Modeling and Managing Urban Growth at the Rural-Urban Fringe: A Parcel-Level Model of Residential Land Use Change

Elena G. Irwin, Kathleen P. Bell, and Jacqueline Geoghegan

As many local and state governments in the United States grapple with increasing growth pressures, the need to understand the economic and institutional factors underlying these pressures has taken on added urgency. From an economic perspective, individual land use decisions play a central role in the manifestation of growth pressures, as changes in land use pattern are the cumulative result of numerous individual decisions regarding the use of lands. In this study, the issue of growth management is addressed by developing a spatially disaggregated, microeconomic model of land conversion decisions suitable for describing residential land use change at the rural-urban fringe. The model employs parcel-level data on land use in Calvert County, Maryland, a rapidly growing rural-urban fringe county. A probabilistic model of residential land use change is estimated using a duration model, and the parameter estimates are employed to simulate possible future growth scenarios under alternative growth management scenarios. Results suggest that "smart growth" objectives are best met when policies aimed at concentrating growth in target areas are implemented in tandem with policies designed to preserve rural or open space lands.

Key Words: growth management, land use change, rural-urban fringe, spatial modeling

Over the last decade, growth management has gained prominence as a policy issue. Coverage of growth management issues by the popular press has risen substantially (e.g., Mitchell, 2001; Lacayo, 1999), and terms such as "sprawl" and "smart growth" are increasingly becoming household phrases. Citizen polls demonstrate concern over urban sprawl (e.g., Pew Center for Civic Journalism, 2000), and organizations representing the full spectrum of political beliefs have published reports commenting on growth management (e.g., Shaw and Utt, 2000; Sierra Club, 2000). In addition, growth management has surfaced as an issue at the ballot box. From 1998 to 2000, approximately 459 ballot initiatives dealing with growth management and the preservation of open space appeared on local and state ballots across the nation. Of these 459 ballot initiatives, 390 passed (an 85% success rate), and together these initiatives committed approximately $14.5 billion to public land acquisition (Land Trust Alliance, 1999, 2000, 2001).

Finally, numerous state and local governments have recently advanced legislation to manage growth or reform land use planning. For example, more than 2000 land use bills were introduced in state legislatures between 1999 and 2001, with approximately 20% enacted into law (American Planning Association, 2002; Frank, 2000). Notable examples include the growth management and planning legislation adopted in Minnesota, New Jersey, Maryland, Pennsylvania, and Tennessee (Hirschhorn, 2000).

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Despite the rise in prominence, the public dialogue on growth management is rife with ambiguity and controversy. Framing growth management as a public policy issue has proven difficult for several reasons. First, growth pressures are difficult to measure rigorously, and measures appropriate for one region may not be suitable for other regions. For example, definitions of sprawl are typically vague and evasive. Some quantitative definitions of sprawl (e.g., *USA Today*'s sprawl index) use population or housing density measures to describe this form of development, in which lower densities of development are interpreted as an indicator of sprawl.

Similarly, growth management policy tools are often complex and cumbersome. For example, "smart growth" (Benfield et al., 2001), which calls for targeting infrastructure projects in select growth areas, encouraging transit-oriented development, and preserving more green spaces via compact development, is not widely understood or easily defined. In addition, many communities and regions simply lack the data resources required to track growth and understand changes in development patterns. Although remotely sensed and geographic information system (GIS) land use and land cover data are becoming more common, few communities have actually established historical data resources that permit changing land use patterns to be documented and growth management strategies to be assessed.

Furthermore, there is only a limited understanding of the benefits and costs of alternative development patterns and the effectiveness of different growth management tools. As a result, public discussions of growth management are often one-dimensional, with some groups focusing on costs and others focusing on benefits. Studies have addressed the public finance (e.g., cost of providing public services) and ecological impacts of alternative development patterns, emphasizing the divergence between the private and social costs of individual development decisions.

Several studies have demonstrated that the costs of servicing a more dispersed population are higher than those of servicing a more clustered population, due to the increased capital outlays necessary to reach a more dispersed population (see Burchell et al., 1998). However, these studies have come under criticism (see Gordon and Richardson, 1997; Shaw and Utt, 2000). Studies on the environmental impacts of alternative patterns of development have also produced mixed conclusions. As better data resources become available, it is likely our understanding of the linkages between development patterns and changes in the quality and quantity of habitat and air pollution, as well as water pollution, will improve.

Finally, public discussions of growth management are affected by issues of governance. Because growth management is often a local government responsibility, discussions can easily become segmented and may overlook regional trends as well as interdependencies across jurisdictions. Numerous studies have called for greater consideration of the linkages among urban, suburban, and rural areas (Katz and Bradley, 1999; Rusk, 1999; Downs, 1999; Orfield, 1997).

As many local and state governments in the U.S. grapple with increasing growth pressures, the need to understand the economic and institutional factors underlying these events has taken on added urgency. From an economic perspective, individual land use decisions play a central role in the manifestation of growth pressures. Changes in land use pattern are the cumulative result of numerous individual decisions regarding the use of lands. Accordingly, the study of land use change at a micro or individual scale provides for novel opportunities to understand the human behavior underlying these decisions, and to assess the effects of environmental, public finance, and growth management policies on these decisions.

In this paper, we address the issue of growth management by developing a spatially disaggregated, microeconomic model of land conversion decisions. We believe models such as the one described here offer great potential to contribute to the broader public discourse on growth management because they allow for individual preferences and growth management tools to be jointly assessed.

The spatially explicit model developed here addresses the conversion of lands to residential use (residential land use change) at the rural-urban fringe. The rural-urban fringe begins where suburbs end, and extends into rural areas. At the rural-urban fringe, changes in land use often coincide with transitions from traditional, rural communities to more developed, urban communities. Urban growth at the rural-urban fringe is of unique concern to citizens and policy makers alike, as "exurban" areas have outpaced urban and suburban areas in population growth for the last several decades (Nelson, 1992; Daniels, 1999).

The model is estimated using data on land conversion in Calvert County, Maryland. The pattern of land use change in Calvert County, one of the fastest growing exurban counties in Maryland, is typical of urban growth occurring elsewhere in the United States at the rural-urban fringe. Between 1981 and 1997, this county experienced a 94% increase in population and a 191% increase in the number of acres in low-density residential use (see figure 1).[1]

We take a spatially disaggregated approach to modeling residential land use change that accounts for the spatial heterogeneity of policies (e.g., zoning) and landscape features (e.g., slope, soil type, locational amenities) influencing individual land use decisions. Our ability to address the spatial heterogeneity of the landscape over time is the direct result of having access to parcel-level land use data. A duration modeling framework is employed which allows us to better capture how the cumulative effects of changes in variables over time influence future land use decisions and the timing of land conversion. The model developed here builds on other spatially explicit and disaggregate models of urban land use change, including the California urban futures model by Landis (1995) and Landis and Zhang (1998a, b), and work in the central Maryland region by Bockstael and Bell (1998), Geoghegan and Bockstael (2000), and Irwin and Bockstael (2002a, b).

Following the estimation of the empirical model of residential land use change, the parameter estimates are used to simulate future growth patterns under alternative policy scenarios. The objective of this predictive exercise is to assess the effectiveness of various growth management strategies in reaching stated growth management objectives. We do not address the economic efficiency of these alternative growth patterns. Rather, it is assumed that an important goal of growth management is to concentrate development in targeted growth areas and deflect it from rural areas. Taking this as the stated goal of local and state growth management efforts, we then consider the actual effectiveness of policies that were designed to accomplish this goal in Calvert County, Maryland.

The remainder of the paper is divided into six sections. First, a description is provided of a theoretical model of individual land conversion decisions. This theoretical discussion is followed by a summary of the empirical model and a detailed discussion of the dependent and explanatory variables used in the empirical model. After the results of the empirical model are summarized, the paper comments on the implications of these results for managing development patterns and depicts the simulated impacts of three alternative policy scenarios. The paper ends with a summary of our findings and concluding comments.

[1] From 1990 to 2000, Calvert County experienced a 45.1% increase in population. The estimated population in 2000 was 74,563.

Theoretical Model

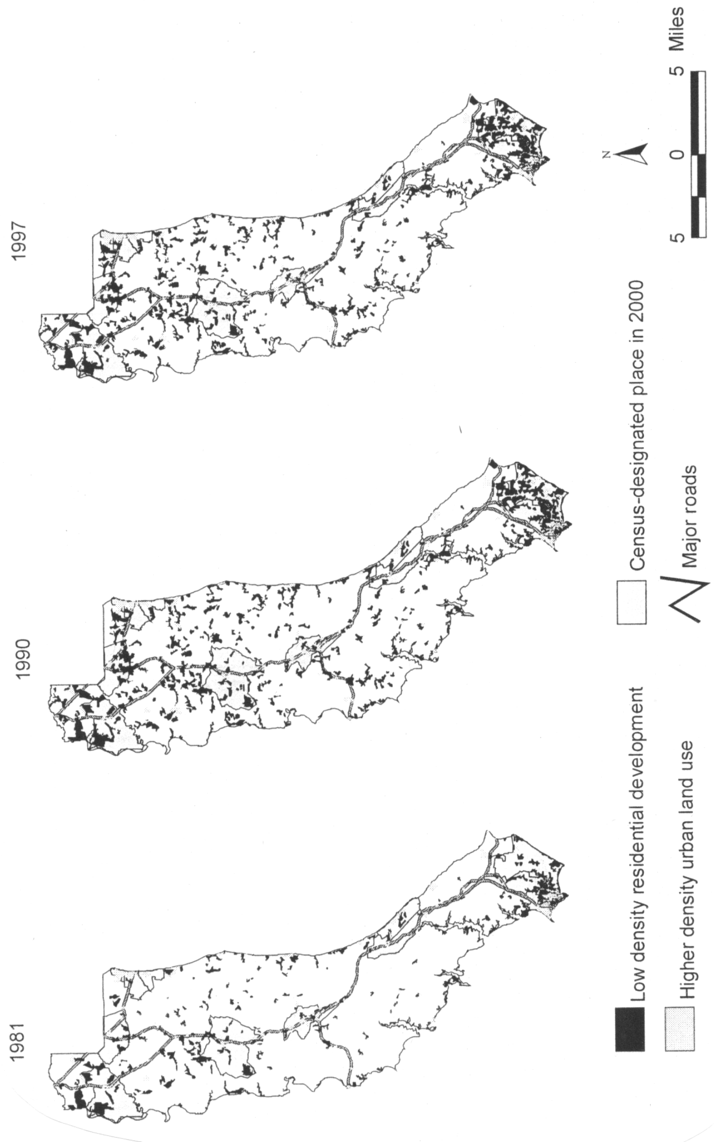
Consider the viewpoint of a profit-maximizing landowner who owns an "undeveloped" land parcel and makes a discrete choice in every period regarding the subdivision of the parcel for residential use. A parcel is considered "undeveloped" if its current use is in agriculture or another resource-producing activity such as commercial forestry, as well as if it is in a natural state. The individual landowner chooses either to convert the parcel by subdividing the parcel into multiple residential lots or to keep the parcel in an undeveloped use. Conditional on the parcel being undeveloped in the present period, the agent's decision is a binary discrete choice of converting the parcel to residential use or keeping the parcel in an undeveloped use, such that the present discounted sum of all future expected returns from the land is maximized. Therefore, the agent faces a dynamic optimization problem in which she will choose to convert the parcel to residential use when the expected present discounted value of the parcel in residential use, net of conversion costs and opportunity costs, is maximized over an infinite time horizon.

Given several simplifying assumptions about the time paths of growth pressures and conversion costs, Irwin and Bockstael (2002a) show the resulting optimal conversion rule posits that parcel j will be converted in the first period in which the following conditions hold:

$$(1) \qquad V_{jrT|u} - \sum_{t=0}^{\infty} V_{juT+t}\,\delta^{T+t} > 0,$$
$$V_{jrT|u} - V_{juT|u} > \delta(V_{jrT+1|u}),$$

where $V_{jrt|u}$ represents the net expected returns from converting parcel j (which is currently in undeveloped land use u) to use r at time t, and δ is the discount factor, which is equal to $1/(1+i)$ where i is the interest rate. The first condition states that parcel j will be converted from use u to use r in time period T, which is the first time period in which the net returns from this conversion are greater than the present value of the expected returns associated with land use u over the infinite time horizon. The second condition states that parcel

Figure 1. Changes in Urban Land Use Pattern, Calvert County, Maryland (1981–1997)



j will be converted in period T only if the expected returns from converting, net the one-period opportunity cost of conversion, are greater than the discounted net returns from converting in period $T+1$.[2]

The value of the net expected returns from developing parcel j, $V_{jrt|u}$, is a one-period payment, net conversion costs, received by the landowner after converting parcel j to use r in period t. This value is hypothesized to be a function of a variety of parcel-level features, including physical variables that influence the parcel's expected returns in an agricultural use as well as the costs of conversion (e.g., soil type and slope), infrastructure variables influencing a parcel's value in residential use (e.g., public sewer access), locational features expected to influence the parcel's residential value (e.g., proximity to urban centers), and interdependencies among neighboring land use decisions (e.g., in the form of land use externalities). Recognizing that some variation will be unaccounted for in the model, and assuming the second condition associated with the optimal conversion rule above is the one that is binding, the conversion rule can be rewritten in probabilistic terms as:

$$(2)\quad P_{jrT|u} = \Pr\{V_{jrT|u} - V_{juT|u} + \varepsilon_{jT} > \delta(V_{jrT+1|u} + \varepsilon_{jT+1}\},$$

where ε_{jT} and ε_{jT+1} represent the unobserved components associated with parcel j in time periods T and $T+1$, and $P_{jrT|u}$ is the probability that parcel j is converted from undeveloped use (u) to residential use (r) in time period T.

If landowners' expectations over the net returns in period $T+1$ are myopic, then this implies $V_{jrT|u} = V_{jrT+1|u}$. Assuming this and rearranging terms, the probabilistic conversion rule can be expressed as:

$$(3)\quad P_{jrT|u} = \Pr\{\varepsilon_{jT+1} - \varepsilon_{jT} < (1-\delta)V_{jrT|u} - V_{juT|u}\}.$$

This expression provides the basis for the empirical model described in the subsequent section.

Empirical Model

While a variety of discrete choice methods are capable of empirically modeling the land conversion decision rule in (3), we opt to employ a duration model because it is capable of describing both the temporal and spatial aspects of land conversion decisions. Duration models explicitly account for the timing of a qualitative change from one state to another, and therefore are an appropriate way to capture the cumulative effects of explanatory variables on the probability of land conversion to residential use.[3] Given the nature of land use changes in growing exurban areas, in which the timing of the conversion is often of great interest, duration models offer an intuitively appealing approach. In this case, we are interested in the timing of land conversion from an undeveloped land use state to a residential land use state.

In specifying the empirical model, it is hypothesized that the net expected returns to maintaining a parcel in an undeveloped state as well as the net expected returns from developing a parcel will be a function of the current characteristics of the parcel. For simplicity, let $\mathbf{Z}_{jT}$ represent the vector of these attributes of parcel j in period T, and $\boldsymbol{\beta}$ the corresponding vector of parameters denoting the marginal effects of these variables on the probability of conversion. Then the probabilistic residential conversion rule shown in (3) can be rewritten as:

$$(4)\qquad P_{jrT|u} = \Pr\{\eta_{jT} < f(\mathbf{Z}_{jT};\boldsymbol{\beta},\delta)\},$$

where $\eta_{jT} = \varepsilon_{jT+1} - \varepsilon_{jT}$.

Using a duration modeling framework, the distribution of durations associated with events (i.e., the duration of a land parcel in an undeveloped state) is described in terms of either a survival function or a hazard function. The survival function is the probability that the event does not occur in period t and is equal to $1 - F(t)$, where $F(t) = \Pr(T \le t)$, which is the cumulative distribution function of the random variable T, the duration length.

The hazard function is the conditional probability that the event occurs between t and Δt, given $T \ge t$ (i.e., given the event has not yet occurred).

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[2] Because the underlying decision model and the resulting optimal conversion rule are developed in full in Irwin and Bockstael (2002a), only a brief discussion is provided here. The main assumptions underlying this result are: (*a*) net discounted returns to development rise over time, but at a decreasing rate, and (*b*) discounted returns to the undeveloped use are constant or decrease over time. The first assumption will hold if growth pressures put upward pressure on residential land prices over time, but in such a way that these prices increase at a decreasing rate and/or that development costs increase over time. Increasing costs of development are often an observed reality in rapidly growing exurban areas, as additional growth controls which increase the costs of development are instituted over time.

[3] The problem is characterized as one of optimal timing of development, since growth pressures are sufficiently strong in this area for most landowners to expect that conversion will be optimal at some time in the future. For a basic description of how duration models are applied in economics, see Gourieroux and Jasiak (2001). For additional details on the practical aspects of estimating a proportional hazards model using SAS, see Allison (1995).

This function is interpreted as the rate at which the event occurs and is usually written as:

$$(5) \qquad h(t) = \lim_{\Delta t \to 0} \frac{\Pr\{t \le T < t + \Delta t \mid T \ge t\}}{\Delta t}.$$

In the land use conversion case, the hazard rate is the function of interest. In this context, the hazard rate is defined as the conditional probability that a parcel is developed in period *t*, given it has remained in an undeveloped state until time *t*. Varying assumptions are possible regarding the distribution of durations. We use the proportional hazards model (or Cox regression model) to estimate the land use conversion model (Greene, 2000, pp. 948–950). This model is advantageous because it does not require a distributional assumption of the duration length. However, this comes at the cost of imposing a particular functional form requiring separability of the baseline hazard rate from the other covariates of the model. Specifically, let $\lambda(T)$ represent the exponential of the baseline hazard rate and, assuming the log of the hazard rate is linear in the other arguments, the hazard rate for parcel *j* is given by:

$$(6) \qquad h(j, T) = \lambda(T) \times \exp(\mathbf{Z}\boldsymbol{\beta}),$$

where $\mathbf{Z}$ is a vector of parcel *j*'s attributes and $\boldsymbol{\beta}$ is a corresponding parameter vector.

Cox's method is a semiparametric approach which relies on formulating the likelihood in terms of a ratio of the hazard functions, so that the baseline hazard, $\lambda(T)$, drops out. Because only the baseline hazard is assumed to be a function of duration length *T*, specification of an error distribution for the resulting expression is unnecessary. This expression is called the partial likelihood function, which states the conditional probability that, given an event occurs in a particular time period, it occurs to a specific land parcel. It is the product of *N* contributions to the likelihood function, where *N* is the number of developable parcels, and the form of the *n*th contribution is given by:

$$(7) \qquad L_n = \frac{h(n, T_n)}{\sum_{j \in J_n} h(j, T_n)},$$

where T_n is the time at which the *n*th parcel is converted, $h(n, T_n)$ is the hazard rate for the *n*th parcel, $h(j, T_n)$ is the hazard rate for the *j*th parcel evaluated at time T_n, and J_n is the set of parcels that have "survived" in the undeveloped state until time T_n. This expression gives the ratio of the *n*th parcel's hazard rate to the sum over the hazards of all other parcels that have not yet been developed as of time period T_n. When multiplied by all other $n-1$ contributions, this forms the conditional probability that, given an event occurs in a particular time period, it occurs to a specific land parcel.

Description of Data

The model is estimated using parcel-level land use change data from Calvert County, Maryland. Calvert County is an "exurban" county located in southern Maryland, approximately 50 miles from the Washington, DC, and Baltimore, Maryland, metropolitan areas. Calvert County is bounded by the Chesapeake Bay on the east and the Patuxent River on the west, and historically had been a rural and agricultural county. The county is approximately 219 square miles in area. Calvert County has two incorporated towns (North Beach and Chesapeake Beach) and seven "town centers" (Dunkirk, Owings, Huntingtown, Prince Frederick, St. Leonard, Lusby, and Solomons).

In 2000, the county population was estimated to be 74,563. As noted previously, between 1981 and 1997, Calvert County experienced a 94% increase in population and a 191% increase in the number of acres in low-density residential use. Such growth is typical of exurban areas in Maryland and in other parts of the United States. Accordingly, this county is a logical area in which to examine urban growth at the rural-urban fringe.[4] Before providing the details of the explanatory variables and data resources employed in the empirical model, it is important to describe the growth management and land use planning policies that apply to land use decisions in Calvert County.

The State of Maryland has responded to the sustained growth it has witnessed over the past several decades by recently passing a host of "smart growth" policies. In 1992, the State of Maryland passed the Maryland Economic Growth, Resource Protection, and Planning Act, which brought attention to the linkages between land use pattern and economic and ecological health. In 1997, the State of Maryland passed Smart Growth legislation,

[4] Because the analysis is limited to one county, we are unable to consider the role of potential spillover effects from neighboring counties' growth or policies on the amount and pattern of growth in Calvert County. While this is a limitation of the current analysis, we do not anticipate it will influence our results. Spillover effects, if they exist, will affect the total demand for residential land in Calvert County, but not necessarily the pattern of land conversion in the county. Here, the focus is on explaining the pattern, not the total amount of growth, in the county.

which further documented these linkages and established a framework for the development of specific policies. A synopsis of the objectives of the Maryland Smart Growth bill is given below:

> ... establishing priority funding areas in the State so as to preserve existing neighborhoods and agricultural, natural, and rural resources; prohibiting State agencies from approving specified projects that are not in priority funding areas; providing for specified exceptions; establishing a certification process for the designation of eligible priority funding areas; requiring municipal corporations to adopt specified development standards and assist counties in the collection of fees to finance specified school construction; etc. (Maryland Senate Bill 389, 1997).[5]

Because these policy initiatives have now been in place for several years, Maryland is an advantageous location to study the effects of such policies on land conversion patterns. We incorporate the impact of this legislation on residential land use change in Calvert County by explicitly considering the location of priority funding areas (PFAs), which are growth areas designated by each county to which the State directs support for infrastructure development. Further, we also consider the State objective of preserving agricultural, natural, and rural areas by explicitly examining lands designated as protected or critical areas or enrolled in agricultural preservation or rural legacy programs.

In addition to State-sponsored policies, land use decisions in Calvert County are also influenced by a host of county-level policies. In 1997, Calvert County approved a revised comprehensive plan whose goals include "directing growth to suitable locations, promoting economic growth, and practicing stewardship of the Chesapeake Bay and the land" (Calvert County Planning Commission, 1997, p. 2). To meet these goals, the comprehensive plan specifically notes the need to reduce the rate of residential growth and preserve prime farm, forest, and sensitive lands. The provision of public sewer and water is controlled at the county level in Calvert County, and provision of these services is expected to influence land use decisions. The model developed here includes multiple policy variables describing Calvert County's zoning and public service policies.

Data used to estimate the land use conversion model include spatially defined, micro-level data on land parcels from the State of Maryland, Department of Planning's (2002) statewide property map and parcel database files (*MdProperty View*). The construction of this data set required merging data from several tax assessment data sources, some of which are not geo-coded, in order to compile an eight-year history of "convertible" parcels within Calvert County. The data set is comprised of all parcels that, as of January 1993, were large enough to accommodate a major subdivision of at least five houses given current zoning and could have been converted to residential use.[6] The year of conversion for those parcels converted during the period 1993 through 2000 is also included. This yields a total of 1,962 observations.

The data set contains variables pertaining to the individual parcel, including lot size and land use. Because the centroids of the parcels are geo-coded, it was also possible to locate the parcels in space and, using a Geographic Information System (GIS), to generate a variety of additional spatial attributes associated with the individual parcels, including zoning, distance measures, and public sewer access.

The model estimates the conditional probability that an event occurs in period t, given that the event has not yet occurred up until period t. An event is defined here as the subdivision of an undeveloped parcel into residential lots in preparation for house construction. Any parcel not converted by 2000, the last year for which data are available, is censored. Based on this definition, the data set contains 163 events and 1,799 censored observations, where events are parcels that were converted to residential use, and censored observations are parcels that remained in undeveloped use from 1993 through 2000.

Because the empirical model is estimated using a reduced-form approach, we sought data on explanatory variables that would explain the costs of conversion from undeveloped to residential use and returns in residential use and undeveloped use. The final set of explanatory variables describes the costs of developing the parcel, the location of the parcel, the availability of public services, and growth management policies. Table 1 reports descriptive statistics for the final set of explanatory variables.

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[5] Maryland Senate Bill 389 can be accessed online at http://mlis.state.md.us/1997rs/billfile/sb0389.thm.

[6] A fair number of minor subdivisions and isolated homes were also developed during this time period. These developments are not represented in this model, and therefore the model does not explain all types of residential development. The analysis focuses on major subdivision development because these are the developments that are the most highly regulated, and specifically are the most affected by the recent "smart growth" legislation. Because we are primarily interested in the effects of such regulation on land conversion patterns, the analysis is limited to major subdivision development.

Table 1. Descriptive Statistics of Explanatory Variables: Hazard Model of Residential Land Conversion, Calvert County, Maryland (1993–2000)

Variable	Description	Mean	Std. Dev.	Minimum	Maximum
AGPRES	Enrolled in agricultural preservation program (dummy variable)	0.0815	0.2846	0.0000	1.0000
AGPRIME	Proportion of parcel in prime farmland	0.3036	0.3553	0.0000	1.0000
BADSEPTIC	Poorly draining soils and serviced by septic (dummy variable)	0.1555	0.2429	0.0000	1.0000
CRITAREA	Proportion of parcel within a Critical Area	0.1304	0.3174	0.0000	1.0000
HDURB200	Proportion of neighborhood within 200 meters that is in high-density urban use	0.0568	0.0905	0.0000	0.6701
HDURB2-400	Proportion of neighborhood between 200–400 meters that is in high-density urban use	0.0585	0.1644	0.0000	1.0000
HDURB4-800	Proportion of neighborhood between 400–800 meters that is in high-density urban use	0.0588	0.1473	0.0000	0.9636
HDURB8-1600	Proportion of neighborhood between 800–1,600 meters that is in high-density urban use	0.0672	0.1312	0.0000	0.9003
HILLY	Steeply sloped terrain (dummy variable)	0.4072	0.3800	0.0000	1.0000
LN$DCDIST	Natural logarithm of distance to Washington, DC (meters)	4.1745	0.2308	3.6990	4.6249
LN$TWNDIST	Natural logarithm of distance to nearest town (meters)	7.1857	1.4311	! 1.655	9.0289
MDPROT	Proportion of parcel classified as protected land	0.0055	0.0491	0.0000	0.8991
MINLOT	Minimum lot size allowed by zoning (acres)	2.4958	2.1138	0.2500	5.0000
NUMLOTS	Maximum number of lots allowed by zoning	16.5411	56.6213	0.7200	1,483.36
OPENCLS200	Proportion of neighborhood within 200 meters that is clustered open space	0.0242	0.0353	0.0000	0.2954
OPENCLS2-400	Proportion of neighborhood between 200–400 meters that is clustered open space	0.0354	0.1106	0.0000	1.0000
OPENCLS4-800	Proportion of neighborhood between 400–800 meters that is clustered open space	0.0253	0.0745	0.0000	0.8384
OPENCLS8-1600	Proportion of neighborhood between 800–1,600 meters that is clustered open space	0.0257	0.0537	0.0000	0.8045
OPENPUB200	Proportion of neighborhood within 200 meters that is public open space	0.0396	0.1042	0.0000	0.8404
OPENPUB2-400	Proportion of neighborhood between 200–400 meters that is public open space	0.0046	0.0513	0.0000	1.0000
OPENPUB4-800	Proportion of neighborhood between 400–800 meters that is public open space	0.0125	0.0806	0.0000	0.8848
OPENPUB8-1600	Proportion of neighborhood between 800–1,600 meters that is public open space	0.0260	0.0913	0.0000	0.8337
PFA	Proportion of parcel within a Priority Funding Area	0.2129	0.3955	0.0000	1.0000
PTAX	Local property tax rate	2.2730	0.1535	2.2300	3.3800
REQOPEN	Amount of parcel land that must be preserved as clustered open space	2.0172	9.8357	0.0000	203.985
RURLEG	Proportion of parcel within a Rural Legacy Program area	0.0390	0.1833	0.0000	1.0000
SCHOOLQ	Percent of graduating high school students who go on to four-year universities	30.9130	4.9540	27.5000	38.1000
SEWER	Access to public sewer (dummy variable)	0.1773	0.3820	0.0000	1.0000
TC	Located in town center (dummy variable)	0.1304	0.3368	0.0000	1.0000
WFACCESS	Inverse of distance to Chesapeake Bay (meters; = 0 if parcel is located beyond two miles)	0.0030	0.0289	0.0000	1.1040
WFBOAT	Within two miles of Chesapeake Bay or lower Patuxent River (dummy variable)	0.4600	0.4985	0.0000	1.0000

The costs of converting the parcel from undeveloped to residential use are measured using biophysical indicators of lands which are less suitable for development, including land that is serviced by septic and has poorly draining soils (*BADSEPTIC*) and terrain that is steeply sloped (*HILLY*). Specifically, these conversion cost dummies are equal to one for parcels on septic having poorly drained soils and steep slopes (more than 15%) and zero otherwise. Both of these measures indicate higher costs, and as a result are expected to have a negative influence on the hazard rate and reduce the probability of conversion, ceteris paribus.

The proportion of parcel land characterized as prime farmland by the Soil Conservation Service (*AGPRIME*) is used as a measure of the value of land in agricultural use or agricultural profitability. Because this variable reflects the opportunity cost of converting from agricultural use to residential use, it is expected to have a negative influence on the hazard rate and reduce the probability of conversion, ceteris paribus.

The location of the parcel is characterized using a suite of explanatory variables. While location affects the return to parcels in a variety of uses, the majority of these variables are expected to influence the return to the parcel in residential use. A parcel's value in residential use is expected to be a function of its accessibility to major metropolitan areas—in this case, Washington, DC. Distance to Washington, DC, is measured via the road network and is included in logarithmic form (*LN$DCDIST*). All else equal, those parcels located within closer proximity to this urban area are expected to have a higher hazard rate of conversion, implying the expected sign of this coefficient is negative.

Accessibility to a town is also expected to influence a parcel's value in residential use. Distance as the crow flies to the nearest town (*LN$TWNDIST*) is included in logarithmic form to capture proximity to a town. A binary dummy variable is also employed to account for parcels located in the town centers (*TC*) identified in Calvert County's comprehensive plan. If the parcel is located in a town center, the *TC* dummy variable is equal to one, and zero otherwise.

A parcel's value in residential use is expected to be a function of its proximity to the waterfront, which includes access to both the Chesapeake Bay to the east and the Patuxent River to the west (see figure 2). A measure of accessibility (*WFACCESS*) is equal to the inverse of the parcel's distance to the water if the parcel is within two miles of the Chesapeake Bay, and zero otherwise. Parcels located nearer the bay are hypothesized to have a higher hazard rate, implying the expected sign of the coefficient is positive. In addition, a dummy variable is included to indicate the parcel is within two miles of either the Chesapeake Bay or the lower portion of the Patuxent River (*WFBOAT*), since these waters are navigable and the middle and upper portions of the Patuxent River are not.

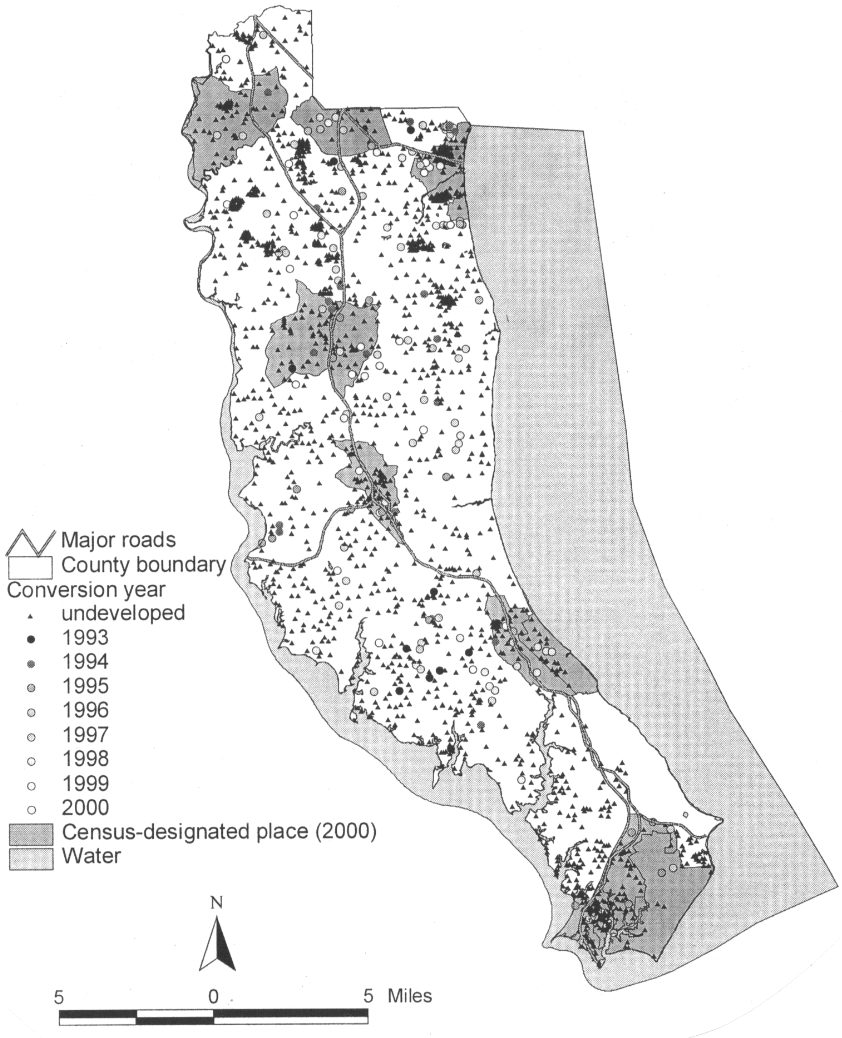
The final set of explanatory variables used to describe location measure the surrounding land use pattern. Spillover effects from neighboring land uses can create an interdependence among neighboring landowner decisions regarding land use conversion (Irwin and Bockstael, 2002a), and as such are likely to influence the value of a parcel in a residential use (Geoghegan, Wainger, and Bockstael, 1997). Such interdependencies are likely to be temporally lagged, and therefore can be captured by measures of existing land uses within a parcel's neighborhood. The spillover effects of surrounding high-density urban development and open space are featured here.

The land use surrounding the parcel was measured using four concentric circular buffers, with the buffers extending from the centroid of the land parcel. The ranges of these buffers were specified as follows: 0 to 200 meters, 200 to 400 meters, 400 to 800 meters, and 800 to 1,600 meters. After characterizing all of the land use types surrounding the parcel, estimates of the proportion of high-density urban development, public open space, and clustered open space within these four buffers were calculated. High-density urban development includes commercial, industrial, and multi-family residential land uses (denoted by the variables *HDURB200*, *HDURB2-400*, *HDURB4-800*, and *HDURB8-1600*).

There are two different residential zoning categories in Calvert County requiring clustered open space. These areas require residential development to be clustered so that a certain percentage of the parcel remains in open space. We measure the amount of surrounding land which is in a preserved open space use as a result of this clustering policy (*OPENCLS200*, *OPENCLS2-400*, *OPENCLS4-800*, and *OPENCLS8-1600*). Last, public open space includes federal, state, and local government open space lands (*OPENPUB200*, *OPENPUB2-400*, *OPENPUB4-800*, and *OPENPUB8-1600*).

The influence of these surrounding land use measures is an empirical question. As Irwin and Bockstael (2002a) discuss, both positive and negative spillovers can be expected. Typically, one might expect high-density urban development to lower the

Figure 2. Actual Pattern of Residential Subdivision Development, Calvert County, Maryland (1993–2000)



return in residential use and open space to increase the return in residential use of nearby parcels.

The availability, quality, and cost of public services influence the value of a parcel in residential use. To capture these effects, we employ three different explanatory variables. School quality is approximated using a measure of college attendance. Specifically, the percentage of students who graduate from high school and go on to four-year colleges is used as a proxy for school quality (*SCHOOLQ*). Higher school quality is expected to increase the return in residential use, and therefore increase the likelihood of conversion to residential use. A binary dummy variable is used to identify parcels that have access to public sewer services (*SEWER*). This variable equals one if sewer access is available and zero otherwise. Because public sewer is also expected to increase the return in residential use, a positive coefficient is expected for this explanatory variable. Finally, the local property tax rate is used to capture the costs of public services (*PTAX*). Higher property tax rates may, ceteris paribus, lower the likelihood of conversion to residential use.

The last set of explanatory variables reflects the diverse set of growth management policies in place in Calvert County, Maryland. These policies are expected to influence a parcel's value in residential use because they establish the intensity at which a developer can build, and define the costs and terms of development. For example, the number of lots allowed by zoning (*NUMLOTS*), amount of land that must be held in open space (*REQOPEN*), and the minimum lot size allowed (*MINLOT*) are expected to affect the return to conversion. As the number of lots allowed increases, the returns to development are expected to increase. Higher requirements for open space may lower the likelihood of conversion—i.e., the cost of conversion is increased. Last, as the minimum lot size increases, the returns to developing the parcel will fall, assuming demand-side factors are held constant.[7]

In a dynamic setting, in which returns to development are increasing over time, the optimal density of development also increases over time (Arnott and Lewis, 1979; Capozza and Helsley, 1989). As a result, an increase in the minimum lot size would be expected to accelerate the timing of development (i.e., increase the hazard rate) if the minimum lot size is a binding constraint. This is because developing at a higher density in the future would not be possible, and consequently there would be reduced gains to postponing development. On the other hand, if the minimum lot size regulation is not a binding constraint (i.e., it is actually optimal to develop at a lower density than what is mandated), then this variable would not be expected to have any discernable effect on the returns to development.

Other types of growth management policies expected to influence the conversion to residential use are those which designate "special" lands. These include designations that encourage development by directing state support for infrastructure to these growth areas (priority funding areas) and discourage development (agricultural and ecological preservation areas). The priority funding areas (PFAs) were established as part of the Maryland Smart Growth legislation. These are growth areas identified by each county to which the State directs support for infrastructure development in an attempt to direct new urban growth.

In contrast, the State has several programs in place to prevent urban growth from occurring in select areas. Maryland's Rural Legacy Program reallocates State funds to purchase conservation easements for large contiguous tracts of agricultural, forest, and natural areas subject to development pressure. A similar program is administered by the Maryland Department of Agriculture to place easements on agricultural lands. Maryland Protected Lands are lands considered to be ecologically sensitive by the Maryland Department of Natural Resources, and development is not allowed on these lands. Maryland's 1984 Critical Area Act designated all lands within 1,000 feet of tidal waters or adjacent tidal wetlands of the Chesapeake Bay as critical areas, and development is restricted in these areas.

Explanatory variables used in the empirical model include the proportion of the parcel falling within the State of Maryland's recently established priority funding areas (*PFA*), the proportion of the parcel falling within the State of Maryland's critical areas (*CRITAREA*), the proportion of the parcel falling within the State of Maryland's rural legacy area (*RURLEG*), and the proportion of the parcel that includes State of Maryland protected lands (*MDPROT*). In addition, an indicator variable is

[7] This is true simply because the minimum lot size regulation limits the number of houses that can be built on a parcel of land. In some cases, however, it is possible that certain market segments may attach a premium to development regulated by large lot restrictions (e.g., as a means of ensuring neighboring low-density development), in which case the returns to individual large lots may be bid up. However, it is questionable as to whether such a premium on lots would actually outweigh the revenue losses from being constrained to develop a lesser number of lots.

included that equals one if the parcel is enrolled in an agricultural preservation program and zero otherwise (*AGPRES*). The priority funding area (*PFA*) variable reflects the State of Maryland's "smart growth" policy and is expected to have a positive influence on the hazard rate. Conversely, the remaining special land designations (*CRITAREA*, *RURLEG*, *AGPRES*, and *MDPROT*) are expected to have a negative influence on the hazard rate.

Empirical Results

The results from the proportional hazards model of residential land conversion are presented in table 2. The significance of the parameter estimates is indicated by a chi-square test of the null hypothesis that the estimates are not significantly different than zero. The parameter estimates show the direction of the effect of a variable on the hazard rate. The hazard ratio conveys the magnitude of their effect on the hazard rate. For 1/0 indicator variables, the hazard ratio can be interpreted as the ratio of the estimated hazard of the two groups (as distinguished by the 1/0 indicator variable), holding all other variation constant. For continuous variables, the hazard ratio can be transformed into an elasticity measure by subtracting 1 and multiplying by 100. This gives the estimated percentage change in the hazard for each one-unit increase in the variable.

From table 2, two of the three development costs variables are found to be significant, although the sign on the measure of prime agricultural land (*AGPRIME*) is unexpected. This measure, which was included as a proxy for the opportunity costs of converting a parcel from an agricultural use, is found to have a positive and significant effect on the hazard rate. Rather than capturing the opportunity cost of developing, this finding likely reflects the fact that prime agricultural land is also prime residential land in many cases. Poorly draining soils where septic fields are required (*BADSEPTIC*) are found to significantly lower the likelihood of a parcel's development. Specifically, the hazard ratio of 0.357 implies the hazard rate of parcels with poorly draining soils that require septic is only 35.7% of those having adequately draining soils. Steeply sloped parcels (*HILLY*) are not found to have a significant effect on a parcel's hazard rate of conversion.

Several of the location attributes of parcels are found to matter (table 2). Surprisingly, distance to Washington, DC (*LN$DCDIST*) is not statistically significant. This suggests the most recent growth in Calvert County has been driven by households which are not tied to Washington, DC, for employment or other reasons—e.g., retirees attracted by recreational opportunities. Results showing the influence of other locational variables support this explanation. Distance to the nearest small town (*LN$TWNDIST*) is found to be negative and statistically significant, confirming the importance of access to local shopping and other services. Access to the waterfront, as measured by *WFACCESS*, is found to be positive and statistically significant, suggesting parcels with high recreational potential or scenic views that are located nearest to either the Chesapeake Bay or Patuxent River have a premium associated with them. However, a significant difference was not found between those parcels located near the navigable portions of the water (*WFBOAT*, i.e., the Chesapeake Bay and the lower portion of the Patuxent River) versus those that are not. Location within one of the town centers (*TC*), holding constant the level of services and other variation captured in this model, is found to reduce the hazard rate. Specifically, the hazard rate of a parcel located within a town center is estimated to be only 44.5% of the hazard rate of an identical parcel located outside a town center.

Several of the surrounding land use measures are found to be significant in the expected directions (table 2). Neighboring high-density urban development within 400 meters of a parcel is found to convey a negative and significant effect on the hazard rate of conversion: a 1% increase (0.3 acres) in the amount of high-density urban development within 200 meters (*HDURB200*) reduces the hazard rate by 93.7%, whereas a 1% increase (0.93 acres) in the amount of high-density urban development between 200 to 400 meters (*HDURB2-400*) reduces the hazard rate by 88.3%. Neighboring open space created by the clustering of neighboring development is found to convey a very positive and significant effect when located within 200 to 800 meters of a parcel. A 1% increase (0.93 acres) in the amount of clustered open space between 200 to 400 meters (*OPENCLS2-400*) increases the hazard rate by 350%, and a 1% increase (3.7 acres) in the amount of clustered open space between 400 to 800 meters (*OPENCLS4-800*) increases the hazard rate by 779%. However, these results are not directly comparable, since a 1% increase in land in the smaller neighborhood is much less in absolute terms than a 1% increase in the larger neighborhood. Putting these values in comparable terms, a one-acre increase in the amount of clustered open space

Table 2. Results from Hazard Model of Residential Land Conversion: Calvert County, Maryland (1993–2000)

Variable	Parameter Estimate	Standard Error	Pr > χ^2	Hazard Ratio
Proxies for Development Costs:				
BADSEPTIC	!1.02987	0.50104	0.0398	0.357
HILLY	!0.45859	0.33938	0.1766	0.632
AGPRIME	0.63213	0.32853	0.0543	1.882
Locational Features:				
LN$DCDIST	!0.24304	0.73287	0.7402	0.784
LN$TWNDIST	!0.25278	0.07577	0.0008	0.777
WFACCESS	3.88677	1.97792	0.0494	48.753
WFBOAT	0.23736	0.20723	0.2521	1.268
TC	!0.80989	0.42857	0.0588	0.445
Neighborhood Land Use Variables:				
HDURB200	!2.70372	0.92627	0.0035	0.067
HDURB2-400	!2.14518	0.93145	0.0213	0.117
HDURB4-800	!0.19877	0.76848	0.7959	0.820
HDURB8-1600	0.30199	1.04941	0.7735	1.353
OPENCLS200	!0.02384	0.71658	0.9735	0.976
OPENCLS2-400	1.50419	0.82760	0.0691	4.501
OPENCLS4-800	2.17433	1.24819	0.0815	8.796
OPENCLS8-1600	2.72436	2.12789	0.2004	15.247
OPENPUB200	1.62277	1.77596	0.3609	5.067
OPENPUB2-400	!0.54380	1.68631	0.7471	0.581
OPENPUB4-800	!1.67156	1.43030	0.2425	0.188
OPENPUB8-1600	!0.24646	0.90275	0.7848	0.782
Public Services:				
SCHOOLQ	0.01809	0.02763	0.5125	0.120
SEWER	1.28926	0.43221	0.0029	3.630
PTAX	!4.21655	1.16946	0.0003	0.015
Zoning Regulations:				
MINLOT	0.44248	0.05902	< 0.0001	1.557
NUMLOTS	0.00216	0.00068	0.0014	1.002
REQOPEN	0.00511	0.00766	0.5041	1.005
Smart Growth Policies:				
PFA	1.40315	0.39809	0.0004	4.068
CRITAREA	!1.99796	0.51093	< 0.0001	0.136
RURLEG	!0.11873	0.50817	0.8153	0.888
AGPRES	!0.85016	0.37278	0.0226	0.427
MDPROT	!6.20935	5.88300	0.2912	0.002

Model Fit Statistics:	**Without Covariates**	**With Covariates**
!2 ((log likelihood)	2,457.79	2,276.38
Akaike's Information Criterion	2,457.79	2,338.38

Notes: Dependent variable: Indicator variable = 1 if parcel was developed in a given year between 1993–2000, and = 0 otherwise. Number of observations = 1,962; number of events = 163 and number of censored observations = 1,799.

within 200–400 meters increases the hazard rate of conversion by 376%, whereas the same change within 400–800 meters increases the hazard rate of conversion by 211%. Therefore, a distance-decay effect is found to be associated with neighboring clustered open space, but the gradient is estimated to be quite flat.

The proxy for school quality, the percentage of students graduating from high school and going to college within the school district (*SCHOOLQ*), is not significant. It is possible this is either a poor proxy for school quality, or school quality is relatively homogeneous across the county. However, the other public service variable included in the model, the presence of public sewer on a developable land parcel (*SEWER*), is found to have a significant and very positive effect on the hazard rate of conversion. Based on the estimated hazard ratio, the mean hazard rate of those parcels with public sewer, holding all other variations constant, is 363% greater than those without public sewer. Thus, just the provision of public sewer to a parcel increases the hazard rate of conversion by almost fourfold. Household expenditures on public services are captured by the property tax rate variable (*PTAX*), which is significant and negative: a 1% increase in the property tax rate applied to a parcel of land is found to lower the hazard rate of conversion by 1.5%.

As observed from table 2, zoning regulations have a very significant effect on the hazard rate of conversion. The minimum lot size restriction on a parcel (*MINLOT*) has a positive and significant effect on the hazard rate. This result is consistent with the theory of optimal timing and residential density: assuming returns to development are increasing over time, an increase in the minimum lot size, which lowers the allowable density of development, will *accelerate* the optimal timing of development if this constraint is binding, and assuming that any countervailing premium which may be attached to large lot restrictions by consumers is sufficiently small. Empirically, this effect is found to be substantial. An increase in the minimum lot size of a parcel by one acre is found to increase its hazard rate by 55%. The number of allowable lots that can be developed on a parcel (*NUMLOTS*) significantly influences the hazard rate of conversion in a positive direction. This finding is consistent with expectations, since an increase in the number of developable lots on a parcel will increase the returns to developing. However, the magnitude of this effect is quite small—an additional lot is found to increase the hazard rate by only 0.2%. The amount of open space required by the clustering of development regulation (*REQOPEN*) is not found to have a significant effect on the hazard rate.

Last, several of the growth management and open space preservation policies which have been implemented within Calvert County have had a significant effect on conversion rates. Parcels falling within the areas designated as priority funding areas (*PFA*) are found to have a much higher hazard rate of conversion. Compared to parcels outside these designated areas, the hazard rate of parcels located within a PFA is found to be about four times larger. In addition, the location of a parcel within an area designated as a critical area (*CRITAREA*) and the enrollment of a parcel in the agricultural preservation program (*AGPRES*) are both shown to significantly reduce the parcel's hazard rate of conversion, although the magnitude of these effects is less than the effect of the PFA designation. The hazard rate of parcels within critical areas is found to be just 14% of those located outside these areas, whereas the hazard rate of parcels located within an agricultural preservation area is 43% of the rate of parcels located outside these areas. In contrast, the hazard rate of a parcel located within either the Rural Legacy (*RURLEG*) or the State's protected lands areas (*MDPROT*) is found to be unaffected by these designations. The former likely reflects the limited budgets the State has allocated for this program since its inception in the mid-1990s.

Implications for Growth Management at the Rural-Urban Fringe

The findings of this analysis suggest a number of interesting relationships among parcel-level characteristics, growth management policies, and the resulting pattern of residential development in our study area. First, spatial heterogeneity among on-site parcel characteristics, including soil type, access to public sewer, and size of the parcel, clearly has an effect on the parcel's hazard rate of conversion. To the extent these variables are positively spatially correlated, i.e., neighboring parcels have similar values, then these sources of spatial heterogeneity would tend to cluster development.

Other sources of spatial heterogeneity shown to foster cluster development include access measures. For example, if proximity to urban or town centers is desirable, then this effect will encourage clustering of development near these centers. Interestingly, distance to the region's large urban center, Washington, DC, is not found to be significantly different from zero. The absence of this effect may be explained by the particular geography of Calvert County. The southern area of Calvert County is surrounded by the Chesapeake Bay, an amenity which could exert an offsetting effect on residential location decisions. The most plausible explanation is that households located in Calvert County are heterogeneous; i.e., there may be a portion of the population concerned with access to Washington, DC, but these households are not the majority. The population is comprised of other types of households, including retirees and those who perhaps are tied to the local economy within Calvert County. As a result, development is more dispersed than it otherwise would be if access to Washington, DC, were a dominant concern. In contrast, access to small towns exerts a relatively substantial effect, suggesting development patterns may tend to cluster on a smaller scale around the smaller towns that are dispersed throughout the county.

The influence of the neighboring land use variables is of interest, but the estimates must be interpreted with caution. As argued by Irwin and Bockstael (2002a), land use externalities generated by land uses which are the result of past decisions by neighboring landowners are in some sense endogenous to the development process. In this case, while the effects are lagged over time and therefore not a simultaneously determined variable, the process by which neighbors were converted in the past is clearly very much related to the process that influences a parcel's conversion potential today. To the extent any of the underlying factors influencing this process are time-invariant and unobserved, problems of consistency will arise, and the estimates associated with the neighboring land uses will be biased. Generally, this bias would tend to be in a positive direction, due to the likely positive spatial autocorrelation of the unobserved factors. Therefore, the positive estimates of the neighboring clustered open space parameters do not necessarily convey a positive relationship since these estimates are biased in a positive direction. However, the negative spillovers associated with neighboring high-density urban development are clearly identified as having a negative influence on the hazard rate of conversion. This result, coupled with the negative influence of a parcel being located within an area designated as a town center, shows a clear repelling effect associated with higher density urban areas. Such effects will tend to offset the other effects found to encourage clustering, and therefore will increase the pattern of scattered development within the county.

Of primary interest is the potential effect of the growth management policies on the spatial pattern of residential development in our study area. Several spatial trends are suggested by the results. First, the results suggest that minimum lot zoning, if used as a growth control measure by itself, could result in a rush of development in areas for which lot size is restricted. This finding is consistent with theoretical models of optimal timing of development, which demonstrate an increase in the optimal density of development when development is postponed into the future (see Arnott and Lewis, 1979; Capozza and Helsley, 1989). By restricting the density at which development can occur in the future, a minimum lots-size policy limits the returns to developing at some future period when the constraint becomes binding. Thus, as soon as the constraint becomes binding, it will be optimal for development to occur. This conclusion is also supported by other empirical results from the literature on land conversion (Geoghegan and Bockstael, 2000; Irwin and Bockstael, 2002a, b; Fleming, 2003).

Second, the results suggest that policies aimed at altering the spatial distribution of the costs and returns to development are an effective restraint on scattered development. Specifically, the State's Priority Funding Area program, in which state financial support for new infrastructure is channeled to designated growth areas, is an effective policy tool for encouraging more concentrated development. Parcels located within these areas are found to be much more likely to be converted, all else equal, than those located outside these areas. In addition, some of the policies designed to discourage development in rural areas appear to be having an effect. Both the critical areas designation and the agricultural preservation program are found to have statistically significant effects on the timing of development of parcels with either of these designations. All else equal, the results indicate development will be deflected from these protected areas.

While these results are suggestive of how growth management policies may impact future development patterns, they are limited because they only convey the marginal effect of each policy variable in isolation from all other effects. In reality, the actual conversion of a parcel is determined by the combination of many factors, and therefore the relative magnitude of these factors is critical in understanding the extent to which policies will have a perceptible effect on altering development patterns. To further evaluate the potential effect of policies on development patterns, we simulate predicted patterns of development within Calvert County under a baseline and several alternative policy scenarios. Specifically, the following four policy regimes are considered:

- SCENARIO 1: *Baseline.* This scenario assumes no change in the current mix of policies.

- SCENARIO 2: *Increase in Enrollment in the Agricultural Preservation Program.* This scenario posits an increase in the enrollment of parcels in the agricultural preservation program based on the location of prime agricultural soils. All those parcels that have a very high percentage of prime agricultural soils (90% or greater) and that are not yet enrolled in the agricultural preservation program are assumed to be enrolled. This yields a total of 104 additional parcels in the agricultural preservation program.

- SCENARIO 3: *Expansion of Priority Funding Areas* (*PFAs*). This scenario posits an expansion of the existing PFA boundaries by an additional mile. The hypothetical expansion of these targeted growth areas resulted in an additional 348 parcels being within a PFA.

- SCENARIO 4: *Combination of Policies.* This scenario assumes that both the increased enrollment in the agricultural preservation program and the expansion of the PFAs occur.

The predicted patterns of development under each of these scenarios are generated by using the estimated coefficients to calculate the survival probabilities for each of the parcels still deemed "developable" as of the year 2000. These probabilities are calculated under the baseline scenario as well as under each of the alternative policy scenarios. Those parcels with the lowest survival probabilities are assumed to be converted. The following predictions are based on the assumption that a constant number of parcels are converted in each scenario. Specifically, we assume an additional 200 parcels (about 11% of the remaining parcels which are still developable as of 2000) are converted to a residential use in each case. This is somewhat more than the 162 parcels observed to be converted between 1993–2000, and therefore would correspond roughly to the predicted amount of development over the following 8–10 years.

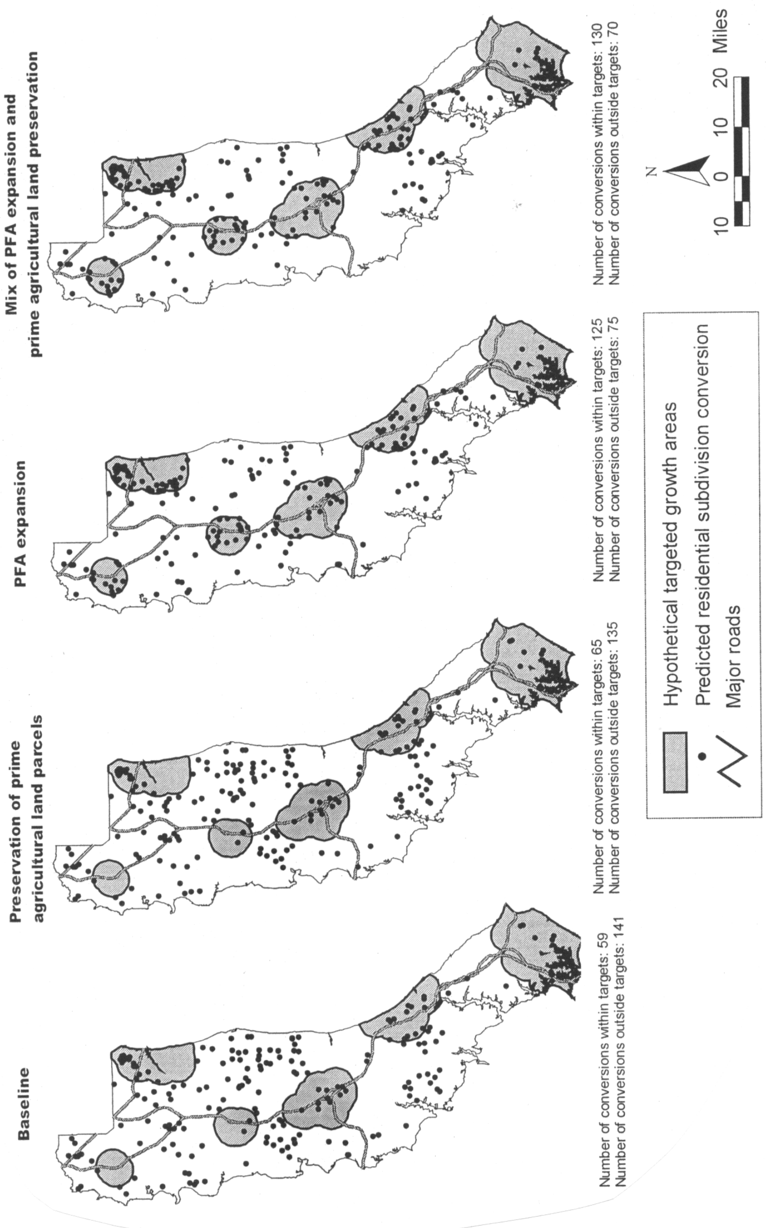
The maps shown in figure 3 illustrate the results of the simulations for each of the four policy scenarios. Also reported are the number of parcels predicted to be developed that fall within one of the hypothetical targeted growth areas—i.e., the areas encompassed by the expanded PFAs. Under the baseline scenario, 29% of the converted parcels (59 parcels) are located within the targeted growth areas. Under scenario 2, the increase in the number of parcels enrolled in the agricultural preservation program is successful at deflecting a moderate amount of development. The percentage of parcels predicted to be converted that fall within the targeted growth areas increases slightly to 32.5% of the total number of parcels converted (65 parcels), thereby decreasing the total number of parcels developed outside the targeted growth areas from 141 to 135, or by 5%.

Under scenario 3, the concentration of development within these targeted growth areas is predicted to increase dramatically. Relative to the baseline, expansion of the PFAs is predicted to increase the total number of parcels estimated to be converted within these targeted growth areas from 59 to 125 parcels, an increase of 112%. The final image shown in figure 3 illustrates the predicted pattern of development under scenario 4, in which both the increase in the agricultural preservation program and the expansion of the priority funding areas are hypothetically implemented. The result is a minor improvement over scenario 3 in terms of the relative concentration of development within the targeted growth areas. Under this scenario, 130 parcels (65% of the total) are predicted to occur within the targeted growth areas, an increase of 4% relative to scenario 3, and an increase of 120% relative to the baseline scenario.

The predictions from the simulation exercise are limited in an important respect which is likely to result in an overestimate of the concentration of development achievable through the PFA policy. In performing the simulation, we assume a static world in which the spillover effect of the predicted additional development is not incorporated into neighboring parcels' survival probabilities. In other words, the predicted pattern of development is generated as if all parcels were simultaneously developed. In reality, these conversions will occur over time and, to the extent that development generates land use externalities, these conversions will alter the survival probabilities of neighboring undeveloped parcels.

The empirical results from the hazard model of conversion suggest these externalities are not insignificant. Specifically, higher density urban development is found to convey negative externalities and depress the hazard rate of conversion of neighboring parcels. For this reason, our simulation results are likely to overstate the effectiveness of any policy that concentrates development, such as the

Figure 3. Predicted Effects of Alternative Growth Management Scenarios on Development Patterns, Calvert County, Maryland
(assuming a constant number of developed parcels across all scenarios)



PFA policy. As the density of development increases in the targeted growth areas, congestion effects are likely to set in and will moderate the attractiveness of these areas as residential locations and reduce the overall amount of development actually occurring in these targeted areas.

Conclusions

The results from the empirical hazard model of residential land use conversion and the simulation of predicted development patterns under alternative policy regimes suggest several further implications for effective growth management policy. First, it is clear that several of the smart growth policies put in place by the State of Maryland in the mid-1990s, as well as agricultural preservation programs that have operated at both county and state levels, have had significant effects on the pattern of residential growth in Calvert County. In particular, the empirical results show the designation of the priority funding areas (PFAs) has a significant influence on accelerating the time at which a parcel is developed. The magnitude of the empirical finding is borne out by the simulation of an alternative scenario in which the PFAs are hypothetically extended beyond their existing boundaries (scenario 3). Patterns of development are predicted to change in substantial ways under this alternative policy scenario.

Second, the simulation results suggest implications for a growth management approach based solely on open space preservation programs versus one in which these are combined with policies designed to cluster development in targeted growth areas. In isolation, open space preservation programs, such as the agricultural preservation program considered in scenario 2, are not an effective means of achieving more clustered growth patterns that are concentrated in existing urban areas. This finding is made especially clear when comparing scenario 2 and scenario 3 as shown by the map images in figure 3. Only very moderate improvements in concentrating development in targeted growth areas are predicted under scenario 2. Relative to the baseline prediction, the hypothetical increase in enrollment in the agricultural preservation program is predicted to increase development within targeted growth areas by 5%. In comparison, this percentage is predicted to increase by 112% under the expanded PFA scenario, and by 120% under the combined policy scenario. Minimum lot size restrictions and designation of priority funding areas have generally had a greater influence on the spatial distribution of residential land conversion decisions in Calvert County than the suite of policies designed to protect critical ecological, agricultural, and rural lands.

There are several explanations for the patterns manifested in our simulation exercise. First, our survival model estimates suggest a parcel located in a priority funding area is significantly more likely to be converted, all else equal, than those located outside these areas. This marginal effect is further supported in the simulation exercises, where the increase in the expected return from conversion induced by the priority funding area extension lowers the survival probabilities of parcels in these areas enough to alter significantly the predicted development patterns. In short, the priority funding area extension dissuades developers from subdividing lands in outlying areas and encourages development within the boundary of the priority funding areas.

Second, the priority funding area program has explicit spatial objectives. Hence, it is not surprising that this policy can effectively manipulate the spatial distribution of residential development. In contrast, the agricultural land preservation program targets individual parcels, and therefore faces greater challenges in trying to achieve spatial policy objectives (e.g., protecting contiguous tracts of agricultural land). Our definition of scenario 2 posits that all parcels meeting an established standard for prime agricultural soils enroll in the state agricultural preservation program. Admittedly, this scenario may underestimate the effectiveness of such a program to protect contiguous tracts because it ignores such objectives. In practice, the state and county agricultural land preservation programs have attempted to address such issues by giving favor to parcels located near other parcels under easements.

Finally, in many instances, the magnitude of the private return from residential development far exceeds that of the private return in an undeveloped use. In such a situation, programs aimed at manipulating the spatial heterogeneity of returns to residential development may be expected to have a greater influence, all else equal, than policies designed to maintain the returns of undeveloped lands. In turn, given budget constraints, programs aimed at preserving lands in undeveloped or open space uses through the purchase of development rights or agricultural easements are at a disadvantage when the difference in expected net returns of residential and undeveloped lands is greater. For these reasons, we have confidence in our finding that open space preservation programs alone are unlikely to achieve smart growth objectives.

At the outset of this paper, we noted our focus on growth management policies that concentrate development in targeted growth areas and deflect it from rural areas. The dual objectives of such policies are worthy of reflection. In short, emphasis must be given to factors that pull development into specific areas and push it from other areas. Our conclusions regarding "smart growth" land use policies are consistent with the conclusions of researchers focusing on other policy areas related to smart growth and regional planning. In particular, studies calling for greater and comprehensive consideration of the linkages among urban, suburban, and rural areas have given considerable emphasis to the dynamics of addressing push and pull factors when addressing land use, housing, public infrastructure, and regional economic issues (Katz and Bradley, 1999; Rusk, 1999; Downs, 1999; Orfield, 1997). Policy makers at the rural-urban fringe have a variety of growth management policies at their disposal. Smart growth objectives are inherently spatial—concentrating development in targeted growth or urban areas and intensifying open space preservation in rural areas.

Based on the findings of this study, the efficacy of policies to meet such objectives may depend largely on the degree to which the policy instrument incorporates spatial influences. This result has important implications for many rural-urban areas in the United States currently struggling with growth issues.

In many cases, localities and states have shied away from implementing what are perceived to be more aggressive policies, such as Maryland's Priority Funding Area policy, and instead have instituted open space preservation programs with the hope these programs will be sufficient to control development. This approach is not surprising, since open space preservation is a goal that attracts the support of a diverse constituency from farmers to homeowners to environmentalists. On the other hand, policies attempting to guide development through directed provision of infrastructure create a clearer picture of winners and losers, are perceived as being more interventionist, and are more likely to be shot down on the basis of individual property rights. For these reasons, we expect to observe considerable variation in future development patterns and growth management strategies at the rural-urban fringe.

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