



Zoning, TDRs and the density of development [☆]

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Abstract

This paper explores the effect of low density zoning regulations and other factors on subdivision density. Using a unique dataset of new subdivisions built over a 34-year period in Calvert County, Maryland, we econometrically estimate a density function using both OLS and censored regression. The variability in density permitted by the county's zoning and TDR rules over the sample period allows us to assess the relative importance of market factors and regulatory constraints on density. We use the censored model to predict what density patterns would have been without zoning.

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1. Introduction

Many communities on the urban fringe are implementing a range of policies to preserve farmland and open space, cluster residential development, and guide development to areas with existing infrastructure. These efforts are an attempt to control overall growth and to counter a trend toward so-called “large lot” development so that growth that does take place results in less consumption of land (Heimlich and Anderson [14]). Planners have argued that policies to manage density are the most important local policy focus for urban areas in the coming years (Danielson et al. [4]).

[☆] The views expressed in this paper are those of the authors and do not necessarily represent those of the US Environmental Protection Agency. No official Agency endorsement should be inferred.

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Some researchers contend that large lot development and “sprawl” more generally are simply the natural result of household preferences and market forces (Gordon and Richardson [12]). Glaeser and Kahn [11] argue that the widespread use of the car as a means of travel has made scattered, low-density development an inevitable market outcome.¹ Davis, Nelson, and Dueker [5] report results of a survey finding that 60% of people who move to so-called “ex-urban” locations beyond traditional suburbs move there to have large lots and a rural lifestyle.

Other authors have argued that local government zoning rules in the form of large minimum lot-sizes may well be contributing to current patterns of low density development. Fischel [8] suggests that growth controls in the form of large lot zoning tend to result in “suburban sprawl.” There have been theoretical analyses showing the conditions under which this might be true (Moss [24], Pasha [26]), but there has been very little empirical work providing any evidence on this issue.

In this paper, drawing on a unique dataset, we are able to address two important questions. Do zoning regulations play a role in creating low density, land-intensive development, or is it primarily market forces that generate such land-use patterns? The second is, if zoning limits account for low-density development in at least some cases, how would development patterns be different if there had been no such rules?

We address these issues by analyzing the factors that explain subdivision density in a rapidly growing county on the fringes of the Washington, DC, metropolitan area, Calvert County, Maryland. Economic variables that influence density are identified, including factors that affect the value and cost of additional development. Regulatory constraints and rules on building are included in the model. Calvert’s long-running transferable development rights (TDRs) program that allows developers to increase density above base zoning limits in some areas by purchasing TDRs is also incorporated. We econometrically estimate the density function in both an OLS and a censored regression framework using detailed data on subdivisions built in Calvert County over a 34-year period. The variability in density permitted by the County’s zoning and TDR rules over the sample period allows us to empirically assess the relative importance of market factors and regulatory constraints on density. We then use the censored model to predict, in the cases where regulatory constraints have been binding, what density patterns would have been without the zoning constraints.

Although there is a large empirical literature looking at population and employment densities, this literature tends to focus on how density changes as distance to the central business district of a metropolitan area increases and how zoning allocations—i.e., the proportion of land zoned residential, commercial, industrial—affect overall density in a wide geographical area.² Among the few studies that analyze residential housing density at a smaller regional scale, Song and Knaap [29] use Census block data to examine how neighborhood density and other measures of urban form have changed in the Portland, Oregon, metropolitan region. The authors find that Portland’s strict development policies appear to be having some success in increasing single-family dwelling densities over time. Peiser [27] in an analysis of density patterns in three different communities finds that discontinuous or infill development results in higher overall density in a suburban region than would occur if only continuous or sequential development was permitted. Thorsnes [31] focuses on the question of whether larger subdivisions, by being better able to

¹ Many studies have emphasized the role played by declining transportation costs (Brueckner [1]); Glaeser and Kahn’s [11] particular point of emphasis is that the car has eliminated the scale economies that existed with older transportation technologies such as ports and railroad hubs.

² McDonald [20] surveys this literature which draws from the theoretical base of Muth [25] and Mills [23].

internalize neighborhood externalities, lead to higher property values than smaller subdivisions, all else equal. Finally, a recent working paper by Lichtenberg et al. [18] examines the effects of land use and forest conservation regulations on open space in suburban Maryland. As part of the analysis, they look at how minimum lot size requirements affect the number of lots in a subdivision and average lot size. They find evidence that zoning constrains development.

Two theoretical studies that model a developer's density decision are Edelson [6] and Cannaday and Colwell [3]. Edelson examines how community tax rates and public services affect the willingness to pay for lots of different sizes in a subdivision and how these may affect the developer's optimal choice of lot size. Cannaday and Colwell [3] solve for a developer's profit-maximizing choice of lot characteristics, and their results suggest which factors are likely to influence development costs and values.

Some empirical evidence suggests that subdivisions are being built at lower density than allowed by zoning, suggesting that at least in some areas it is not zoning but other factors driving density decisions (Fulton et al. [10]). However, to our knowledge, no study examines the relative effects of zoning constraints and market forces on the net density of residential development. Moreover, most studies do not have extensive subdivision level data. Subdivisions are the ideal unit of observation since this is the predominant way that residential development takes place in suburban and ex-urban locations. Also, by limiting our analysis to one county we are able to hold constant many factors that also might influence land and housing markets.³

The next section explains the developer decision on how many lots to build, taking into account regulatory constraints. Section 3 gives background Calvert County's zoning and TDR program rules. Section 4 describes the econometric model and data, and presents the results of the empirical analysis. Section 5 concludes.

2. The developer decision

We assume that the developer has already made a subdivision location choice and is deciding about the density of development on the parcel.⁴ Although one can certainly argue that the density decision is made jointly with the decision about where to build, developers may only have access to certain parcels, depending on which landowners are willing to sell. Developers in high growth suburban areas, such as the one considered in our empirical analysis, will build a subdivision on virtually any greenfield that becomes available to them. Thus they purchase land for development where and when they can.⁵

For each parcel, the developer decides how many building lots to create to maximize profits at that site, given regulatory constraints. This decision depends on variables that affect the revenues and costs of development, zoning regulations about what density is allowed, and whether and how

³ Segmenting the housing market in the right way has been a long-standing issue with hedonic property value models. See Straszheim [30] for more on this point. Our results, however, would be most applicable to similar types of urban fringe locations and not more urban centers or other areas.

⁴ It is useful to distinguish here between the developer and the builder. We are modeling the developer's decision to subdivide the parcel into buildable lots. Developers may then sell lots to builders or build the houses themselves.

⁵ See Jaklitch [16]. During the decade of the 1990s, Calvert County had the highest population growth rate of any county in the state of Maryland, 45%; the state average was 10.8% [19].

many transferable development rights can be purchased. The developer takes the rules governing zoning and the ability to purchase TDRs as given for any parcel.⁶

Revenues from development depend on the number of lots built in the subdivision, the total acreage of the subdivision, the natural amenities of the site itself, such as the topography, views, and so forth, land uses of the properties immediately surrounding the site, and the site's location and accessibility to employment and commercial centers. The surrounding land uses can have a complex effect on the value of development. There may be increased value from being adjacent to like uses, or there could be positive or negative spillover effects from different uses.

The costs of development depend on the number of lots, the total acreage of the subdivision, and the costs of providing infrastructure at the site, which depends on soil characteristics and topography. Cannaday and Colwell [3] show that even the shape of the parcel to be subdivided can affect the development costs.

The developer's profit-maximizing choice over number of lots to build in a subdivision is constrained by zoning regulations. These regulations establish a minimum average lot size which, given total subdivision acreage, constrains the number of lots a developer can build.⁷

TDRs provide a tool for allowing flexibility in zoning in designated regions. If a community wants to encourage protection of undeveloped land in some areas, landowners in these so-called TDR "sending areas" may be permitted to sell their development rights and put their land in a permanent preservation easement status. The development rights can be used by developers in so-called TDR "receiving area" regions to build more lots than what is allowed under baseline zoning restrictions.⁸ Developers purchase the rights at a price determined in the market for TDRs.

The developer's profit-maximizing decision is shown in Figs. 1 and 2.⁹ Figure 1 illustrates the basic developer problem for a given tract of developable land in a region where TDRs cannot be used to increase density. Suppose the zoning rule (specified as a minimum average lot size) permits a maximum \bar{l} lots to be built on the parcel. Then the developer with a marginal revenue curve of MV_1 is not constrained by zoning, and builds l_1 lots, achieving an average density of l_1/L , where L is total subdivision acreage. If, however, the marginal revenue from building at the site is MV_2 , then the developer is constrained by zoning, and must choose the allowable limit, \bar{l} , rather than the profit-maximizing choice, l_2 . In this case, the subdivision is less dense—i.e., has larger average lot sizes—than what the private market would have chosen. If the number of lots allowed, \bar{l} , is reduced, the zoning restriction is more likely to be binding.

Figure 2 shows the way in which the availability of TDRs affects density decisions in areas where TDRs can be purchased. MV_1 is left off the graph because, as in Fig. 1, if MV_1 is the marginal revenue from additional lots and MC_1 is the cost per lot, then profit-maximizing number of lots, l_1 , are built. The availability of TDRs does not affect the developer's decision. If the marginal revenue is MV_2 , however, the developer is constrained by the baseline zoning limit, but TDRs can now be purchased at price P_{TDR} . In this case, the profit-maximizing number of lots is where $MV_2 = MC_2$, or l'_2 , and the developer creates t_2 lots through TDRs. A final constraint is

⁶ In some jurisdictions, developers or builders might be able to influence the zoning rules governing a property, through petitions and zoning variances. Here, we treat the zoning as exogenous, which is in keeping with the empirical analysis which follows later in the paper.

⁷ Residential zoning limits are sometimes specified in terms of an absolute minimum lot size, e.g., no lot can be smaller than 1 acre. More often it is a minimum lot size averaged across the entire subdivision parcel. In the application analyzed below, Calvert County uses average minimum lot size zoning.

⁸ Here we assume that only one TDR is needed to create one additional lot.

⁹ These graphs follow from the Field and Conrad [7] model of efficiency and equity in TDR markets.

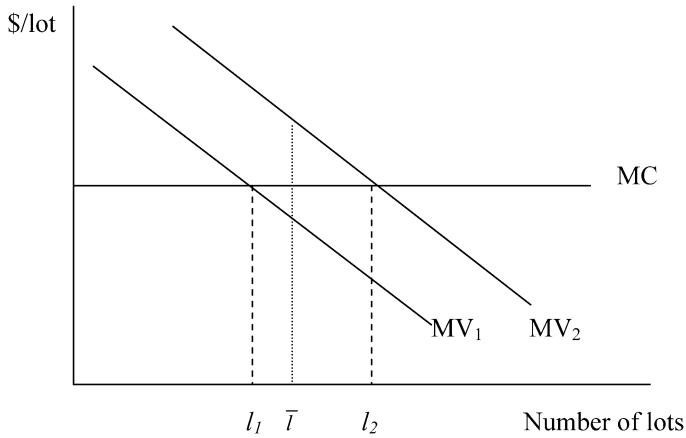


Fig. 1. Developer's density decision: no TDRs allowed.

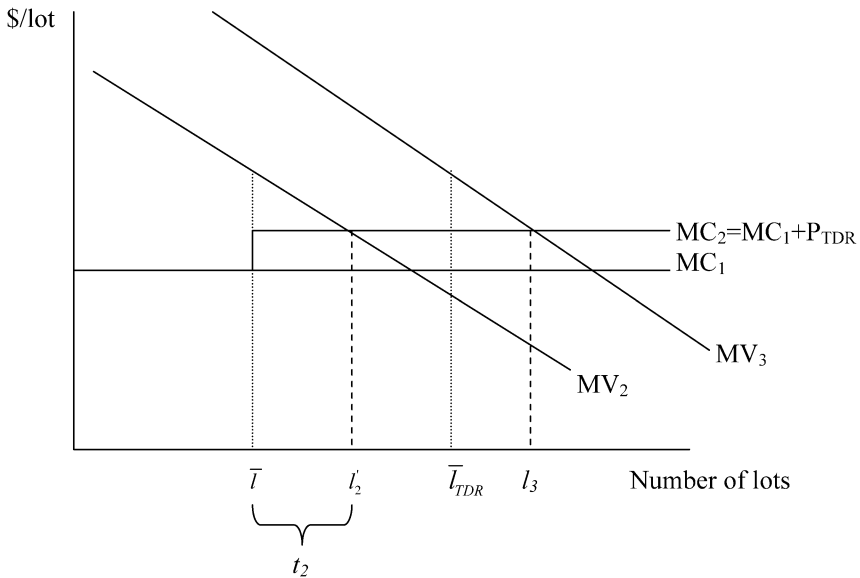


Fig. 2. Developer's density decision: purchase of TDRs allowed.

that in most TDR programs, there is a maximum density that is permitted with the use of TDRs. In Fig. 2, this limit is shown as \bar{l}_{TDR} . If the marginal revenue of additional lots is as high as MV_3 , the developer is again constrained even with the availability of TDRs. The profit-maximizing number of lots in the subdivision would be l_3 , but the developer can only build up to \bar{l}_{TDR} lots.

In summary, Figs. 1 and 2 illustrate that there are a range of possible density levels across subdivisions. The number of lots may be determined by market forces or it may be determined by the local density restrictions, including baseline zoning rules or by the number of TDRs allowed. We explore all of these possibilities in the empirical analysis below.

3. Land uses, zoning, and TDR history in Calvert County, Maryland

Calvert County is a 215-square mile peninsula in southern Maryland bordered by the Chesapeake Bay and the Patuxent River. The northern-most town in the county, Dunkirk, is approximately 30 miles south of Annapolis, Maryland, and southeast of Washington, DC. It is a historically rural, agriculture-based county, but it has seen rapid population growth over the past twenty to thirty years because of its proximity to major centers of employment.¹⁰

Table 1 summarizes the residential density limits imposed by zoning regulations over time. In 1967, the county adopted its first Comprehensive Plan in which all rural land was zoned to a maximum density of 1 dwelling unit per 3 acres. In 1975, the county updated the Plan to reflect a “slow growth” goal and changed the maximum density to 1 dwelling unit per 5 acres. Despite the 5-acre minimum lot requirement, there continued to be substantial population growth and conversion of land from agricultural uses to housing developments throughout the county. In 1978, the county adopted a TDR program in an attempt to protect many of the prime farmland areas of the county from development.¹¹ The first TDR was sold in 1981.

The program targeted the TDR receiving regions to include Town Centers, residential zones, and some rural areas known as Rural Communities (RC). Land in the RC could be used as receiving or sending areas for TDRs. The remaining rural land was identified as prime farmland and became known as the Designated Agricultural Area (DAA). Parcels in the DAA could only

Table 1
Maximum density allowed by zoning rules in Calvert County, Maryland

Year	Rural		Residential	Town centers ^b
	DAA ^a	Rural communities (RC)		
1967–1974	3.3 units/10 acres	3.3 units/10 acres	10 units/10 acres ^c	–
1975–1980	2 units/10 acres	2 units/10 acres	10 units/10 acres ^c	–
1981–1998				
w/o TDRs	2 units/10 acres	2 units/10 acres	10 units/10 acres ^c	40 units/10 acres
with TDRs	2 units/10 acres	5 units/10 acres ^d	40 units/10 acres ^c	140 units/10 acres
1999–present				
w/o TDRs	1 unit/10 acres	1 unit/10 acres	5 units/10 acres	20 units/10 acres
with TDRs	2 units/10 acres	5 units/10 acres ^d	40 units/10 acres	140 units/10 acres

^a After 1992, this includes some additional farming regions that lie outside the original DAA areas. From 1981–1992, these additional areas could achieve the same density with TDRs as in the Rural Communities (RC). After 1992, they were treated the same as the DAA. See footnote 12.

^b The Town Center zoning classification came into effect in 1983.

^c Prior to 1999, multifamily homes and townhouses were allowed in a small part of the Residential zone (known as R-2). Density could go as high as 140 units/10 acres in these areas without the use of TDRs. After 1999, all residential areas (R-1 and R-2) had the same zoning and TDR rules.

^d Density in Rural Communities that are within 1 mile of a Town Center can go as high as 1 unit/acre with the use of TDRs.

¹⁰ The population has more than doubled since 1980 to about 87,000 in 2005.

¹¹ Other growth controls were implemented over the years as well. For example, in 1988, the county adopted an adequate public facilities ordinance which halts building when it is determined that public facilities such as schools cannot handle additional growth. Critical Areas near waterways were outlined in 1989 (as required by the state) and maximum residential density was reduced to 1 dwelling unit per 20 acres in those areas. See Calvert County Planning Commission [2] for more detail.

be used as TDR sending areas.¹² Figure 3 helps to illustrate the spatial aspects of these different zoning classifications.¹³

In 1999, due to rapid growth in the region and the county's reluctance to expand roadways, all regions were downzoned in order to reduce overall development in the county. As shown in the last two rows of Table 1, the baseline zoning in all areas was reduced by 50%. Density permitted with TDRs, however, remained the same as before the downzoning. Thus the pre-1999 maximum density levels in all areas can still be attained, but only with the purchase of more TDRs.

Since the TDR program began, the sale of TDRs has preserved over 13,000 acres of farmland in Calvert County.¹⁴ Developers used TDRs in slightly less than 30% of the new subdivisions built over the 1980–2001 period; in total, 2130 additional housing units were created with TDRs. The TDR program rules, along with the zoning changes over time, have led to variability in housing density in the county and allow us to look at the factors that explain density.

4. Empirical models, data, and results

4.1. Model specification

Following the developer decision described in Section 2, we estimate an equation for the number of lots in a residential subdivision, given all exogenous factors affecting the marginal revenue and marginal cost of an additional lot. These include the total size of the plat area, the amenities and physical characteristics of the site, the characteristics of the neighboring areas, and the zoning and TDR rules in place. For subdivisions located in TDR receiving regions, the developer faces a TDR price as determined in the overall market for TDRs. Initially, we account for the density restrictions by including the maximum number of lots allowed in the subdivision (calculated based on the subdivision's recording date and location in the county) as a covariate in the OLS estimation of the density equation.

We can write a reduced form equation for the profit-maximizing number of lots as a function of all of the exogenous variables affecting profits. We specify the log of the number of lots in subdivision i as:

$$\ln(l_i)^* = a + B_1 \ln L_i + B_2 n_i + B_3 u_i + B_4 d_i + B_5 s_i + B_6 \bar{l}_i + B_7 p_{TDR} + e_i, \quad (1)$$

where L_i = size of subdivision i , in acres, n_i = vector of natural amenities in subdivision i , u_i = vector of neighboring land uses at the time subdivision i is built, d_i = vector of accessibility variables for subdivision i , s_i = vector of soil and topography characteristics for subdivision i , \bar{l}_i = maximum number of lots allowed given subdivision i 's recording date and location, p_{TDR} = price of a TDR as determined in the overall TDR market in the year the subdivision is recorded.

¹² In 1992, additional prime farmlands and environmentally sensitive lands were designated as sending areas only, and effectively became part of the DAA. All of the sending area-only regions were generally referred to as Farm Community Districts (FCD) or Resource Preservation Districts (RPD) after this time. Since the original DAA is a subset of the FCD/RPD region, for simplicity, in this paper we will continue to refer to the sending area-only regions as DAA and the regions that were added on in 1992 as "regions added to DAA."

¹³ A little over 40% of the county lies in the Rural Communities (the rural regions outside the DAA), another 40% is in the DAA, and about 16% lies in the residential and Town Center zones. The remainder is zoned for commercial/industrial use.

¹⁴ Approximately 13,000 additional acres have been preserved through other programs, including five State programs: the Maryland Agricultural Land Preservation Program (MALPF), Rural Legacy Program (RLP), Maryland Environmental Trust (MET), Program Open Space (POS), and Program GreenPrint.

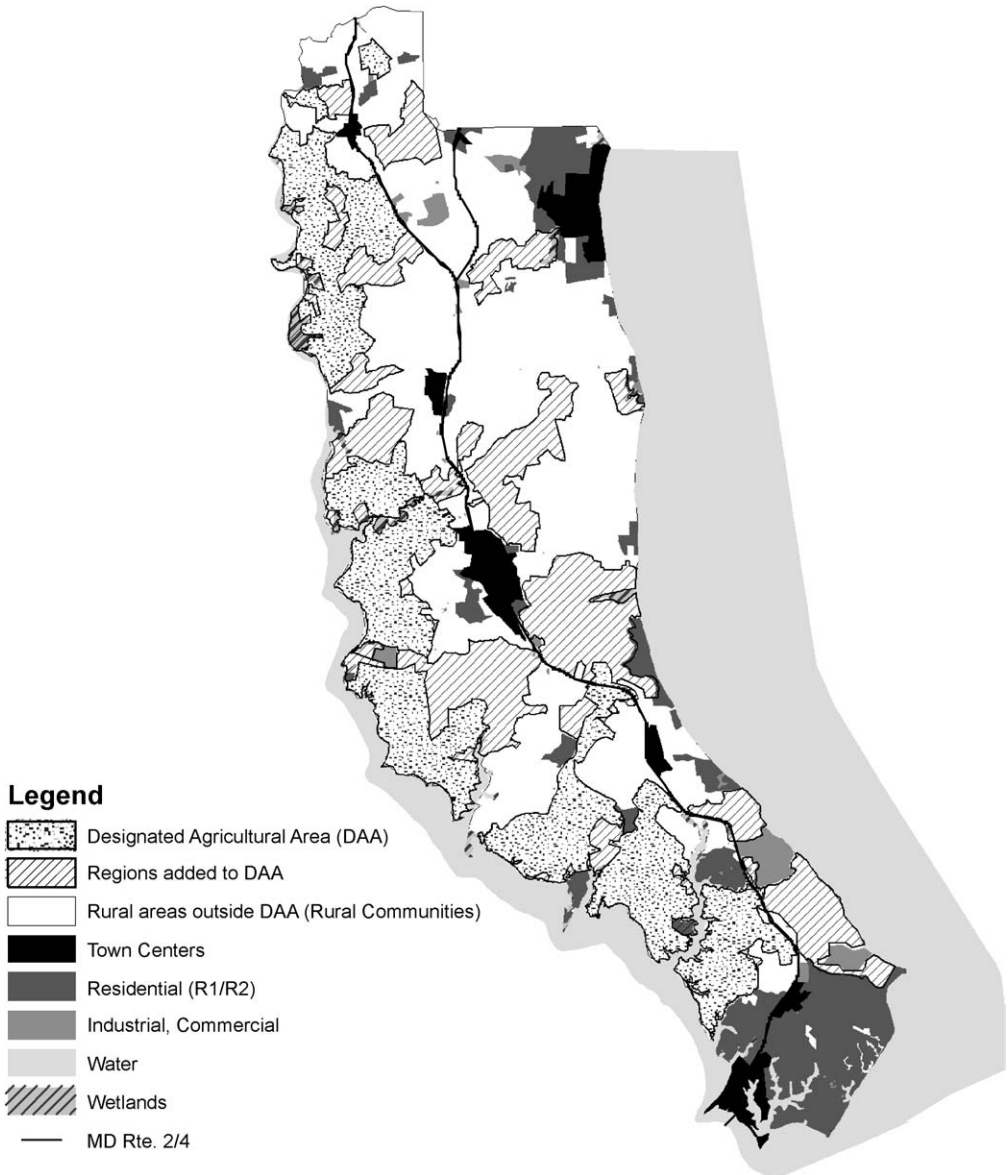


Fig. 3. Zoning map, Calvert County, Maryland.

The statistical significance and magnitude of the estimated coefficient on \bar{l}_i allows us to say to what extent zoning determines density relative to the market factors.

An alternative and useful way to estimate the density function, however, is to employ a censored regression framework. The censored model takes into account that the likelihood function consists of the probability that an observation is uncensored—i.e., below the limit set by zoning—and, conditional on being uncensored, the likelihood that particular exogenous variables explain the variation in lots built. Accounting for the censored nature of the dependent

variable not only gives us a more accurate way to model the error structure, but also allows us to use the equation to predict what development would have been if the constrained subdivisions had not been constrained.

We employ this second approach by adding two constraints to the model given by Eq. (1)¹⁵:

$$l_i = \begin{cases} l_i^* & \text{if } l_i^* < \bar{l}_i, \\ \bar{l}_i & \text{if } l_i^* \geq \bar{l}_i, \end{cases}$$

where \bar{l}_i is the maximum number of lots allowed on the parcel, as given by the baseline zoning or maximum TDR purchases allowed in that region in the year that the subdivision was recorded. If a developer is not constrained by the zoning regulations, then the dependent variable, l_i , is equal to the optimal number of lots, l_i^* . If the optimal number of lots is greater than what is allowed, \bar{l}_i , however, then the choice over density is constrained. As can be seen in Table 2, 30 observations in the dataset, about 8% of the sample, are censored.¹⁶

It is important to note that we are treating the density restriction as exogenous in this model. It has been argued in the literature that local zoning, especially over a period of time as long as that considered here, is likely to be endogenous (Rolleston [28], Wallace [32], McMillen and McDonald [22], McDonald and McMillen [21]). In Calvert County, there are several reasons to believe that the zoning and TDR rules are exogenous to the individual developer's decision. First, the zoning rules and the ability to exceed those rules using TDRs are spelled out in the regulations, and exceptions and variances for any one property are not allowed.¹⁷ Second, the changes in overall zoning rules in 1975 and 1999 affected all regions of the county uniformly and were a result of concern over population growth and the size of the transportation system. This leaves only the inception of the TDR program in 1981 as the other significant zoning change. Though adoption of the TDR program may have been market-led—i.e., in response to concern over declining farmland—the designation of particular regions as sending or receiving areas and

Table 2
Number of subdivisions in Calvert County at maximum density by zoning category

	Rural areas	Residential areas/ Town centers	Total
Total number of subdivisions	334	64	398
Number constrained by zoning or TDR limit	28	2	30
Number unconstrained by zoning and/or TDR limit	306	62	368

¹⁵ In addition, the variable \bar{l}_i is dropped from the censored model since the censored regression technique accounts for the constraint imposed by this variable.

¹⁶ Specifically, we right censor all observations where $\bar{l} - 1 < l_i$. (This is necessary because the \bar{l} calculated from the parcel acreage and the average minimum lot size is rarely an integer.) Since other lot requirements (e.g., minimum setbacks) could potentially prevent a developer from creating all the lots allowed by the average minimum lot size regulations, we also estimated the model when censoring all observations where the dependent variable is with 2 or 3 units of \bar{l} —i.e., when $\bar{l} - 2 < l_i$ and when $\bar{l} - 3 < l_i$. (Using these stricter censoring specifications, the number of censored observations increases to 38 and 46, respectively.) We find the results to be qualitatively the same across these different censoring rules.

¹⁷ Unlike many local governments, Calvert County generally does not allow rezonings on a case by case basis. The only exemption to zoning rules is that parcels deeded before 1975 retain some grandfathered lots, as compensation for the 1975 3-acre to 5-acre lot downzoning. We account for this in our empirical analysis.

the zoning limits set in those areas do not appear to be market-driven. Prior to 1981, development had been taking place everywhere in the county, and at relatively similar densities across the different rural areas.¹⁸ The regions the county designated as TDR sending areas were those with the most productive farming soils in the county. All others were receiving areas with baseline zoning unchanged but density increases allowed with TDRs.

Finally, our specific concern about possible endogeneity has to do with whether the zoning limit variable in the OLS regression is correlated with the error term—i.e., are unobserved factors that explain a developer's decision over the number of lots to build in a subdivision correlated with the zoning established by the government for that subdivision? We employ a Hausman test [13] for endogeneity using the percentage of subdivision soils that is classified as prime farmland as an instrument for the lots allowed by zoning variable and find that we are unable to reject that the zoning variable is exogenous. We must point out that this finding is also consistent with our soils variable being a weak instrument. Nonetheless, the combination of the history in Calvert County, the way the TDR program was structured, and our Hausman test lead us to conclude that zoning is exogenous in this case.

4.2. Data

Data on each new subdivision was gathered from the Calvert County Planning Department records and then digitized into GIS format using ArcMap software. We have a total of 398 subdivisions built over the 1967–2001 time period. Data on the individual parcel characteristics and surrounding land uses were constructed from Maryland Property View and county records. Topographical and soil quality information was also available in digitized GIS format from the state of Maryland. Table 3 shows summary statistics for all variables included in the econometric models.

The size of the subdivisions in our sample varies from 4 acres to almost 600 acres with an average size of 71 acres. The number of lots in each subdivision ranges from 3 to 268; the average is 27. Some subdivisions are surrounded by between 40 and 50% preserved farmland or parks, while others are adjacent to no open space. The average percentage of surrounding land that is part of another subdivision is 18%.¹⁹ We use location dummy variables in our model to capture differential effects of location on density. Location 1 is the northern-most area and includes 22% of all subdivisions in the sample; the greater the location number, the farther south it is in the county. The location areas were chosen to roughly correspond to traffic lights and town center locations along the main commuting highway, Route 2/4. The average subdivision is located about 1.5 miles from Route 2/4. Proximity to shopping and other commercial areas is measured by a gravity index that is a weighted average of proximity to the major town centers in the county.²⁰

Most of Calvert County relies on septic systems, thus only 2.3% of subdivisions have sewer available. Our soils and topography data allow us to calculate the percentage of land in each

¹⁸ For example, in our sample, average subdivision density in the DAA region before 1983 was 3.455 acres/lot. In the non-DAA rural areas, it was 3.589 acres/lot.

¹⁹ The percentage of surrounding land in a given use is calculated as the share of the subdivision perimeter that lies in the specified land use at the time of subdivision recording.

²⁰ Specifically, the index is defined as: $I_i = \sum_{k=1}^c (M_k/d_{ik}^2)$ where i denotes the subdivision, c is the number of town centers, M_k is the size of town center k , and d_{ik} is the distance from subdivision i to town center k .

Table 3
Summary statistics of total subdivision sample, $N = 398$

Variable	Mean	Std. Dev.	Min	Max
Total number of lots	27.211	31.499	3.000	268.000
Number of lots permitted by zoning/TDR restrictions	51.781	92.333	2.496	1043.098
Total plat area (acres)	70.647	71.353	4.029	589.590
Length of subdivision perimeter (feet)	8211.555	4335.655	1947	33,992
% Subdivision land in steep slopes	36.756	29.795	0	100
Within 1 mile of Patuxent/Chesapeake Bay	0.221	0.416	0	1
Sewer service availability	0.023	0.149	0	1
% Surrounding land in preserved open space/farmland (privately held)	1.666	5.969	0	42.916
% Surrounding land in parkland	1.353	5.538	0	48.671
% Surrounding land in subdivisions	17.751	21.341	0	100
% Surrounding land in commercial/industrial zone	2.591	8.676	0	100
Located in residential or town center areas	0.161	0.368	0	1
Location 1 ^a	0.224	0.417	0	1
Location 2 ^a	0.236	0.425	0	1
Location 3 ^a	0.241	0.428	0	1
Location 4 ^a	0.083	0.276	0	1
Location 5 ^a	0.148	0.356	0	1
Location 6 ^a	0.068	0.252	0	1
Distance to Route 2/4 (in miles)	1.503	1.148	0.005	4.840
Access to town center index	0.040	0.508	0.000	9.970
TDR price (in 1999 dollars) ^b	1248.498	1105.587	0	2582
Year of subdivision recording	1986.862	8.946	1967	2001

^a Location 1, the omitted dummy in the regression model, is the northern-most area of the county; Location 2 is just south of Location 1, and so forth, with Location 6 the southernmost region.

^b TDR price is averaged over those subdivisions that used TDRs, not all subdivisions.

subdivision that lies in steep slopes (a grade of 15% or higher). The average subdivision in our sample has steep slopes in 37% of its land area.

4.3. Results

We estimate Eq. (1) for all of the 398 subdivisions in our sample, using both the OLS and censored regression framework. The results are shown in Table 4. Our focus in the OLS model is on the effect of zoning relative to the other factors in explaining density. We then use the censored model to see what factors affect density and to predict what would have occurred in the absence of zoning.

In any spatial model such as this one, we must address the issue of unobserved spatial correlation in the error term.²¹ We test for spatial autocorrelation by creating a weighting matrix in which we assign positive and equal weight to subdivisions that are directly adjacent to each other and consider both a row-normalized and non row-normalized weighting scheme. Using the Moran I test for OLS and a generalized Moran I test for the censored model (Kelejian and Prucha [17]), we cannot reject, at the 95% confidence level, the null hypothesis that no spatial correlation exists.²²

²¹ See Irwin [15] for a general discussion of the issue.

²² The Moran I test statistic is 0.907 and 0.500 for the row-normalized and non row-normalized weighting specifications, respectively in the OLS case. (Lagrange multiplier and robust Lagrange multiplier tests for spatial error dependence and

Table 4
Regression of subdivision density (with robust standard errors)

Dependent variable: ln(Lots)	OLS		Censored regression	
	coeff.	(s.e.)	coeff.	(s.e.)
ln(Total Lots Permitted)	0.247***	(0.046)		
<i>Subdivision size and characteristics</i>				
ln(Acres)	0.624***	(0.133)	0.952***	(0.142)
STEEP (% land in steep slopes)	-0.068**	(0.034)	-0.086**	(0.037)
ln(Acres) * STEEP	-0.004	(0.003)	-0.005*	(0.003)
ln(Perimeter)	-0.137	(0.229)	-0.294	(0.260)
ln(Perimeter) * STEEP	0.009*	(0.005)	0.012**	(0.005)
Within 1 mile of Patuxent River/Chesapeake Bay	0.021	(0.064)	0.021	(0.065)
Sewers	0.393	(0.257)	0.472*	(0.284)
Residential/Town Center dummy	0.260*	(0.133)	0.784***	(0.088)
<i>Surrounding land uses</i>				
% surrounding land in privately owned preservation status	-0.006**	(0.003)	-0.009***	(0.003)
% surrounding land in parks	-0.012**	(0.006)	-0.011*	(0.007)
% surrounding land in another subdivision	0.0004	(0.001)	0.001	(0.001)
% surrounding land in commercial/industrial zone	0.001	(0.004)	0.001	(0.004)
<i>Accessibility variables</i>				
Location 2	-0.067	(0.065)	-0.066	(0.070)
Location 3	-0.070	(0.072)	-0.079	(0.076)
Location 4	-0.035	(0.095)	-0.028	(0.103)
Location 5	-0.019	(0.076)	-0.002	(0.081)
Location 6	-0.114	(0.126)	-0.201*	(0.123)
ln(Distance to Route 2/4)	-0.045*	(0.026)	-0.088***	(0.026)
Access to town centers	0.114***	(0.024)	0.141***	(0.024)
<i>Time trend</i>	-0.008**	(0.003)	-0.002	(0.004)
<i>Constant term</i>	0.908	(1.588)	1.781	(1.802)
No. of observations		398		368
No. of right-censored observations				30
R^2		0.7432		

* Statistical significance at the 90% level.

** Idem., 95%.

*** Idem., 99%.

Zoning vs. other factors Table 4 column 1 shows the OLS results for the log of density and provides further evidence that zoning regulations have had a constraining effect on subdivision density. The first row shows that the coefficient on the lots permitted variable is positive and highly significant. Holding all else equal, a 10% increase in the number of permissible lots through zoning would tend to increase the actual number of lots by about 2.5%. Zoning limits have therefore reduced the density of development below what it would have been. This provides some evidence of the “zoning causes sprawl” argument.

From Table 2, however, we know that the number of subdivisions built at the limit of the allowable density is relatively small, only about 10%. Other factors are clearly also important in determining density, as shown in Table 4. In fact, an F test of the hypothesis that all of the non-zoning/TDR variables in the first column of results are jointly insignificant is soundly rejected at

a spatial lag could also not be rejected for the OLS.) Under the censored model, the generalized Moran I test statistics are 1.127 and 0.948 for the row-normalized and non row-normalized specifications.

the 99% level.²³ We discuss these economic variables next. The results are quite similar across the two model specifications in Table 4, so to simplify the exposition, we focus only on the censored model results.

Subdivision size and characteristics A key subdivision characteristic is the size of the subdivision plat area in acres. The coefficient on $\ln(\text{Acres})$ is significant and almost equal to 1 in the censored model; increasing the amount of available acreage by a given percentage leads to approximately the same percentage increase in the number of lots built.²⁴

Among variables likely to affect the cost of developing an additional lot, the slope of the land is found to exert some influence over density but the overall shape of the subdivision does not. The coefficient on the variable measuring the percentage of the total subdivision acreage that is steeply sloping is negative and significant as expected. The variable that interacts subdivision size and the percent steep slopes is also found to be negative, indicating that the positive effect of a larger acreage on the number of lots built is somewhat offset when the subdivision is more steeply sloped. Note, however that the coefficient on this variable is only significant in the censored specification at the 90% level. The estimated coefficient on the perimeter variable, which, holding acreage constant, captures how irregularly shaped the parcel is, is negative but insignificant. Somewhat surprisingly, we also find that the more irregular the shape, the less the effect of steep slopes on the number of lots that can be built.²⁵

The coefficient on the dummy variable indicating whether the subdivision is located near the major bodies of water—the Patuxent River or the Chesapeake Bay—is statistically insignificant. The coefficient on the sewer availability dummy is highly significant. In the censored specification we find that, all else equal, sewer service increases the number of lots by nearly 50%. This result makes sense as septic systems require larger lots to accommodate the septic drain field.

The final subdivision variable that is included is a dummy variable equal to one if the subdivision is located in a residential or Town Center area. This variable serves as a proxy for any advantages or unique characteristics of more urbanized areas and possibly any amenities from separation of uses that residential zoning provides (Fischel [9], Rolleston [28]). The coefficient on this variable is positive and significant as expected.

Surrounding land uses The inclusion of the four surrounding land use variables allows us to assess whether the market tends to put more or less dense subdivisions next to preserved farms, parkland, commercial or industrial uses, and other residential subdivisions.²⁶ The results in Table 4 support the notion that subdivision density will be lower if the subdivision is located next to permanently preserved, privately owned land. In the censored model, we find that a 10 percentage point increase in the amount of preserved farmland on the boundary of the subdivision leads to about a 9% decrease in the number of lots built in that subdivision. The coefficient on the percent of the subdivisions that is adjacent to parkland is also negative, significant and slightly larger in magnitude, suggesting that the additional value that adjacent preserved land provides

²³ The F -test statistic, with (20, 376) degrees of freedom, is 16.02.

²⁴ More precisely, however, when evaluated at the sample mean of STEEP, the elasticity of lots with respect to total plat area decreases slightly to 0.774 (0.081) in the censored model. The coefficient on the STEEP-plat interaction term is discussed below. We also estimated the equation including a squared term in subdivision plat size. The coefficient is found to be statistically insignificant and does not add much explanatory power to the model.

²⁵ In fact, when evaluated at the sample mean of the perimeter (and total plat area), the elasticity of STEEP becomes 0.0007 (0.0008).

²⁶ These variables are measured as the percentage of land on the perimeter of the subdivision that is in a given use at the time the subdivision is recorded.

to lower density development is higher if the open space is available for public use. Finally, neither the percentage of a subdivision's boundary that is in commercial or industrial status nor the percentage in another subdivision appears to affect density.²⁷

Accessibility In accordance with conventional urban models, we expect subdivisions in the northern regions of Calvert County that are more accessible to major cities to be denser than those in the southern areas. The location dummy variables are delineated by towns located along the major commuting highway, Route 2/4, which often has bottlenecks during commuting hours.²⁸ The signs of the coefficients on the location dummies are all negative, although only the region most distant from the top of the county (region 6) is significant at the 90% level in the censored model, indicating approximately 20% lower density subdivisions than in the northernmost region.

In addition to distance from major cities, we also find the subdivision's closeness to the major commuting road, Route 2/4, to increase density slightly, as expected. Proximity to shopping and other commercial areas in the County, as measured by the gravity index,²⁹ is also found to increase subdivision density.

Time trend The negative coefficient on the linear time trend suggests that density has been declining over time, all else equal. However, the coefficient is insignificant in the censored model.

TDR prices Finally, because the cost of purchasing TDRs will only affect the number of lots built in subdivisions that are permitted to use TDRs—approximately 59% of the sample—we do not estimate the full model with the TDR price as a covariate. However, to look at the effects of the TDR price, we estimate the OLS and censored model on the sub-sample of subdivisions built in TDR receiving areas including the annual average price of a TDR, in inflation-adjusted terms.³⁰ We find that the estimated coefficient on this variable is negative but statistically insignificant in explaining differences in density in both models. This may be because in the period after about 1993, the price was relatively constant, rising only slightly each year.

In summary, we find that many of the economic variables—including physical site characteristics, accessibility measures, and surrounding land uses—have a significant influence on subdivision density. We can now use the results of the censored model to make some predictions about what density levels would have been in the absence of the zoning rules.

4.4. Forecasts of development patterns

The censored regression framework provides a useful way to look at the extent to which the zoning/TDR limits constrain subdivision density. The different zoning categories combined

²⁷ We explored more specific ways that surrounding land uses might affect subdivision density, especially the density of the existing residential densities at the time the subdivision was initiated. We found no consistent evidence that subdivision densities would be higher when surrounding densities were higher. Hence we display only the simplest results here.

²⁸ The omitted region is the northern most area. We also estimated versions of the model that had a continuous variable measuring distance to the northern border of the county instead of the location dummies. The distance variable also had a negative and statistically insignificant coefficient.

²⁹ This index is defined in footnote 20.

³⁰ If the demand for TDRs increases county-wide, price will rise, but the price facing each developer is set in the market. Hence we assume that the average annual price of a TDR remains exogenous to the individual developer decision (see McConnell, Kopits, and Walls [19]).

with the TDR program and downzonings that occurred over the sample period also enable us to examine how the degree of constraint varies by region and over time.

We first use the results from the second column of Table 4 to predict the number of lots using the values of the independent variables for each subdivision. We find that the equation predicts quite well over the whole sample. The mean predicted and actual number of lots are 25 (with a standard deviation of 21) and 27 (31.5), respectively. What is of most interest, however, is to use the equation to predict density for the 30 censored observations. The difference in the predicted and the actual lots for those 30 subdivisions is about 2.95, with more lots, or higher density, in the predicted equation as expected. The predicted number of lots is 24.15 (standard deviation of 17.04), and the mean actual number is 21.2 (19.03). Since this difference is rather small, it suggests that there was not much excess demand for additional lots beyond what was allowed by zoning.

Considerable differences exist, however, across locations and time periods. Table 5 shows the actual and predicted average lot sizes for the 28 constrained subdivisions in rural areas by zoning limits and year.³¹ Before 1975, the average actual lot size for the constrained subdivisions in rural areas is at the regulatory limit of 3 acres. The average predicted lot size is slightly smaller (meaning more dense development), at 2.64 acres. From 1975 to 1982, the average lot size of the constrained subdivisions in the rural areas was 5 acres, while the predicted lot size was a little less than 3 acres in the rural areas outside the DAA area and closer to 4 acres in the DAA. These predicted average lot sizes are 40 and 25% below the constrained average, thus the differences are substantial. This provides evidence that developers would have preferred to build to a higher density in these locations. Our results suggest that, over the sample period, 46% more lots would have been built in the 20 subdivisions that are most constrained by the zoning regulations. Of all the subdivisions facing a 3- or 5-acre minimum lot size requirement, this translates to approximately 1.2 and 22% more lots, respectively, and 11% more lots overall.³² It is important to point out, however, that even if subdivisions had built with 3- and 4-acre average lot sizes they would still be considered relatively low-density developments.

With the introduction of TDRs, the maximum allowed density in the rural areas outside the DAA increased (i.e., the minimum lot size allowed fell from 5 acres to 2). The predictions from the censored model suggest that this new limit is approximately what the market demands. The

Table 5
Actual and predicted lot sizes by density limit for censored subdivisions in rural areas

Minimum average lot size allowed	Zoning areas and years applicable	Number of subdivisions	Average actual lot size (acres)	Average predicted lot size (std.dev.)
3 acres	All rural areas before 1975	5	2.99	2.64 (0.25)
5 acres	Rural areas outside the DAA, 1975–1982	8	4.86	2.80 (0.54)
	DAA areas, 1975 on	7	5.03	3.64 (0.67)
2 acres	Rural areas outside the DAA, 1983 on	8	2.02	2.63 (0.25)

³¹ We omit the 2 subdivisions in residential areas since this sample size is so small.

³² Note that the rural subdivisions that were awarded grandfathered lots in 1975 (see footnote 17) are uncensored observations and are therefore excluded from these calculations. The number of subdivisions actually subject to and constrained by the 5-acre restriction would have been greater had grandfathering not been allowed.

predicted average lot size is 2.63 acres for these subdivisions compared to the actual average lot size of 2.02 (see the last row of Table 5).³³ This is consistent with the rest of Table 5 results; at least in Calvert County, residential subdivision density appears to be most constrained by zoning regulations that require average lot sizes of 3 acres or more.

5. Conclusions

Concern over urban “sprawl” is at least in part a concern over dispersed, low-density residential development patterns in suburban and ex-urban locations. In this paper, we examined the developer’s decision about density of development at the disaggregated, subdivision level, and studied the relative influence of zoning rules versus market forces. Some observers have argued that it is zoning that forces developers to build at lower densities than they would like and is a major cause of low-density suburban growth patterns. On the other hand, economic factors can influence the density of development on a site—developers may be giving households the lot sizes and spatial structure they want and that developers are able to build given site conditions. We found that both zoning rules and economic variables are important in determining density. Many of the economic variables affect density in the predicted ways, but we also find evidence that some density limits are binding. About 8% of subdivisions in the sample were developed to the maximum density allowed by regulation.

Our results showed that factors affecting both the value and cost of additional lots are important in the density decision. We found the size of the subdivision land area to be important, as well as the steepness of the terrain. Existing uses of land surrounding the subdivision also appeared to affect the density of the subdivision. Accessibility to sewers, to the major highway in the region, and to town centers were all found to be important determinants of density.

The results do provide evidence that zoning regulations are contributing to low density residential development in some areas. Although the number of constrained subdivisions is relatively small, we find that those constrained by the lowest density limits (5-acre average minimum lot size) would have been nearly 50% denser absent any zoning regulations. However, we estimate that, if zoning restrictions were relaxed, only a little over 10% more lots would have been added overall in subdivisions facing relatively low density limits over the sample period. On the one hand, this means that relatively large lots would still predominate in these rural areas even if they were no longer constrained by zoning. On the other, this increase in lots may represent a substantial reduction in land used for residential development.

We hasten to point out that while our data may be typical of many ex-urban, fast-growing rural jurisdictions around large metropolitan areas, the results could be somewhat different in the case of a more urban or older suburban area. A comparison to other areas is an avenue of important future research.

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³³ In estimating the censored model, we assume that any subdivision that we observe being at the limit of the number of allowable lots is censored. However, it is possible that some of those subdivisions are at exactly the profit-maximizing level (see Figs. 1 and 2). This may be the case for these 8 subdivisions built in the RC areas from 1983 on. Because of the integer problem—one cannot build a fraction of a lot—it is difficult to evaluate these differences precisely.

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