Open Space and Urban Sprawl: The Effects of Zoning and Forest Conservation Regulations in Maryland

Erik Lichtenberg

Rapid urbanization enhances the desirability of policies for preserving open space but policies intended to preserve open space may extend the urban boundary and create leapfrog development. We investigate this potential conflict between open space preservation and urban sprawl conceptually and empirically using data from the Baltimore-Washington suburbs. In accord with previous theoretical and empirical results, the estimated econometric model indicates that both zoning and forest planting requirements contribute to sprawl by increasing the amount of land needed to accommodate the current number of households. These results point to a conflict between preserving open space incorporated into private building lots or internal to subdivisions and public open space at the urban fringe.

Key Words: Maryland Forest Conservation Act, open space, sprawl, zoning

Preserving open space is an important component of land use policy in rapidly urbanizing areas. Both current and incoming residents place a significant value on nearby open space, as evidenced by the fact that the presence of nearby open space—especially open space that has been permanently preserved in some form—increases residential property values (Cheshire and Sheppard 1995, Geoghegan, Wainger, and Bockstael 1997, Tyrväinen and Miettinen 2000, Geoghegan 2002, Thorsnes 2002, Irwin 2002, Geoghegan, Lynch, and Bucholtz 2003, Wu, Adams, and Plantinga 2004, Hardie, Lichtenberg, and Nickerson 2007). Preservation of open space is a common justification for land use regulations like zoning (Brueckner 1990). It also motivates programs such as easement purchases or transferable development rights whose explicit purpose is permanent preservation of open space (Bockstael and Irwin 2000).

But open space preservation can exacerbate problems of urban sprawl both by extending the urban boundary out farther into rural areas and by promoting leapfrog development. Zoning, for instance, can create a conflict between provision of "semi-private" open space in the immediate vicinity of homes and preservation of public open space at the urban fringe (Bento, Franco, and Kaffine 2006). Zoning can be used to force developers to accommodate home buyers' preference for open space in the immediate vicinity of their homes (Nechyba and Walsh 2004). At the same time, zoning and other forms of land use regulation can induce developers to reduce the number of housing lots within subdivisions, in which case more extensive land development is needed to accommodate any given increase in population. Theoretical analyses show that, by reducing density, minimum lot size zoning pushes the equilibrium urban boundary outward (Moss 1977, Pasha 1996). An econometric study of Calvert County, Maryland, provides evidence supporting this prediction, finding that zoning reduces density (McConnell, Walls, and Kopits 2006).

Policies aimed at preserving public open space at the urban fringe are not immune to forms of slippage that reduce their effectiveness [see Wu

Erik Lichtenberg is Professor in the Department of Agricultural and Resource Economics at the University of Maryland in College Park, Maryland.

This paper was presented at the workshop "The Economics of Land Use Change: Advancing the Frontiers," organized by Lori Lynch (Center for Agricultural and Natural Resource Policy, University of Maryland) and Jacqueline Geoghegan (Clark University), in Washington, D.C., June 25–26, 2009. The workshop received financial support from the U.S. Environmental Protection Agency, the Lincoln Institute of Land Policy, and the Center for Agricultural and Natural Resource Policy at the University of Maryland. The views expressed in this paper are the author's and do not necessarily represent the policies or views of the sponsoring agencies.

This research was supported in part by McIntire-Stennis Project No. MD-AREC 0514.

Agricultural and Resource Economics Review 40/3 (December 2011) 393–404

(2000) for an analysis involving a similar case of offsets in an agricultural context]. Econometric evidence from Maryland shows that proximity to permanently preserved open space increases the likelihood that a parcel of land will be developed, suggesting that open space preservation can foster non-contiguous, "leapfrog" development (Irwin and Bockstael 2004). Simulation studies based on data from Portland, Oregon, similarly show that open space preservation can create leapfrog development (Wu and Plantinga 2003).

This paper investigates how minimum lot size zoning, maximum density zoning, and forest planting requirements under the Maryland Forest Conservation Act affect the design of suburban residential subdivisions; in particular, the average size of lots, the number of lots, and the amount of land used for roads and other infrastructure. We present a conceptual model of how these two regulations influence the way that a developer chooses to subdivide land into building lots, forested and non-forested open space, and infrastructure such as roads and sidewalks. We use that conceptual model to specify an econometric model using data from subdivisions developed in the Baltimore-Washington suburbs during the mid-1990s. We then use the econometric results to draw inferences about the impacts of these regulations on the amount of land needed to accommodate population growth in the Baltimore-Washington corridor and hence on urban sprawl.

The Maryland Forest Conservation Act

From the 1960s through the 1980s, Maryland lost a great deal of forested land due to the rapid pace of urban expansion. In response, the state enacted the Forest Conservation Act (FCA). Sensitive areas such as flood plains, stream banks, steep slopes, and critical wildlife habitat were of special concern to legislators because even when developers choose to retain trees, they may choose to eliminate stream buffers, for example, rather than to let a riparian forest regenerate; to clear land of mature trees while building and replant young trees afterwards; or to otherwise provide forest in ways that provide less than desired levels of amenities.

The FCA applies to any project involving grading on 40,000 or more square feet (slightly less than an acre). Under the FCA, developers must have an approved forest conservation plan as part of the overall development permit approval process. That forest conservation plan must specify the total amount and location of forested area retained, protective measures for stand edges and specimen trees, and measures that will protect retained forested areas permanently (e.g., covenants or easements incorporated into land deeds). The FCA also specifies minimum amounts of forested area to be provided, set according to the area and land use category of the site, existing forest cover, and proposed cleared area. County planning agencies administer the FCA as part of the overall development permit approval process but have little if any flexibility in how the requirements of the Act are met: levels of reforestation or afforestation and exemption from the Act are determined by pre-established formulas specified in the Act (Galvin, Wilson, and Honeczy 2000, Hardie, Lichtenberg, and Nickerson 2007, Lichtenberg, Tra, and Hardie 2007).

A Model of Land Allocation Within a Residential Subdivision

Our conceptual framework extends Hardie, Lichtenberg, and Nickerson's (2007) model of the choices made by a subdivision developer. A land developer subdivides a parcel of fixed size L into n identical lots of size s; forested and non-forested open space, z and a, respectively; and land devoted to roads, sidewalks, and other forms of infrastructure. Forested open space provides amenities $f(z, \phi s, z^o)$, where ϕ denotes the share of forested area incorporated into building lots, and z^o denotes forested open space nearby but outside of the subdivision. Non-forested open space provides amenities $h(a, a^o)$, where a^o denotes non-forested open space nearby but outside of the subdivision. Identical buyers have a willingness to pay per unit of developed land (bid rent),

$$(1)\quad R(s, f(z, \varphi s, z^o), h(a, a^o), y, T, g, u, i) = \frac{y - T - x(s, f(z, \varphi s, z^o), h(a, a^o), g, u, i)}{s}.$$

Here, y denotes household income, T commuting cost, x a composite of all other purchased commodities, g other public good amenities (e.g., school quality), u the equilibrium level of utility in the metropolitan area, and i the amount of land devoted to roads, sidewalks, and other infrastructure.

The land developer's goal is to maximize the rent generated by the subdivision,

$$V \equiv R(\cdot)ns - c(z) - k(a) - m(i) - Q(L)\,, \tag{2}$$

where $c(z)$ is the increasing and convex cost of afforestation, $k(a)$ is the increasing and convex cost of developing other open space, $m(i)$ is the increasing and convex cost of infrastructure development, and $Q(L)$ is the acquisition cost of the parcel—that is, the price of raw land prior to subdivision.

Development is subject to several constraints. First, development is constrained by the total area of the subdivision,

$$ns + z + a + i = L\,. \tag{3}$$

Second, zoning imposes a restriction on minimum lot size,

$$s \geq \sigma\,.\text{[1]} \tag{4}$$

Third, the FCA requires that the developer provide a minimum amount of forested area, which can consist of forested open space z or forested area incorporated into building lots ϕns,

$$z + \varphi ns \geq \zeta. \tag{5}$$

Because developers in the Maryland suburbs typically purchase entire parcels for subdivision, we assume that the constraint on total land availability [equation (3)] is always binding. If both regulatory constraints are binding as well, the developer's problem can be concentrated into the choice of forested space, non-forested open space, and infrastructure (z,a,i). The necessary conditions characterizing these choices are:

$$\frac{\partial R}{\partial f}\frac{\partial f}{\partial z}(L-z-a-i) - \frac{\partial f}{\partial \varphi}\frac{\sigma(L-\zeta-a-i)}{(L-z-a-i)} - R - c' \leq 0 \tag{6}$$

$$\frac{\partial R}{\partial h}\frac{\partial h}{\partial a}(L-z-a-i) + \frac{\partial R}{\partial f}\frac{\partial f}{\partial \varphi}\frac{\sigma(\zeta-z)}{(L-z-a-i)} - R - k' \leq 0 \tag{7}$$

$$\frac{\partial R}{\partial i}(L-z-a-i) + \frac{\partial R}{\partial f}\frac{\partial f}{\partial \varphi}\frac{\sigma(\zeta-z)}{(L-z-a-i)} - R - m' \leq 0. \tag{8}$$

When land is allocated to all three, the choice of forested open space equates the increased value of building lots due to forested open space,

$$\frac{\partial R}{\partial f}\frac{\partial f}{\partial z}(L-z-a-i)\,,$$

with the opportunity cost of land R plus the marginal cost of developing forested open space c' adjusted for any change in the value of building lots due to substitution of forested open space for permanent forested land portions of building lots,

$$\frac{\partial R}{\partial f}\frac{\partial f}{\partial \varphi}\frac{\sigma(L-\zeta-a-i)}{(L-z-a-i)}\,.$$

The choice of non-forested open space similarly equates the increased value of building lots due to non-forested open space,

$$\frac{\partial R}{\partial h}\frac{\partial h}{\partial a}(L-z-a-i)\,,$$

with the marginal cost of developing that open space k' plus the opportunity cost of land R adjusted for any change in the value of building lots due to the substitution of non-forested open space for permanent forested portions of building lots,

$$\frac{\partial R}{\partial f}\frac{\partial f}{\partial \varphi}\frac{\sigma(\zeta-z)}{(L-z-a-i)}\,.$$

The choice of infrastructure area also equates the increased value of building lots due to infrastructure,

$$\frac{\partial R}{\partial i}(L-z-a-i)\,,$$

with the marginal cost of developing that infrastructure m' plus the opportunity cost of land di-

[1] In some cases, zoning may limit maximum density rather than minimum lot size, in which case the relevant zoning restriction can be written as $n \leq v$, where v denotes the maximum number of building lots allowed on the parcel.

verted R adjusted for any change in the value of building lots due to the substitution of infrastructure land for permanent forested portions of building lots,

$$\frac{\partial R}{\partial f}\frac{\partial f}{\partial \varphi}\frac{\sigma(\zeta - z)}{(L - z - a - i)}.$$

Hardie, Lichtenberg, and Nickerson (2007) used this basic framework to study the effects of minimum lot size zoning and FCA forest planting requirements on developed land values. Using data from a random sample of suburban single-family residential subdivisions in the Washington-Baltimore corridor, they found that the average value of land in these subdivisions was decreasing in zoned minimum lot size and increasing in the FCA forestation requirement, as predicted by analysis of the theoretical model when forested portions of building lots and infrastructure requirements are ignored ($\phi = \gamma = 0$). A subsequent study by Lichtenberg, Tra, and Hardie (2007) using these same data found that minimum lot size zoning decreased total open space and that a one-acre increase in the FCA forest planting requirement increased total open space by an amount less than one, confirming a prediction (derived from the theoretical model under an assumption of Cobb-Douglas utility) that FCA forest planting requirements crowd out other forms of open space. Both the average value of land and total open space within a subdivision were unaffected by the amounts of open space nearby but outside that subdivision, indicating that the benefits of open space are largely internalized within subdivisions. A third study using these same data by Lichtenberg and Hardie (2007) found that minimum lot size zoning increased the average size of building lots and reduced the number of building lots in each subdivision, especially in subdivisions with public sewer access, confirming earlier findings that zoning reduces density (Moss 1977, Pasha 1996, McConnell, Walls, and Kopits 2006). In contrast, FCA planting requirements increased the average size of building lots but left the number of lots unchanged.

Data

We investigate the effects of these regulations on average lot size, number of lots, and infrastructure area empirically using these same data, which are described in detail in Hardie, Lichtenberg, and Nickerson (2007) and Lichtenberg, Tra, and Hardie (2007). The data set comprises a random sample totaling half of the single-family residential subdivisions approved for development between 1991 and 1997 in five Maryland counties (Charles, Carroll, Howard, Montgomery, and Prince George's) in the Baltimore-Washington corridor. Two of these counties (Montgomery and Prince George's Counties) have densely populated urban areas adjacent to Washington, D.C. Two others (Charles County southeast of Washington and Carroll County west of Baltimore) are less densely populated, with subdivisions either dispersed throughout the countryside or clustered around county town centers. The fifth, Howard County, is located between Washington and Baltimore; residents commute to both.

The subdivisions included in the study have five or more lots for single-family dwellings. Some of these subdivisions consist entirely of detached homes, others entirely of townhouses, and still others of combinations of the two. None of them have commercial or industrial sites or lots developed for apartment buildings. We omitted small subdivisions with less than five lots to avoid cases where land is subdivided primarily to provide residences for family members.

The data include information on the size of each developed lot in the subdivision; forest planting requirements under Maryland's Forest Conservation Act; minimum lot size and maximum density zoning requirements; the availability of public water and sewer services; total subdivision size; geographical attributes of the subdivision such as areas of floodplain and wetlands and linear stream frontage; commuting distances from Washington and Baltimore; and the amounts of land surrounding the subdivision in farms, residential use, parks and recreational facilities, and undeveloped forest and brush.

County planning agency files were the source of information on geographic features of each subdivision (e.g., areas of floodplain and wetlands and linear stream frontage), subdivision size, the physical utilization of space within the subdivision (including the number and sizes of building lots and total area designated as open space), forest conservation plans (including FCA forest planting requirements), and the availability of public sewer service. The amount of land in roads, sidewalks, and other forms of infrastructure in each subdivision was calculated as a residual by subtracting land in building lots, open space, wetlands, and floodplain from the total area of the subdivision.

Maryland Property View GIS databases were the sources of information used to calculate commuting (road) distance from each subdivision to the nearest central business district (Washington, D.C., or Baltimore) and the surrounding area within a given distance of the centroid of each subdivision in farmland, parks and recreational facilities, and undeveloped forest and brush. The latter were calculated under the assumption that the subdivision occupied a circle with an area equal that of the subdivision around its centroid. The Property View data were then used to calculate the amounts of land in farms, parks/recreation areas, and forest/brush in a ring of a half-mile radius surrounding the circle representing the subdivision.

County zoning documents were used to determine minimum lot sizes and maximum allowable densities corresponding to zoning codes obtained from the Property View data. In cases where zoning codes did not specify maximum allowable density (about 12 percent of the sample), density restrictions were calculated as the reciprocal of minimum lot size. Zoned maximum allowable density was then multiplied by the net (buildable) area of the subdivision (total subdivision area less the area in floodplain and wetlands) to obtain the maximum allowable number of lots in each subdivision. Subdivisions regulated under transferable development rights (Montgomery County) or planned use development zoning (Prince George's and Charles Counties) were excluded from the analysis, resulting in a usable sample of 228 subdivisions. Descriptive statistics are shown in Table 1.

Specification and Estimation of the Econometric Model

Our econometric model has three dependent variables for each subdivision: the average size of building lots; the number of building lots; and land in roads, sidewalks, and other forms of infrastructure. Following the conceptual framework, we assume that all three are functions of zoning and regulation under the FCA. Also included in each regression equation were control variables such as the size of the subdivision, geographic features of the subdivision that may limit the way space can be used, land uses outside but nearby the subdivision, and the location of the subdivision.

All three dependent variables were treated as functions of FCA forest planting requirements. A dummy variable indicating subdivisions exempt from the FCA was also included in all three equations. Because minimum lot size and the maximum allowable number of lots were so closely related in many cases (the maximum allowable number of lots was calculated using the reciprocal of minimum lot size for about 12 percent of the sample), we tested statistically whether minimum lot size and/or the maximum allowable number of lots was the pertinent form of zoning regulation. As one would expect, minimum lot size was a statistically significant determinant of average lot size while the maximum allowable number of lots was not, so the maximum allowable number of lots was excluded from the average lot size equation. Similarly, the maximum allowable number of lots was a statistically significant determinant of the actual number of lots while the minimum lot size was not, so minimum lot size was excluded from the number of lots equation. Both forms of zoning regulation were used in the infrastructure land equation because preliminary regressions indicated that both might have statistically significant effects.

Control variables such as floodplain and wetlands acreage and linear stream frontage were included in all three regression equations to measure geographical features that might limit the ways developers are able to use land within the subdivision. Measures of open space in the vicinity of the subdivision were also included as control variables. Some previous hedonic studies have found housing prices to be increasing in various forms of nearby open space, raising the possibility that developers might choose to substitute permanently preserved open space in close proximity to the subdivision in place of open space within a subdivision. All three regression equations also included distance from the subdivision to the nearest urban center (Washington or Baltimore) and dummies for the county in which the subdivision was located, the latter to control for unobserved attributes of these very different jurisdictions.

The availability of public sewer service may influence the effects of zoning and FCA forest

Table 1. Descriptive Statistics of the Data Used in the Econometric Analysis

Variable	Subdivisions with Public Sewer Access		Subdivisions w/out Public Sewer Access	
	Mean	Std. Dev.	Mean	Std. Dev.
Average subdivision lot size (acres)	0.408854	0.4446604	3.008105	2.8734212
Number of lots in subdivision	38.60366	55.1894249	19.79104	17.699116
Acres in roads, sidewalks, and other infrastructure	2.7346524	11.3113169	11.8273582	32.5009619
Subdivision exempt from FCA (yes = 1)	0.195122	0.3975083	0.119403	0.3267094
Forested acres required by FCA	6.111159	10.3775542	22.66403	25.7391033
Zoned minimum lot size (acres)	0.313773	0.3106216	1.922164	1.3616676
Zoned maximum number of lots	53.31677	76.9839086	30.55684	36.6930959
Total site acreage	19.74052	26.6988004	73.90503	77.7979909
Acres of floodplain in subdivision	1.548781	4.7727947	7.431343	24.4997106
Acres of wetland in subdivision	1.15122	2.8868963	4.430303	7.9599182
Linear feet of stream in subdivision	577.2744	1226.83	1664.04	2911.32
Percentage of land within ½ mile in farmland	10.30601	13.3123776	38.88156	20.6566289
Percentage of land within ½ mile in parks, public spaces, etc.	2.887145	6.0749432	0.118967	0.4369511
Percentage of land within ½ mile in forest, brush, or undeveloped	28.30204	17.8050248	37.98824	20.8223467
Commuting distance to nearest CBD (road miles)	17.65915	12.5054776	38.0806	21.4802463
Subdivision located in Carroll County	0.036585	0.1883165	0.343284	0.4783887
Subdivision located in Charles County	0.079268	0.2709845	0.298508	0.4610569
Subdivision located in Howard County	0.256098	0.4378132	0.074627	0.2647716
Subdivision located in Montgomery County	0.27439	0.4475731	0.19403	0.3984366
Number of observations	164		67	

planting requirements because the amount of land required for septic systems to meet health regulations may supersede minimum lot size zoning (and, in doing so, change the opportunity cost of land, which affects the attractiveness of open space and infrastructure). Likelihood ratio tests indicated statistically significant differences between subdivisions with and without public sewer, so we estimated separate models for each.[2]

[2] The likelihood ratio test statistics were 54.19 for the average lot size equation, 95.08 for the number of lots equation, and 136.65 for the infrastructure area equation; all had 16 degrees of freedom and corresponding p-values of 10^{-5} or lower.

A number of studies have shown that zoning designations may be altered over time in response to economic pressures (Wallace 1988, McMillan and McDonald 1991, Munneke 2005). Features of the zoning regulations in the counties we consider give further grounds for this potential endogeneity. Howard County zoning regulations include an explicit formula trading off lot size for open space; other counties set different open space requirements for townhouses and for detached homes.

We tested for potential endogeneity of minimum lot size and maximum number of lots zoning regulations separately using road miles to the

Chesapeake Bay Bridge, to the nearest town center, to the nearest large shopping mall, to the nearest sports facility, and to the nearest military installation as instruments for each form of zoning. Regressions of average lot size, numbers of lots, and infrastructure area in subdivisions without public sewer access showed no correlation between this set of instruments and each dependent variable. A regression of the number of lots in subdivisions with public sewer access yielded the same result (Table 2). Regressions indicated that distance to the Chesapeake Bay Bridge was correlated with average lot size in subdivisions with public sewer access and that distance to the nearest sports facility was correlated with infrastructure area in subdivisions with public sewer access. Distance to the Chesapeake Bay Bridge was thus not used as an instrument in the average lot size model for subdivisions with public sewer access, while distance to the nearest sports facility was not used as an instrument in the infrastructure area model for subdivisions with public sewer access. In every case, regressions indicated correlation between minimum lot size and the maximum number of lots and the relevant set of instruments (Table 2).

We conducted Hausman tests using the residuals from first-stage reduced-form regressions of minimum lot size and the maximum number of lots on all of the independent variables. Those Hausman tests indicated no correlation between unobserved factors influencing zoned minimum lot size and infrastructure area or zoned maximum allowable density and both the number of lots and infrastructure area so we estimated the econometric model treating zoning as exogenous in these two equations. A Hausman test did indicate correlation between minimum lot size and average lot size in subdivisions with public sewer access but not in subdivisions without public sewer access (Table 2). We thus treated minimum lot size zoning in the infrastructure area as endogenous in subdivisions with access to public sewer service and exogenous in subdivisions without public sewer access.

We estimated the models for subdivisions with and without public sewer access as separate systems of three equations taking into account correlation between unobserved factors affecting average lot size, the number of lots, and infrastructure area in the same subdivision. The model for subdivisions with public sewer access was estimated using three-stage least squares using the instruments enumerated above. The model for subdivisions without public sewer access was estimated using a seemingly unrelated regressions model.

Estimation Results

The econometric models for both classes of subdivisions fit the data quite well (Table 3). The estimated coefficients confirm that both zoning and FCA forest planting requirements influence how developers organize space within these subdivisions. How they do so in closer-in subdivisions with public sewer access differs noticeably from how they do so in more remote subdivisions without public sewer access.

Impacts of Zoning

In subdivisions with public sewer access, both minimum lot size and maximum density zoning influence the size and number of housing lots; neither has a statistically significant effect on the area devoted to roads, sidewalks, and other forms of infrastructure. A one-acre increase in minimum lot size increases average lot size by roughly one and a half acres (the coefficient is 1.53, the t-statistic for the hypothesis that this coefficient is greater than one is 2.44). A one-unit decrease in the maximum allowable number of lots reduces the number of lots by a little over three-fifths of a lot (the coefficient is 0.63, the t-statistic for the hypothesis that this coefficient is less than one is 7.12). In these subdivisions, then, more restrictive zoning results in fewer homes on substantially larger lots. The econometric results obtained by Lichtenberg, Tra, and Hardie (2007) using these same data suggest that developers mitigate the effects of more restrictive zoning by allocating to building lots land that otherwise would have gone to open space, i.e., by providing more open space as a private good (located within individual building lots) in lieu of open space as a local public good within the subdivision. Such an outcome is, of course, completely consistent with the use of zoning as a means of providing open space.

In subdivisions without public sewer access, zoning influences the size of lots and the area devoted to roads, sidewalks, and other forms of infrastructure, but not the number of lots. A one-acre increase in minimum lot size increases average lot size by about three-fifths (the coefficient

Table 2. Specification Test Statistics

	Subdivisions with Public Sewer Access			Subdivisions without Public Sewer Access		
	Average Lot Size	Number of Lots	Infrastructure Area	Average Lot Size	Number of Lots	Infrastructure Area
F-statistic, coefficients of all instruments = 0 in regression on all independent variables	1.77 (p = 0.1392)	0.69 (p = 0.6289)	1.13 (p = 0.3461)	0.46 (p = 0.7656)	0.47 (p = 0.7969)	0.66 (p = 0.6553)
PANEL A: MINIMUM LOT SIZE						
R^2, regression of lot size on instruments only	0.1177		0.0641	0.3258		0.3258
F-statistic, coefficients of all instruments = 0 in regression of minimum lot size on instruments only	5.27 (p = 0.0005)		2.71 (0.0323)	5.89 (p = 0.0002)		5.89 (p = 0.0002)
Hausman test t-statistic	-2.12 (p = 0.0356)		0.65 (p = 0.5180)	0.79 (p = 0.4313)		0.51 (p = 0.6115)
PANEL B: MAXIMUM NUMBER OF LOTS						
R^2, regression of lot size on instruments only		0.0304	0.0304		0.0756	0.0756
F-statistic, coefficients of all instruments = 0 in regression of maximum number of lots on instruments only		0.98 (0.4328)	0.98 (0.4328)		0.98 (0.4365)	0.98 (0.4365)
Hausman test t-statistic		0.45 (p = 0.6539)	-0.07 (p = 0.9428)		-0.40 (p = 0.6390)	0.61 (p = 0.5418)

Notes: Full set of instruments: Road miles to the Chesapeake Bay Bridge, to the nearest town center, to the nearest large shopping mall, to the nearest sports facility, and to the nearest military installation. Set of instruments for minimum lot size in the average lot size equation in subdivisions with public sewer access excludes road miles to the Chesapeake Bay Bridge. Set of instruments for minimum lot size in the infrastructure area equation in subdivisions with public sewer access excludes road miles to the nearest sports facility.

Table 3. Estimated Effects of Zoning and Forest Conservation Act Requirements on Lot Size, Number of Lots, and Infrastructure Area

	Subdivisions with Public Sewer Access			Subdivisions without Public Sewer Access	
Variable	OLS	2SLS	3SLS	OLS	SUR
PANEL A: AVERAGE LOT SIZE					
Subdivision exempt from FCA (yes = 1)	-0.02293 (0.04123)	-0.02866 (0.046475)	-0.02874 (0.046475)	4.03485** (0.99072)	4.045513** (0.990613)
Forested acres required by FCA	0.01095** (0.00365)	0.002570 (0.006076)	0.002395 (0.006067)	0.02153 (0.02617)	0.020901 (0.026156)
Zoned minimum lot size (acres)	1.13917** (0.06401)	1.524652** (0.217169)	1.533162** (0.216770)	0.65777* (0.31124)	0.571127* (0.287637)
R^2	0.8256	0.7058	0.6508	0.4974	0.8942
PANEL B: NUMBER OF LOTS					
Subdivision exempt from FCA (yes = 1)	-14.39120* (6.71908)		-14.4425* (6.719078)	-7.15250* (3.54813)	-7.28269* (3.551771)
Forested acres required by FCA	1.68290** (0.64162)		1.598351* (0.641532)	0.00738 (0.09339)	0.010218 (0.093372)
Zoned maximum number of lots	0.65209** (0.05143)		0.634270** (0.051379)	0.08837* (0.04332)	0.063588 (0.035602)
R^2	0.7032		0.6508	0.8275	0.8942
PANEL C: INFRASTRUCTURE AREA					
Subdivision exempt from FCA (yes = 1)	1.75142 (1.51764)		1.719287 (1.517283)	0.58539 (6.49876)	0.717756 (6.498042)
Forested acres required by FCA	-0.80822** (0.14727)		-0.82492** (0.146764)	-0.37584** (0.17147)	-0.38261** (0.171281)
Zoned minimum lot size (acres)	2.51621 (2.72718)		1.731483 (2.446406)	0.23160 (2.16796)	-0.62674 (1.663441)
Zoned maximum number of lots	0.01966 (0.01301)		0.014155 (0.012735)	0.49064** (0.08437)	0.495729** (0.0817526)
R^2	0.6708		0.6508	0.7820	0.8942
Number of observations	162		162	66	66

Notes: Standard errors reported in parentheses. Model for subdivisions with public sewer access estimated using three-stage least squares. Model for subdivisions without public sewer access estimated using seemingly unrelated regressions. Independent variables included in all regressions: total site acreage; acres of floodplain; acres of wetland; linear feet of stream; percentage of land within one-half mile in farmland; percentage of land within one-half mile in parks, public spaces, etc.; percentage of land within one-half mile in forest, brush, or undeveloped; commuting distance to nearest CBD; and fixed effects for county in which subdivision is located. Model for average lot size in subdivisions with public sewer access also includes distance to the Chesapeake Bay Bridge. Model for infrastructure area in subdivisions with public sewer access also includes distance to the nearest sports facility. ** denotes significantly different from zero at a 1 percent significance level, and * denotes significantly different from zero at a 5 percent significance level.

is 0.57, the t-statistic for the hypothesis that this coefficient is less than one is 1.49); additional land already needed for septic systems may explain why average lot size increases by less than an acre in response to a one-acre increase in minimum lot size, i.e., why this form of zoning is less than fully binding. A one-unit decrease in the maximum number of lots decreases area devoted to infrastructure by about half an acre. Minimum lot size zoning has no effect on the area allocated to infrastructure, though, while maximum density zoning has no effect on the number of lots. These results suggest that developers relax constraints imposed by maximum density zoning by laying out building lots in ways that economize on area devoted to roads and other forms of infrastructure. Combining these results with those of Lichtenberg, Tra, and Hardie (2007) suggests that developers mitigate the effects of more restrictive lot size zoning by substituting open space within individual building lots for common open space amenities within the subdivision.

Impacts of FCA Forest Planting Requirements

In subdivisions with access to public sewer systems, an increase in the FCA forest planting requirement has no effect on average lot size but increases both the number of lots and the area allocated to roads and other forms of infrastructure. A one-acre increase in required forest planting increases the number of lots by 1.68 and reduces infrastructure area by as much as an acre (the coefficient is -0.82, the t-statistic for the hypothesis that this coefficient is less than one in absolute value is 1.23). These results suggest that FCA planting requirements promote the use of clustering.

In subdivisions without public sewer access, FCA forest planting requirements influence the amount of land allocated to infrastructure but not average lot size or the number of lots. In these subdivisions, a one-acre increase in the FCA forest planting requirement reduces infrastructure area by roughly two-fifths of an acre (the coefficient is -0.38, the t-statistic for the hypothesis that this coefficient is less than one in absolute value is 3.62), suggesting that developers respond to FCA planting requirements in these subdivisions by laying out building lots in ways that economize on area devoted to roads and other forms of infrastructure.

Impacts of Regulation on Sprawl

An estimate of the effect of these regulations on sprawl can be obtained by differentiating the land availability constraint [equation (3)] with respect to each form of regulation to obtain the change in subdivision size due to a change in regulation. Following this procedure for an arbitrary regulation $\gamma = (\sigma, \zeta, v)$ (where v represents the zoned maximum allowable number of lots) and converting to elasticity form yields

$$(9) \quad \eta_\gamma \equiv \frac{\gamma}{L}\frac{dL}{d\gamma} = \frac{\gamma}{L}\left(n\frac{\partial s}{\partial \gamma} + s\frac{\partial n}{\partial \gamma} + \frac{\partial (z+a)}{\partial \gamma} + \frac{\partial i}{\partial \gamma} \right).$$

For minimum lot size and FCA forest planting requirements, the elasticities given by equation (9) equal the percentage change in the total amount of land in the region needed to accommodate the existing population, a measure of how each of these regulations influences sprawl. For the zoned maximum allowable number of lots, the elasticity given by equation (9) gives the percentage change in land per household in existing subdivisions; the percentage change in the total amount of land needed to accommodate the existing population due to a one percent reduction in the maximum allowable number of lots (i.e., more stringent density zoning) can be found by subtracting the elasticity obtained from equation (9) from one (i.e., $1-\eta_v$).

The coefficients of the models estimated here give $\partial s/\partial\gamma$, $\partial n/\partial\gamma$, and $\partial i/\partial\gamma$. Lichtenberg, Tra, and Hardie (2007, Table 3) find $\partial(z+a)/\partial\zeta$ equal to 0.39 in subdivisions with public sewer access and 0.85 in subdivisions without public sewer access; $\partial(z+a)/\partial\sigma$ equal to -7.98 in subdivisions with public sewer access and -6.44 in subdivisions without public sewer access; and $\partial(z+a)/\partial v$ equal to zero in both kinds of subdivisions. We used these parameter estimates along with the coefficient estimates obtained here and the sample means of average lot size, number of lots, subdivision size, FCA planting requirements, minimum lot size, and maximum allowable number of lots in subdivisions with and without public sewer access to calculate the elasticities in equation (9).

Our estimates indicate that sprawl is quite responsive to zoning. In subdivisions with access to public sewer systems, minimum lot size requirements have the largest impact: a one percent increase in minimum lot size results in a 0.83 percent increase in the amount of land needed to accommodate the existing population of the Baltimore-Washington corridor. The effect of density requirements is smaller in these subdivisions: a one percent decrease in the maximum allowable number of lots increases the amount of land needed to accommodate the existing population by 0.33 percent. In subdivisions without public sewer access, density zoning has a greater effect than minimum lot size zoning: a one percent reduction in the maximum allowable number of households increases the amount of land needed to accommodate the existing population by 0.74 percent, while a one percent increase in minimum lot size increases that amount of land by only 0.17 percent.

Overall, these results are in line with the claim that zoning promotes urban sprawl by reducing density and thus pushing the urban boundary out farther into rural areas. They support the results of theoretical models such as Pasha's (1996) that predict that minimum lot size zoning has a large effect on land use in close-in suburban areas. They also confirm existing empirical evidence, notably the results of McConnell, Walls, and Kopits' (2006) Calvert County study. As we noted earlier, these results are entirely consistent with the use of zoning to preserve open space within individual building lots.

How do policies that primarily preserve open space as a public good influence sprawl? Planting requirements under Maryland's Forest Conservation Act fall into this category (Lichtenberg, Tra, and Hardie 2007). Our calculations using equation (9) indicate that FCA forest planting requirements also foster sprawl, albeit considerably less than zoning. A one percent increase in FCA forest planting requirements increases the amount of land required to accommodate the existing population by 0.09 percent in subdivisions with access to public sewer systems and 0.27 percent in subdivisions without public sewer access. These effects are more or less commensurate with the effects of some forms of zoning—but only the forms of zoning that impose only second-order constraints. Thus, the effect of the FCA planting requirement is similar in magnitude to the effect of density zoning in subdivisions with access to public sewer systems, where minimum lot size zoning is the principal constraint on developers. Similarly, the effect of the FCA planting requirement is similar in magnitude to the effect of minimum lot size zoning in subdivisions without public sewer access, where density zoning is the principal constraint on developers.

Concluding Remarks

Rapid urbanization threatens the availability of and access to open space and thus often triggers the enactment of policies designed to preserve open space. Both theoretical studies and prior econometric studies suggest that some of those policies may result in more extensive development by reducing housing density so that more land is needed to accommodate population growth. In other words, open space preservation policies may contribute to urban sprawl.

We present a conceptual framework of the choices facing a developer subdividing a parcel of fixed size and use it to specify an econometric model of average lot size, the number of lots per subdivision, and land allocated to roads, sidewalks, and other forms of infrastructure. Lot size, lot numbers, and infrastructure are functions of minimum lot size and maximum density zoning, forest planting requirements under the Maryland Forest Conservation Act, and control variables influencing the use of space such as subdivision size, geographic features of the subdivision, subdivision location, and land use in areas surrounding the subdivision. We fit the parameters of the econometric model using data from suburban subdivisions in five counties in the Baltimore-Washington suburbs.

The estimated coefficients indicate that minimum lot size zoning increases average lot size and that maximum density zoning reduces the number of lots and, in subdivisions without public sewer access, infrastructure area. Consistent with previous theoretical results and empirical evidence, zoning has a significant impact on sprawl: the elasticity of land needed to accommodate the existing population of the Baltimore-Washington corridor is close to one for minimum lot size zoning in close-in subdivisions with access to public sewer systems and for maximum density zoning in more remote subdivisions without public sewer access.

The estimated coefficients also indicate that forest planting requirements increase the number of lots in subdivisions with public sewer access and reduce infrastructure area in all subdivisions. As a result, forest planting requirements also contribute to sprawl, albeit only very modestly so. The elasticity of land needed to accommodate the existing population of the Baltimore-Washington corridor is about 0.1 in close-in subdivisions with access to public sewer systems and under 0.3 in more remote subdivisions without public sewer access.

These results point to a conflict between preserving "semi-private" open space in the immediate vicinity of homes and preserving public open space at the urban fringe. Zoning requires developers to provide open space incorporated into building lots, where it is enjoyed primarily by homeowners and secondarily by their immediate neighbors, with little spillover beyond that. Forest planting requirements result in the provision of "semi-public" open space used mainly by homeowners within a subdivision, again with little spillover outside the subdivision [and, as Lichtenberg, Tra, and Hardie (2007) show, with some offsetting reductions in non-forested open space within the subdivision as well]. Both types of regulation increase the amount of land needed to accommodate a population of any given size, which, in a growing metropolitan area, means that both types of regulation contribute to sprawl and hence to the loss of open space at the urban fringe.

References

Bento, A.M., S.F. Franco, and D.T. Kaffine. 2006. "Efficiency and Spatial Impacts of Development Taxes: The Critical Role of Alternative Revenue-Recycling Schemes." *American Journal of Agricultural Economics* 91(5): 1304–1311.

Bockstael, N.E., and E.G. Irwin. 2000. "Economics and the Land Use–Environment Link." In T. Tietenberg and H. Folmer, eds., *International Yearbook of Environmental and Resource Economics 2000/2001*. Cheltenham, UK: Edward Elgar.

Brueckner, J.K. 1990. "Growth Controls and Land Values in an Open City." *Land Economics* 66(3): 237–248.

Cheshire, P., and S. Sheppard. 1995. "On the Price of Land and the Value of Amenities." *Economica* 62(246): 247–267.

Galvin, M.F., B. Wilson, and M. Honeczy. 2000. "Maryland's Forest Conservation Act: A Process for Urban Greenspace Protection During the Development Process." *Journal of Arboriculture* 26(5): 275–280.

Geoghegan, J. 2002. "The Value of Open Spaces in Residential Land Use." *Land Use Policy* 19(1): 91–98.

Geoghegan, J., L. Lynch, and S. Bucholtz. 2003. "Capitalization of Open Spaces into Housing Values and the Residential Property Tax Revenue Impacts of Agricultural Easement Programs." *Agricultural and Resource Economics Review* 32(1): 33–45.

Geoghegan, J., L.A. Wainger, and N.E. Bockstael. 1997. "Spatial Landscape Indices in a Hedonic Framework: An Ecological Economics Analysis Using GIS." *Ecological Economics* 23(3): 251–264.

Hardie, I., E. Lichtenberg, and C.J. Nickerson. 2007. "Regulation, Open Space, and the Value of Land Undergoing Residential Subdivision." *Land Economics* 83(4): 458–474.

Irwin, E.G. 2002. "The Effects of Open Space on Residential Property Values." *Land Economics* 78(4): 465–480.

Irwin, E.G., and N.E. Bockstael. 2004. "Land Use Externalities, Open Space Preservation, and Urban Sprawl." *Regional Science and Urban Economics* 34(6): 705–725.

Lichtenberg, E., and I. Hardie. 2007. "Open Space, Forest Conservation, and Urban Sprawl in Maryland Suburban Subdivisions." *American Journal of Agricultural Economics* 89(5): 1198–1204.

Lichtenberg, E., C. Tra, and I. Hardie. 2007 "Land Use Regulation and the Provision of Open Space in Suburban Residential Subdivisions." *Journal of Environmental Economics and Management* 54(2): 199–213.

McConnell, V., M. Walls, and E. Kopits. 2006. "Zoning, TDRs and the Density of Development." *Journal of Urban Economics* 59(3): 440–457.

McMillan, D.P., and J.F. McDonald. 1991. "A Simultaneous Equations Model of Zoning and Land Values." *Regional Science and Urban Economics* 21(1): 14–27.

Moss, W.G. 1977. "Large Lot Zoning, Property Taxes and Metropolitan Area." *Journal of Urban Economics* 4(4): 408–427.

Munneke, H.J. 2005. "Dynamics of Urban Zoning Structure: An Empirical Investigation of Zoning Change." *Journal of Urban Economics* 58(3): 455–473.

Nechyba, T.J., and R.P. Walsh. 2004. "Urban Sprawl." *Journal of Economic Perspectives* 18(4): 177–200.

Pasha, H.A. 1996. "Suburban Minimum Lot Size Zoning and Spatial Equilibrium." *Journal of Urban Economics* 40(1): 1–12.

Thorsnes, P. 2002. "The Value of a Suburban Forest Preserve: Estimates from Sales of Vacant Residential Building Lots." *Land Economics* 78(3): 426–441.

Tyrväinen, L., and A. Miettinen. 2000. "Property Prices and Urban Forest Amenities." *Journal of Environmental Economics and Management* 39(2): 205–223.

Wallace, N.E. 1988. "The Market Effects of Zoning Undeveloped Land: Does Zoning Follow the Market?" *Journal of Urban Economics* 23(3): 307–326.

Wu, J.J. 2000. "Slippage Effects of the Conservation Reserve Program." *American Journal of Agricultural Economics* 82(4): 979–992.

Wu, J.J., R.M. Adams, and A.J. Plantinga. 2004. "Amenities in an Urban Equilibrium Model: Residential Development in Portland, Oregon." *Land Economics* 80(1): 19–32.

Wu, J.-J., and A.J. Plantinga. 2003. "The Influence of Public Open Space on Urban Spatial Structure." *Journal of Environmental Economics and Management* 46(2): 288–309.