- and exchange-related carbon appropriation, especially in increasingly affluent areas of advanced market societies.

However, a prominent sociological theory of space offers a different perspective. This perspective corresponds more tightly with classic distinctions between use and exchange values and how tensions between the two produce unequal social space within societies.

3.2 *Political Economy of Space*

In his classic work, *The Social Production of Space*, Lefebvre ([1974] 1991) begins with the same basic propositions as Logan and Molotch: that local development reflects the socio-cultural context in which it occurs; and, that within advanced market societies, this context includes tensions between the social production of use and exchange values. Lefebvre then goes on to explain how societies attempt to resolve these political tensions by decoupling them spatially rather than materially, that is, by separating use and exchange-intensive activities across unequal social space. In this way, local tensions between the production of use and exchange values highlighted by growth machine theory become *spatialized* as a means of containing local political conflict in developing areas.

As this spatialization occurs, Lefebvre argues, two ideal types of places, or local spaces, begin to emerge at either end of a society's socio-economic continuum. At one end are "dominated spaces" that are disproportionately "exploited for the purpose of and by means of *production* (of consumer goods)" for market exchange and consumption by increasingly distant consumers (1991, p. 353; original italics and parentheses). At the other end are "appropriated spaces" that are disproportionately "exploited for the purpose of and by means of the *consumption of space*," by which Lefebvre means, "a certain quality of space" – one increasingly freed from dirty, unwanted exchange activities, such as carbon-intensive industry (ibid.). In this way, exchange-oriented activities and the market systems and networks that make them possible continue to expand over space as consumption, or end use, remains disproportionately grounded in more powerful places.

Take cars for example. Their production releases carbon into the atmosphere, as does the production of steel, plastic and energy needed for that production. All of these exchange-oriented activities now typically occurs some place other than where the car is eventually driven to provide local use value for a specific driver. Lefebvre's contention is that as market societies develop, they put increasing space between these two contradictory dimensions of development: commodity production and consumption. Furthermore, as this spatial dislocation occurs it becomes more difficult to undo. Dominated spaces can become so exploited for exchange purposes that they become decreasingly attractive spaces for local use, or social appropriation. According to Lefebvre, the root cause of this spatial disjuncture lies not just in local politics but in the deployment of space by more affluent areas to maintain and increase control over their own development as spaces of consumption – a process that Molotch (1976, p.328) once called aristocratic conservation.

This line of argument has clear parallels in environmental social science. The concept of metabolic rift, for example, highlights the spatial dislocation of agricultural production from consumption and how this dislocation breaks nitrogen cycles that sustain organic farming, thereby causing an unsustainable rift, or break, between ecological and economic bases of ongoing development (Foster 1999). Similarly, the concept of an ecological footprint emphasizes the extensive spatial hinterland required to sustain locally intensive development, including lands needed to provide needed resources and offset local carbon emissions (Rees and Wackernage1996). The common point – regardless of scale – is that market-based development does not decouple itself materially from environmental degradation so much as it decouples itself spatially by separating carbon-intensive production and consumption activities. The result is growing social as well as spatial inequality in use- and exchange-oriented carbon appropriation as advanced market societies develop.

Note that this perspective does not deny the possibility of new carbon-efficient technologies. Rather, it questions whether these technologies actually reduce carbon appropriation, especially in increasingly affluent areas. To illustrate this contention, York (2006) draws on Jevon's classic observation that rising coal efficiencies during the 19th Century actually lead to greater coal consumption. He argues that the same dynamic applies today. For example, advances in telecommunications have not produced the paperless office but instead increased paper consumption, as well as energy and materials needed to produce the paper to feed this consumption. The main point is that development may bring new, carbon-efficient technologies but these innovations do not reduce carbon appropriation in and of themselves in and of themselves, especially in market-based societies where new efficiencies often lead to expanded consumption and production.

3.3 *Research Hypotheses and Unit of Analysis*

Drawing from the above literature review, we advance two main hypotheses for empirical investigation. One draws from theories of ecological modernization and predicts that areas experiencing socio-economic development – especially rising incomes – will decrease use- and exchange-oriented emissions more or less equally. The result is an aggregate decline in local carbon appropriation with little or no shift between the two ideal types of appropriation. A counter-hypothesis draws from sociological theories of place and space and predicts that areas experiencing development – especially rising incomes – will shift carbon emissions away from exchange-oriented appropriation toward use-oriented appropriation. This shift can occur in one of two ways. In the simple version of the hypothesis, socio-economic development brings *absolute* divergence by maintaining local carbon-intensive consumption while decreasing, or outsourcing, carbon-intensive production to other areas. In the comparative version of the hypothesis, socio-economic development brings *relative* divergence between the two types of appropriation by decreasing exchange-oriented appropriation more than use-oriented appropriation. Driving both versions of the hypothesis – simple and comparative – is the idea that carbon-intensive production is easier and more socially desirable to reduce than carbon-intensive consumption and that socio-economic development empowers such divergence spatially.

To test these hypotheses at the local level we use all counties (and county equivalents) in the continental United States (N=3,108). This unit of analysis allows us to disaggregate data below the national level to test local-scale processes using a wide array of socio-economic indicators critical for assessing and controlling different dimensions of local development. Yet even with these advantages, it is important to note that no spatial unit is perfect. Although our modeling strategy (discussed below) controls for time invariant differences among counties (e.g., geographic size and location as well as topographic features such as mountains and coastlines), there is still the "modifiable areal unit problem" (Openshaw 1984). This problem arises from the fact that the same data can yield different results when the unit of spatial aggregation changes, say, from nation to state or county. One implication is that all research using spatial units – including nations – should take care not to assume that results apply similarly across all scales. Another implication is more technical: smaller spatial units (e.g., counties rather than metro areas or states) tend to produce smaller observed correlations with the same data. This tendency lends a conservative bias to our hypothesis testing, thereby increasing confidence in observed findings.

4. DATA AND METHODS

4.1 *Dependent Variables*

County-level data on carbon emissions come from the 2001 and 2006 waves of the Vulcan Project (Gurney et al. 2009). The Vulcan Project is funded by NASA and the U.S. Department of Energy and combines data from existing emissions-monitoring and fuel-consumption inventories conducted regularly by government agencies. Unlike prior subnational datasets (see Olivier et al. 1999), these data come directly from local point and nonpoint sources, which are then smoothed and aggregated to the county level using spatial surrogates prepared by the U.S. Environmental Protection Agency. This direct observation of local emissions opens new opportunities for studying carbon appropriation over time and space within the United States (e.g., Parshall et al. 2010).

Using these data we compute change scores between 2001 and 2006 for three dependent variables. We operationalize *Use Emissions* as the natural log of metric tonnes of CO_2 released by residential consumption. This sector includes all carbon emitted for energy consumed directly by households for domestic activities such as heating, cooking, cleaning and powering appliances. It does not include energy used for transportation by household members; nor does it include emissions released in the making of electricity and products consumed by households (i.e., embodied energy, or embedded carbon). It includes only emissions released by immediate residential consumption of natural gas and other fossil fuels, using data from all master-metered apartments, mobile homes, and family dwellings. During the time period covered by this study, this sector accounted for roughly 6% of all carbon directly emitted in the United States; meanwhile, residential activities account for 4% of all carbon emitted globally (Gurney et al.

2009). Although carbon appropriated for residential use is typically transacted through market exchange, it is primarily for nonmarket purposes. Thus, the variable's change over time provides a valid, reliable indicator of relative adoption (or not) of energy efficient appliances, practices and lifestyles in the home.

We compute *Exchange Emissions* as the natural log of metric tonnes of CO_2 released by local industrial activities. This sector covers all manufacturers that emit carbon through a stack or identifiable exhaust feature. It does not include emissions released primarily to heat manufacturing facilities or to run their office machinery; nor does it include carbon appropriated by the transportation sector to move these commodities or by the commercial sector to market them. Thus, the variable conservatively reflects direct appropriation of carbon to make physical commodities for market exchange. This type of appropriation accounted for roughly 16% of all direct carbon emissions in the U.S., and accounts for nearly 6% of all global emissions. Because 36 counties release no industrial emissions, we add 1 metric tonne to the value of all counties before taking the natural logarithm. (Recall that the natural log of one is zero.)

We compute the *Local Carbon Ratio* as the difference between logged *Use* and *Exchange* emissions, which is mathematically equivalent to taking the log of their unlogged ratio (i.e., $\log(Y_{use}) - \log(Y_{exchange}) = \log(Y_{use}/Y_{exchange})$). This measure adds no new data to the analysis, but when analyzed as a change score between 2001 and 2006, it offers direct, statistical assessment of relative shifts from one type of carbon appropriation to another over time. Positive values indicate increasing use-oriented appropriation of the carbon cycle; negative values indicate increasing exchange-oriented appropriation the carbon cycle.

4.2 *Independent Variables*

Prior socio-environmental research has operationalized multiple dimensions of development (e.g., Clement and Elliott 2012; Liu et al. 2003; York et al. 2003). We follow this convention and compute change scores between 2001 and 2006 for seven indicators. Conceptually, the most central is *median household income*, which reflects the relative status and resources available to local residents, which is theorized to influence lifestyle choices and local politics. In addition, we include the following common indicators: *population size* (measured as the total number of residents); *percent productive-age* (measured as the share of residents between ages 18 and 65); *mean household size* (reverse coded so that larger values indicate larger declines in size); *economic production* (measured as total reported earnings from all non-farm industries, yielding an estimate of local Gross Domestic Product); and *percent urban* (measured as the share of residents living in Census-defined urban areas).

Because the latter does not account for the density of urban and non-urban space, and because density is considered vital for achieving local environmental efficiencies (Fitzgerald 2010; Newman 1996; see also Clement 2011), we compute a measure of *population density*. This indicator is calculated as the number of residents per square mile of developed land. Data for developed land come from the National Land Cover Database (Fry et al. 2011). Data for all other variables come from *USA Counties*, which is compiled and published by the U.S. Census Bureau. When demographic data are unavailable for 2001 or 2006, we use the 2000 and 2010 population censuses to linearly interpolate values for respective years. Descriptive statistics for all variables appear in Table 1.

-- Table 1 about Here --

4.3 *Regression Analysis*

Our regression analysis uses change scores for all dependent and independent variables after taking their natural logarithms. Because $\log(X_2) - \log(X_1) = \log(X_2 / X_1)$, this difference-of-logs approach yields a growth rate, or proportional change, model that has several advantages (Firebaugh and Beck 1994). It produces coefficients that are readily interpreted as the effect of one rate on another. It generally avoids out-of-bounds estimates. It minimizes the influence of outliers, yielding more robust results. And, it controls for omitted variable bias (Allison 2009; Halaby 2004). The estimated slope coefficients are interpreted as the percentage change in the dependent variable for every one-percent change in the respective independent variable, holding all other variables in the model constant. This approach standardizes slope estimates for comparison and directs attention to relative rather than absolute effects of local development on carbon appropriation (see also York et al. 2003).

To relax the "constancy of effect" assumption in these models and to test whether the influence of change in a given dimension of development varies by its starting value, we include initial values for each independent variable at $time_1$ (2001) in all models. The slope estimate for each of these predictors reveals the extent to which pre-existing differences between counties at $time_1$ moderate the effect of a given variable on carbon emissions over time (Allison 2005). We also include the starting value of the dependent variable (in 2001) in all models to control for aggregate, national-level shifts and local regression to the mean.

In addition to these temporal considerations, we also perform diagnostics for spatial dependence (see Anselin and Bera 1998). *Moran's I* statistics computed with a queen, first-order contiguity matrix indicate that all three dependent variables exhibit significant, positive spatial autocorrelation, as do measures of local development (at 999 permutations). To correct for this autocorrelation and to get a sense of how neighboring counties influence local carbon appropriation, we use spatial autoregressive models with spatial autoregressive disturbances. Known as a SARAR model, this form of spatial regression combines the spatial lag and the spatial error models using maximum likelihood estimation (Anselin and Florax 1995). The spatial lag component accounts for autocorrelation among neighboring counties. The spatial error component then addresses the assumption of uncorrelated error terms. Both issues make regression with Ordinary Least Squares problematic. To control for spatial differences in temperature change over time that can influence fossil fuel consumption (e.g., Quayle and Diaz 1980), we also include a simple dummy control variable in all models. This variable equals one if mean annual temperature increased from 2001 to 2006; otherwise, it equals zero.

5. RESULTS

Results are organized into four sections. The first reviews descriptive data to establish general context and trends. The second examines links between local development and carbon appropriation. The third and fourth sections then assess how these links vary by past and surrounding levels of development, respectively.

5.1 *Recent Trends*

Table 1 indicates that the United States reduced *Use* and *Exchange* emissions by 3% and 5% respectively during the early 2000s. National reports indicate that residential emissions fell largely because of more efficient lighting and home appliances. Industrial emissions fell largely because of shifts from more to less energy-intensive activities – e.g., from producing bulk chemicals, iron, and glass to producing plastics, computers, and transportation equipment (U.S. Energy Information

Administration 2013). The differential decline between the two sectors indicates that as a whole, the nation is now shifting back toward the *Use* side of the carbon cycle, although *Exchange* emissions still predominate. A central question for the present study is how this trend varies spatially and what this variation can tell us about the social bases of carbon appropriation.

To begin answering this question, Figure 1 presents a map of shifting *Local Carbon Ratios* across the United States, which reveals spatial clustering that underscores the need for a spatial regression model. Results indicate that the biggest shifts toward *Use* emissions clustered in the West; whereas, the biggest shifts toward *Exchange* emissions clustered in the Midwest and South Central region (i.e., the middle of the country). These patterns depict divergent carbon appropriation over *geographic* space. To investigate variation over *social* space, we turn to indicators of local development.

-- Figure 1 about Here --

By way of context, Table 1 shows that, on average, median household incomes decreased by $66.58 (or 0.2%) in real terms. Yet, substantial variation persists, with some counties averaging more than $100,000 in annual income, while others average below $17,000. Other indicators of development show general increase. In order of magnitude, they include economic production (↑10%), urban residence (↑3.2%), total population (↑1.5%), working-age population (↑1.5%), and declining household size (↑1.1%). So, nationally, the period under investigation is characterized by steady development with declining but highly unequal incomes. Next, we examine how local variation in these trends reshaped carbon appropriation.

5.2 *Effects of Local Development on Carbon Appropriation*

Table 2 reports regression results for all three dependent variables. Subsequent discussion of estimated coefficients assumes an all-else-equal condition. To start, we find no evidence that rising incomes reduce local *Use* emissions. This finding casts doubt on the hypothesis that growing affluence leads to greater carbon efficiencies at home. Instead, another factor historically associated with development– declining household size – exerts the biggest effect (Salcedo, Schoellman and Tertilt 2012). Results indicate that for every 1% decline in average household size, there is a corresponding 1.1% increase in *Use* emissions. The implication is that, if anything, development *increases* residential carbon output through reductions in household size.

-- Table 2 about here --

Where rising incomes do matter directly, however, is in local *Exchange* emissions. Specifically, results indicate that for every 1% increase in median household income there is a corresponding .29% decline in local industrial emissions, increasing the *Local Carbon Ratio* by .33% (towards *Use* emissions). This finding implies that the direct effect of rising income lies in the displacement of carbon-intensive production to other areas, not in the adoption of more sustainable lifestyles at home. Results also indicate that this negative effect on *Exchange* emissions is more than twice that of economic growth's positive effect. In other words, income growth influences industrial emissions more than growth in local economic production, and in the opposite direction.

As for other dimensions of development, results indicate that increased urban settlement matters more for the *Local Carbon Ratio* than population density. Specifically, results indicate that for every 1% increase in urban residence there is a corresponding .09% shift towards *Use* emissions. So, in the United States, local shifts in population from rural to urban areas are now linked more to carbon-intensive consumption than to carbon-intensive production – and this link is stronger than that between emissions and the population density of the local built environment, which is statistically insignificant.

Table 2 also shows that population growth increases *Use* and *Exchange* emissions at roughly the same rate. The implication is that within United States local demographic growth influences how much – but not how – carbon is appropriated locally, which is consistent with recent sociological research in the structural human ecology tradition (e.g. Dietz et al. 2007; Jorgenson and Clark 2012; York, Rosa, and Dietz 2003). Table 2 shows similar results for shifts in the local age distribution: As shares of working-age residents increase, *Use* emissions rise but produce little net effect on the *Local Carbon Ratio*.

So, when assembled, the main findings from Table 2 offer collective support for the spatial hypothesis that local development shifts *Use* emissions up and *Exchange* emissions out. The implication is that local development is not reducing carbon emissions so much as moving them around, from county to county, and from one type of appropriation to another. To test these findings further, we estimated supplemental models with the quadratic form of each indictor of development entered alone and in various combinations. Results (not shown) indicate no significant curvilinear scalar effects, adding additional support to findings reported in Table 2.

5.3 Effects of Initial Levels of Development

Next, we turn to estimated coefficients for initial values of development (also in Table 2). These coefficients are analogous to interactions terms between time and respective predictors in a stacked, or unit-time, data configuration. In both cases, the estimated coefficient for the initial value of a covariate has two valid interpretations (Allison 2005). It tells us how the contemporaneous effect of a predictor changes over time, from 2001 to 2006; and, it tells us how the temporal effect of a predictor varies by its starting value in 2001. We adopt the latter line of interpretation because we are interested in how main findings discussed above vary by pre-existing levels of development.

Again, we start with household income. Findings show that pre-existing levels do influence subsequent shifts in carbon appropriation. Specifically, results indicate that areas with 1% higher median incomes in 2001 experienced, on average, .11% greater increases in the *Local Carbon Ratio* over the next five years, largely because of increases in *Use* emissions. Note that this effect differs from the main effect of rising incomes. Whereas, rising incomes tend to increase the *Local Carbon Ratio* by displacing *Exchange* emissions; high starting incomes tend to feed local increases in *Use* emissions. Combined, these findings imply that areas that are already affluent and getting more so experience the greatest shift away from *Exchange* toward *Use* emissions, as spatial theories generally predict.

We turn next to household size. The main effects discussed above indicate that local declines in this variable lead to local increases in *Use* emissions over time, raising the *Local Carbon Ratio*. However, when we consider the initial value of household size in 2001, we find no significant effect on the *Local Carbon Ratio* (-.079; $p > .05$). The implication is that the strong effect of declining household size on carbon appropriation is relatively constant, regardless of whether the county's starting value is low or high.

By contrast, the effects of urbanization do appear to vary by starting value. Findings show that urbanization exerts less upward pressure on the *Local Carbon Ratio* in areas that are already highly urbanized. We suspect that this finding may reflect a ceiling effect associated with the fact that this commonly used measure of development cannot exceed 100% at any point in time. Either way, the finding implies that urbanization's effect on local carbon appropriation is greatest during earlier rather than later shifts in population from rural to urban areas.

Together, these findings offer a richer picture of how carbon is appropriated along the U.S. socio-spatial continuum. At one end of this continuum are wealthy, urbanized areas where incomes continue to rise and household sizes continue to fall. At this leading edge of local development, carbon appropriation is shifting noticeably away from *Exchange* emissions toward *Use* emissions. At the other end of the socio-spatial continuum are poorer areas where incomes, household size and urbanization all remain relatively stagnant. At this trailing edge of local development, carbon appropriation is shifting in the opposite direction, away from *Use* toward *Exchange*. The implication is that behind national declines in carbon emissions lies a dynamic reshuffling of different sources of appropriation between more and less developing areas.

5.4 *Effects of Development in Neighboring Areas*

As a final step, we examine if development in neighboring counties amplifies or mutes local trends. Such spillover effects may result from diffusion, geographic divisions of labor (e.g., between central and suburban counties), or other types of socio-political interaction among neighboring areas. The spatial autoregressive parameter, ρ, reported in Table 2 indicates that such effects are generally positive and statistically significant in each model, affirming broad spatial association. Estimated coefficients for respective spatial lags offer insight into how this influence occurs among nearby counties. We are primarily interested in these spillover effects if they qualify main findings discussed above.

To start, results indicate that rising incomes in surrounding counties significantly amplify the effects of locally rising incomes. If we accept a p-value of .08 (two-tailed test), then results indicate that for every 1% increase in average incomes in neighboring counties, there is an additional .71% increase in the *Local Carbon Ratio* (from *Exchange* toward *Use*). So, for example, if incomes in both the referent county and in surrounding counties increased by 1%, we would expect the *Local Carbon Ratio* in the referent county to shift toward *Use* by 1.04% (.33 + .71). Moreover, results imply that this spillover effect of .71% occurs even if there is no change in income within the referent county, largely through displacement of carbon-intensive production.

Declining household size shows even stronger spillover effects. Specifically, results indicate that a 1% decline in the average household size in neighboring counties increases the *Local Carbon Ratio* in the referent county by 5.71%, even if the referent county experiences no decline in household size itself. This amplification occurs by increasing *Use* emissions and by decreasing *Exchange* emissions. Moreover, when local declines in household size occur alongside declines in neighboring counties, local effects are amplified, greatly shifting how carbon is appropriated locally. For example, if household size declined by 1% in both local and neighboring counties, we would expect the *Local Carbon Ratio* to shift toward *Use* by an impressive 7.33% (1.52 + 5.71).

Spillover effects from urbanization show similar patterns but to a lesser degree. Here, results indicate that a 1% increase in urban residence in surrounding counties brings a corresponding .21% increase the *Local Carbon Ratio*, mainly through increases in local *Use* emissions. Again, these spillover effects amplify the direct effects of local urbanization discussed above. So, as spatially contiguous counties urbanize together, they reinforce and amplify local shifts toward *Use* emissions.

The overarching implication is that when it comes to local development and carbon emissions, what happens in neighboring counties does not stay in neighboring counties. Moreover, when these spillover effects are considered alongside local effects, we can begin to see how links between development and emissions can "scale up" over time to produce and reinforce broader regional trends, such as those evident geographically in Figure 1.

6. CONCLUSION

This study examined how local areas appropriate the global carbon cycle for use and exchange purposes as they develop. Results offer both complexity and insight. With respect to complexity, findings support ecological modernization's claim that advanced market societies can become more efficient in their residential and industrial appropriation of carbon. But, findings also question how this accomplishment is achieved. Looking at local areas, as we did here, shows no indication that rising incomes (or urbanization or economic growth) are reducing residential emissions. However, findings do show that rising incomes drive out industrial emissions, shifting them to poorer areas with larger households and stagnant incomes. Findings also indicate that these trends have a certain spatial inertia. Thus, where incomes are rising in neighboring as well as local areas – the nation's growth centers – emissions are shifting even faster from exchange to use purposes. But in poorer areas, surrounded by other poor areas, the opposite shift is occurring. These diametric trends have important implications for existing theory, methods and policy.

With respect to theory, our findings imply that explaining national-level changes in carbon emissions through increased efficiencies of particular companies, sectors and cities can be misleading because such approaches inadequately account for the social production of space by and for local development. Taking this dynamic into account highlights how advanced market societies shift carbon-intensive production to poorer areas within their own borders, as well as to other places around the globe. It also highlights how this spatial decoupling is part of a more general process by which rising affluence enables residents to reclaim the use values of local environments. Through aristocratic conservation, richer areas are now turning back the clock to when environmental impacts of local development were more localized and industrial emissions were less dominant. But in the process, they are also contributing to counter-developments in other areas. We, like other scholars working in the tradition of the political economy of place and space, suspect that this spatial divergence may be a fundamental feature of modernization: *Alongside innovations and efficiencies capable of reducing environmentally harmful effects of development comes an increasing spatial disarticulation between carbon-intensive production and consumption within as well as across societies*. This spatial decoupling complicates local efforts to address global environmental problems produced by local development.

With respect to methods, results indicate that comparative local analyses of emissions can complement and extend ongoing cross-national research in several ways. In addition to continuing to assess the "scalability" of core claims across different levels of social space, such analyses can also make use of new spatial regression techniques to contextualize local dynamics in both time and space, lending analytical depth to hypothesis testing. As future studies pursue these possibilities, other methodological advances will be necessary. For example, scholars will want to extend the current study to examine how hybrid, or mixed, forms of use- and exchange-oriented emissions respond to different modes of local development. One question might be how transportation emissions – released for a combination of use and exchange purposes – respond to rising population densities, and whether this response counters that of rising incomes and falling household size. Future research should also investigate how links between local development and carbon emissions are affected by broader, less time-variant contexts in which they're embedded. These contexts might include broader regions that vary by climate, mode of energy production, and vulnerability to the environmental impacts of global warming.

With respect to policy, results indicate that the United States' current "bottom up" approach to carbon mitigation is shifting different types of emissions around as local areas strive to decrease emissions *and* increase incomes. For more affluent areas, these twin goals will likely push local growth machines to adopt political strategies that continue outsourcing carbon-intensive industry while increasing local use values through environmental protection. For most other areas, though, uneasy choices will remain between pursuing more carbon-intensive manufacturing that raises local incomes and pursuing less carbon-intensive production that is difficult to lure away from more affluent areas. Moreover, findings indicate that spillover effects from neighboring areas will only reinforce this conundrum, leaving less-advantaged areas of less-developed sections of the country to face the nation's most difficult policy decisions regarding local development and global warming. Combined, these trajectories imply that it will be hard for any local area – affluent or poor – to adopt truly meaningful mitigation strategies on their own. Thus, local actors might push elected officials and government agencies to design carbon policies at the state and federal levels that explicitly acknowledge and address the types of divergent but connected trends documented here. We look forward to these and related efforts.

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Table 1. Descriptive Statistics for Dependent Variables and Local Development Measures, N=3,108

	2001			2006			Change between 2001 and 2006
	Mean (SD)	Min	Max	Mean (SD)	Min	Max	
Dependent Variables							
Local Carbon Ratio	-0.277 (1.756)	-8.316	8.619	-0.260 (1.732)	-8.015	8.810	0.0162**
Use Emissions	9.105 (1.438)	4.121	15.000	9.073 (1.446)	3.925	14.981	-0.032***
Exchange Emissions	9.382 (2.267)	0.000	16.580	9.334 (2.230)	0.000	16.157	-0.048***
Local Development Measures							
Total Population	10.236 (1.414)	4.127	16.081	10.250 (1.448)	4.007	16.094	0.015***
Percent Productive Age	4.091 (0.066)	3.818	4.369	4.106 (0.061	3.848	4.366	0.015***
Mean Household Size[a]	-0.925 (0.074)	-1.471	-0.693	-0.914 (0.0763)	-1.463	-0.690	0.011***
Population Density	8.254 (0.743)	4.174	11.493	8.245 (0.766)	4.181	11.525	-0.009***
Percent Urban	2.965 (1.676)	0	4.615	2.996 (1.662)	0	4.615	0.032***
Median Household Income	10.582 (0.236)	9.767	11.573	10.581 (0.237)	9.740	11.521	-0.002*
Economic Production	12.892 (1.708)	7.420	19.472	12.991 (1.720)	7.336	19.550	0.099***

* p<0.05; ** p<0.01; *** p<0.001 (two-tailed significance tests)

[a] The 2001 and 2006 values for "Mean Household Size" have been multiplied by negative 1. Thus, the positive value for the variable's change score (0.011, p<0.001) indicates a decline in mean household size between 2001 and 2006.

Table 2. Spatial Autoregressive Model with Spatial Autoregressive Disturbances (SARAR Model), N=3,108

	Change in Local Carbon Ratio		Change in Use Emissions		Change in Exchange Emissions	
	Model 1		Model 2		Model 3	
	b	SE	b	SE	b	SE
Local Development Δ Measures (2001-06)						
Total Population	0.120	0.244	0.197*	0.098	0.185	0.218
Percent Productive Age	0.464	0.430	0.440*	0.177	-0.057	0.382
(Decline in) Mean Household Size[a]	1.522*	0.654	1.079***	0.266	-0.177	0.581
Population Density	0.058	0.250	0.031	0.100	-0.032	0.223
Percent Urban	0.091**	0.034	0.019	0.013	-0.055†	0.030
Median Household Income	0.327*	0.161	-0.045	0.066	-0.293*	0.143
Economic Production	-0.117†	0.067	-0.009	0.027	0.128*	0.059
Initial Values (2001)						
Total Population	0.087***	0.025	0.194***	0.012	-0.021	0.022
Percent Productive Age	0.339*	0.131	0.012	0.050	-0.224†	0.120
Mean Household Size	-0.079	0.111	0.096*	0.043	0.106	0.100
Population Density	-0.021	0.021	-0.019*	0.008	0.008	0.018
Percent Urban	-0.020***	0.005	-0.003	0.002	0.016***	0.005
Median Household Income	0.105*	0.048	0.075***	0.019	-0.010	0.043
Economic Production	-0.055**	0.019	0.001	0.007	0.048**	0.017
Dependent Variable	-0.056***	0.004	-0.192***	0.008	-0.054***	0.004
Spatial-Lags for Δ Measures						
Total Population	0.512	0.542	0.138	0.230	-0.205	0.471
Percent Productive Age	-1.164	1.152	0.356	0.497	1.895†	1.003
(Decline in) Mean Household Size[a]	5.708***	1.630	2.082**	0.708	-3.689**	1.396
Population Density	-0.456	0.596	0.063	0.252	0.524	0.518
Percent Urban	0.214*	0.095	0.101**	0.038	-0.077	0.085
Median Household Income	0.709†	0.410	-0.251	0.177	-0.738*	0.354
Economic Production	-0.236	0.188	-0.010	0.078	0.247	0.164
Control for Climate Change						
Increase in Mean Annual Temperature	-0.099*	0.047	-0.006	0.019	0.084*	0.041
Constant	-2.462***	0.697	-0.936**	0.274	0.940	0.628
λ	-0.621***	0.057	-0.543***	0.041	-0.613***	0.059
ρ	0.745***	0.026	0.852***	0.014	0.697***	0.031
AIC	1166.550		-1779.529		845.521	

† p<.1; * p<.05; ** p<.01; *** p< .001 (two-tailed significance tests)

[a] Decline in Mean Household Size is measured as the inverse of Change in Household Size (-1 * Mean Household Size) to conform with the notion of development leading to smaller, not larger, households.

Figure 1. Change in Local Carbon Ratio, 2001-2006