Maryland's Forest Conservation Act and the Impact on Residential Development and Forest Cover Change

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Abstract
We analyze the effects of a unique forest conservation regulation on residential development and assess the additionality in forest cover due to this regulation. We combine panel data on forest cover change from satellite imagery and parcel-level modeling on residential development, including residential subdivisions occurring before and after regulation adoption. Our results indicate that after introducing the regulation, there was a 22% increase in forest cover within subdivisions relative to the amount without the regulation. The heterogeneous effects of this regulation suggest that forest cover increased on average for parcels with lower levels of existing forest cover. However, parcels with the highest levels of forest cover continue to have significant decreases in forest cover, despite the regulation, thereby resulting in fragmentation in regions with the most intact forest cover.

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JEL codes: Q24, R14, R52

Forest cover provides ecosystem services that are not fully considered in private landowner decisions. Substantial work has analyzed the targeting of voluntary incentive payments for rural landowners to encourage forest cover and the provision of ecosystem services (e.g., Nelson et al. 2008; Lewis, Plantinga and Wu 2009; Lewis et al. 2011; Lawler et al. 2014). The incentive-based policies in these studies have incorporated important aspects into targeting payments such as the incomplete information on landowner opportunity costs and nonlinear forest benefits for habitat preservation. Other research has focused on land-use regulatory policies using parcel-level models of residential land development to examine the effects of regulations such as clustering requirements (e.g., Irwin and Bockstael 2004), zoning (e.g., Newburn and Berck 2006; Lewis, Provencher, and Butsic 2009; Butsic, Lewis, and Ludwig 2011), and permitting (e.g., Wrenn and Irwin 2014). Meanwhile, the effect of forest conservation regulations on residential development has received less attention. An exception is Lichtenberg, Tra, and Hardie (2007) and Lichtenberg and Hardie (2007) who assess how the Forest Conservation Act (FCA) in Maryland influences residential density and open space provision within subdivisions. They find that forest conservation requirements crowd out public non-forested open space and reduce residential density. Their analysis, however, relies only on parcels already converted to subdivision after the FCA regulation was adopted rather than analyze the effect of FCA regulations on the dynamic process of residential land conversion.

The purpose of this study is to analyze the heterogeneous effect of the FCA regulation on residential development and estimate the additionality in forest cover due to this regulation. We use a spatially explicit panel dataset of residential subdivisions during

1985-2000 in Baltimore County, Maryland. The econometric model is a panel Heckman selection model with two stages that are jointly estimated. The first stage is a panel probit model of the landowner decision to develop or remain undeveloped. In the second stage, we estimate the change in the percentage of forest cover on the property, conditional on development in the first stage. The FCA regulation was adopted in 1993 allowing us to model landowner development decisions during the periods before (1985-1992) and after (1993-2000) FCA implementation. Land-use decisions are assumed to be a function of the existing forest cover, zoning, distance to Baltimore City, riparian buffer area, slope, and other parcel attributes. To characterize parcel-level forest cover change, we utilize satellite-based data from the North American Forest Dynamics Project measuring forest cover on roughly a biennial basis between 1985 and 2004.

Our analysis yields several main results. Prior to the FCA regulation, forest cover decreased following residential development across the entire distribution of existing forest cover values. After the FCA regulation, forest cover increased on average for developed parcels with lower levels of existing forest cover between 0-60%. However, parcels with the highest levels of existing forest cover have significant decreases in forest cover even after the FCA regulation, suggesting that parcels with the most intact forest cover continue to have habitat fragmentation. Overall, there is an expected increase in total forest cover of approximately 22% on residential subdivisions with the FCA regulation relative to what would have occurred without the regulation, according to landscape-level simulation analysis in the region.

This research makes several contributions to the literature. This is the first study, to our knowledge, that combines analyses of fine-scale panel data on forest cover change from satellite imagery and spatially explicit parcel-level modeling on residential development decisions. By using historical forest cover data, we are able to better represent the variation in initial levels of existing forest cover that occurs within landowner parcel boundaries. Importantly, we are able to more accurately assess the partial loss in forest cover that, even prior to the FCA regulation, occurs on subdivision developments. Forest land converted to urban development in prior studies is often implicitly assumed to result in a complete loss of forest, thus, overestimating the environmental damages from development. In our study, we empirically estimate forest cover change with data from satellite imagery rather than rely on assumptions for the relationship between urban development and forest cover loss. Furthermore, since our analysis spans periods before and after the FCA regulation, this allows us to provide baseline estimates of forest loss in the pre-regulatory period in order to estimate the level of additionality in forest cover that is achieved with regulation adoption. The FCA regulation in Maryland is the only statewide forest conservation regulation in the United States that focuses on forest retention and replanting requirements within residential subdivisions. Our analysis suggests that the implementation of the FCA regulation provided an increase in the level of forest area and could provide guidance to other regions interested in implementing similar policies to promote forest conservation in areas threatened by residential development.

The remainder of this paper is laid out as follows. In the next section, we provide a brief background on the Forest Conservation Act in Maryland. Next, we outline the econometric approach based on the panel Heckman selection model for residential development and forest cover change, followed by a description of the data used. We then present the empirical results and provide several robustness checks including temporal falsification of the regulatory event. We conclude with landscape-level simulations and summary remarks on the main findings and implications for forest conservation regulation.

Background on Maryland's Forest Conservation Act

Forest cover loss is a major concern for states, such as Maryland, that have experienced rapid urban development. For instance, there was a loss of over 300,000 acres of forest land in Maryland during the period from 1964 to 1986, representing approximately a 13% loss in total forest cover (US Forest Service Northern Research Station 2002. Meeting goals for water quality improvements in local streams and the Chesapeake Bay has increased attention on the importance of maintaining and restoring forested areas. Priority areas for forest protection and restoration include environmentally sensitive areas, such as riparian buffers, 100-year floodplains, steep slopes and critical habitat.

The Forest Conservation Act (FCA) was passed as a statewide law by the Maryland legislature in late 1991 and implemented locally by county and municipal governments in 1993. Starting in January 1993, the law applies to any subdivision development with grading over 40,000 square feet (approximately one acre) and is designed to reduce forest loss following property development. Prior to development, a landowner completes a forest conservation plan (FCP) that specifies the forest conservation requirement on the property, including a plan for retaining existing forest cover and new tree plantings (Galvin, Wilson and Honeczy 2000).[1] The FCP must be approved by county planning agencies as part of the overall subdivision approval process for land use and environmental permitting. The county planning agencies must comply with state mandated requirements under the FCA regulations.

Thresholds for afforestation and conservation under the FCA regulations are determined based on the existing forest cover and the prevailing zoning. The afforestation threshold is twenty percent in rural regions zoned for either agricultural and resource areas or medium residential areas. For parcels with less than twenty percent existing forest cover, the landowner must plant new trees up to the afforestation threshold, even if no trees are cleared in the process of development. The conservation threshold is fifty percent in rural regions zoned for agricultural and resource areas and twenty-five percent when zoned for medium residential areas. In order to avoid replanting requirements entirely, a landowner must retain at least twenty percent of existing forest cover above the conservation threshold, which is referred to as the break-even point. Forest land cleared below the break-even point but above the conservation threshold must be replanted at one-fourth the rate of the amount cleared. Forest land cleared below the conservation threshold must be replanted at twice the rate of the amount cleared.[2] Prior to the adoption of FCA regulations, there were no afforestation or conservation thresholds for the entire region.

Econometric Model

In this section, we develop a panel Heckman selection model to estimate the effect of the FCA regulation on land development and forest cover change decisions. The landowner is assumed to be a profit-maximizing agent who decides either to develop parcel i or remain undeveloped in each period t. Conditional on a parcel being selected for development, the landowner determines forest cover change on the parcel after subdivision. A positive level of forest cover change indicates a net gain in forest area while a negative forest cover change indicates a decrease in forest area. We use a bivariate sample selection model because land development and forest cover change decisions may be correlated (Heckman 1979). For the first stage, let Y_{it}^* represent the unobserved latent variable on the value from residential development for the landowner on parcel i in period t net the value from remaining undeveloped in the existing use. Conditional on a parcel being undeveloped, parcel i develops in period t if $Y_{it}^* > 0$, and conversion decisions are assumed to be irreversible. Let Y_{it} be a binary variable to indicate when a parcel develops such that

(1) $$Y_{it} = 1 \quad if \ Y_{it}^* > 0, \quad Y_{it} = 0 \quad if \ Y_{it}^* \leq 0 \ .$$

In the first stage, a panel probit model is used to estimate land development decisions as a function of a number of observable parcel attributes. We expect the effect of the FCA on land development decisions to vary based primarily on the parcel-level existing forest cover. Due to the afforestation and conservation thresholds under the FCA requirements described above, we expect the effect of the FCA to vary nonlinearly over the distribution of existing percent forest cover. Therefore, we use categorical ranges of existing percent forest cover to allow flexibility in the model specification to represent the potential nonlinear relationship between land use decisions and the existing percent forest cover. Let F_{it} be a vector of existing forest categories grouped into quintile values (i.e., 0-20%, 20-40%, 40-60%, 60-80%, 80-100%), with the lowest quintile of 0-20% existing forest cover as the baseline category. Let τ be a post-regulatory dummy variable equal to one for any period after the introduction of the FCA regulation in 1993. We also include interactions terms between the forest cover categories F_{it} and the post-regulatory dummy variable τ to estimate whether the effect of existing forest cover in the period after the FCA regulation changes relative to the baseline period prior to the FCA regulation. Let X_{it} represent a vector of control variables, such as distance to major roads, riparian buffer area, slope, and other parcel attributes. Let Z_{it} represent a vector of exclusion restrictions included in the first stage model but omitted from the second stage in the Heckman selection model. Let T_t represent annual time dummy variables, where a single year is omitted from each period before and after the FCA regulation for identification. Equation 2 shows the specification for the first stage panel probit model for the probability of development where the error term ε_{it} is an independently and identically distributed standard normal random variable but clustered at the parcel level

(2) $$Y_{it}^{*} = F_{it}\beta_1 + \tau\beta_2 + \tau F_{it}\beta_3 + X_{it}\beta_4 + Z_{it}\beta_5 + T_t\beta_6 + \varepsilon_{it} \ .$$

In the second stage, we estimate the percent forest cover change after development, represented by the variable ΔF_{it}. It should be noted that we only observe forest cover change for parcels actually selected for development. Let ΔF_{it}^{*} represent a latent variable of forest cover change, such that the forest cover change is observed as $\Delta F_{it} = \Delta F_{it}^{*}$ when parcel *i* is developed in period *t*, $Y_{it}^{*} > 0$, and otherwise it is not considered. Equation 3 shows the specification for forest cover change which is similar to Equation 2 except we drop the exclusion restriction Z_{it} from the second stage for identification purposes

(3) $$\Delta F_{it}^{*} = F_{it}\gamma_1 + \tau\gamma_2 + \tau F_{it}\gamma_3 + X_{it}\gamma_4 + T_t\gamma_5 + \mu_{it} \ .$$

The land development and forest cover change decisions in Equations 2 and 3 are estimated simultaneously using a full information maximum likelihood (FIML) approach. We assume that errors are correlated between Equations 2 and 3 which are jointly and normally distributed

(4) $$\begin{bmatrix} \varepsilon_{it} \\ \mu_{it} \end{bmatrix} = N\left(\begin{matrix} 0 \\ 0 \end{matrix}, \begin{bmatrix} 1 & \rho \\ & \sigma^2 \end{bmatrix} \right) .$$

The correlation coefficient between the first and second stage is represented by the parameter ρ. Parcels may be selected for development based upon their expected forest clearing costs. If ρ is significant, then ignoring the correlation between these two land use decisions would result in inconsistent parameter estimates. A positive correlation coefficient would imply that, controlling for observed parcel attributes, parcels selected for development have higher levels of forest cover change than would occur on undeveloped parcels if they were developed.

We calculate the marginal effects of covariates on the probability of development in first stage and forest cover change in the second stage. Let $\Omega_{it} = \{F_{it}, X_{it}, Z_{it}, \tau, T_t\}$ be a vector of covariates included in Equations 2 and 3 and let $\omega_{it}^{k} \in \Omega_{it}$ be the covariate *k* for subsequent marginal effects. For the first stage, the marginal effects of the covariate ω_{it}^{k} on the annual probability of development is calculated as

(5) $$\frac{\partial \Pr\left[Y_{it} = 1 \mid \Omega_{it}\right]}{\partial \omega_{it}^{k}} = \frac{\partial \Phi\left[\Omega_{it}\beta\right]}{\partial \omega_{it}^{k}} \ .$$

As noted in Ai and Norton (2003), coefficients need not have either the same sign or significance as marginal effects for interaction terms in nonlinear models, such as the interaction term on τF in our case. For this reason, we emphasize the interpretation of statistical significance based on the marginal effects in Equation 5 rather the coefficient estimates in Equation 2. Marginal effects of covariates on forest cover change decisions are represented in Equation 6 and are calculated conditional on a parcel being selected for development

(6) $$\frac{\partial E\left[\Delta F_{it} \mid Y_{it}=1,\Omega_{it}\right]}{\partial \omega_{it}^{k}} = \gamma_k - \rho\left(\frac{\phi\left[\Omega_{it}\beta\right]}{\Phi\left[\Omega_{it}\beta\right]}\right)\left(\Omega_{it}\beta + \frac{\phi\left[\Omega_{it}\beta\right]}{\Phi\left[\Omega_{it}\beta\right]}\right) .$$

Marginal effects in Equation 6 account for the direct effect of the covariate *k* on the forest cover change decision, represented by the coefficient γ_k, as well as an indirect effect on which parcels are selected for development.

To assess the potential effect of the FCA, we compute the expected forest cover change conditional on development for the periods before and after the FCA regulation

(7) $$E\left[\Delta F_{it} \mid Y_{it}=1,\tau=1,\Omega_{it}\right] - E\left[\Delta F_{it} \mid Y_{it}=1,\tau=0,\Omega_{it}\right] .$$

In general, we expect an increase forest cover change on subdivisions after relative to before the FCA regulation. We calculate the forest cover change in Equation 7 separately for each existing forest cover quintile to examine whether there is heterogeneity in the potential effect of the FCA by the existing forest cover categories. In addition to the change in the FCA regulation, we recognize that there are other factors potentially influencing land use decisions that may change over time and will discuss these potential effects and robustness tests in the Results section. These robustness tests includes alternative specifications that use a more narrow time window of subdivision activity in 1988-1997, temporal falsification tests that only use either the pre-FCA data or post-FCA data and move the regulation event to an arbitrary time within those time periods, and sensitivity tests to the specification using quintile categories on existing forest cover by further examining the model specification using decile categories.

Data

Baltimore County is located adjacent to the City of Baltimore, and the majority of residents commute to work in the county or Baltimore City (see figure A1 in the Appendix). Land-use decisions that disturb forest cover affect water quality in local waterways and the Chesapeake Bay. Furthermore, the rural area in Baltimore County has three large reservoirs that provide the regional drinking water supply for over 1.8 million residents in the Baltimore Metropolitan Region. An urban growth boundary (UGB) was implemented in Baltimore County in 1967, also referred to as the urban-rural demarcation line (URDL). An UGB is designed to reduce development and conserve agricultural and forested areas in rural areas by restricting municipal sewer and water access exclusively to parcels located within the UGB. Although the UGB may limit higher density development on sewer service, it does not prevent lower density residential development in rural areas where subdivisions are instead served by individual private septic systems and groundwater wells. Despite the efforts of smart growth policies, the majority of acreage developed in Maryland occurs as low density residential development on septic systems in rural areas.

Our study region focuses on the rural area located outside the UGB to understand the effect of the FCA regulation on residential development and forest cover change in this region with the majority of forest area and land conversion. This rural area covers 387 square miles, which is approximately two-thirds of the county land area. The resource conservation (RC) zoning was created in the rural area in 1976 and includes three main zoning types (figure A1). RC2 zoning for agricultural preservation covers the majority of the rural area and designated the minimum lot size zoning at 50 acres per housing unit. RC4 zoning was created for watershed protection and designated the minimum lot size zoning at 5 acres per housing unit. RC5 zoning was created to allow rural residential development and has minimum lot size zoning at 2 acres per housing unit. Minor subdivisions with two lots are also allowed in RC2 zoning for a parcel with 2 to 100 acres and allowed in RC4 zoning for a parcel with 6 to 10 acres. RC2 and RC4 zoning are considered agricultural and resource areas under the FCA regulations outlined above. Hence, these two zoning types, representing the majority of land area, have a conservation threshold of fifty percent. RC5 zoning is considered as medium residential area and thus has a conservation threshold of twenty-five percent. All three zoning types have an afforestation threshold of twenty percent.

Data used to estimate the residential land-use conversion model in Baltimore County rely on spatially explicit parcel data from the Maryland Department of Planning. We manually reconstruct the panel of residential subdivisions using historic archives for all recorded plats from 1985 to 2000. The historic plat maps provide the year of subdivision for the timing of the residential conversion events. By identifying all those parcels in the same subdivision, we determine the original “parent” parcel and, thus, reconstruct the landscape for parcel boundaries in 1985. For the land-use conversion model, we determine all developable parcels that as of 1985 were eligible for residential development in the RC zoning area with more than five acres and could subdivide into two or more buildable residential lots.[3] There were a total of 3,388 developable parcels starting in 1985, of which there were 427 residential subdivisions that occurred during 1985-2000. This includes 240 subdivisions in 1985-1992 prior to the adoption of the FCA regulation and 187 subdivisions in 1993-2000 after the FCA regulation.

Forest cover data are obtained from the North American Forest Dynamics Project, a NASA funded project under the North American Carbon Program (NACP) (Goward et al. 2008; Goward et al. 2012). The NACP collects detailed forest cover data starting in 1984 for 55 selected locations across the United States, including the Baltimore-Washington corridor, based on Landsat satellite imagery at approximately 30-meter resolution. The Vegetation Change Tracker (VCT) algorithm, developed by Huang et al. (2010), is applied to Landsat imagery on an annual to biennial basis to provide forest cover maps, which are used to determine the timing and spatial distribution of deforestation, reforestation, and afforestation. For the Baltimore-Washington corridor, the existing forest cover maps are available as raster files for 12 different time periods including the following years: 1984, 1986, 1987, 1988, 1990, 1991, 1994, 1996, 1998, 2000, 2002, and 2004. We intersect these 12 snapshots of forest cover with the parcel boundary layer to create variables for the percentage of existing forest cover on each parcel, calculated as the amount of existing forest cover divided by the total parcel area. The Landsat imagery used by the NACP did not cover a portion of northern Baltimore County (11% of the county area), and this area was thus excluded from the analysis.

Forest cover change is calculated as the difference between the percent forest cover after development and percent existing forest cover prior to development. For parcels developed in 1985-1992, forest cover change is calculated as the difference between percent forest cover in 1996 and existing percent forest cover prior to development. For parcels developed in 1993-2000, forest cover change is calculated as the difference between percent forest cover in 2004 and existing forest cover prior to development. For example, a subdivision event occurring in 1989 would use the existing forest cover prior to development in 1988 and the forest cover following development in 1996 to determine forest cover change. Negative values for forest cover change indicate a loss of forest cover due to development whereas positive values indicate a gain in forest cover following development.

Figure 2 shows the average forest cover change for subdivisions occurring before the FCA regulation in 1985-1992 and after the FCA regulation in 1993-2000. Prior to the FCA regulation, the average forest cover change was negative across the entire distribution of existing forest cover. The largest losses occurred on subdivisions with higher levels of existing forest cover ranging from approximately 40 to 100%. After the FCA regulation, a modest gain in forest cover occurred on average for subdivisions with existing forest cover less than 40%; meanwhile, forest cover change decreased continuously for subdivisions with greater than 60% existing forest cover. The largest difference in forest cover change occurred for subdivisions with approximately 50% existing forest cover, where subdivisions had no change in forest cover after the FCA regulation versus an average loss of 9% prior to the FCA regulation (net gain of 9%). This difference was positive for most of the distribution of existing forest cover, except at the highest forest cover values of 90-100%. This suggests an overall positive effect of the FCA regulation on forest retention and afforestation, albeit heterogeneous effects by parcel-level existing forest cover.

Forest cover change is the dependent variable in the outcome equation for the second stage, while the first stage in the Heckman selection model is a panel probit model for whether the parcel is developed or not. We derive parcel attributes within a geographic information system (GIS) to create explanatory variables for each parcel in our dataset. Summary statistics for these covariates are reported in table 1. This includes the existing percent forest cover prior to development represented in quintile categories. We use quintiles to allow flexibility to capture the potential nonlinear relationship between forest cover change and the existing amount of forest cover. Removal of existing forest cover is often required to make room for development on subdivisions. Because FCA requirements are based largely upon parcel-level existing forest cover, we expect variation in forest cover change decisions over the distribution of existing forest values.

Zoning is represented as a categorical variable based on the dominant zoning type on the parcel. We manually reconstruct the historical zoning map in 1976 to represent the zoning designations that existed prior to the model period of subdivision development in 1985-2000. There are three major zoning types in rural Baltimore County, as outlined above. We create dummy variables for whether the parcel was located in either RC2 or RC4 zoning, while the least restrictive zoning type (RC5 zoning) is used as the baseline zoning category. The variable authorized minor is a dummy variable that takes on a value of one if the zoning on the parcel only allows a minor subdivision with two or three lots. Authorized minor parcels tend to be smaller parcels with fewer development options that are expected to be less likely to develop. The FCA requirements apply the same to both major subdivisions with four or more lots and minor subdivisions with two or three lots. We therefore treat the authorized minor variable as an exclusion restriction in the first stage and assume that being zoned for minor development may affect probability of development but not forest clearing, conditional on being selected for subdivision. Parcel area is represented in natural log form and used as an exclusion restriction in the first-stage equation on the development decision. Since forest cover is scaled by parcel area, we assume that parcel area does not directly affect the forest cover change decision in the second stage. The distance from each parcel to Baltimore City in miles is used to represent accessibility to regional employment opportunities. Similarly, the distance from each parcel to the closest major road or highway is used to represent access to the transportation infrastructure.

We construct the riparian buffer variable based on the stream hydrology and 100-year floodplains according to the riparian setback requirements in Baltimore County. We represent the riparian buffer variable as the percent of parcel area located within a 50-foot buffer around intermittent and perennial streams starting in 1986. Beginning in 1989, we expand the riparian buffer variable to a 100-foot of buffer of intermittent and perennial streams, due to an updated in the setback regulation. When the 100-year floodplain is larger than the minimum riparian setback requirements described above for a given parcel, then the riparian buffer variable is set equal to percent of parcel area within the 100-year floodplain. The average percent slope and elevation in meters are both calculated for each parcel using the digital elevation model (DEM) at 10-meter grid cell resolution. Surrounding land use variables are used to capture the potential spatial spillover effects from neighboring protected areas and developed land uses. These surrounding land use variables include the percent area within a 500-meter buffer around the boundary for each parcel in non-residential use (e.g., commercial, industrial, etc.), residential use, parks, and undeveloped land use. The variables are lagged temporally to represent the surrounding land uses prior to development, and the undeveloped category is omitted as the baseline. We also create a dummy variable for whether there was an existing house on the parcel.

Results

Table 2 reports the FIML estimation results of the Heckman model for a panel probit model of residential development in the first stage and forest cover change in the second stage. The estimated correlation coefficient $\hat{\rho}$ between the first and second stage is 0.74 and significant at the one percent level. This correlation implies that estimating these equations separately would result in inconsistent parameter estimates. The positive correlation coefficient suggests that, controlling for observable parcels attributes, parcel selected for development have higher levels of forest cover change relative to the undeveloped parcels. In table 3, we provide the marginal effects for each of the covariates computed at the observed values. For the first stage, the marginal effects on the average annualized probability of development are calculated based on Equation 5. For the second stage, the marginal effects for forest cover change conditional on development are calculated based on Equation 6, which account for the indirect effects from the selection process of land development in the first stage. Standard errors for marginal effects are calculated using the delta method.

In the first stage, the marginal effects of covariates in table 3 on the average annualized probability of development yield the following results. The marginal effects for existing forest cover are not significant for any quintile category, relative to the omitted baseline category of 0-20% existing forest cover. This suggests that, prior to the FCA regulation, there was no significant difference in the likelihood of development for parcels with high existing forest cover relative to those with low existing forest cover. The post-regulatory dummy variable in table 2 is also not significant, indicating that the overall rate of development was similar between the periods in 1985-1992 and 1993-2000. The marginal effects of interaction terms between the post-regulatory variable and existing forest cover are also not significant. This further implies that the selection process for land development did not vary by existing forest cover after the FCA regulation compared to the period prior to the FCA regulation.

Marginal effects for several other covariates on the probability of development are significant in table 3 and generally conform to expectations when significant. For example, the marginal effect of distance to Baltimore City is negative and significant at the one percent level, indicating that parcels farther from this regional employment center are less likely to be developed. Parcels with larger riparian buffer area are less likely to be developed, suggesting that the riparian setbacks requirements and 100-year floodplains reduce the suitability for development, as expected. The marginal effect of surrounding residential land use is positive and significant, suggesting that neighboring development potentially provides infrastructure to increase the likelihood of development; meanwhile, the marginal effect for surrounding parks is not significant.

Coefficients for the variables on authorized minor and parcel area, which are used as exclusion restrictions, are both highly significant in the first stage. The coefficient for authorized minor is negative and significant at the 1% level in the first stage, suggesting that parcels zoned to allow minor subdivisions are less likely to be developed. The coefficient for parcel area is positive, indicating that parcels with larger area are more likely to be developed presumably due to economies of scale for larger sized developments. With two exclusion restrictions, this system of equations is over-identified and we test the suitability of these exclusion restrictions using likelihood ratio tests. In these tests, we compare the log-likelihood from table 2 with both variables excluded from the second stage to the log-likelihood for a model that respectively includes either the authorized minor or parcel area variable in the second stage. If the variable is a suitable exclusion restriction, then we should expect no significant difference in log-likelihood between these models using a chi-squared test with one degree of freedom. The p-value on the chi-squared test is 0.13 for the authorized minor variable and 0.48 for the parcel area variable, suggesting that both variables are suitable exclusion restrictions.

The primary interest of our analysis is the marginal effect of existing forest cover on the expected forest cover change conditional on development. In particular, we aim to examine whether heterogeneous effects occur across the quintile categories of existing forest cover. Marginal effects for existing forest cover in table 3 are negative and significant for all quintile categories, relative to the baseline category for existing forest cover at 0-20%. Hence, this implies larger losses in forest cover occurred for developed parcels with higher levels of existing forest cover during the period 1985-1992 prior to adopting the FCA regulation. For example, developed parcels with 20-40% existing forest cover have on average approximately 5.8% more forest cover loss compared to developed parcels with 0-20% existing forest cover during this period. The post-regulatory dummy variable is positive and significant in table 2, suggesting that there was an increase in forest cover on developed parcels in 1993-2000 relative to those developed in 1985-1992. The marginal effects of the interactions between the post-regulatory variable and existing forest cover categories in table 3 indicate heterogeneous effects according to the existing levels of forest cover. Consider, for example, the negative and significant interaction effect for existing forest cover at 80-100%. This result suggests that larger decreases in forest cover occurred between the periods after versus before the FCA regulation for developed parcels with 80-100% forest cover, as compared to the forest cover change on developed parcels for the baseline category with 0-20% forest cover. Regarding the other covariates in table 3, the marginal effect of the average percent slope is positive and significant at the five percent level. This indicates that steeply sloped parcels have less forest clearing, as expected. The marginal effect is also positive and significant for the riparian buffer variable, presumably because riparian setback regulations provide more forest retention and restoration since they reduce the area allowed for residential development. Furthermore, the RC4 zoning has a significant and positive effect on forest cover change, whereas the effect for RC2 zoning is positive but not significantly different from RC5 zoning.

To further investigate the potential effect of the FCA on land use decisions, we provide the expected forest cover change conditional on development in table 4 for each quintile category of existing forest cover. We base the results shown in table 4 upon the same set of 3,010 parcels that were undeveloped as of 1993, in order to represent those parcels that were developable when the FCA regulation was adopted. Then, according to Equation 7, the expected forest cover change is calculated, conditional on development, in the period 1985-1992 and in the period 1993-2000. The difference indicates the expected increase in forest cover after the FCA regulation relative to the period prior to the FCA regulation, while accounting for the selection process of land development.

Table 4 shows that the expected forest cover after development decreases on developed parcels in the period 1985-1992 for all existing forest cover categories. Prior to implementation of the FCA regulation, forest cover loss ranges from -3.1% on parcels with 0-20% existing forest cover to approximately -11.0% on parcels with 60-80% existing forest cover. During the period 1993-2000, after the FCA regulation, there is a modest increase in forest cover change on average for developed parcels with existing forest cover between 0-60%. However, there is a decrease in expected forest cover change for developed parcels with greater than 60% existing forest cover.

When considering the difference between the time periods after versus before the FCA regulation in table 4, there is an expected net increase in forest cover conditional on development for parcels with 0-60% existing forest cover. The baseline category of 0-20% existing forest cover, for example, reports an expected decrease in forest cover of -3.1% in 1985-1992 and an expected increase of 5.2% in 1993-2000, leading to an overall net increase of 8.3% between these two periods. The largest overall net increase in forest cover is 15.3% for parcels with 40-60% existing forest cover. These results suggest that the afforestation and conservation thresholds implemented under the FCA regulation likely increased the amount of forest cover, relative to what would have occurred without the regulation, but primarily on parcels with lower existing forest cover. In contrast, parcels with highest levels of existing forest cover at 80-100% have no significant difference in expected forest cover on developed parcels between the periods before and after the FCA regulation. Specifically, we predict an expected decrease in forest cover of -7.3% in 1985-1992 and -9.1% in 1993-2000, which was not statistically different between these periods. This result may be due to the FCA regulation setting a maximum conservation threshold at 50%, meaning the parcels with high levels of existing forest cover, above this threshold may deforest large tracts of forest area without penalty. This has consequences for land fragmentation and suggests that the most intact forested areas continue to have the largest losses in forest cover despite the implementation of this forest conservation regulation.

Robustness Checks

As mentioned above, it should be acknowledged that, in addition to the effect of the FCA regulation, there may be other market or parcel attributes that vary between these two time periods. It would be desirable to use another neighboring region that is unaffected by the FCA regulation as a control region. However, the FCA is a statewide regulation that was adopted at the same time in neighboring counties in Maryland. Additionally, the forest cover data from the NACP (Goward et al. 2012) only covers the Baltimore-Washington corridor and does not extend into neighboring Yorke County, Pennsylvania. In the absence of such a control region, we conduct several robustness checks to examine the potential sensitivity of our estimation results.

First, we conduct temporal falsification tests that restrict the sample to include either the pre-FCA or post-FCA data only and move the regulation event to an arbitrary year within those respective time periods. We start by performing a falsification test using only the post-FCA data spanning the period in 1993-2000. We then estimate the model specified in Equations 1-3 while hypothetically considering the false regulation event occurring in 1997, such that 1993-1996 is considered before the regulation versus 1997-2000 after the regulation. If there were significant differences in the forest cover change conditional on development between these two periods, it would suggest potential confounding influence of time-varying unobservable factors affecting forest cover change decisions. table A1 in the Appendix is analogous to the calculations made for the results in table 4. Table A1 shows that there were no significant differences in the expected forest cover change conditional on development between these two periods in 1993-1996 versus 1997-2000. We repeated this method for the falsification test using only the pre-FCA data spanning 1985-1992 while hypothetically considering the false regulation event in 1989. Table A2 in the Appendix similarly shows that there were no significant differences in forest cover change between the periods 1985-1988 versus 1989-1992.

Second, we estimate the model over a shorter ten-year horizon in 1988-1997 as a comparison to our main results over the longer horizon in 1985-2000. By narrowing the time window, we focus the analysis to the period immediately before and after the introduction of the FCA regulation. Hence, this may reduce potential bias from confounding temporally varying unobservable factors. The estimated covariate marginal effects are presented in table A3 in the Appendix. The marginal effects in table A3 change quantitatively but the significance for covariates are qualitatively similar to those in table 3, except that marginal effect of RC4 zoning on forest cover change is positive but no longer significant in table A3. Table A4 shows the expected forest cover change conditional on development for the periods 1988-1992 versus 1993-1997. The results on estimated forest cover change in table A4 are qualitatively the same as those reported in table 4. This analysis for a shorter period in 1988-1997, of course, has fewer subdivision events to estimate the model, which is the reason we use the longer period in 1985-2000 for our main results.

Third, we examine the sensitivity to the specification using quintile categories of existing forest cover. We also explore the model estimation using decile categories to saturate the potential nonlinear effects. Tables A5 presents the covariate marginal effects based on decile forest cover categories. The main findings remain unchanged between table A5 and table 3. Table A6 shows the expected forest cover change conditional on development for 1985-1992 and 1993-2000 based on the decile categories for existing forest cover. The difference in expected forest cover change between these two periods is positive for existing forest cover values less than 80%. The net increase in expected forest cover change is largest for parcels with 40-50% existing forest cover, which is similar to the results in table 4.

Simulation on Landscape-Level Forest Cover Change

In this section, we provide results of a simulation to analyze the landscape-level implications of the FCA regulation on forest cover change in rural Baltimore County. The analysis uses 1,000 bootstrapped samples of the original data set, followed by model estimation according to the specification provided in Equations 1-3. Parcels that are developable as of 1993 are used to predict the amount of land development and forest cover change that would occur under the scenarios with and without the FCA regulation during the period 1993-2000. The dummy variable τ is set to one for the scenario with the FCA regulation and set to zero for the scenario without the FCA regulation, while all other variables and coefficients are unchanged between these scenarios.

For each bootstrapped iteration, we predict the parcel-level expected annual probability of development with and without the FCA regulation in each year during 1993-2000. Then, analogous to the methodology in Lewis, Provencher and Butsic (2009), the expected annual probability of development for each parcel is compared to a random number drawn from a uniform distribution for each parcel and year. The parcel is considered developed in the first year spanning 1993-2000 in which the expected annual probability of development is greater than the random uniform number; and otherwise, it is considered to remain undeveloped in 2000. If the parcel is predicted to develop, then the expected forest cover change conditional on development in that given year is calculated.

The simulation results are summarized in table 5 showing the land area, existing forest area, and forest cover change on subdivisions under the scenarios with and without the FCA regulation. The bootstrapped 95% confidence intervals (CIs) are also included based on the 25th and 975th largest simulation result from the 1,000 iterations. The null hypothesis is a test on whether the bootstrapped 95% CIs contain zero for the difference between the results under scenarios with and without the FCA regulation. Table 5 shows that there is a similar amount of total land area on subdivisions under the scenarios with and without the FCA regulation. There is actually slightly more total developed land area on subdivisions with the FCA regulation, specifically about 8,567 acres developed with the FCA regulation and 7,380 acres developed without the FCA regulation. This difference, however, is not statistically significant since the bootstrapped CIs range from -2,973 to 468. Furthermore, the amount of existing forest cover on subdivisions with and without the FCA regulation is 3,965 acres and 3,561 acres, respectively; but this difference is also not statistically significant.

The results for forest cover change in table 5 demonstrate that there are larger predicted losses in forest cover for the scenario without the FCA regulation. We predict a total loss of 733 forested acres out of 3,561 acres of existing forest cover under the scenario without the FCA regulation during 1993-2000, representing about a 21% loss of forest cover. Meanwhile, we predict a total loss of only 103 forested acres out of 3,965 acres of existing forest cover for the scenario with the FCA regulation. This indicates an overall net difference of 633 forested acres between these two scenarios, approximately a 22% increase in forest cover with the FCA regulation relative to forest cover on subdivisions without the FCA.

Importantly, the results for forest cover change are heterogeneous by the parcel-level existing forest cover, particularly for the scenario with the FCA regulation. Table 5 indicates that significant decreases in forest cover occur for all five existing forest cover categories for the scenario without the FCA regulation. With the FCA regulation, there is no significant decrease in forest cover for parcels with 0-60% existing forest cover, whereas there are significant decreases in forest cover for parcels with 60-100% existing forest cover. It is informative to compare the difference in forest cover change between the scenarios by the existing forest cover categories. For parcels with 0-20% existing forest cover, the difference in forest area increased significantly by approximately 105 acres with the FCA regulation relative to without it. This increase is expected because parcels with less than 20% existing forest cover are required to afforest during the subdivision process under the FCA regulations. The largest gain in forest cover occurred on subdivisions for parcels with 40-60% existing forest cover, which had an increase of 291 forested acres compared to the simulation without the FCA regulation. This result suggests that parcels with existing forest cover near the conservation threshold are significantly affected by the FCA regulation, which results in either higher retention of existing forest cover or more reforestation to compensate for areas cleared during the subdivision process. For parcels with 80-100% existing forest cover, there is no significant difference in forest area between the scenarios with and without the FCA regulation. This result indicates continued loss in forest cover under both scenarios for parcels with the highest level of existing forest cover. According to the FCA regulation, parcels with high levels of existing forest cover may remove a significant amount of forest acreage above the conservation threshold without requiring reforestation or afforestation. Hence, forest fragmentation may continue unabated for the parcels with the most intact forest habitat.

Conclusion

The purpose of this paper is to analyze the heterogeneous effect of the FCA regulation on residential development and assess the change in forest cover due to this regulation. We find that prior to the FCA regulation, forest cover decreases on subdivision developments across the entire distribution of existing forest cover values. However, after the FCA regulation, forest cover increases on average but only for parcels with between 0-60% existing forest cover. The largest difference in forest cover change between the post-FCA and pre-FCA periods occurred on parcels with 40-60% existing forest cover. Meanwhile, parcels with 80-100% existing forest cover had no significant difference in the level of forest loss between the post-FCA and pre-FCA periods. Hence, parcels with the highest levels of forest cover at 80-100% continue to have the largest decrease in forest cover, despite the FCA regulation, thereby resulting in forest habitat fragmentation in regions with the most intact forest cover.

Our analysis suggests that there was an overall significant and positive effect of this regulation on total forest cover in the region. Based upon landscape-level regulation simulations, we find that total expected forest cover in rural Baltimore County increased by approximately 633 acres due to the introduction of the FCA regulation, representing a 22% increase in forest area relative to the expected total forest cover that would have occurred on subdivisions without the FCA regulation. Regulatory effectiveness could be further improved, for instance, if regulators increased the conservation threshold. In doing so, landowners subdividing their properties would be required to assume larger amounts of forest conservation and would reduce the amount of forest acreage that could be removed without penalty. Since the most intact forests are currently the least affected by the introduction of the FCA regulation, another approach would be to target funding from purchase of development rights programs to protect these high priority forested areas. Hence, land managers may find complementary and synergistic strategies between current land-use policies and incentive programs by targeting payments to areas where the FCA regulation is expected be less effective in meeting landscape-level forest conservation goals. However, assessing the tradeoffs needed to set priorities for targeting forest conservation would require a more detailed evaluation of the spatial distribution of ecosystem services provided by forests rather than only the total level of forest cover change provided in this study.

There is growing interest and research in programs designed to reduce deforestation and promote afforestation, including both incentive-based payments for ecosystem services (Lubowski, Plantinga, and Stavins 2006; Nelson et al. 2008; Lewis, Plantinga and Wu 2009; Lewis et al. 2011) and land-use regulations (Lichtenberg, Tra and Hardie2007; Lawler et al. 2014). In this study, we integrate parcel-level modeling of residential development decisions with fine-scale panel data on forest cover change from satellite imagery. Hence, we are able to better characterize the spatial heterogeneity of the initial level of existing forest cover across the parcels. More importantly, we are also able to more accurately assess the partial loss in forest cover that occurs on subdivision developments even prior to regulation adoption, as well as estimate the additionality of forest cover due to regulation adoption. This forest loss is often overestimated in prior studies that assume a complete loss in forest cover occurs with development or use uniform rule-based assumptions on the relationship between development and forest loss. For instance, Lawler et al. (2014) make a heroic effort to provide a comprehensive national assessment for land-use change and ecosystem services; however, the urban containment policies assume a uniform rule that only 10% of the initial forest carbon stock remains after development (implying a 90% loss in forest carbon with development). We anticipate that the combination of micro-level land use decisions and fine-scale panel data on forest cover change used in our study will have future research opportunities in other regions since the North American Forest Dynamics Project provides similar publically available data on historic forest cover at 55 sites located across the United States (Goward et al. 2012).

Table 1. Covariate Summary Statistics

Variables	Mean	Standard Deviation	Min	Max
Existing Forest Cover Quintile				
Forest cover 0-20%	0.1986	0.3990	0	1
Forest cover 20-40%	0.1644	0.3707	0	1
Forest cover 40-60%	0.1469	0.3540	0	1
Forest cover 60-80%	0.1423	0.3494	0	1
Forest cover 80-100%	0.3478	0.4763	0	1
Zoning Type				
RC 5	0.1629	0.3693	0	1
RC 4	0.2079	0.4058	0	1
RC 2	0.6292	0.4830	0	1
Parcel Characteristics				
Distance to Baltimore City	21.4410	8.9726	3.2167	39.1890
Distance to Major Road	0.7643	0.6635	0.0270	4.7063
Slope	10.9220	4.8201	0	42.9550
Elevation	16.6108	4.9259	0.1006	28.8327
Existing House	0.3563	0.4789	0	1
Riparian Buffer Area (%)	19.4562	19.5880	0	100
ln(Parcel Area)	2.8715	0.9046	1.6094	5.8538
Authorized Minor	0.7940	0.4044	0	1
Surrounding Land Use within 500 meter buffer				
Non-residential (%)	0.0189	0.0540	0	0.5565
Parks (%)	0.0343	0.1013	0	0.9785
Residential (%)	0.1891	0.1611	0	0.9563
Number of Parcels	3,388			
Observations	49,148			

Table 2. Full Information Maximum Likelihood Estimation Results on Panel Heckman Selection Model

	Probability of Development		Forest Cover Change	
Variables	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Forest Cover Quintiles[a]				
Forest cover 20-40%	-0.10964	0.09999	-6.67854**	1.87897
Forest cover 40-60%	0.08965	0.09094	-5.86740**	1.94954
Forest cover 60-80%	0.09250	-0.09232	-7.20691**	-2.35234
Forest cover 80-100%	0.01915	-0.08483	-4.10248**	-1.58868
Post-1993 Forest Cover Quintiles[a]				
Post-1993* Forest cover 20-40%	0.21267	-0.13557	5.75130	-2.97732
Post-1993* Forest cover 40-60%	0.01350	-0.1306	7.17126*	-2.84029
Post-1993* Forest cover 60-80%	0.02220	-0.13054	-0.88349	-2.70729
Post-1993* Forest cover 80-100%	-0.03651	-0.11784	-10.29618**	-2.60728
Post-1993	0.02061	-0.13628	8.44116***	-2.97329
Zoning Type[b]				
RC 4	-0.02877	0.05961	3.74657**	1.33365
RC 2	-0.09880	0.07886	-0.49982	1.53809
Parcel Characteristics				
Distance to Baltimore City	-0.00766**	-0.00291	-0.04066	-0.08176
Distance to Major Road	-0.00983	-0.98918	-0.71884	-0.03356
Slope	0.00249	-0.00439	0.27861*	-0.12795
Elevation	-0.00671	-0.00558	-0.04723	-0.1256
Riparian Buffer Area (%)	-0.00679**	-0.0013	0.03825	-0.03489
Existing House	-0.08743*	-0.04084	-0.74077	-0.91336
Ln(Parcel Area)	0.14965**	-0.02577	--	--
Authorized Minor	-0.31194**	-0.06359	--	--
Surrounding Land Use within 500 meter buffer				
Non-residential (%)	-0.00331	-0.00382	-0.03572	-0.09553
Parks (%)	0.00038	-0.002	0.03529	-0.04468
Residential (%)	0.00994**	-0.00119	0.11670**	-0.03696
Constant	-2.40515**	-0.15275	-33.23625**	-6.43279
ρ	0.74614**	-0.16393	--	--
Annual Time Fixed Effects	Yes		Yes	
Observations	49,148		427	

Note: Asterisks ** and * denote statistical significant at 1% and 5% levels, respectively.

[a] Baseline forest cover category = 0-20% existing forest cover

[b] Baseline zoning type = RC 5 zoning

Table 3. Marginal Effect of Covariates on Annual Probability of Development and Forest Cover Change

Variables	Probability of Development Coefficient	Probability of Development Standard Errors	Forest Cover Change Coefficient	Forest Cover Change Standard Errors
Forest Cover Quintiles[a]				
Forest cover 20-40%	-0.00190	0.00172	-5.7755**	1.7440
Forest cover 40-60%	0.00190	0.00192	-6.6025**	1.8222
Forest cover 60-80%	0.00197	0.00196	-7.9653**	2.2224
Forest cover 80-100%	0.00038	0.00165	-4.2598**	1.4169
Post-1993 Forest Cover Quintiles[a]				
Post-1993* Forest cover 20-40%	0.00233	0.00212	-1.7709	2.1403
Post-1993* Forest cover 40-60%	0.00233	0.00222	0.4592	2.2098
Post-1993* Forest cover 60-80%	0.00262	0.00225	-9.0293**	1.7340
Post-1993* Forest cover 80-100%	-0.00030	0.00178	-14.2560**	2.3195
Zoning Type[b]				
RC 4	-0.00070	0.00138	3.9820**	1.2302
RC 2	-0.00210	0.00171	0.3099	1.3983
Parcel Characteristics				
Distance to Baltimore City	-0.00020**	0.00006	0.0222	0.0744
Distance to Major Road	-0.00020	0.00071	-0.6382	0.9866
Slope	0.00005	0.00009	0.2582*	0.1213
Elevation	-0.00010	0.00012	0.0078	0.1148
Riparian Buffer Area (%)	-0.00010**	0.00003	0.0939**	0.0321
Existing House	-0.00190*	0.00087	-0.0238	0.8560
Ln(Parcel Area)	0.00317**	0.00056	--	--
Authorized Minor	-0.00661**	0.00138	--	--
Surrounding Land Use within 500 meter buffer				
Non-residential (%)	-0.00007	0.00008	-0.0086	0.0855
Parks (%)	0.00001	0.00004	0.0321	0.0389
Residential (%)	0.00021**	0.00003	0.0351	0.0274

Note: Asterisks ** and * denote statistical significant at 1% and 5% levels, respectively.

[a] Marginal effects based upon a discrete change from the baseline 0-20% existing forest category

[b] Marginal effects based upon a discrete change from the baseline RC 5 zoning category

Table 4. Percent Forest Cover Change Conditional on Development in 1985-1992 and 1993-2000

Forest Cover Quintile	Forest Cover Change in 1985-1992	Forest Cover Change in 1993-2000	Difference
Forest cover 0-20%	-3.0823	5.1893**	8.2715**
	(2.5666)	(1.3006)	(2.7147)
Forest cover 20-40%	-8.8558**	3.4164*	12.2722**
	(3.0218)	(1.6671)	(3.3536)
Forest cover 40-60%	-9.6865**	5.6465**	15.3329**
	(3.005)	(1.8638)	(3.3259)
Forest cover 60-80%	-11.0493**	-3.8423**	7.2070
	(3.8689)	(1.2126)	(3.6418)
Forest cover 80-100%	-7.3424**	-9.0665**	-1.7241
	(2.7472)	(1.8403)	(3.0936)

Notes: Asterisks ** and * denote statistical significant at 1% and 5% levels, respectively. Robust standard errors in parentheses.

Table 5. Landscape-Level Predictions on Land Acreage, Existing Forest Cover and Forest Cover Change With and Without FCA Regulation

	Subdivisions without FCA Regulation			**Subdivisions with FCA Regulation**			**Difference**		
Forest Cover Quintile	Land area	Existing forest area	Forest cover change	Land area	Existing forest area	Forest cover change	Land area	Existing forest area	Forest cover change
Forest cover 0-20%	1255*	140*	-80*	1311*	147*	25	57	7	105*
	[443, 2253]	[43, 256]	[-191, -11]	[618, 2081]	[61, 250]	[-16, 70]	[-938, 963]	[-104, 110]	[26, 219]
Forest cover 20-40%	1280*	378*	-155*	2173*	643*	3	893	265	161*
	[444, 2335]	[129, 698]	[-332, -41]	[1171, 3293]	[352, 981]	[-90, 92]	[-81, 2128]	[-22, 613]	[21, 350]
Forest cover 40-60%	1865*	906*	-228*	2020*	980*	62	155	74	291*
	[859, 3119]	[419, 1527]	[-449, -80]	[1097, 3091]	[524, 1506]	[-15, 152]	[-1093, 1246]	[-534, 612]	[123, 522]
Forest cover 60-80%	1326*	903*	-162*	1470*	1002*	-69*	144	98	93
	[538, 2349]	[366, 1591]	[-356, -44]	[698, 2336]	[480, 1583]	[-138, -22]	[-796, 1001]	[-540, 697]	[-23, 258]
Forest cover 80-100%	1654*	1234*	-107*	1592*	1194*	-124*	-62	-41	-16
	[742, 2880]	[553, 2075]	[-231, -28]	[919, 2421]	[646, 1811]	[-213, -52]	[-1246, 804]	[-905, 616]	[-125, 97]
Total	7380*	3561*	-733*	8567*	3965*	-103	1187	404	633*
	[4148, 11376]	[2071, 5517]	[-1314, -321]	[6620, 10743]	[2998, 4978]	[-272, 61]	[-2973, 4688]	[-1524, 1964]	[193, 1222]

Notes: All numbers above reported in acres. Asterisk * denotes statistical significance of the bootstrapped 95% confidence interval not containing zero.

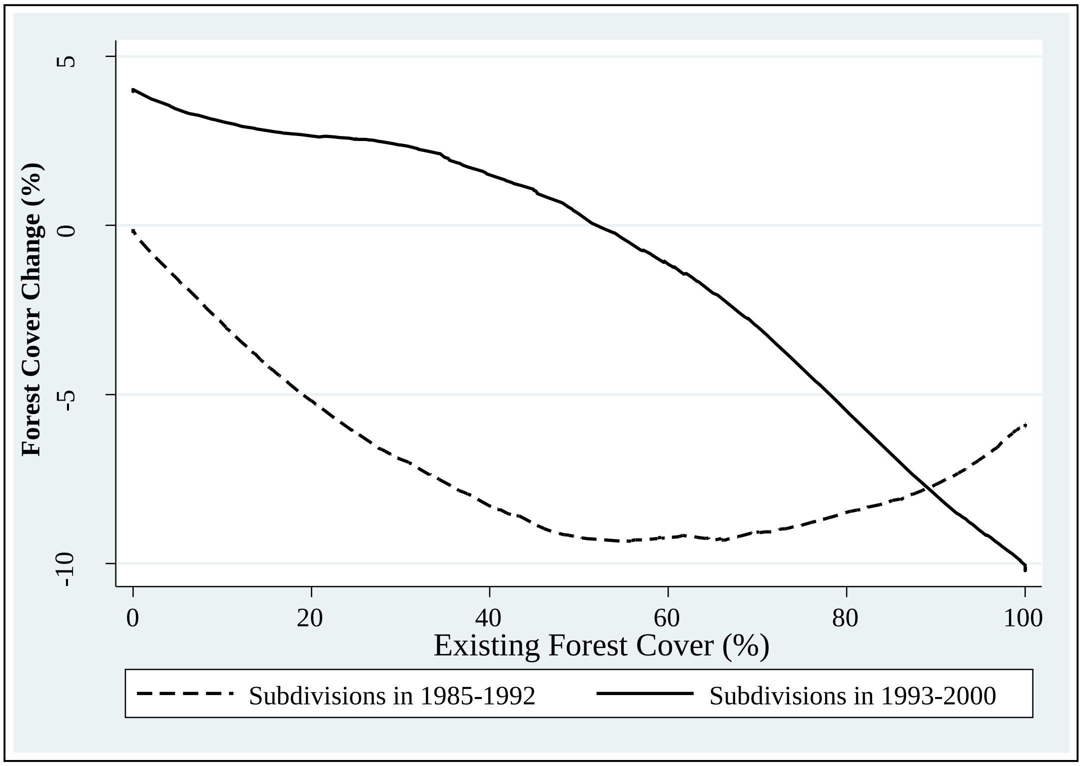

Figure 1. Lowess of average forest cover change for subdivisions before FCA regulation (1985-1992) and after FCA regulation (1993-2000)

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Appendix

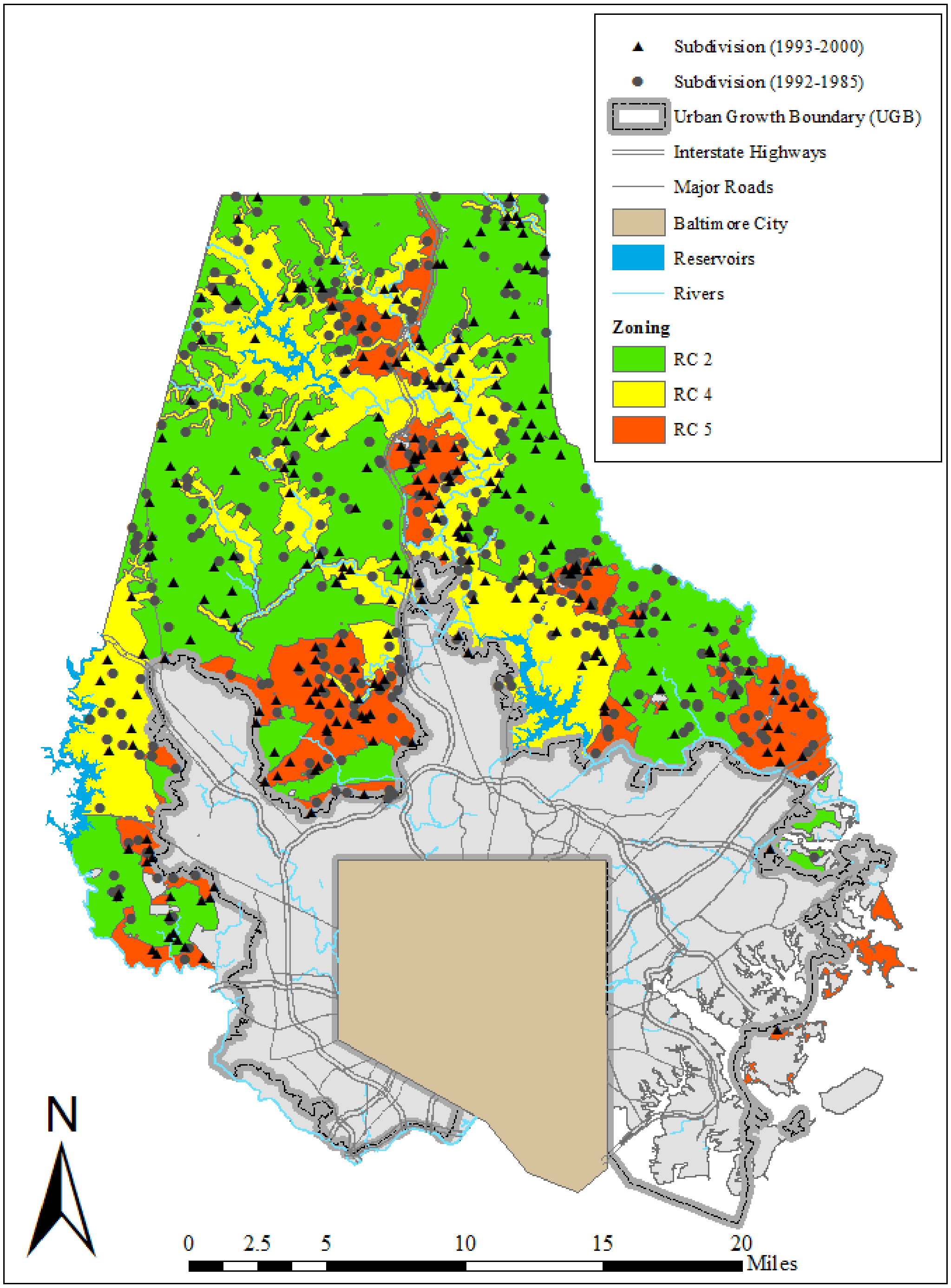

Figure A1. Residential subdivisions in 1985-2000 in rural Baltimore County

Table A1. Temporal Falsification Test on Percent Forest Cover Change Conditional on Development in 1993-1996 and 1997-2000 (False Regulatory Event=1997)

Forest Cover Quintile	Forest Cover Change in 1993-1996	Forest Cover Change in 1997-2000	Difference
Forest cover 0-20%	0.0225	0.0535	0.0309
	(2.6944)	(0.8896)	(2.6074)
Forest cover 20-40%	-6.8809	-5.3191**	1.5618
	(3.6930)	(1.4090)	(4.1888)
Forest cover 40-60%	-9.1644**	-2.7668**	6.3976
	(3.0207)	(1.0154)	(3.3461)
Forest cover 60-80%	-7.3209**	-8.0327**	-0.7118
	(2.3251)	(2.9609)	(4.4023)
Forest cover 80-100%	-3.0228	-4.4408**	-1.4180
	(2.1193)	(1.1071)	(2.3590)

Notes: Asterisks ** and * denote statistical significant at 1% and 5% levels, respectively. Robust standard errors in parentheses.

Table A2. Temporal Falsification Test on Percent Forest Cover Change Conditional on Development in 1985-1988 and 1989-1992 (False Regulatory Event=1989)

Forest Cover Quintile	Forest Cover Change in 1985-1988	Forest Cover Change in 1989-1992	Difference
Forest cover 0-20%	5.7252	7.2198**	1.4946
	(3.3051)	(1.9661)	(3.8734)
Forest cover 20-40%	5.9372	2.2252	-3.7120
	(3.4378)	(2.3233)	(3.9989)
Forest cover 40-60%	2.9598	8.2385**	5.2787
	(3.3317)	(2.7727)	(4.316)
Forest cover 60-80%	-2.6671	-3.2635	-0.5964
	(2.8116)	(1.9673)	(3.1408)
Forest cover 80-100%	-12.1336**	-7.8246**	4.3090
	(4.3542)	(2.5633)	(4.5438)

Notes: Asterisks ** and * denote statistical significant at 1% and 5% levels, respectively. Robust standard errors in parentheses.

Table A3. Marginal Effect of Covariates on Annual Probability of Development and Forest Cover Change (1988-1997)

	Probability of Development		Forest Cover Change	
Variables	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Forest Cover Quintiles[a]				
Forest cover 20-40%	-0.00126	0.00226	-5.1281**	1.5634
Forest cover 40-60%	0.00033	0.00237	-4.0448*	1.5377
Forest cover 60-80%	0.00062	0.00253	-7.6663**	2.9344
Forest cover 80-100%	-0.00094	0.00212	-4.1067**	1.3812
Post-1993 Forest Cover Quintiles[a]				
Post-1993* Forest cover 20-40%	-0.00027	0.00262	0.6130	2.5182
Post-1993* Forest cover 40-60%	0.00017	0.00274	-1.1306	2.6433
Post-1993* Forest cover 60-80%	0.00199	0.00292	-6.5848**	1.9547
Post-1993* Forest cover 80-100%	-0.00153	0.00229	-13.1875**	2.8300
Zoning Type[b]				
RC 4	-0.00207	0.00183	2.4715	1.3380
RC 2	-0.00384	0.00236	-0.6795	1.6616
Parcel Characteristics				
Distance to Baltimore City	-0.00018*	0.00008	0.0566	0.0867
Distance to Major Road	-0.00033	0.00093	-1.4135	1.1493
Slope	0.00015	0.00012	0.2228*	0.1133
Elevation	-0.00006	0.00016	-0.0844	0.1361
Riparian Buffer Area (%)	-0.00011**	0.00003	0.0872*	0.0363
Existing House	-0.00228*	0.00109	-0.4459	0.9564
Ln(Parcel Area)	0.00342**	0.00070	--	--
Authorized Minor	-0.00631**	0.00181	--	--
Surrounding Land Use within 500 meter buffer				
Non-residential (%)	-0.00012	0.00011	-0.0994	0.1169
Parks (%)	-0.00003	0.00006	0.0345	0.0546
Residential (%)	0.00018**	0.00003	-0.0004	0.0345

Note: Asterisks ** and * denote statistical significant at 1% and 5% levels, respectively.

[a] Marginal effects based upon a discrete change from the baseline 0-20% existing forest category

[b] Marginal effects based upon a discrete change from the baseline RC 5 zoning category

Table A4. Percent Forest Cover Change Conditional on Development in 1988-1992 and 1993-1997

Forest Cover Quintile	Forest Cover Change in 1988-1992	Forest Cover Change in 1993-1997	Difference
Forest cover 0-20%	-2.7801	5.1898**	7.9700**
	(2.4825)	(1.5856)	(2.7325)
Forest cover 20-40%	-7.9074**	5.8030**	13.7104**
	(2.9799)	(2.1191)	(3.5091)
Forest cover 40-60%	-6.8251*	4.0591	10.8842**
	(2.9632)	(2.1072)	(3.4231)
Forest cover 60-80%	-10.4468*	-1.3961	9.0508*
	(4.6222)	(1.2669)	(4.2748)
Forest cover 80-100%	-6.8862**	-7.9967**	-1.1105
	(2.6373)	(2.1522)	(3.1476)

Notes: Asterisks ** and * denote statistical significant at 1% and 5% levels, respectively. Robust standard errors in parentheses.

Table A5. Marginal Effect of Covariates on Annual Probability of Development and Forest Cover Change Using Existing Forest Cover Deciles (1985-2000)

	Probability of Development		Forest Cover Change	
Variables	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Forest Cover Deciles[a]				
Forest cover 10-20%	0.00138	0.00263	-0.1659	1.9611
Forest cover 20-30%	0.00030	0.00250	-4.8730**	1.8207
Forest cover 30-40%	-0.00269	0.00216	-7.7409*	3.1362
Forest cover 40-50%	0.00369	0.00268	-7.1546**	2.3523
Forest cover 50-60%	0.00134	0.00259	-6.1692*	2.4853
Forest cover 60-70%	0.00279	0.00263	-5.9277**	2.2802
Forest cover 70-80%	0.00241	0.00267	-10.3887**	3.1646
Forest cover 80-90%	0.00162	0.00260	-5.3523*	2.1084
Forest cover 90-100%	0.00078	0.00205	-4.0798*	1.7508
Post-1993 Forest Cover Deciles[a]				
Post-1993*Forest cover 10-20%	-0.00124	0.00268	-2.9871	2.3324
Post-1993*Forest cover 20-30%	0.00211	0.00301	-2.5108	2.6900
Post-1993*Forest cover 30-40%	0.00140	0.00294	-3.5547	3.1812
Post-1993*Forest cover 40-50%	0.00069	0.00289	0.4021	3.3512
Post-1993*Forest cover 50-60%	0.00314	0.00343	-2.1753	2.9804
Post-1993*Forest cover 60-70%	0.00319	0.00311	-11.2038**	2.2799
Post-1993*Forest cover 70-80%	0.00067	0.00315	-8.9941**	2.5973
Post-1993*Forest cover 80-90%	-0.00010	0.00298	-16.4236**	3.8211
Post-1993*Forest cover 90-100%	-0.00125	0.00232	-15.3063**	2.8519
Zoning Type[b]				
RC 4	-0.00070	0.00139	4.0092**	1.2641
RC 2	-0.00210	0.00172	0.2834	1.4365
Parcel Characteristics				
Distance to Baltimore City	-0.00016**	0.00006	0.0164	0.0746
Distance to Major Road	-0.00014	0.00071	-0.6434	0.9672
Slope	0.00006	0.00009	0.2680*	0.1199
Elevation	-0.00014	0.00012	-0.0057	0.1172
Riparian Buffer Area (%)	-0.00014**	0.00003	0.0921**	0.0315
Existing House	-0.00188*	0.00087	-0.0172	0.8673
Ln(Parcel Area)	0.00314**	0.00056	--	--
Authorized Minor	-0.00663**	0.00139	--	--
Surrounding Land Use within 500 meter buffer				
Non-residential (%)	-0.00007	0.00008	0.0061	0.0862
Parks (%)	0.00001	0.00004	0.0258	0.0405
Residential (%)	0.00021**	0.00003	0.0352	0.0278

Note: Asterisks ** and * denote statistical significant at 1% and 5% levels, respectively.

[a] Marginal effects based upon a discrete change from the baseline 0-20% existing forest category

[b] Marginal effects based upon a discrete change from the baseline RC 5 zoning category

Table A6. Percent Forest Cover Change Conditional on Development in 1985-1992 and 1993-2000 Using Existing Forest Deciles

Forest Cover Decile	Forest Cover Change in 1985-1992	Forest Cover Change in 1993-2000	Difference
Forest Cover 0-10%	-3.0708	6.4299**	9.5007**
	(2.8822)	(1.7603)	(3.1605)
Forest Cover 10-20%	-3.2381	3.444*	6.682*
	(2.625)	(1.6669)	(3.0191)
Forest Cover 20-30%	-7.9441**	3.9174*	11.8614**
	(3.0653)	(1.9933)	(3.6707)
Forest Cover 30-40%	-10.8086**	2.8741	13.6827**
	(3.8858)	(2.6692)	(4.5852)
Forest Cover 40-50%	-10.2286**	6.8314*	17.06**
	(3.3029)	(2.8977)	(4.2294)
Forest Cover 50-60%	-9.2413**	4.2521	13.4934**
	(3.2293)	(2.3823)	(3.8831)
Forest Cover 60-70%	-9.001**	-4.7764**	4.2246
	(3.2466)	(1.4646)	(3.1653)
Forest Cover 70-80%	-13.4617**	-2.5648	10.8969*
	(4.7609)	(1.8552)	(4.8902)
Forest Cover 80-90%	-8.4247**	-9.9936**	-1.5689
	(3.0512)	(3.3868)	(4.3736)
Forest Cover 90-100%	-7.1514**	-8.8753**	-1.7238
	(2.7083)	(2.1645)	(3.2685)

Notes: Asterisks ** and * denote statistical significant at 1% and 5% levels, respectively. Robust standard errors in parentheses.

Endnotes

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[1] The landowner may also meet the conservation requirement through offsite mitigation. Offsite forest mitigation is relatively uncommon for our study region in rural Baltimore County, representing less than 10% of forest acres conserved based on available data.

[2] For further details on FCA requirements, see the Chesapeake Bay Foundation "A Citizen's Guide to the Forest Conservation Act in Maryland" http://www.cbf.org/document.doc?id=148.

[3] Hence, we have screened out areas zoned for non-residential uses (e.g., commercial, industrial, parks, etc.) and parcels that were already developed. We have also excluded areas in zoning types covering a minor portion of the landscape and had limited development activity, including the critical area for the 1000-foot buffer along the tidal zone of the Chesapeake Bay (RC20/RC50) and RC3 zoning. Parcels that are put into land preservation easements were considered developable from 1985 until the date of easement, after which they were not considered developable.