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Evaluating the impact of government land use policies on tree canopy coverage

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ABSTRACT

Many cities around the world are experiencing the negative effects associated with not sustaining a sufficient level of tree canopy coverage. Tree canopy provides environmental benefits such as clean water and air, erosion prevention, climate control, and native species habitat and provides economic benefits such as higher housing values and lower energy expenditures. We study local government policies in a large U.S. metropolitan area (the Atlanta Metropolitan Statistical Area) to find which policies perform the best at preserving or increasing urban forests. Empirical analysis reveals that a set of effective tree ordinance clauses, zoning ordinances, and having high quality smart growth projects in the community all help in preserving tree canopy in economically and environmentally meaningful amounts. Other actions, such as simply having a tree ordinance, designating a key management person in charge of tree programs, the presence of a tree board, and multiple communication channels were shown to be ineffective for our data set. Because benefits from tree canopy accrue to the local government's budget, to residents and to business owners, the entire community should gain from the passage of effective policies to preserve their local tree canopy. Estimated economic benefits from preserving tree canopy through an effective set of public policies are in the range of $10–15 million annually in an average county, mostly due to savings on stormwater management.

Introduction

Many cities around the world are experiencing the negative effects associated with not sustaining a sufficient level of tree canopy coverage. Trees and tree canopy play a crucial role in the environment, providing benefits such as clean water and air, erosion prevention, climate control, and sustained ecological resources and native species habitat (cf., Taha, 1996; Scott et al., 1999). Additionally, trees and tree canopy play an economic role by increasing housing values, alleviating expenditures related to erosion destruction, decreasing spending on sewer standards, increasing energy efficiency, and reducing medical costs related to health issues, such as asthma, that are associated with environmental degradation (Georgia Forestry Commission, 2006; McPherson et al., 2005).

In Europe, where realizing the importance of urban forests has lagged a little behind the U.S., increasing urban forests is now a high priority in Belgium, Denmark, Ireland, The Netherlands, and the United Kingdom (Konijnendijk, 2003). Also, a new ethos is emerging in Europe where urban forests are expected to serve societal needs rather than just produce lumber (Wiersum, 1999). However, one should note that this study examines tree canopy preservation in an American urban/suburban setting.[1] This would include urban forests, but also would include trees in the yards of private homes which would fall outside the common European concept of urban forestry (Ireland and the U.K. do include private trees under some policies[2]). In urban settings, public trees and private trees often offset each other. Planning codes which pertain to public spaces reference zoning codes with site design requirements (cf. the authors' local Athens-Clarke County Planning Code, 2009). These cross references in code mean that public and private urban forest cover are highly intertwined and often one impacts the other (Zhu and Zhang, 2008). For these reasons we are interested in trees of all types – public trees and private trees, natural forests, planted forests, trees in private yards – and the effect of local government policies which preserve or encourage an increase in tree numbers and tree canopy.

To study which local government policies are the most successful in preserving tree canopy, an empirical study was performed using Greater Metropolitan Atlanta (the ninth largest metropolitan statistical area in the U.S., consisting of 28 counties each with

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[1] Transferring these results into policy recommendations in a European setting should be done very cautiously.
[2] We think a reviewer for alerting us to this fact.

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a government, over 21,000 km^2 and approximately 5 million people) as the study area. Atlanta has experienced explosive population growth: 27% from 1970 to 1980, 33% from 1980 to 1990, and 39% from 1990 to 2000 (CensusScope, 2006). The result of this population growth has been considerable land conversion, with a gain of 12 ha per day of impervious surface from 1991 to 2001. This land conversion was accompanied by significant loss of tree canopy[3] coverage, averaging a loss of 23 ha per day from 1991 to 2001 (Natural Resources Spatial Analysis Laboratory, 2007). These trends are troubling, given the environmental and economic benefits of tree canopy listed above.

A significant problem that may affect tree canopy loss is that many relatively rural counties in the Atlanta region are incurring high rates of population growth that they historically have not experienced. Excess housing demand has led homeowners to settle in neighboring counties where housing is both available and affordable. Although expanding land development due to population growth is inevitable, many of the urbanizing counties in which this growth is occurring face the same dilemma as metropolitan fringe counties all over the country: the need to address growth issues where the demand and/or resources to implement such practices previously did not exist (Daniels, 1999). For example, lenient land use policies such as low-density and single-use zoning, lack of impact fees on development, and minimum lot-size requirements are implemented in a number of counties in the Atlanta Metropolitan Statistical Area (Brookings, 2000; Giles et al., 1980; Heim, 2001). However, the complexity of administration through elected government officials, difficulty in changing administrative structures, and developer opposition to implementing more stringent standards are all challenges that impede county policy makers from instituting better conservation land use policies (Olsen, 2000).

In order for policy makers such as county commissioners to make the most efficient and effective policy choices, they must be supplied with information concerning both the benefits of tree canopy and the influence of policies that they can create to preserve it. An abundant amount of studies have examined the benefit of tree canopy (see Center for Urban Forestry Research, 2008, for a collection); however, to date, few studies have analyzed the influence of policies to preserve it.

Given this need, the central question of this study is: how much benefit does government intervention – through land use policies – have in reducing tree canopy loss (public and private combined) throughout the 28-county metropolitan Atlanta area? To answer this question, a variety of land use and tree protection policies are examined to see which can be empirically linked to the protection of tree canopy. The results of our empirical study should prove useful to policy makers and environmental advocates who wish to preserve tree canopy but need to know what policies are actually effective as opposed to those which look good on paper but do not actually produce results. Choosing better policies will be of benefit in the United States. In Europe, where very few cities outside of the United Kingdom and Ireland have comprehensive local urban forest policies, these recommendations could serve as the foundation for writing the first such policies (Konijnendijk, 1999).

Previous works on land use policies and practices in relation to tree canopy

Urban morphology, which can primarily be described by development patterns, local land use, and population density can have considerable effects on tree canopy coverage. A popular local government decision-making program created by CITYgreen (American Forests, 2002) delineates tree coverage into five categories for each land use category, including very light (0–5%), light (6–20%), medium (21–40%), heavy (41–60%), and covered (>60%). This is useful since different land uses often experience different degrees of development. For example, development patterns can have a huge effect on tree canopy coverage, with 1–2 family homes (31.4%), undeveloped land (44.5%), and parkland (47.6%) having the highest mean percent tree canopy coverage in urban areas, while land uses such as industrial (19.9%), and commercial (7.2%) are much lower. It can be inferred from this data that urban communities with a higher percentage of residential, undeveloped, or parkland will have higher levels of tree canopy coverage (Nowak et al., 1996). These findings are reflected in American Forests' goal standards for U.S. cities, which encourages cities to strive for a 40% average, but also has differing average percentage requirements for differing land uses, such as downtown and industrial area (15%), urban residential and light commercial areas (25%), and suburban areas (50%) (American Forests, 2002).

It is widely accepted that particular land use policies used by local governments have an effect on tree canopy coverage. Comprehensive plans, zoning ordinances, tree ordinances, subdivision regulations, and participation in tree programs are all instruments that can be used to help protect trees, and therefore improve tree canopy coverage (Coughlin et al., 1988; Gatrell and Jensen, 2002; Heynan and Lindsey, 2003; Nowak et al., 2002).

Communities may also implement tree ordinances, which in the U.S. context are local government policies which incorporate a variety of requirements and regulations in regards to sustaining trees on private lands. At a minimum, most tree ordinances establish a community tree board, encourage regular tree upkeep and maintenance, include a tree inventory, and implement rules regarding the preservation of a certain number and type of trees during development. More sophisticated ordinances have provisions such as requirements for private property care, establishment of penalties and fines for violations, regulation of disease and abatement, and educational requirements and programs (Elmendorf et al., 2003).

A multitude of studies have examined the relationship between tree ordinances and their effect on trees. Trieman (2004) conducted a study on 602 Missouri communities that attempted to capture the knowledge and strategies that were taken by local officials in regards to adopting and managing tree ordinances. Among its many conclusions, the study found that in the areas surveyed, many communities are reactive in caring for trees, do not have a sufficient budget, and often do not employ tree specialists. This is an issue considering that tree management, employee training and education, and financial assistance are crucial for the operation of successful tree protection policies (ODF, 2004). Other studies have been conducted concerning tree ordinance effectiveness. These include: Green et al. (1998) who researched funding, tree management, education and public awareness in smaller communities; Ricard (1994) who studied municipal needs for tree programs, officials' opinions concerning public tree value, support for community tree programs, and the need for technical assistance; Clark and Matheny's (1998) survey study on policies and practices that influenced municipal tree programs; and Allen (1995) studied municipal employees' opinions and attitudes towards urban forestry policies and programs. Olsen (2000) also discusses some of the challenges facing local government policy makers trying to improve land use policies; leading issues are found to be complex administration, rigid administrative structures, and developer opposition. These studies illustrate that issues are present for not only the existence and components of tree ordinances, but in the management, enforcement, and support of the ordinances by communities.

[3] We use the term tree canopy in most places in this article because our satellite-based data measured tree canopy, not tree numbers, and so while most policies are concerned with tree numbers, we measure impacts on canopy.

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Two studies of particular importance were conducted by Elmendorf et al. (2003) and Schroeder et al. (2003). Both took a comprehensive approach to surveying municipalities by combining questions concerning municipal employee attitudes and factual information that influenced the well-being of trees in both large and small communities. Elmendorf attempted to determine what trends in urban forestry practices, programs, and sustainability influence tree numbers and their prosperity. The study concluded that although ordinances do provide indirect influence, the factors that influence tree density and health are the levels of enforcement and management implemented by municipalities and communities. Specifically, time, energy, knowledge, support, politics, and municipal cooperation are correlated with ordinance success. Schroeder used a similar approach and concluded that inadequate tree policies exist in smaller communities which lack the knowledge, support, and funding to implement protective practices, in comparison to larger communities which are more likely to have educated tree care specialists, better tree care services, existing and well-specified tree ordinances, and a superior chance at receiving state and federal grants for tree protection. Also, expanding efforts to include private trees is crucial to success in preserving tree canopy, because that is where most of the trees are.

These studies provide some evidence on variables to investigate in our study. Overall, they show that simply passing policies is not sufficient to preserve tree canopy; instead a community must have the correct, effective policies and then must enforce them.

Study area

This analysis will use data for the 28-county Metropolitan Statistical Area (MSA) defined for metropolitan Atlanta, Georgia.[4] The 21,694 km^2 Atlanta MSA region accounts for 14% of the area in Georgia (150,000 km^2), and as of 2005, 4,917,717 inhabitants resided in the Atlanta MSA region, accounting for 54.20% of the state's population (9,072,576 inhabitants) (U.S. Census Bureau, 2005). The region has had extraordinarily high population growth, which has increased from 1,840,280 in 1970 to 4,917,717 in 2005 in the 28-county metropolitan area (Real Estate Center, 2005).

The high population growth rate in Atlanta is just one reason that this region is an ideal area for this study. Additionally, nearly all of the counties in the Atlanta MSA region lay within the Piedmont Uplands, with similar physiographic characteristics such as gently rolling hills, isolated mountains, presence of rivers and ravines, and mixed deciduous forests, which are predominated by oak–hickory–pine forests (Hodler and Schretter, 1986; GWW, 2000).[5] The physiographic consistency throughout the counties is useful to this study since, as noted by Heynan and Lindsey (2003), ecological and geological factors both directly and indirectly influence tree canopy sources, such as vegetation and population habitability, respectively. This characteristic of the Atlanta MSA region will aid in identifying land use policies that effect tree canopy coverage, since the effect from heterogeneous physiographic regions on tree canopy is minimized.

Expert survey for data collection

Data on some variables and policies of interest for this study were unavailable from secondary data sources. In order to collect this data, an online survey was created and administered to knowledgeable persons within Atlanta MSA counties and cities.[6] The survey design and implementation followed Dillman's Total Design Method (1978) and Tailored Design Method (2007) in order to maximize both the reliability of results and response rates. It was administered throughout the study area in September 2006. Prospective respondents were contacted via e-mail, using contact information collected through public sources and a database managed by the Georgia Forestry Commission. Recipients included arborists, urban planners, decision-makers, and other qualified recipients who potentially held a significant amount of knowledge in respects to planning and tree management in their community. If a recipient agreed to complete the internet survey, they were directed to the survey website.[7] The participant then received instructions that guided them to the community that they wished to evaluate. This process utilized a community hierarchy, beginning with the MSA region, from which the user could narrow down to a specific county, and if chosen, an incorporated city that they wished to evaluate.

Upon completing the survey, each participant received a thank you note for their time and a reminder that they were still eligible to complete surveys for other communities if they wished to do so. A follow-up reminder e-mail was sent to non-respondents two weeks later, and a second and final reminder e-mail was sent four weeks after the initial invitation. The questions asked in the survey were primarily created using findings from previous studies that suggested what policy and management factors may influence a community's percent change in tree canopy. Specifically, questions to account for a county's tree ordinance and its clauses, management, communication efforts, zoning, development regulations, and inhibitors to maintaining tree canopy were of main interest to this study. The survey was designed to address trees in both private and public landscapes. Note that due to the limited degrees of freedom created by the small sample size used in this study, as well as the desire to include all influential factors that held the promise of influencing tree canopy, some explanatory variable modifications and consolidations, such as indices, were used.

In all, 2380 people were invited to participate in this study's survey, 308 surveys were collected through internet and postal mail for a response rate of 12.94%. Of the returned surveys, 22 were either unusable or the participant asked to have it discarded, which resulted in a final sample size of 286 responses, or 12.02% of the initial sample population. This number is not surprising given the high level of knowledge required about community trees to complete this survey, which likely reduced the number of qualified survey participants. Usable responses were obtained for 22 out of the 28 counties in the Atlanta MSA, so our models will be confined to observations on those 22 counties. Only surveys returned for counties were used; responses specific to cities were saved for use in future work on cities.

To evaluate if this sample size is adequate, we use the following formula for the sample size necessary to achieve a desired degree

[4] Counties are the U.S. level of government one step below states, with counties containing cities which generally have their own government. Policies such as zoning and development approval are sometimes shared by cities and counties and sometimes split so that counties only control such decisions outside the city boundaries.

[5] Two counties lie partially in the Tennessee physiographic region, and one lies partially in the Southern region.

[6] Due to incongruity in the availability of data for cities within the MSA region, city results will be set aside for use in a future study.

[7] In the initial e-mail invitation, recipients were also given the option to request a paper survey to complete and return by mail. Those who so requested were sent a survey and a return mailing envelope with prepaid postage.

of accuracy:

$$Ns = \frac{(Np)(p)(1-p)}{(Np-1)(B/C)^2 + (p)(1-p)}$$

where *Ns* is the sample size needed, *Np* is the population size, *B* is the acceptable sampling error, *C* is the critical value, and *p* is the response percentage to a yes/no question. Our population *Np* is 2380; *B* will be set at ±5%; for a confidence level of 90%, *C* is 1.645; and *p* will be set as a 50/50 split.[8] This yields a needed sample size of *Ns* = 223 people. Given that we are able to use 286 responses, we should exceed the desired statistical precision (Dillman, 2007).

Data and variables used

The dependent variable used in this study was the change in percent of county land area covered in tree canopy from 1991 to 2001 (*canopy*). This data was provided by the Natural Resources Spatial Analysis Laboratory (NARSAL, 2007) at the University of Georgia. It is based on calibration of aerial photos with pixels of 1 m^2 and Landsat satellite images with pixels of 30 m^2. NARSAL used computer algorithms to compute the percent of tree canopy coverage in each pixel, allowing a computation of the change in tree canopy between the two years. In regards to classification error associated with the tree canopy data, the root mean square error (RMSE) is approximately .75–.85 for each model, which implies the classification of land cover is highly accurate.

A very important variable for the model is the change in impervious surface, *IS*. This is because impervious surface accounts for several types of land use, including parking lots, rooftops, roads, sidewalks, and other areas that are characterized by compacted materials such as concrete, asphalt and brick that water cannot pass through and trees cannot grow on (Lu and Weng, 2006). Data for this variable were derived from the same NARSAL land cover dataset as our dependent variable, again taking the percent change from 1991 to 2001. Given that these two variables were collected at the same time, on the same 30 m^2 pixel scales, and with the same collection methods, no additional discrepancies in positional accuracy are created by this spatial data (Lo and Yeung, 2002).

A weighted index of tree canopy given 2001 land use types (*landuse*) was used to illustrate the nature of the development pattern in each of the Atlanta MSA counties. As noted by Nowak et al. (1996), due to inherent differences between land use types, variation in tree canopy coverage is expected to exist for differing land use categories. In order to weight each of the land use types by the expected percent tree canopy, tree canopy goals set forth by American Forests were used. Their research indicates that communities east of the Mississippi should attempt to attain (or sustain) an overall tree canopy coverage of 40%, achieved for most communities through 15% coverage in downtown and industrial areas (light coverage), 25% in urban residential and commercial areas (medium coverage), and 50% in suburban residential areas (heavy coverage) (American Forests, 2002). These coverage goals offer a rough approximation of the development patterns that are associated with specific land use types, therefore making it possible to designate expected percent tree canopy weights to land use types considered in this study. In constructing a county-wide goal value that would serve to correct different tree canopy levels for each county's specific mix of land use types, these weights are multiplied by acreage in each land use category and then the sum was divided by the total acreage in each county, resulting in a value for each county ranging from zero to one. Mathematically, the *landuse* variable was:

$$Landuse = \frac{industrial\,(0.15) + commercial\,(0.25) + residential\,(0.5) + other\,(1.0)}{total\ county\ acres}$$

This value provided an estimate of the degree of difficulty counties face in regards to sustaining their existing tree canopy coverage, with values closer to one representing counties that should have less trouble sustaining tree canopy, given that a large majority of their land is undeveloped/sparsely developed land.

Another factor controlled for in this study is whether counties have managed to implement quality growth projects in their community (*ex*). In order to account for this, data on the number of exemplary local planning and quality growth projects were collected from data offered on the Georgia Department of Community Affairs' Georgia Quality Growth Partnership website.[9] Seven project characteristics are considered as demonstrating quality growth: infill development, cluster development, voluntary conservation subdivision design, creative design for higher density, riparian buffers, park creation and financing, and heat island mitigation. In addition, two other factors are considered to demonstrate quality growth in the community: an ordinance mandating conservation subdivision design and the presence of a local land trust.[10] In order to account for all of these practices, a simple index was created in which counties were awarded one point for each listing on the quality growth website in any of the above nine categories. Many counties have a score greater than nine on this index since they can have multiple examples of each characteristic or factor.

Tree management (*mgt*) is a binary variable that accounts for whether or not a county had either a manager or department whose responsibilities included overseeing the well-being of trees in the community. These responsibilities generally include tree welfare on all public lands plus often oversight of ordinances and consultations with property owners regarding regulations and best management practices for trees on private lands.

Communication (*comm*) was also considered an important factor when assessing tree canopy, since public support and input has been shown to have a positive effect on trees (Green et al., 1998). Therefore, our survey included a question asking whether or not the county had made an attempt to communicate to its citizens about trees through public events, educational programs, radio, television, printed material, or other mediums. The results from this multiple choice question were condensed using a composite index, which accounted for each individual communication medium used, with counties having the ability to score on a 0–6 scale, 6 meaning the county communicates to the community using all six possible mediums.

The effect of zoning on the percent change on tree canopy (*zoning*) was a bit problematic. Since zoning was partially accounted through the land use variable previously mentioned, a need to account for the direct effects of both planning and zoning was desired. This was done using two survey questions. Both were designed to give participants the opportunity to rate planning and

[8] Assuming a 50/50 split produces a conservative estimate of the needed sample size.

[9] The information can be found at http://www.georgiaplanning.com and http://www.georgiaqualitygrowth.com.

[10] Conservation subdivision design is a type of site engineering that leaves the average density of a project unchanged while concentrating all the building in a portion of the land involved (usually 40–60 percent of the project site) so as to preserve the remaining land in a natural state. Land trusts are a type of U.S. non-profit that hold legal easements on parcels to protect its undeveloped status in perpetuity.

zoning using a Likert scale of 1–10. The first question asked participants to rate the planning and zoning regulations in their county in terms of helping to promote quality growth, with 10 being the most effective. Second, participants were asked to rate the planning and zoning regulations in their county in terms of protecting and promoting tree canopies, with 10 being the most regulated. In order to gain a comprehensive view of both the effectiveness and regulation through planning and zoning in regards to tree quality, these two questions were combined into one regressor, with counties having the ability to attain a score on a 0–20 scale, with 20 signifying that the county's planning and zoning are designed to promote both effective quality growth and tree protection, both of which are hypothesized to positively influence tree canopy.

Development regulation (*develreg*) was based on a multiple choice question. Specifically, survey participants were asked if development in the county was unregulated, somewhat regulated, or heavily regulated. The subjective nature of this question may pose problems that could affect the validity and significance of this regressor. Although the same issue with subjectivity exists for the zoning questions included in this survey, less bias is expected due to both the larger scale and the dual explanation provided by these similar questions.

Finally, survey participants were asked whether any inhibitors (*inhibit*) existed that prevented the county from attaining their desired quality of tree management. These inhibitors included insufficient budget, insufficient staff and equipment, competing priorities, lack of public support and political will, and lack of community recognition concerning the importance of tree management. Such factors could affect either public or private trees, or both. The results from this multiple choice question were condensed using a composite index, which accounted for each inhibitor, with counties having the ability to score on a 0–7 scale, 7 meaning the community is inhibited by all of the problems presented in the question.

Information on a county's tree board (*board*) and ordinance establishment (*treeord*), as well as well as information on the clauses within a county's tree ordinances (*clauses*) were collected. The existences of a county tree board to deal with both public trees and tree ordinances that regulate and make policy related to private trees were recorded using binary dummy variables, with one implying the county has established a tree board or tree ordinance, zero otherwise. This information was collected from two ordinance reviews and two surveys. The first ordinance review was conducted for the survey at hand, using information given in county ordinances listed on Municode (Municipal Code Corporation, 2006). However, due to missing and/or outdated ordinances, questions were included in this study's survey to gather more up-to-date information on specific tree ordinances. Head's (2006) review of ordinances was also used to supplement any missing information. Of the possible clauses to include in a tree ordinance, nine were hypothesized to have a positive influence on tree canopy, including:

1. Establishment of tree banks or alternative compliance
2. Site requirements during development, such as specification of tree preservation areas, allowances on tree removal, landscape plans, or tree replacement
3. Requirement of a tree removal permit for previously developed private land
4. Requirement of a tree removal permit for new development
5. Buffer requirements for root zone protection during development
6. Adherence to protect exceptional trees during development (i.e. specimen and historic tree protection)
7. Allowance for tree unit credits or replacement fees of no less than 100% the costs of the tree removed
8. Requirement of street trees (i.e. street lining, minimum quantities, and species requirements)
9. Parking lot requirements (i.e. islands, trees per space, and percent of parking lot dedicated to tree requirements).

In order to include the effects from all of these factors, an index was created which assigned each clause one point for being included in a county's tree ordinance, and zero otherwise. Therefore, the possible values attainable by each county ranged from 0 to 9 for this regressor, 9 meaning all clauses were included, and 0 meaning none had been established (which in most cases implied that the county had not established a tree ordinance). One can see from the specific clauses covered, that these ordinances include public and private trees, probably with most of the focus on private trees.

Finally, given the drastically different makeup of each county's characteristics in the Atlanta MSA, consideration was given towards creating a variable to indicate the difference between the five core counties of the Atlanta MSA, which includes the counties of Cobb, Fulton, Gwinnett, Clayton, and DeKalb. However, within these five counties vast differences in policies and demographics exist, raising the question of whether or not it would be appropriate to dummy out all five of these counties, or instead to only dummy out some of them. To investigate this, the Euclidean distance between each county's vectors of explanatory variables was computed. The results from this procedure show that a minimal difference exists between the sum of the squared explanatory variables for Clayton and Cobb counties, but Fulton, Gwinnett, and DeKalb were considerably different. In order to account for this unique relationship, an indicator variable was created, with one indicating Clayton or Cobb County, zero otherwise (*CCdum*).

The model

To estimate the effect of local government policies on the preservation of tree canopy in the Greater Atlanta region, we estimated the linear regression model:

$$\begin{aligned}canopy_i \; &= \beta + treeord_i\beta_{treeord} + mgt_i\beta_{mgt} + pop_i\beta_{pop}\\ &+comm_i\beta_{comm} + IS_i\beta_{IS} + ex_i\beta_{ex} + inhibit_i\beta_{inhibit}\\ &+landuse_i\beta_{landuse} + clauses_i\beta_{clauses} + zoning_i\beta_{zoning}\\ &+board_i\beta_{board} + develreg_i\beta_{develreg} + CCdum_i\beta_{CCdum}\\ &+\varepsilon_i^{canopy}\end{aligned}$$

Table 1
Variable names and descriptions.

Variable	Description
Canopy	Change in the percent of tree canopy cover, 1991–2001
IS	Change in the percent impervious surface, 1991–2001
Landuse	Weighted index of land use types: residential (.50), commercial (.25), industrial (.15), other (1.0)
Pop	Change in the percent population, 1990–2000
ex	Index of the number of exemplary quality growth examples
mgt	County has established a tree care entity
comm	Index of mediums used by county to communicate about trees
Zoning	Index of quality growth and tree canopy efforts exhibited in zoning (0–20)
develreg	Degree of development regulation (none, somewhat, and significant regulation)
Inhibit	Index of inhibitors faced by a county that prevent meeting tree goals
Board	County has established a tree board
treeord	County has established a tree ordinance
Clauses	Index of tree preserving clauses in tree ordinance
CCdum	Dummy variable defining Cobb and Clayton County as one, otherwise zero.

Table 2
Summary statistics for variables in model.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Δ % tree canopy	28	−0.034	0.033	−0.121	0.029
Δ % impervious surface	28	0.021	0.021	0.001	0.078
Landuse	28	0.828	0.113	0.535	0.968
% Δ population	28	0.428	0.294	0.005	1.232
Quality growth examples	28	1.536	2.925	0.000	13.000
Management	28	0.393	0.497	0.000	1.000
Communicate	26	1.654	1.623	0.000	5.000
Zoning	22	11.206	2.849	3.500	16.000
Degree of regulation	22	2.405	0.359	2.000	3.000
Inhibitors	28	3.196	2.315	0.000	7.000
Tree board	28	0.179	0.390	0.000	1.000
Tree ordinance	28	0.571	0.504	0.000	1.000
Ordinance clauses	28	3.571	3.501	0.000	9.000
Cobb/Clayton dummy	28	0.071	0.262	0.000	1.000

where the variables are defined in Table 1, constructed as described in the previous section, and have their summary statistics displayed in Table 2. The β's are parameters to be estimated and the subscript i refers to the county, which is our level of observation.

Because of questions about endogeneity with regard to certain variables (that is, does a county appoint a person to manage tree issues because they are losing or have lost significant tree canopy?), the model was estimated by generalized method of moments using instruments to correct for endogeneity problems (Greene, 2008). The instruments used included data on population, percent of urban population, age, income, and college education levels in each county. Data on these variables were collected from the decennial 1990 and 2000 U.S. Census Bureau long-forms.

Empirical results and discussion

The GMM estimates of the above model are presented in Table 3. The R^2 of 0.80 is excellent for this type of cross-sectional data. Furthermore, nine out of fourteen explanatory variables are statistically significant, a pretty good percentage given the small number of degrees of freedom. Diagnostic tests indicate the model is well-specified and does not suffer from undue heteroscedasticity or multicollinearity. Endogeneity issues are handled through the use of GMM estimation. Select estimation results are discussed below. In the discussions, all references to gains (or losses) in tree canopy refer to increases in canopy coverage relative to the expected change without a particular policy or event; relative gains might lead to actual tree canopy changes over the time period that are positive or negative depending on what other factors, events, and policies in each county were over the study period.

Table 3
Tree canopy preservation model parameter estimates.

Variable	*B*	Standard Error	*z* score	Sig.
Constant	−0.1866	0.0371	−5.03	0.000
Tree ordinance	0.0037	0.0165	0.23	0.821
Management	−0.0565	0.0091	−6.2	0.000
% Δ population	0.0218	0.0136	1.61	0.108
Communicate	−0.0025	0.0021	−1.19	0.233
% Δ impervious surface	−1.5633	0.3883	−4.03	0.000
Quality growth examples	0.0058	0.0016	3.6	0.000
Inhibitors	0.0115	0.0026	4.34	0.000
Landuse	0.1200	0.0328	3.66	0.000
Ordinance clauses	0.0103	0.0028	3.74	0.000
Zoning	0.0026	0.0009	2.93	0.003
Tree board	−0.0089	0.0128	−0.7	0.486
Degree of regulation	−0.0137	0.0101	−1.36	0.175
Cobb/Clayton dummy	0.0864	0.0212	4.08	0.000
R^2 = .8015				

The coefficient on *IS* suggests that, holding all other factors equal, for every additional one percent increase in a county's land area covered by impervious surface from 1991 to 2001, it is expected to have lost tree canopy equal to 1.56 percent of county land area at the end of the time period. Detailed examination of the county-by-county ratio of impervious surface gain to tree canopy loss indicate that as urbanization increases, the ratio of tree canopy removed to gains in the impervious surface tends to decrease, moving towards a one-to-one ratio. One possible driver for this trend is that as population density increases, urbanized counties will experience more infill and smaller scale development, therefore resulting in less trees being removed than would be in large scale land development. Another reason that impervious surface is low relative to tree canopy loss in more rural counties is land speculation. Landowners will often cut down trees on their undeveloped land in order to prepare it for residential development. Therefore, during the transitional phase when land is no longer forested but has not yet been developed for residential purposes tree canopy loss can greatly exceed impervious surface gain.

The coefficient on *ex* shows that, holding all other factors constant, each additional exemplary quality growth example that a county reported led to a gain in tree canopy equal to 0.58 percent of the county land area during the period from 1991 to 2001. Therefore, if a county were to implement one of each of the nine examples considered in this study, they would experience a gain in tree canopy equal to 5.26 percent of the county land area relative to what the tree canopy would have been without those smart growth projects. Note that counties could have implemented more than one quality growth example, such as in the case of Fulton County, which implemented 13 examples, which implies that they experienced a relative gain in tree canopy equal to 7.60 percent of the county land area during the decade.

The coefficient on *mgt* indicates that if a county establishes a department and/or person who is responsible for the management of a county's trees, the county is expected to lose tree canopy equal to 5.65 percent of the county land area during the ten year period over and above the change had they not established a management entity during that time. This result is surprising, since it was expected that management would have a positive effect on tree canopy coverage. Perhaps the data on *mgt* fails to capture whether a real priority is put on preserving and promoting trees versus simply designating a person or agency to be "in charge."

The coefficient on *zoning* implies that each additional point gained on the composite scale of 0–20 used to measure a county's emphasis on quality growth and tree canopy protection led the county to gain tree canopy equal to 0.26 percent of the county's

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land area during the period from 1991 to 2001 over the change in tree canopy. This implies that if a county were to score all 20 points, it could expect to gain tree canopy equal to 5.14 percent of the county land over ten years. This is an unlikely situation; however, given that the mean value for a county's zoning score was 11.2, it is not improbable for a county to raise its score by five points, which would lead to an expected gain in tree canopy equal to 1.29 percent of the county land area during the decade.

The results for *inhibit* illustrate that, holding all else constant, each additional factor that inhibits a county from successful tree management leads to a gain in tree canopy equal to 1.15 percent of the county land at the end of the period from 1991 to 2001 compared to the change if they did not face the inhibitor. If a county faces all seven of the inhibitors accounted for in this study, it suggests that a county would expect a gain in tree canopy equal to 8.02 percent of the county land at the end of the ten year period. One explanation for the sign on this coefficient is that broadly speaking, *inhibit* reflects the need for resources and support to protect trees in a county. Therefore, it makes sense that in order for counties to feel they are facing inhibitors, they must be making an effort to acquire resources and support to protect trees in the county. That is, if you do not care about saving or gaining trees, you do not face any inhibitors.

The coefficient on *clauses* suggests that, with all other factors constant, each ordinance clause added to a tree ordinance leads to an expected 1.03 percent increase in county land area covered with tree canopy at the end of the ten years. This means that if a county were to enact all nine of the clauses included in this study, it would have an expected 9.25 percent increase in land covered with tree canopy at the end of the ten year period. This result is quite interesting, given that the act of establishing a tree ordinance is not significant in itself (its coefficient is statistically insignificant). It is the clauses within the tree ordinance that can significantly influence the change in the percent of tree canopy covering land in the county. Therefore, having an ordinance that is robust with meaningful clauses is essential in the establishment of policies to alleviate the loss of tree canopy; compromising on content in order to get an ordinance passed would be self-defeating according to our model results.

Potential economic benefits of local government policies

In order to determine the economic implications for counties associated with sustaining tree canopy cover, avoided costs for stormwater management, health benefits from air quality improvements, and decreased summer energy savings were considered. To do this, consider an imaginary county with land area equal to the average for an Atlanta MSA County, 81,034 ha. Then several policy scenarios were envisioned in order to demonstrate the magnitude of economic net benefits that might be captured such a county and its residents through those tree-friendly policies.

The avoided costs or societal benefits are valued on a per hectare basis, using earlier studies on the economic value of trees (American Forests, 2002; McPherson et al., 2005). Existing estimates suggest an average of $19.81 in terms of energy savings and approximately $590 in terms health benefits from improved air quality for each hectare of tree canopy.[11] These benefits go to individuals and to local governments to the extent that they subsidize health expenses of their residents. Direct benefits to the county primarily appear in the form of avoided costs associated with stormwater management. Based on a 1996 study created by American Forests for the City of Atlanta, each hectare of tree canopy provides $14,464 savings from reduced stormwater runoff. This, however, is also a function of factors such as a county's existing impervious surface, which is six times greater in the City of Atlanta than in an average county; therefore, $2,411, which is one-sixth of the estimated savings per hectare associated with stormwater runoff in the City of Atlanta, will be used as a conservative estimate for the benefit that tree canopy provides to our imaginary county.[12]

Using the above values to make concrete the potential economic impact of local tree-related policies, we consider several policy change scenarios. First, consider an example in which the imaginary county establishes a tree ordinance containing five meaningful clauses. Since each tree ordinance clause is expected to lead to a 1.03 percent increase in county land covered with tree canopy over ten years, it is expected that five tree ordinance clauses will lead to a 5.15 percent increase in county land covered with tree canopy. This implies that by establishing five ordinance clauses, the imaginary county would annually gain $82,606 in energy savings, $2,472,000 in air quality benefits, and $10,052,800 in stormwater management savings, for a total of $12,607,406. These savings would be shared among residents, businesses, and the local governments.

Consider another example of the benefits from implementing land use policies in which counties improved their score on *zoning* by five points. Recall that each additional zoning point leads to a 0.26 percent increase in tree canopy covering land within the county, or a 1.3 percent increase in tree canopy total. This implies that by gaining the five zoning points, the imaginary county could annually gain $19,248 in energy savings, $576,000 in air quality benefits, and $2,342,400 in stormwater management savings, for a total savings of $2,937,648. Overall, if a county were to enact five meaningful tree ordinance clauses and gain five zoning points, the average county in the Atlanta MSA could have been saving approximately $15,545,054 annually in 2001 compared to if it had not enacted these land use policies.

Conclusions

The analysis of data from the greater Metro Atlanta area on local government policies clearly shows that some local government policies are effective in preserving tree canopy coverage. However, not all policies are effective, so governments should choose the most beneficial policies if they wish to have the largest impact on tree canopy protection. In particular, the most effective policies in protecting tree canopy were found to be: a set of tree ordinance clauses, zoning ordinances, and having high quality smart growth projects in the community. These policies produced effects that were both statistically significant and of a sufficient magnitude to have meaningful environmental impacts. Other policies, such as simply having a tree ordinance, designating a key management person in charge of tree programs, the presence of a tree board, and multiple communication channels were shown to be ineffective for our data set.

These findings should encourage local governments to focus on effective policies, leading to positive trends in tree canopy protection. The economic impact of effective policies is not trivial, with possible benefits on the order of $10–15 million per year for an average-sized county. Because benefits from tree canopy accrue to both the local government's budget and its res-

[11] These values were created using energy savings estimates proposed by American Forest for the City of Atlanta and air pollution savings calculated using the U.S. Forest Service's Effects of Urban Forests and their Management on Human Health and Environmental Quality Pollution Program.

[12] The average of the ratios of impervious surface in the City of Atlanta to the average county was taken for 1991 (7.32 times greater) and 2001 (4.95 times greater) in creating this number.

idents and business owners, the entire community should gain from the passage of effective policies to preserve their local tree canopy.

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