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The Environmental Consequences of Rural and Urban Population Change: An Exploratory Spatial Panel Study of Forest Cover in the Southern United States, 2001–2006

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Abstract This exploratory study examines the effects of rural and urban population change on forest cover at the local level across the southern United States. Using county-level data from the National Land Cover Database and other U.S. government sources, we regressed the total area of forest cover on rural and urban population size in spatial panel models with two-way fixed effects. When we controlled for several other factors, including the number of forestry operations at the county level, regression results indicate that urban change had no effect, but rural population size was positively related to total forest area, and this effect was most pronounced in and around Georgia. Thus, in areas of the southern United States, rural growth was associated with afforestation, not deforestation. We speculate on how this unusual finding contributes to the debate between ecological modernization and urban political economy implicated in previous cross-national research.

Introduction

Forest cover change is a fundamental human activity (Chew 2001; FAO 2012; Williams 2010) and is implicated in a number of socioenvironmental problems and activities, including global warming, appropriation of net primary productivity (i.e., the net amount of solar energy converted to plant organic matter through photosynthesis), habitat loss, the spread of invasive species, wildfires, landslides, flooding, forestry, agriculture, biofuels, recreation, and sprawl, among other concerns (Cramer and Hobbs 2007; Egan and Luloff 2000; Ellis 2011; Holleman 2012; Krausamann et al. 2013; MacDonald and Rudel 2005; Miller 2012; Neumann et al. 2007; Perz 2001; Riall 2007; Walker and del Moral 2003). While several sociologists have contributed to this diverse literature on forest cover change, researchers in the discipline have had a particular focus on the systemic causes of deforestation, using quantitative analysis to examine the demographic and economic drivers behind this type of anthropogenic impact (e.g., Austin 2010a; Burns, Kick, and Davis 2003; Ehrhardt-Martinez 1998; Jorgenson 2006, 2008; Jorgenson and Burns 2007; Rudel 1989; Shandra, Esparza, and London 2012). Furthermore, within this literature, there has been a fair amount of attention paid to the relative effects of rural and urban population change, either as variables of primary theoretical interest or as important controls. While the findings from this research have changed as the quality of forest cover data has improved, an issue we will discuss below, the vast majority of these studies have been conducted at the national level, with negligible attention paid to local-level dynamics (for an exception see MacDonald and Rudel 2005).

The following exploratory study aims to fill this gap in the literature, conducting a local-level analysis of the relative effects of rural and urban population change on total forest area across the southern United States between 2001 and 2006. The southern United States at the start of the twenty-first century represents an ideal context in which to examine the systemic drivers of change in total forest area. We will discuss this context in greater detail below; for now we highlight that not only does the southern United States currently contain a significant portion of the world's forest area, but recently it also has experienced a high degree of rural and urban population change as well as deforestation *and* afforestation (Hanson et al. 2010). On that note, the following analysis makes two general contributions to the literature: it contributes a local-level perspective to a theoretical debate largely taking place at the national level concerning the relative environmental effects of rural and urban population change, and it uses a spatial panel model to test these effects. A spatial panel model incorporates spatial effects into a regression analysis using longitudinal data, thereby addressing the issue of spatial dependence in repeated observations over time for areal units (Lesage and Pace 2009). This type of panel model represents an advance in the methodology commonly used in quantitative studies of deforestation, which frequently controls for temporal dependence (e.g., Austin 2010a) and only rarely controls for spatial dependence (e.g., MacDonald and Rudel 2005), but not both.[1]

To that end, the study proceeds through the following steps. First, we report changes in forest cover in the southern United States at the start

[1] Unlike other social scientists (e.g., Liu et al. 2014), sociologists in general have not readily incorporated spatial procedures into panel models. In fact, even when there are repeated observations over time for areal units, the longitudinal structure of the data is evaded with the use of change scores, which are then incorporated into a conventional spatial regression model (e.g., Elliott and Clement 2014; Genter, Hooks, and Mosher 2013).

of the twenty-first century, highlighting the utility of this context in analyzing rural and urban population change as systemic drivers of deforestation and afforestation. Second, we review literature in sociology to discuss the effects of rural and urban population change on the natural environment, with a particular emphasis on forest cover. In this review, we frame the competing arguments about these effects in terms of the debate between ecological modernization theory (EMT) and urban political economy (UPE). Third, we describe the data and the analytic technique used to test hypotheses based on the literature review. The study combines demographic and economic indicators from U.S. government sources with data on total forest area from the National Land Cover Database (NLCD) (Fry et al. 2011). Fourth, we report and discuss the results from spatial panel models, providing a comparison with results from conventional panel models that do not control for spatial autocorrelation. Last, in the conclusion, we elaborate on the ways that rural and urban population change might be differentially related to forest cover in the southern U.S. context.

Forest Cover and Rural and Urban Change in the Southern United States

The southern United States occupies an area of roughly 885,000 square miles, on which sits a little more than 280,000 square miles of forests, representing nearly 32 percent of the region's area and, according to Hanson et al. (2010), about 2 percent of total global forest area. Based on data from the NLCD, all four U.S. census regions (Northeast, Midwest, South, and West) experienced net deforestation between 2001 and 2006; nonetheless, the South had the largest amount of forest loss *and* gain (i.e., deforestation and afforestation), both in terms of total square miles and as a fraction of total area (see Figure 1).[2] In the southern United States, the total area covered by forests declined from 284,698 square miles in 2001 to 281,199 square miles in 2006, a net loss of almost 3,500 square miles. However, this net loss obscures the total amount of land transformed during this time, in which 11,310 square miles of trees were cut down and 7,810 square miles of land was forested. Thus, a little more than 19,000 square miles of land experienced either deforestation or afforestation, an area roughly the size of Costa Rica.

[2] We use the term "afforestation" to refer to forest gain. The NLCD data are based on two waves of satellite imagery, one from 2001 and one from 2006 (more details below); as a consequence, we use the term "afforestation" rather than "reforestation" because we cannot tell whether any of the forest gain had taken place on land that was previously forested before 2001.

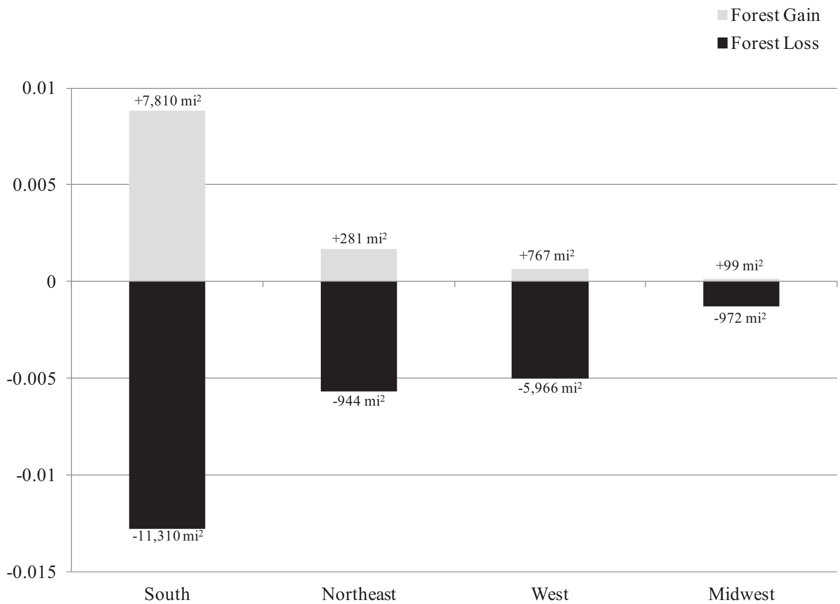

Figure 1. Relative and Absolute Area of Forest Gain and Loss by U.S. Census Region, 2001–2006. *Note*: Total gain and loss (in square miles) are reported above and below the bars. Alaska and Hawaii are not included in the region West.

Yet within the South, rates of de- and afforestation were not evenly distributed across space. Figure 2 displays percentage change in forest cover at the county level across the southern United States for the period 2001–2006. During this time, 1,064 southern counties (nearly 75 percent of the sample) experienced net deforestation, 336 counties experienced a net increase in forest cover, and the remaining 23 counties experienced no change at all. Based on the Moran's *I*, a measure of spatial autocorrelation, we see significant clustering of forest gain and loss at the county level during this time ($I = 0.296$; $p < .001$). For instance, counties that experienced afforestation tended to cluster in the west and southern tip of Texas; parts of Louisiana and Arkansas, and western Mississippi; southeastern Alabama, southern Georgia, and South Carolina; and the Chesapeake Bay area. Counties that experienced the greatest forest loss tended to cluster in southeastern Texas, along the border of Mississippi and Alabama, and along the coast of North Carolina. Outside the notable areas of clustering, there were other hot spots with very high rates of forest loss, including, for example, the corridor between Bexar and Travis Counties in Texas (where the cities of San

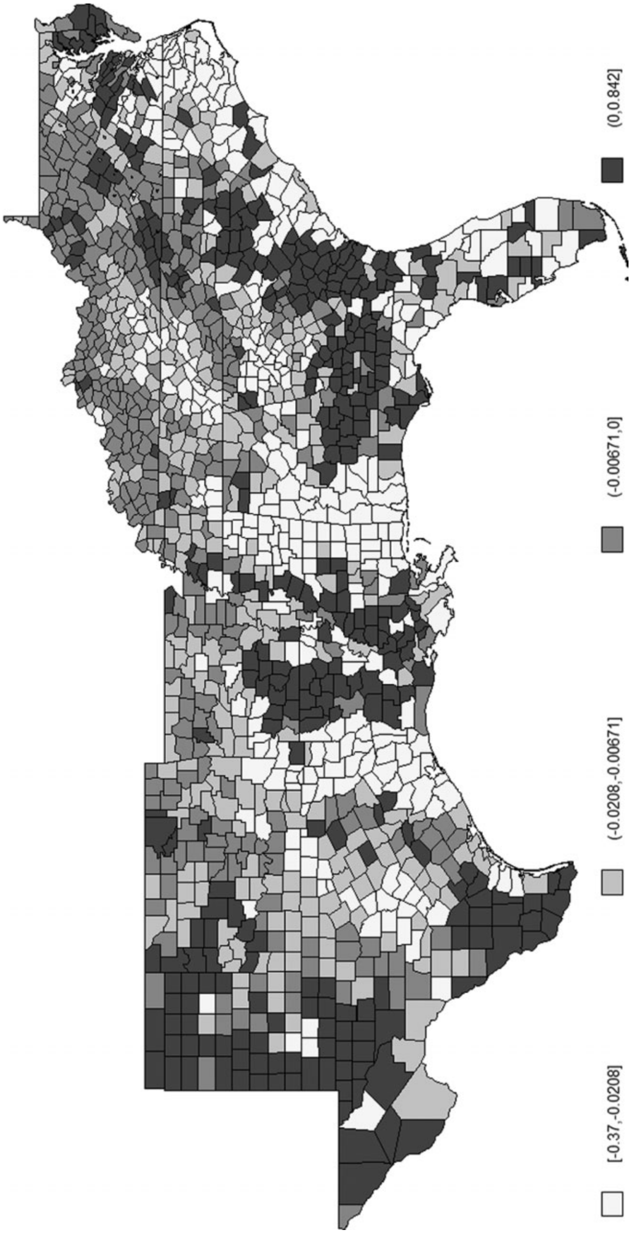

Figure 2. Map of Percent Change in Forest Area, 2001–2006 (N = 1,423).

Antonio and Austin are located, respectively) and the greater metropolitan areas of Atlanta in Georgia and Orlando in Florida.[3]

Of the four U.S. census regions, the South not only has the largest area of de- and afforestation, it also witnessed the greatest change in rural and urban populations, in both absolute and relative terms (see Figure 3). In the South, between 2001 and 2006, while the number of people living in rural areas increased by roughly 224,000, the percentage rural declined by nearly 1.5 percent. Thus, while the South's rural population grew, its urban population grew faster. None of the other three census regions experienced an equivalent level change, in either absolute or relative terms. Nevertheless, an aggregate summary of rural and urban population change for the entire southern United States masks the wide variation evident at the county level. For instance, while the rural population of Wake County, North Carolina, declined by nearly 10,000 residents, the number of people living in rural areas in St. Johns County, Florida, increased by approximately 8,300; the size of St. Johns's rural population in 2006 was 1.73 times its size in 2001. Similarly, while 794 counties in the South experienced urban population growth, 365 counties saw their urban populations decline and 264 counties had no change at all (see Figure 4).

In summary, the absolute scale and relative degree of change highlight the utility of the southern United States as an ideal context for examining connections between rural and urban population size and forest cover at the county level. But how have sociologists theorized rural and urban population as a systemic driver of environmental change, in general, and de- and afforestation, in particular? Most of this work has happened at the national level; thus, while we have demonstrated the importance of the southern United States as a context for examining this socioecological process at the local level, we recognize that most theorizing concerns a higher level of analysis. Consequently, we highlight the exploratory character of this study but argue that the hypothesized mechanisms through which rural and urban population size drive forest cover change can be tested at the subnational level.

[3] Based on the NLCD definitions, which we describe below, only four counties in the southern United States had no forest cover in 2001 and 2006. Three of these counties (Cochran, Loving, and Winkler) are located in the dry climate of west Texas and the Texas Panhandle. The fourth county (Monroe) contains both the Florida Everglades and the Florida Keys. According to NLCD criteria, Monroe is covered by woody and herbaceous wetlands, not by forests. We discuss the limitations of these criteria in the Data and Methods section.

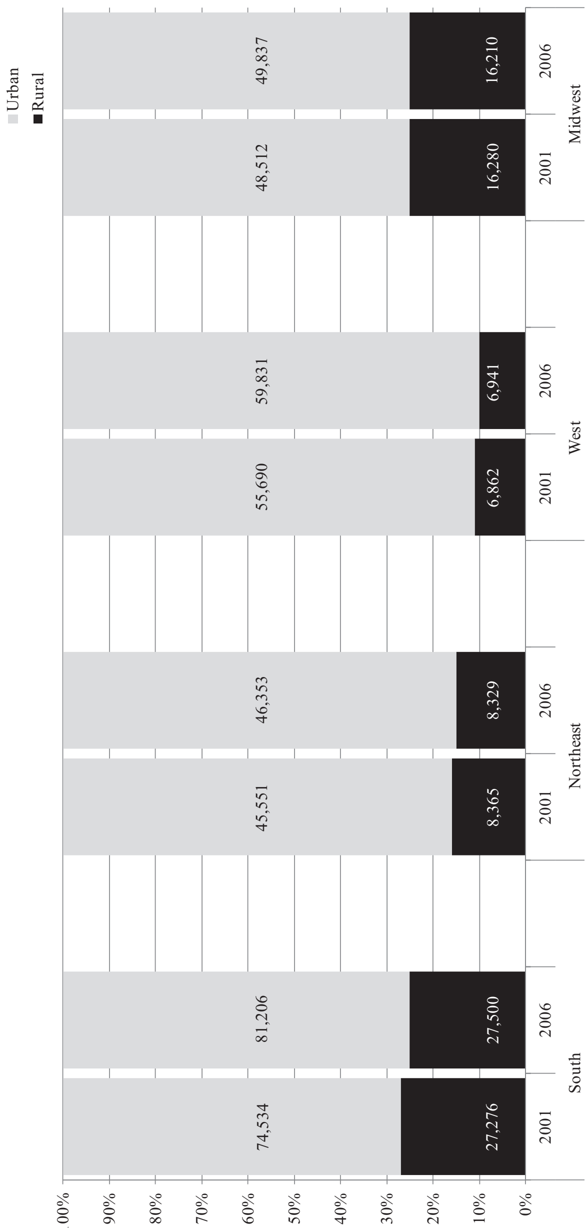

Figure 3. Relative and Absolute Size of Rural and Urban Population by U.S. Census Region, 2001–2006.
Note. The bars represent the percent of the total population living in rural and urban areas. The numbers inside the bars indicate population size (in thousands).

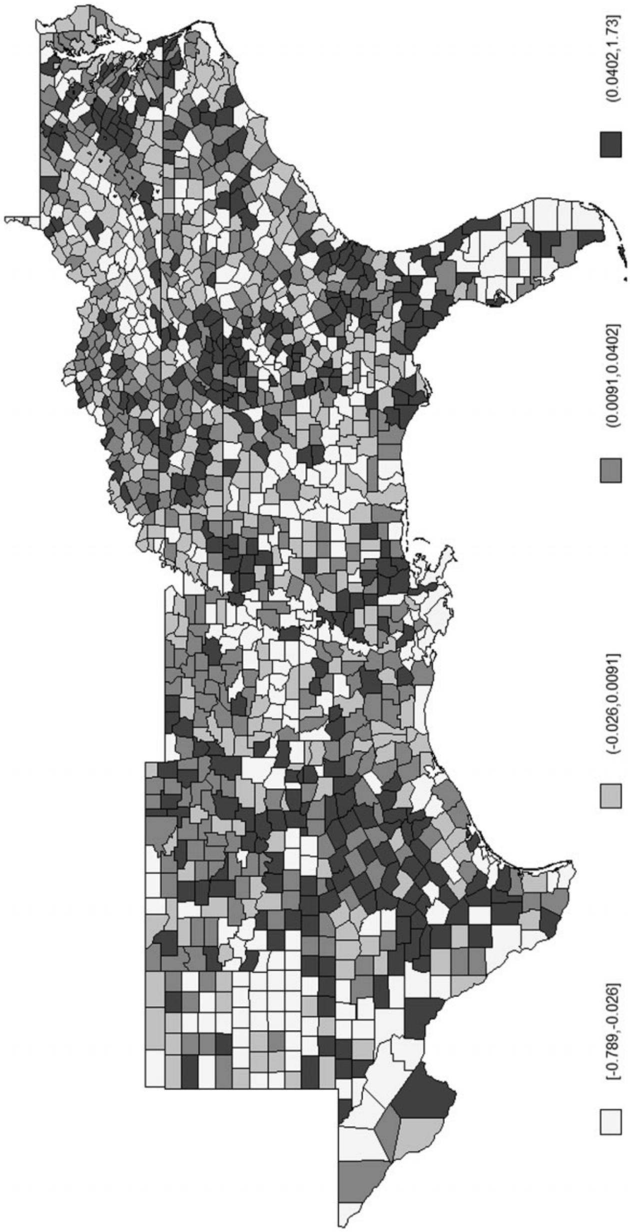

Figure 4. Map of Percent Change in Rural Population, 2001–2006 (N = 1,423).

Literature Review and Theory

There has been much sociological research examining environmental change in rural areas (for overviews see Albrecht and Murdock 2002; Field and Burch 1988). A good portion of this has been concerned with agricultural practices, forestry, mining, and recreation; indeed, discussion about rural environmental problems tends to focus on the extractive nature of rural economies. Scholars have credited rural sociology's focus on environmental and natural resource issues as having an influence on the development of environmental sociology (e.g., Buttel 1996). Thus, even though environmental sociologists had long recognized the environmental consequences of urban areas (e.g., Anderson 1976; Catton 1980), more attention had been focused on the connection between rural areas and environmental change. More recently, however, this attention has shifted; there have been several theoretical and empirical studies examining the links between urbanization, city life, and the natural environment (e.g., Chew 2001; Clement 2010; Elliott and Clement 2014; Ergas 2010; Jorgenson, Rice, and Clark 2010; McKinney 2013; Taylor 2009; Wachsmuth 2012; Weinberg, Pellow, and Schnaiberg 2000). While these authors ask a variety of research questions, one basic question has motivated a number of studies: What are the relative ecological impacts of rural and urban population growth? Empirically, this question has been the focus of discussion in quantitative studies of deforestation (DeFries et al. 2010; Ehrhardt-Martinez 1998; Ehrhardt-Martinez, Crenshaw, and Jenkins 2002; Jorgenson and Burns 2007; MacDonald and Rudel 2005; Rudel 2012, 2013). As a whole, this literature draws from different theoretical perspectives, presenting competing arguments that suggest rural and urban population growth are differentially related to changes in forest cover. At their root, these competing arguments involve the debate between ecological modernization theory (e.g., Ehrhardt-Martinez 1998) and urban political economy (e.g., Burns et al. 2003). We now review the EMT and UPE arguments as a way to develop hypotheses that we then test at the county level in the southern United States, again, an area that has experienced much change in both rural-urban population size and area of forest cover.

Ecological Modernization versus Urban Political Economy

In general, the literature on deforestation has reported three different findings with respect to the association between changes in rural-urban population size and area of forest cover:

1. Urban growth is associated with afforestation (e.g., Ehrhardt-Martinez 1998; Ehrhardt-Martinez et al. 2002; Jorgenson 2006; Jorgenson and Burns 2007; Rudel 1998).
2. Rural growth is associated with deforestation (e.g., Jorgenson 2006; Jorgenson and Burns 2007; Shandra, Leckband, and London 2009; Shandra, Shircliff, and London 2011; Shandra et al. 2012).
3. Urban growth is associated with deforestation (e.g., Burns et al. 2003; DeFries et al. 2010; Rudel 2013).[4]

The first two findings are compatible and are seen as part of the same theoretical framework: Rural population growth is detrimental to the environment, whereas urban population growth is beneficial. These processes are generally framed as support for EMT, with urbanization being a principal indicator of modern development that relieves anthropogenic pressures on the natural environment (Ehrhardt-Martinez 1998; Ehrhardt-Martinez et al. 2002). In contrast, the third finding implicates the UPE framework, which emphasizes the negative environmental consequences of urbanization (Jorgenson and Clark 2011).

On the one hand, EMT argues that the "path to sustainability lies in understanding the [modernization] process" (Scheinberg and Anschütz 2006:268). Mol (2002) describes how environmental thinking and stewardship emerged in modern societies in the 1970s and have since permeated governmental policies and economic practices. As a result, Mol argues, these activities have become institutionalized, ensuring their "permanence" in modern society. In this light, the environmental consequences of human actions are generally taken into account through the ongoing development of various modern institutions and processes (see Mol 2002:94). For instance, in much of the early work on EMT, discussion about the modernization process had focused on the dematerialization of economic growth, that is, "[e]nvironmental improvement can go together with economic development via a process of delinking economic growth from natural resource inputs and outputs of emissions and waste" (Mol 1997:141). Although modernization scholars outside the environmental literature had previously emphasized the connection between urbanization and development (Kasarda and Crenshaw 1991), the environmental implications of this connection were not adequately scrutinized until Ehrhardt-Martinez (1998) and

[4] There are a few qualifications to note in this summary. For instance, Burns et al. (2003) find that the detrimental effect of urbanization is most pronounced in semiperipheral and peripheral nations. Ehrhardt-Martinez (1998) and Ehrhardt-Martinez et al. (2002) find an environmental Kuznets curve between urbanization and deforestation. And several studies have found no significant effect of either rural or urban population (e.g., Austin 2010a, 2010b, 2012; Shandra 2007).

Rudel (1998).[5] Nevertheless, these and other studies treat urbanization as a proxy for the degree of industrialization in an economy or the type of fuel used in the economy. That is, as the size of the rural population dwindles and the urban population grows, the number of farms and the level of agricultural activity decline, which reduces the pressure placed on forest resources, helping to slow down deforestation. Similarly, according to this argument, urbanization is also related to technological innovation. Among other things, technological innovation means wood products are replaced with fossil fuels, which also helps to relieve pressure on forest resources. In summary, according to EMT, urbanization is beneficial for the environment.

On the other hand, according to the UPE framework, rural and urban areas are involved in an unequal economic exchange (Lobao, Hooks, and Tickamyer 2007; London and Smith 1988), which takes an ecological form, with rural areas treated as a supply depot and repository for urban activities (Burns et al. 2003; Buttel and Flinn 1977; Lichter and Brown 2011). To make this point, environmental sociologists draw on growth machine theory (Molotch 1976), arguing, for example, that "[c]ities remain centers of growth that require massive amounts of natural resources to sustain daily operations" (Jorgenson and Clark 2011:240). According to growth machine theory, urban-based political and economic elites strive to extract more and more exchange value through land development projects. These elites also encourage the expansion of commodified activities that generate revenue for themselves and their companies' shareholders. In environmental terms, this heightened level of human activity amplifies the socioecological metabolism of urban areas, increasing the scale of natural resource use. With respect to forest resources, in particular, this process generates an unequal rural-urban exchange, which calls to mind metabolic rift theory (Burns et al. 2003; Foster 1999). Indeed, DeFries et al. (2010) argue that urbanization raises consumption levels, which means that more trees are cut down in rural areas to accommodate commercial food production to feed residents in urban areas. Rudel (2013) makes a similar argument; agricultural production, which contributes to deforestation, is driven by urbanization, which creates a demand for a diet richer in animal products (cf. York and Gossard 2004). Thus, in the UPE framework,

[5] Citing unpublished results, Crenshaw and Jenkins (1996) describe a set of propositions about the effect of urbanization on greenhouse gas emissions, hypothesizing that urban agglomeration improves the efficiency of fossil fuel use, thereby helping to reduce greenhouse gas emissions. In contrast, Ehrhardt-Martinez et al. (2002:229) argue that advanced urbanization is "characterized by . . . increased use of petroleum, coal, and electricity," thereby intensifying the human production of greenhouse gases.

urbanization is treated as a proxy for the expansion of farmland. Meanwhile, this research acknowledges that low-income nations are generally net importers of food but still supposes that domestic agricultural production is directed towards the domestic market (Ng and Aksoy 2008; Rakotoarisoa, Iafrate, and Paschali 2011; Rudel 2013). Thus, exactly how does domestic urbanization contribute to agriculture-led deforestation within a country if its agricultural products are exported?

Exploratory Hypotheses for a Local Level Study in the Southern United States

The majority of the research examining the drivers of forest cover change has been conducted at the national level. Nevertheless, in terms of the effects of rural and urban population change, we argue that the mechanisms described in this research are not exclusive to that level of analysis, and the same propositions about rural and urban change can be applied to the subnational level. Indeed, as previously noted, these researchers talk about urbanization in terms of the level of industrialization, the presence of primary production, and the socioecological metabolism, all three of which are characteristics of urbanization that can be operationalized at various subnational levels (e.g., state, metropolitan, and county). Furthermore, the effects of rural and urban population change have been examined in a variety of contexts, including in both developed and less developed nations. Thus, this exploratory study contributes a local-level evaluation of a theoretical debate that has taken place largely at the national level. Basing our work on EMT and UPE, we test the same hypothesized mechanisms through which rural and urban population are said to drive changes in forest cover. These hypotheses are as follows:

H_1: Urban population size is positively associated with forest cover.

H_2: Rural population size is negatively associated with forest cover.

H_3: Urban population size is negatively associated with forest cover.

Nonetheless, these three propositions are not exhaustive of the different possible ways that rural and urban population growth could potentially drive forest cover change. In particular, this list leaves out the possibility that *rural population size is positively associated with forest cover.* There are two points to make with respect to this latter hypothesis. First, it is not compatible with EMT. According to EMT, rural population growth would be a reversal of the modernization process, so rural population size should be negatively related to forest cover: As the size of the rural population declines, the area covered by forests should increase. Likewise, as the rural population increases, which is opposite to the trend that characterizes the modernization process, the area covered by forests should decrease. Second, a positive association between rural population size and forest cover would be the converse to the third hypothesis, which is based on urban political economy. In the literature, the UPE argument, however, has focused specifically on the way urbanization amplifies the socioecological metabolism, which indirectly drives changes in forest cover through the expansion of farmland. This framework has not examined the converse process, that rural life moderates or restrains the socioecological metabolism, thereby limiting environmental impact. Thus, for a more exhaustive list of hypotheses, we include the following fourth proposition in our exploratory study:

H_4: Rural population size is positively associated with forest cover.

Data and Methods

Dependent Variable

The data for the dependent variable in this study come from the National Land Cover Database, which is published by the Multi-Resolution Land Characterization Consortium (Fry et al. 2011). The consortium is composed of members from the following 10 different federal agencies: the U.S. Geological Survey, National Aeronautic and Space Administration, Environmental Protection Agency, National Oceanic and Atmospheric Administration, U.S. Forest Service, Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and National Agricultural Statistical Service of the USDA. Using satellite imagery from the Landsat program, this research collaboration has produced geographic information systems raster data on land cover for the entire continental United States at a resolution of 30 by 30 square meters for the years 2001–2006. Of the 16 different types of land cover identified in the NLCD, there are three categories for forest cover: "deciduous," "evergreen," and "mixed forests." According to the NLCD, forests are "areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover." The distinction between the three types of forest cover depends on whether most of the trees in the 30-by-30 square meter parcel shed leaves seasonally. If at least 75 percent of the parcel is covered by trees that shed seasonally, it is designated deciduous. If at least 75 percent is covered by trees that hold onto their leaves annually, the parcel is designated evergreen. And if neither deciduous nor evergreen make up at least 75 percent, then the parcel is considered mixed forest.

Using the Zonal Tabulate tool in ArcGIS, we quantified and summed up the area covered by deciduous, evergreen, and mixed forest for all 1,423 counties in the southern United States. Yielding total forest cover at the county level, this procedure was done for both 2001 and 2006, giving a total sample size of $N = 2,846$ county-years. Next, to normalize the data, we log-transformed the values of the dependent variable; we discuss other reasons for the log-transformation in the Methods section.[6]

Independent Variables

There are two primary independent variables and several controls incorporated into the regression analysis. The data for these predictors come from several U.S. government sources. Controlling for total population size, the two primary independent variables are rural population size and urban population size. These variables are based on data from the U.S. census. "Total population" is the total number of people residing in a county; "urban population" is the number of people residing in census-defined urban areas, which include all incorporated places with at least 2,500 residents; and "rural population" includes all people not living in census-defined urban areas (for discussion about urban and rural designations see U.S. Census Bureau 2013). Rural and urban populations are counted in the decennial census. Thus, we linearly interpolated values for 2001 and 2006 using the 2000 and 2010 censuses. To normalize the data, we log transformed all three primary predictors. Last, we also created interaction terms between rural population size and a state-level dummy variable we use to examine whether the effect of the main variable varies across space.

[6] The type and quality of data used in this study are comparable to what have been used in previous cross-national analyses of the drivers of deforestation based on satellite imagery (DeFries et al. 2010; Rudel 2013). Here, we address three issues regarding the limitations of these satellite-based data. First, while cross-national data report forest cover change between 2000 and 2005, this study examines the period between 2001 and 2006. Future research would benefit from longer intervals of coverage. Second, deforestation data based on satellite imagery do not distinguish between managed and unmanaged forests. Consequently, as DeFries et al. (2010) acknowledge, these data may include changes due to tree plantation harvesting and regrowth, in addition to natural disasters, and they do not differentiate between primary and secondary forests as well as different species of trees apart from evergreen and deciduous (181). Third, in this study, we focus on land identified as forest based on the NLCD definitions, which excludes woody and herbaceous wetlands. As previously mentioned, this approach means we do not observe change in places like the Florida Everglades, an important yet vulnerable ecosystem. While we recognize these data limitations, we maintain their use for comparability with previous research; nevertheless, we also incorporate controls and other methodological strategies to address these limitations directly; for instance, in the spatial panel models, we include the percentage of the county covered by forests in 2001 as a control for floor-ceiling effects.

For theoretical and methodological reasons, the following eight control variables are incorporated into the analysis (in addition to total population size described above): number of farms, number of forestry operations, median household income, total payroll, percentage white, percentage elderly, percentage forest area in 2001, and a dummy variable for year. Data for these variables come from the U.S. census, the *Census of Agriculture*, and the USDA's Economic Research Service. We define specific variables as follows: Number of farms is the number of business operations that produce and sell at least $1,000 of agricultural products.[7] Number of forestry operations is the number of business establishments in a county that grow and harvest timber. These first two variables control for the organization of the local economy, as both agriculture and forestry are land-based activities that have been implicated in forest cover and social change in rural areas (Befort, Luloff, and Morrone 1988; Egan and Luloff 2000; Neumann et al. 2007; Perz 2001). Total payroll is to the total private nonfarm payroll in a county, which includes all forms of compensation, such as salaries, wages, and officer and executive pay, among other items. Based on growth machine theory (Molotch 1976) and treadmill of production theory (Schnaiberg 1980), median household income and total payroll control for the effects of residential affluence and the size of the local economy on forest cover. Percentage white is the percentage of the total population who identify their racial category as "white." Previous research has indicated that whites live in areas with more tree cover and nonwhites in areas with less tree cover (Harlan et al. 2008; Jesdale, Morello-Frosch, and Cushing 2013). Percentage elderly is the percentage of the population aged 65 years or older and controls for the potential effect of an aging population (Luloff and Krannich 2002), which includes the development of retirement communities and amenity migration (Egan and Luloff 2000; Gosnell and Abrams 2011). *All else equal*, these processes should contribute to deforestation. Percentage forest cover in 2001 is the percentage of the county's total area covered by forests in 2001; this predictor controls for the possibility of floor-ceiling effects (Firebaugh and Beck 1994); counties with a large area of forest cover have more to lose than counties with little forest cover, and vice versa. Last, the inclusion of a dummy variable for year incorporates a fixed effect for time (Allison 2009). With the exception of the dummy variable for year, all predictors have been log-transformed.

[7] Using data from the 1997, 2002, and 2007 *Censuses of Agriculture*, we linearly interpolated values for number of farms in 2001 and 2006.

Methods

Area of forest cover is regressed on the independent variables in four different models. Because the dependent variable and the predictors have all been logged, we interpreted the slope estimates from the regression models as elasticities, representing the percentage change in forest cover for every 1 percent change in the predictor, holding the rest of the equation constant. This procedure not only yields standardized (and thus comparable) estimates, but it also situates our study within the broader STIRPAT research program in sociology (Dietz and Jorgenson 2013; York and Rosa 2012). STIRPAT offers a basic regression model that can be used to evaluate competing theoretical frameworks on the systemic drivers of environmental change.

We estimated the slopes using a conventional panel model and a spatial panel model (Belotti, Hughes, and Mortari 2013; see also Lesage and Pace 2009), both with two-way fixed effects. In a spatial panel model, not only can we examine change over time while controlling for temporal autocorrelation, as with a conventional panel model (Allison 2009), but we can also incorporate additional controls for related issues with respect to space, which is a concern when using areal units of analysis (Anselin and Bera 1998). With this procedure, the regression model controls for spatial autocorrelation in the dependent variable for each time period. Without controls for spatial autocorrelation, regression analysis not only violates the assumption of independent observations but also runs the risk of producing deflated estimates for the standard errors, which could yield overly generous results for significance tests (Anselin 2002). For this study, we incorporated panel data into a spatial autoregressive model with spatial autoregressive disturbances, known as a SARAR or SAC (spatial autocorrelation) model. This form of spatial regression incorporates both a spatial lag and a spatial error term, which control for spatial clustering not only in the values of the dependent variable but also in the residuals (Anselin and Florax 1995).

With two-way fixed effects, the generic equation for this type of spatial panel model is as follows:

$$y_{it} = \alpha + \rho W y_{it} + x_{itk}\beta_k + \upsilon_{it}$$

$$\upsilon_{it} = \lambda W \upsilon_{it} + \varepsilon_{it}$$

The symbol α is the constant, y_{it} indicates the values of the dependent variable for the i^{th} case at time t, and x_{itk} indicates the value of the k^{th}

predictor for the i^{th} case at time t, with β_k representing the effect of the k^{th} predictor on the dependent variable. The spatial lag term ρ represents the weighted effect of the values of the dependent variable in neighboring units on the values of the dependent variable for the i^{th} case. This weighted effect ρ is based on the spatial weights matrix W. In our study, since county borders did not change between 2001 and 2006, W is the same for all t; it is a row-standardized, first-order queen contiguity spatial weights matrix, where the weight equals "1/# of neighbors" for any county that touches the i^{th} case and "0" otherwise. Thus, the spatial lag for the i^{th} county at time t is equal to the average forest area at time t for all of the counties that immediately border the i^{th} case. The error term υ_{it} is decomposed into two parts. The first part estimates the spatial error term λ, which is based on the same contiguity weights matrix W, and the second part ε_{it} represents all the leftover unobserved variation in the dependent variable. This estimation procedure was carried out in Stata using the command "xsmle" (Belotti et al. 2013).

Results and Discussion

Table 1 reports the summary statistics for the primary predictors and six controls for the two years of data (2001 and 2006) in addition to their change scores during this time interval. Because all variables have been logged, the change scores are measures of proportional change. For instance, the mean value for the change-score for forest area ($\bar{x} = -0.009$; $p < .001$) indicates that the average area covered by forest declined by nearly 1 percent between 2001 and 2006. With the exception of forest area, forestry operations, and percentage white, the change

Table 1. Summary Statistics (All Variables Log-Transformed).

	2001		2006		Δ 2001–2006
	Mean	SD	Mean	SD	
Forest area	4.621	1.641	4.612	1.634	–0.009***
Urban population	7.785	4.037	7.871	4.045	0.085***
Rural population	9.405	1.483	9.413	1.481	0.008**
Total population	10.262	1.228	10.289	1.263	0.027***
Number of farms	6.158	0.957	6.209	0.912	0.051***
Forestry operations	1.167	0.028	1.059	0.027	–0.108***
Median household income	10.507	0.239	10.510	0.244	0.003**
Total payroll	18.945	1.955	19.018	1.976	0.073***
Percentage white	4.353	0.279	4.348	0.278	–0.005***
Percentage elderly	2.615	0.274	2.643	0.258	0.027***

$N = 1{,}423$.
** $p < .01$; *** $p < .001$ (one-tailed paired t-tests).

scores for all variables are positive, indicating that their mean values increased during this time interval. Table 2 reports the results from the panel and spatial panel models both with two-way fixed effects. We discuss these results in four steps. First, we compare estimates from the panel and spatial panel models, focusing on significance levels. Second, we discuss the effects of urban and rural population size. Third, we examine variation in the effects of rural population size across space. Fourth, we briefly report results for control variables.

First, as previously noted, the area of forest cover is spatially autocorrelated at the county level. Thus, the estimates from a conventional panel model are unreliable because it assumes independent observations. Looking at the models in Table 2, we see evidence that spatial autocorrelation is affecting the results; indeed, the significance levels change when we control for spatial autocorrelation. Models 1 and 3 do *not* control for spatial autocorrelation; Models 2 and 4 do. Comparing Models 1 and 2, after controlling for spatial autocorrelation, the estimate for rural population size becomes more strongly significant, the estimate for population size is now only marginally significant, and the estimate for total payroll becomes significant. Comparing Models 3 and 4, we notice that the main effect of rural population size and the estimate for total payroll become significant whereas percentage elderly is no longer significant. In the spatial panel model, we also see that the interaction terms between rural population size and state become marginally significant and significant, respectively, for South Carolina and Virginia. While there are also differences in the magnitudes of the slope estimates, here we focus on their significance levels to emphasize the need to incorporate spatial controls into longitudinal regression analyses of environmental change.

Second, looking at Model 2, we discuss the estimates for urban and rural population size. While the former is positive but not significant, the latter is positive and significant ($b = 0.024$; $p < .01$).[8] For every 1 percent

[8] To address concerns of multicollinearity, we estimated variance inflation factors for three models: two cross-sectional ordinary least squares regression models (one for each time period, i.e., 2001 and 2006) and a first-difference, change-score ordinary least squares regression model with the same dependent variable and predictors. Because there are only two time periods, the results of the change-score model are identical to Model 1 (a panel model with two-way fixed effects) (Allison 2009). For all three models, the maximum and mean variance inflation factors were less than 10, which is below the threshold conventionally used to identify problems of multicollinearity. Thus, the nonsignificant effect of urban population size, in particular, is not due to an inflated standard error because of multicollinearity. Moreover, basing our work on Ehrhardt-Martinez (1998), we also tested for the presence of an environmental Kuznets curve in urban population size. In this supplemental analysis, neither the log-linear nor the quadratic term for urban population was significant.

Table 2. Results from Panel Models and Spatial Panel Models with Two-Way Fixed Effects, 2001–2006.

	Panel Model		Spatial Panel Model		Panel Model		Spatial Panel Model	
	Model 1		Model 2		Model 3		Model 4	
	b	SE	*b*	SE	*b*	SE	*b*	SE
Primary variables								
Urban population	–0.000	0.005	0.001	0.002	0.002	0.005	0.003	0.003
Rural population	0.035*	0.014	0.024**	0.007	0.032	0.033	0.039*	0.017
Rural population × state (Texas is the reference)								
Alabama	. . .	. . .	. . .	. . .	0.071	0.147	0.007	0.074
Arkansas	. . .	. . .	. . .	. . .	–0.006	0.141	–0.030	0.067
Delaware	. . .	. . .	. . .	. . .	–0.181	0.856	–0.057	0.428
Florida	. . .	. . .	. . .	. . .	0.017	0.054	–0.025	0.029
Georgia	. . .	. . .	. . .	. . .	0.191***	0.057	0.079**	0.028
Kentucky	. . .	. . .	. . .	. . .	0.072	0.104	0.034	0.053
Louisiana	. . .	. . .	. . .	. . .	0.400***	0.090	0.159***	0.045
Maryland	. . .	. . .	. . .	. . .	0.068	0.280	0.035	0.156
Mississippi	. . .	. . .	. . .	. . .	0.024	0.099	–0.014	0.049
North Carolina	. . .	. . .	. . .	. . .	–0.036	0.081	0.003	0.041
Oklahoma	. . .	. . .	. . .	. . .	0.105	0.117	0.038	0.055
South Carolina	. . .	. . .	. . .	. . .	0.184	0.145	0.148†	0.077
Tennessee	. . .	. . .	. . .	. . .	0.037	0.123	0.019	0.061
Virginia	. . .	. . .	. . .	. . .	–0.045	0.038	–0.048*	0.020
West Virginia	. . .	. . .	. . .	. . .	–0.029	0.149	–0.026	0.077
Controls								
Total population	–0.037*	0.018	–0.015†	0.008	–0.068**	0.020	–0.033**	0.009
Number of farms	0.002	0.004	0.001	0.002	0.002	0.004	0.000	0.002
Forestry operations	0.001	0.003	0.001	0.002	0.000	0.003	0.000	0.002
Median household income	0.003	0.030	0.018	0.014	0.012	0.030	0.021	0.014
Total payroll	–0.003	0.002	–0.003**	0.001	–0.003	0.002	–0.003**	0.001
Percentage white	0.204**	0.065	0.105**	0.031	0.177**	0.064	0.077*	0.032
Percentage elderly	–0.041†	0.023	–0.018†	0.011	–0.039†	0.023	–0.016	0.011
Percentage forest area (2001)	0.005***	0.001	0.001**	0.000	0.006***	0.001	0.001***	0.000
Year dummy (2006)	0.017***	0.004	0.004*	0.002	0.021***	0.004	0.006**	0.002
ρ	. . .	. . .	0.820***	0.018	. . .	. . .	0.805***	0.019
λ	. . .	. . .	–0.607***	0.048	. . .	. . .	–0.594***	0.049
R^2 within	0.074		0.081		0.105		0.121	
Counties	1423		1423		1423		1423	
Years	2		2		2		2	

N = 2,846 county-years.

Note: We estimated spatial panel models using a row-standardized, first-order queen contiguity weights matrix.

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

change in rural population size, the area of forest cover changes in the same direction by 0.024 percent. Controlling for total population, this result indicates that rural population size has an independent effect on forest cover but urban population size does not, and the effect of rural population size is not in the direction hypothesized by EMT. That is, the size of the rural population is positively associated with the area covered by forest. All the same, the nonsignificant effect of urban population size deviates from UPE's argument that urbanization raises consumption levels, which acts as a distal driver of deforestation (DeFries et al. 2010; Rudel 2013). The nonsignificant effect of urban population on forest cover (which does not change even after removing the variable for the number of farms) suggests that the effect of urban population at the local level is different than it is at the national level, even though we hypothesized that the mechanism is not contingent on scale. We discuss the implications of the positive estimate for rural population size in the conclusion.

Third, studies in spatial data analysis encourage researchers to explore whether the effect of an independent variable exhibits spatial heterogeneity, that is, whether the effect of a predictor varies across space (Fotheringham and Brunsdon 1999). Geographically weighted regression (GWR) (Fotheringham et al. 2002) is an exploratory tool that allows researchers to do this, and it has been employed by environmental social scientists who are examining whether the drivers of environmental change are spatially heterogeneous (e.g., Videras 2014). In our analysis, considering the significant slope estimate for rural population size in Model 2, we asked if its effect varies across the southern United States. To answer this question, we ran a GWR model using change scores for the same dependent variable and predictors; we present the results as a map in Figure 5, which displays variation in the direction and magnitude of the *t*-values for the slope coefficient for rural population size.[9] These results suggest that there is spatial heterogeneity in the effect of rural population size, with a strongly significant and positive effect clustered in and around Georgia. Based on the results from this exploratory tool, we further investigated the evidence for spatial heterogeneity, running a second spatial panel model with interaction terms between rural population size and state-level dummy variables, with Texas as the reference group. These results are presented in Model 4 and mostly support the findings from the GWR model, with a few differences. In Model 4, the positive coefficient of rural population size is still significant

[9] The spatial weighting matrix used for the GWR model is an inverse-distance, adaptive bandwidth (e.g., Videras 2014; see also Fotheringham et al. 2002).

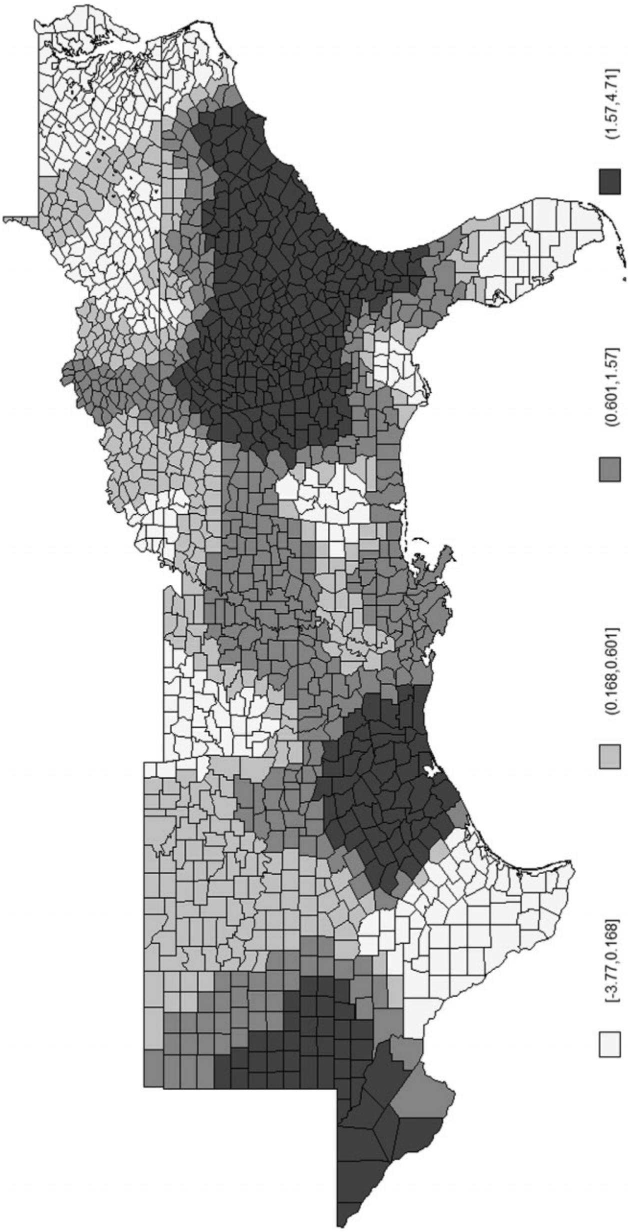

Figure 5. Map of T-Values for Rural Population Change from Geographically Weighted Regression (N = 1,423).

in and around Georgia but also in Louisiana, South Carolina, and Texas (the reference category). Also, while the spatial panel model suggests that rural population size in Virginia is negatively associated with forest cover, results from the GWR model do not provide corroborating evidence. (Note again that the conventional panel results in Model 2 show nonsignificant estimates for Texas, South Carolina, and Virginia.) Overall, the results from the GWR model and Model 4 suggest that the positive association between rural population size and forest cover is spatially heterogeneous, focused largely in and around Georgia. Nevertheless, considering that GWR is an exploratory tool, we present these results as motivation for future research to examine these findings in greater detail.

Last, we briefly report on the findings for the control variables. Based on the results from Model 2, only the estimates for total payroll and percentage white are significant ($p < .05$) and in the hypothesized direction. The negative coefficient for total payroll indicates that, as the size of the local economy grows, the amount of forest area declines, which is consistent with the treadmill of production theory (Schnaiberg 1980). The positive coefficient for percentage white supports previous work in environmental inequality, which has found that whites live in areas with more tree cover and nonwhites in areas with less tree cover (Harlan et al. 2008; Jesdale et al. 2013). In the results in Model 4, the estimate for total payroll and percentage white are still significant and the negative estimate for total population size becomes fully significant; the latter finding confirms research in STIRPAT and structural human ecology that emphasizes how overall population growth has a negative environmental impact (Dietz and Jorgenson 2013; Jorgenson and Clark 2011).

In summary, the conventional panel model and the spatial panel model yield different results; therefore, we broadly encourage researchers to consider issues of *both* temporal and spatial dependence in longitudinal research on the drivers of environmental change. Moreover, in terms of the effects of rural and urban population size on forest cover, the results from this local-level study present a picture that is different from the one presented in cross-national studies. In particular, urban population size has no effect on local forest cover whereas rural population size does, and this latter effect is in the direction opposite to what is hypothesized by EMT. That is, rural population growth at the county level is associated with afforestation, not deforestation. For local-level research, this finding also solicits a reevaluation of the way UPE has focused on urbanization as a distal driver of forest cover change. In the conclusion, we discuss these implications in greater detail and speculate on the reasons behind this unusual finding.

Conclusion

The above is an exploratory study to investigate the relative effects of rural and urban population size on forest cover at the local level in the southern United States. Even though we controlled for issues of *both* temporal and spatial dependence, we highlight the exploratory character of this study because previous sociological research on the systemic drivers of forest cover change mostly has been conducted at the national level. Nonetheless, as discussed above, the southern United States, compared to other census regions, contains vast areas of forest and large rural and urban populations; it also has experienced high rates of change not only in rural and urban population but also in forest loss and forest gain. For these reasons, the southern United States serves as an ideal context in which to carry out an exploratory analysis of rural and urban population as drivers of de- and afforestation at the local level.

In the conclusion, we highlight two general results from this study: the positive effect of and the spatially heterogeneous slope estimate for rural population size. We find that rural population size is positively associated with forest cover change in many areas of the southern United States, even controlling for a variety of other factors, including variables not always operationalized in national-level studies: the scale of primary production (i.e., the number of forestry and farming operations), size of the local economy, residential affluence, age structure, racial composition, and initial extent of forest cover. Thus, controlling for several potentially confounding predictors, we find that rural population size still has an independent effect on forest cover, and this effect is uniquely positive. Further, we note that the association between rural population growth and afforestation in the southern United States is spatially heterogeneous, and that this unique effect is most pronounced in and around Georgia.

On the one hand, the positive effect of rural population size and the nonsignificant effect of urbanization contrast with the claims made by EMT that rural living results in deforestation whereas city living contributes to afforestation. According to EMT, rural population growth is the reverse of modernization; it should *not* be associated with afforestation. On that note, the positive slope estimate for rural population size contradicts Mol's (2002:94) notion of permanency, or the assertion that ecological practices have become institutionalized in modern societies. According to Mol, a reflexive society would continue on a trajectory of modernization and environmental stewardship. Nevertheless, our findings suggest that this trajectory is not fixed and the ecological modernization process *can* be reversed. That is, at least in terms of forest cover in the southern United States, rural living, *not* urban living, contributes to environmental stewardship.

On the other hand, the findings from our study are compatible with an unexplored dimension of the UPE framework. *In terms of forest resources at the local level in the southern United States*, our study challenges the specific claim that cities are centers of growth that "require massive amounts of natural resources to sustain daily operations" (Jorgenson and Clark 2011:240). To be clear, this finding does not contradict research that points to urbanization as a distal driver of deforestation at the national level. Nevertheless, we still encourage future cross-national research to incorporate other measures to test more explicitly the mechanism through which urbanization puts greater pressure on forest resources. For instance, this literature has argued that urbanization drives up domestic food production even though many low-income nations, which are included in cross-national studies, are net food importers (Ng and Aksoy 2008; Rakotoarisoa et al. 2011; Rudel 2013). So if the food consumed by urban residents in one country is being produced in another country, then how exactly does urbanization contribute to domestic deforestation? Again, while the results of our study do not contradict cross-national research, we present our findings as an opportunity to illuminate the ways in which urbanization drives environmental change at multiple scales.

Meanwhile, at the local level, the positive association between rural population size and forest cover can be interpreted in different ways. We offer two potential interpretations here, the first of which more directly implicates the UPE framework. First, rural areas in the southern United States are characterized by a relatively slow socioecological metabolism. Again, this argument is the converse to UPE's focus on the amplified urban metabolism, that is, if urban areas raise consumption levels then rural areas depress them. The attenuating effect of rural population size is implied in growth machine and metabolic rift theories, which suggest that, *all else equal*, rural areas experience lower levels of human activity and present fewer opportunities to engage in commodified productive and consumptive activities. In environmental terms, rural living involves a slower socioecological metabolism and less natural resource use. In this study, however, there is no evidence that urban areas affect consumption of forest resources at the local level, which has not been the case for other environmental outcomes (e.g., use of fossil fuels). Nevertheless, previous research on other environmental outcomes has argued that urbanization at the local level is multidimensional, and the different dimensions have countervailing environmental impacts (Elliott and Clement 2014). Therefore, given the nonsignificant effect of urban population size in this study, future quantitative analyses of forest cover change might consider the different dimensions of urbanization (e.g., population size, density, and social organization) as separate independent variables.

Second, as we controlled for the initial extent of forest cover, the positive association between rural population size and forest cover could also mean that as the rural population declines so too does the area covered by forests. That is, many forests are located in rural areas with a variable number of residents; as fewer humans inhabit these rural areas, the opportunity to exploit forest resources grows. Although the UPE framework is less directly implicated here, this second interpretation is still compatible with UPE, particularly its focus on the unequal economic exchange across the rural-urban divide (Lobao et al. 2007), in which rural areas are treated as supply depots and repositories for urban society (Burns et al. 2003; Buttel and Flinn 1977; Lichter and Brown 2011). But in this case, it is not the size of the urban population that determines the degree of resource exploitation but the size of the rural population, which acts as a buffer to deforestation. This second interpretation does not necessarily imply anything about the consumptive and productive levels of rural or urban residents; it simply says that residents occupying rural land in certain areas of the southern United States will slow down deforestation.

Which of these two potential interpretations can help explain the human dimensions of forest cover change in the southern United States at the start of the twenty-first century? And is either sufficient? Additional research is needed to answer these questions. Indeed, to distinguish between and evaluate adequately these possible interpretations requires a methodological approach that can address details about the larger structural contexts that have shaped the relationship between changes in rural-urban population and forest cover in specific areas of the southern United States. Again, there is strong evidence that the positive effect of rural population size varies across space, with the most robust findings in and around Georgia. Why is the positive association most pronounced in that area? Future qualitative analyses can examine this question in greater detail. Until then, this exploratory study at the local level pursued two objectives: It evaluated competing hypotheses at the local level that have been tested mostly in cross-national research, and to do this, it addressed analytic issues of spatial and temporal dependence in quantitative research. On that note, while acknowledging the exploratory nature of this study, we hope future quantitative sociological work will consider both the substantive findings presented here (in terms of the positive and spatially heterogeneous effect of rural population size) and the benefits of a spatial panel model for longitudinal studies that examine the systemic drivers of environmental change.

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