Growth Management Policies for Exurban and Suburban Development: Theory and an Application to Sonoma County, California

David A. Newburn and Peter Berck

This study examines the effectiveness of growth management policies on influencing future patterns of exurban and suburban development. We initially estimate a spatially explicit model of residential development with parcel data in Sonoma County, California. This estimated model is then used to simulate the effect of urban growth boundaries (UGBs) versus allowing municipal sewer service expansion. The UGB policy decreases the amount of suburban development but is less effective in managing exurban development. The downzoning policy in agricultural and resource areas reduces the amount of exurban development, but only partially due to the prevalence of grandfathered lots in rural areas.

Key Words: exurban development, urban growth boundaries, sprawl, spatial modeling, urban fringe

Although most people reside in urban and suburban areas (Nechyba and Walsh 2004), these land uses occupied only 1.9 percent of the land area within the United States in 1992 (Burchfield et al. 2006). Sutton, Cova, and Elvidge (2006) used nighttime satellite imagery and found that exurban development occupies 14 percent of the land area. Exurban large-lot development (at one acre or more per house) has been recognized as a much greater threat to farmland loss in the United States than urban and suburban development combined (Heimlich and Anderson 2001). Hence, it is important to understand the effectiveness of various growth management policies on influencing future patterns of exurban versus suburban development.

In this paper, we examine whether development at exurban and suburban densities responds differently to land-use regulations on urban growth boundaries (UGBs) and minimum lot-size zoning requirements. The adoption of a UGB essentially acts as a stricter regulation on annexation because it limits the extension of municipal sewer and water service areas (SWSAs) for a given time beyond the boundary. We initially estimate a spatially explicit model of residential land-use change with parcel-level data in Sonoma County, California. We use a discrete choice model to estimate the landowner decision to convert an undeveloped parcel to residential development, which includes multiple density classes. Specifically, the two higher density classes, which are both greater than one unit per acre, represent suburban development. The two lower density classes represent exurban development. The discrete break at one housing unit per acre is made between suburban and exurban development because this is the density limit for residential use with septic systems prescribed in the Sonoma County General Plan. We expect that development at suburban densities

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therefore will be less likely outside designated SWSAs. Development at exurban densities is expected to be less constrained within designated SWSAs because septic systems easily allow individual homes to be noncontiguous and leapfrog into rural areas.

We then use the estimation results for the residential land-use change model to examine alternative policy scenarios on two types of growth management strategies. First, we analyze the effect of a UGB policy around each incorporated city. UGBs were recently adopted in eight of nine cities within Sonoma County. We contrast the UGB policy with the policy allowing municipal sewer service expansion around each city. Second, we analyze the effect of a major downzoning in the General Plan for designated agricultural and resource areas. The objective is to examine the effectiveness of these growth management policies in influencing the future distribution of both new households and acreage developed at exurban versus suburban densities.

The remainder of the paper is laid out as follows. In the next section, we briefly summarize the related literature on how local growth controls influence residential development patterns. Then we provide an overview on the growth management policies and housing development patterns in Sonoma County. Then, we describe the empirical model and provide a detailed discussion of the dependent and explanatory variables for the residential land-use change model. After discussing the estimation results, we perform simulations to predict residential development and developed acreage under various growth management scenarios, including policies on UGBs, SWSA expansion, and downzoning in rural areas. Lastly, we provide summary remarks and conclusions.

Prior Research

Our analysis builds on the extensive literature that has examined how local growth controls influence housing development patterns. We discuss some of the prominent studies based on two spatial scales for measuring residential development outcomes, specifically those studies mainly using aggregated census-level data on homebuilding or urban density and those studies using spatially disaggregated parcel-level data on individual landowner decisions.

Regional studies based on aggregated data often examine how various local land-use controls may contribute to interjurisdictional spillover effects. Mayer and Somerville (2000), for example, analyzed growth controls in major metropolitan areas between 1985 and 1996 and found a 45 percent decline in housing starts in jurisdictions with more stringent growth controls, citing higher transaction costs and uncertainty in the approval process as reasons for this effect. Using a survey of 490 city and county governments in California, Levine (1999) found that growth-control policies that downzoned or limited land availability had significantly displaced new homebuilding, particularly rental housing, from coastal metropolitan areas into less regulated interior regions. Pendall (1999) provided evidence that growth-control policies placing cost of development onto new growth (e.g., development impact fees) encouraged higher urban densities, while policies mandating lower density zoning resulted in lower urban densities and UGBs had no significant effect. Jun (2004) analyzed the effect of Portland's UGB on housing development within and outside the boundary. The empirical results indicate that the UGB did not significantly affect the location of new housing development, but this was partially attributed to increased development within the neighboring jurisdiction of Clark County, Washington. While these regional studies provide some evidence for interjurisdictional spillover effects, zoning and other land use regulations, including UGBs, are often spatially delineated policies that operate at a finer spatial scale relative to the aggregate census-level data used. Hence, aggregated data is limited in its ability to examine explicitly how land-use regulations may have different effects on different residential densities, particularly for low density exurban development.

Spatially explicit parcel-level models of residential development have been helpful in revealing the effects of growth management policies on individual landowner behavior [see Irwin et al. (2009) for a review]. Cunningham (2007), for instance, analyzed the effect of the UGB around Seattle, Washington, on the timing of residential development. He found that the UGB lowers the likelihood of residential development outside the boundary; however, the effect is decreased because the boundary reduces price uncertainty for development outside the UGB. Cho et al. (2006) used a binary probit model on residential development to investigate the effect of the UGB adopted in Knoxville, Tennessee, finding that the residential development was more likely within the City of Knoxville but not within the newly designated UGB area outside the city limits. In Maryland, the regulatory approach of UGBs was deemed politically infeasible (DeGrove 2005, p. 265), and therefore the smart-growth initiatives opted for an incentive-based approach in which state funding for infrastructure (e.g., sewers, water, roads) is targeted within priority funding areas (PFAs). Although Lewis, Knaap, and Sohn (2009) argued that PFAs have yet to be effective in managing residential growth, evidence from parcel-level residential land-use change models in Maryland counties indicates that residential development is more likely to occur within designated PFAs (Irwin, Bell, and Geoghegan 2003, Shen and Zhang 2007). Irwin, Bell, and Geoghegan (2003) used their model estimation results to simulate policy scenarios before and after PFA expansion, demonstrating that PFA expansion is a growth management policy that is highly effective at concentrating future residential development into these priority areas.

An important issue with these parcel-level models, however, is that they treat residential development as a binary outcome (i.e., develop or remain undeveloped). Specifically, Irwin, Bell, and Geoghegan (2003) and Cunningham (2007) both used a binary hazard model, while Cho et al. (2006) and Shen and Zhang (2007), respectively, used binary probit and logit models for residential development. Consequently, this binary model specification assumes that growth management policies, such as UGBs and PFAs, have a uniform effect on all residential densities. In our analysis, we develop a spatially explicit parcel-level model using a discrete choice model that includes multiple residential density alternatives. Hence, we are able to empirically test whether land-use regulations have different effects on different residential densities. Similar to Irwin, Bell, and Geoghegan (2003), we then use our estimated model results to examine various growth management scenarios. The policy scenarios demonstrate that, in contrast to prior studies, growth management scenarios vary in their effectiveness for managing future development at suburban versus exurban densities in terms of both acreage developed and number of households.

Growth Management Policies in Sonoma County

Sonoma County spans a region between 30 to 100 miles north of San Francisco along the Pacific Ocean and borders Marin, Napa, and Mendocino counties. In 2000, the county population was estimated to be 458,000 residents, and the land area is approximately 1,576 square miles. Sonoma County had been primarily rural until the construction of the Golden Gate Bridge in 1937, which connected this region to San Francisco. Since the 1940s, there has been a surge in population as small towns serving the agricultural economy became "edge cities" within the greater San Francisco Bay Area, including Santa Rosa (pop. 154,000) and Petaluma (pop. 54,000) in 2000.

Despite the rapid population growth, the vast majority of the county land area remains outside the municipal SWSAs (Figure 1). The SWSAs associated with incorporated cities and unincorporated towns cover only 5.8 percent and 1.2 percent of the land area, respectively. Hence, SWSA boundaries for small cities and towns have expanded relatively slowly. The radius of the largest city, Santa Rosa, has a SWSA boundary expanding to about five miles during the decades since the Golden Gate Bridge was built. Other cities and towns are even smaller. Agricultural land was often converted to large-lot exurban development with septic systems and wells rather than agricultural landowners waiting until the municipal SWSAs arrived to develop at higher density. Exurban development (0.025 to 1 unit per acre) occupies 12.9 percent of the land area. Yet most of the land remains in agricultural and resource uses, such as grazing, forestry, and vineyard use.

The Sonoma County General Plan, adopted originally in 1978 and later updated in 1989, provides jurisdiction over the unincorporated region of the county. Prior to plan adoption, however, a significant amount of exurban development had already occurred in some areas while a lower regulatory regime prevailed. The General Plan has a broad range of minimum lot size restrictions because the designated zoning areas had to be reconciled with the historic housing-density patterns. We use the minimum lot size zoning in the 1989 General Plan because our residential land-use change model spans the development period in 1994–2001. Parcels located within nonresiden-

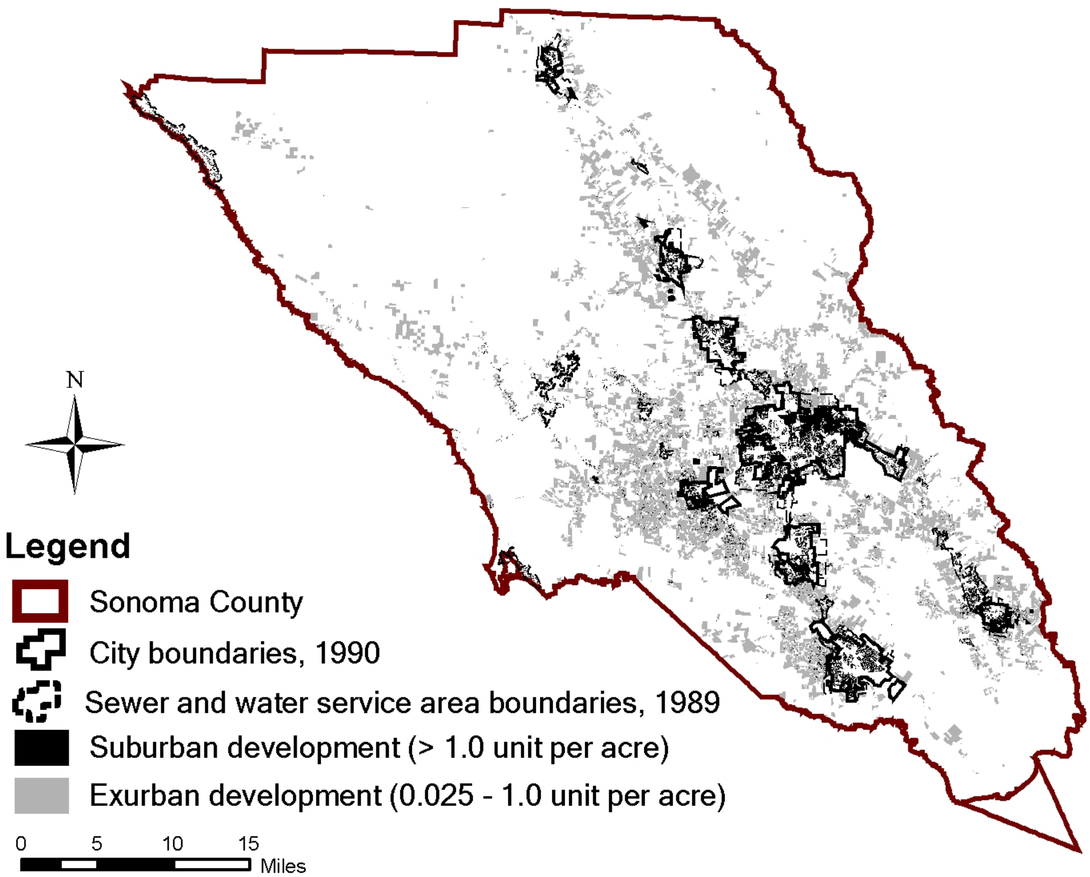

Figure 1. Actual Pattern of Residential Development in 2001 for Sonoma County, California

tial zoning types (e.g., commercial, industrial, public land) were excluded from the analysis. Furthermore, we restrict our analysis to parcels in the unincorporated region outside the 1990 city boundaries because the 1989 General Plan covers only the unincorporated region for Sonoma County.

There are two types of designated SWSAs in the 1989 General Plan. First, there are nine incorporated cities, each of which operates its own municipal services. Second, ten unincorporated towns exist which historically have developed independent SWSAs. SWSA expansion is essential to the annexation process for incorporated cities to accommodate the growing urban population. Under California law, the State established criteria that require municipalities to provide sewer and water service prior to annexation. Local citizens and conservation groups have rallied around anti-sprawl initiatives, such as UGBs, to restrict the annexation process for urban expansion.

The process of UGB adoption in California has been distinctly local, which contrasts with the statewide UGB mandates in Oregon, Washington, and Tennessee. Most UGBs in California were passed in three counties, namely Sonoma, Alameda, and Ventura (Pendall, Martin, and Fulton 2002). In Sonoma County, eight of the nine cities have passed UGBs, including Cotati in 1991, Santa Rosa, Healdsburg, Rohnert Park, and Sebastopol in 1996, Petaluma and Windsor in 1998, and the City of Sonoma in 2000. The UGBs that were adopted restrict the boundary for a 20-year period and require another voter ballot initiative to be overturned. These UGBs were set to correspond closely with the designated SWSA boundaries in the 1989 General Plan.

Empirical Model and Data on Residential Development

We formulate the problem as a utility-maximizing landowner who owns an undeveloped parcel in the current period. The individual landowner faces a set of J alternatives and makes a discrete choice in the following period on whether to convert the parcel into one of $J - 1$ residential density alternatives or choose the alternative to remain undeveloped. We assume a random utility model in which the landowner's utility from being in alternative use j on parcel i is U_{ij} for $j = 1, ..., J$. The utility has a systematic portion, V_{ij}, which is a function of observable variables influencing the net present value of alternative j, and a random unobservable portion, ε_{ij}, which is an extreme value distributed error term (Train 2009). The probability that the landowner chooses a specific alternative k on parcel i is

$$P_{ik} = \Pr\left(V_{ik} + \varepsilon_{ik} > V_{ij} + \varepsilon_{ij} \quad \forall j \neq k\right). \tag{1}$$

There are two types of variables in the logit regression model, namely those that vary over alternatives and those that do not vary over alternatives. For instance, zoning is an alternative-specific variable that may constrain some alternatives at higher density while allowing other alternatives at lower density on a given parcel i. Meanwhile, some parcel attributes, such as the distance to major highway, for a given parcel i is the same regardless of the residential density alternative. The former type of variables, which vary across parcels and alternatives, is denoted as the vector x_{ij} with corresponding parameter vector γ. The latter type of variables, which vary across parcels but not across alternatives, is denoted as the vector z_i with parameter vector β_j for each alternative j. One alternative must be omitted for model identification, and so the baseline alternative remains undeveloped in this formulation. The logit partworths, U_{ij}, are specified to be linear in the parameters

$$U_{ij} = \gamma x_{ij} + \beta_j z_i + \varepsilon_{ij}. \tag{2}$$

These partworths determine the logit system, and the logit probabilities are

$$P_{ik} = \frac{e^{\gamma x_{ik} + \beta_k z_i}}{\sum_{j=1}^{J} e^{\gamma x_{ij} + \beta_j z_i}}. \tag{3}$$

The data used for the residential land-use change model comes from the Sonoma County Tax Assessment Office. The assessor database obtained in 2002 includes information on the lot size, date of last subdivision starting in 1993, number of single-family housing units, year built, and other characteristics for each parcel. Hence, the residential land-use change model focuses on the development process for single-family housing construction. The assessor database was linked to the parcel boundary map in a geographic information system (GIS). First, the "parent" parcel boundaries in 1993 were reconstructed based on adjacent parcels with the same subdivision date. Then, the 1993 parcel boundaries were used to determine whether the parcel was recently developed in 1994–2001, conditional on being undeveloped in 1993. A parcel was considered undeveloped if it was vacant in 1993 or the existing housing density in 1993 was less than one housing unit per 40 acres. This yielded a total data set of 19,090 undeveloped parcels in 1993.

The observed housing density was then calculated based on the number of single family housing units in 2001 divided by the 1993 parent parcel lot size. Residential density was categorized into five classes: high density (≥ 4 units per acre), medium density (1 to 4 units per acre), low density (0.2 to 1 units per acre), very-low density (0.025 to 0.2 units per acre), and remain undeveloped (< 0.025 units per acre). Remember that a categorical break is made between suburban and exurban development at one unit per acre because, owing to public health concerns, adequate spacing is required for development with septic systems and groundwater wells. Hence, high and medium density correspond to suburban development, whereas very-low and low density correspond to exurban development. The data set contained the following residential conversion events during the period 1994–2001: 427 parcels at high density, 459 parcels at medium density, 365 parcels at low density, 269 parcels at very-low density, and 17,570 parcels remaining undeveloped. "Remain undeveloped" serves as the base alternative in the logit model. Explanatory variables include access to sewer and water service, locational characteristics, physical land characteristics, neighboring land uses, and zoned minimum lot size restrictions.

We first describe explanatory variables for parcel attributes, z_i, that vary across parcels but not across residential density alternatives. Four mutually exclusive regions are defined to specify the level of access to municipal sewer and water service. These regions are as follows: (i) "annexation region" includes areas located outside the 1990 incorporated city boundaries but located within the designated 1989 SWSA boundaries, (ii) "unincorporated towns," which also already have existing SWSAs, (iii) "ring region" includes the unincorporated areas within one kilometer of, but outside, the 1989 SWSA boundaries associated with incorporated cities, and (iv) "outside-ring region" includes the remaining unincorporated areas farther than one kilometer from the 1989 SWSA boundaries associated with incorporated cities. High and medium density development are expected to be less likely in the ring and outside ring regions since they are located outside the 1989 SWSA boundaries. However, very low and low density development are expected to be unaffected in these regions because this type of development typically depends on septic systems, not sewers. The ring region is used to account for any differences in the likelihood of development just outside the SWSA boundary relative to those unincorporated areas farther away in the outside-ring region.

Accessibility to employment in major towns and cities is expected to influence the parcel land value in residential use. For each parcel, the travel time to San Francisco was calculated using a minimum path algorithm weighted by speed limits along the road network. The distance to the nearest major highway in kilometers was also calculated for each parcel. All cities and towns in Sonoma County are located along major highways; therefore, this locational attribute on distance to nearest highway represents accessibility to local employment and shopping. Parcels located farther from either major highways or San Francisco are expected to have a lower likelihood of residential development for all density classes.

Physical land quality attributes are used to represent the cost of converting the undeveloped parcel to residential use. The average slope in percent and elevation in meters was determined for each parcel using the digital elevation model (DEM) at 10-meter grid cell resolution. The terrain varies tremendously throughout the region from flat valleys to rugged coastal mountains with slopes often exceeding 30 percent, particularly in northwestern Sonoma County and along the eastern border with Napa County. Steeper slopes raise landowner construction costs and thus are expected to lower the likelihood of residential development for all density classes. Higher elevation has an ambiguous effect because it represents better views that provide a positive amenity for development but may also serve as another indicator for steeper slope. A dummy variable on the 100-year floodplain was included for each parcel because residential development is expected to be more constrained in this region.

Neighboring land uses can create spillover effects that influence the parcel's likelihood of residential development. An explanatory variable was created for the percentage of urban development (e.g., commercial, industrial, residential greater than one unit per acre) that was located within 500 meters of each undeveloped parcel. This variable was determined based on the 1993 land-use distribution that was predetermined relative to the development period in 1994–2001. Surrounding urban development may be expected to create a disamenity. As such, an undeveloped parcel would less likely be converted with a neighboring existing development, resulting in more dispersed development patterns (Irwin and Bockstael 2002). Additionally, surrounding urban development may indicate that higher density development is imminent, thereby creating an "exurban dead zone" in which landowners of undeveloped parcels would not convert to lower density exurban development (Newburn and Berck 2011).

Unlike the other explanatory variables described above, the zoning variables are parcel attributes, x_{ij}, that vary across both parcels and residential density alternatives. The minimum lot size zoning from the 1989 General Plan is used because it is predetermined relative to the housing development in 1994–2001. "Zoning" is a dummy variable that equals one if residential density alternative j is not allowed under the zoned minimum lot size on parcel i. For example, consider a parcel with a minimum lot size zoning of 10 acres. The zoning variable would equal one for the high, medium, and low density classes, but it would equal zero for the very-low density class. The zoning variable is always zero for the alternative to remain undeveloped. Minimum lot size zoning may differ in how strictly it is enforced within the unincorporated area. Therefore, interaction terms were created between the zoning variable and the four SWSA regions. It is expected that the minimum lot size zoning will be less strictly enforced in the annexation region because this region is being serviced to allow more dense development. In contrast, residential development located outside the SWSA boundaries is more likely to be built in accordance with the designated minimum lot size zoning in the General Plan.

Grandfathered lots are an important exception to the minimum lot size zoning. The General Plan regulations allow one house to be built on a vacant parcel when the preexisting lot size for the parcel was already smaller than the minimum lot size zoning. A dummy variable called "grandfather zoning" was created that equals one if residential density alternative j is not allowed under grandfathering rules on parcel i. Consider a vacant parcel with lot size equal to four acres and with minimum lot size zoning of ten acres. This parcel would be allowed one housing unit but no subdivision. Hence, the grandfather zoning variable would equal one for the high and medium density classes, but it would equal zero for the other three classes. Grandfathered lots are relatively common within the unincorporated area located outside the SWSA boundaries. Therefore, interaction terms were created between the grandfather zoning variable and each of the two regions outside the SWSA boundaries.

Estimation Results on Residential Land-Use Change Model

Table 1 shows the logit estimation results for the residential land-use change model. The parameter estimates β_j are shown in the upper portion of Table 1 for the explanatory variables z_i that do not vary across residential alternatives. Note that these parameter estimates often differ across the residential density alternatives. Hence, it is important to have a model that accounts for different effects across the multiple residential density alternatives because otherwise a binary model specification (i.e., develop or remain undeveloped) implicitly assumes that an explanatory variable has the same effect across all residential density alternatives.

Consider the parameter estimates for the SWSA regions, for example, where the annexation region serves as the baseline SWSA region. The coefficients for the outside-ring region at high and medium density are -2.04 and -1.61, respectively, indicating that a parcel without sewer and water service is significantly less likely to be developed at these two higher density classes, relative to the same parcel within the annexation region. In contrast, the coefficients for the outside-ring region are not even significant for very-low and low density, implying that being without sewer and water service had no significant influence on the likelihood of development at these two lower density classes. Similarly, the coefficients for the ring region were negative and significant at high and medium density, but the coefficients were not significant at very-low and low density. The coefficients on unincorporated towns with SWSAs were more similar to the annexation region (baseline region), rather than to either the ring or outside-ring region. The fundamental implication is that SWSAs were an important constraint on suburban development at high and medium density. However, exurban development at very-low and low density is not significantly constrained within SWSAs and, thus, will more easily leapfrog into the rural landscape.

The coefficients on locational characteristics indicate that, as expected, parcels farther away from either a major highway or San Francisco were less likely to be developed. For example, the coefficients on distance to nearest major highway were negative and significant for high and medium density. This suggests that development at these two higher densities is less likely for parcels with lower accessibility to local employment in the towns and cities located along the major highways in Sonoma County. The coefficients on travel time to San Francisco were negative and significant for very low, low, and high density development, indicating that accessibility to San Francisco also had a significant influence on the likelihood of residential development.

Parcels on steeper slopes were less likely to be developed at higher density. The coefficient estimates on the slope variable were most negative for the high density class, indicating that increasing site construction costs in steeply sloped areas have the largest influence on higher density suburban development. The coefficient estimates on elevation were negative and significant for high density development, but were positive and significant for medium and low density development. The coefficient estimates on elevation have

Table 1. Results from Logit Model of Residential Development, 1994–2001, in Sonoma County, California

	Housing-Density Classes[a]			
Variable	High	Medium	Low	Very-Low
SEWER AND WATER SERVICE AREAS (SWSAs)[b]				
Outside-ring region	-2.0445** (0.2675)	-1.6164** (0.2114)	0.1502 (0.2340)	-0.1225 (0.4349)
Ring region	-3.4050** (1.0826)	-1.4958** (0.3758)	-0.0403 (0.2754)	-0.0869 (0.4672)
Unincorporated towns with SWSA	0.1569 (0.1878)	-0.6418** (0.2152)	-0.3170 (0.3651)	-1.4177 (1.1034)
LOCATIONAL CHARACTERISTICS				
Distance to major highway	-0.3011** (0.0675)	-0.2298** (0.0528)	-0.0399 (0.0332)	-0.0070 (0.0306)
Travel time to San Francisco	-0.0117** (0.0033)	0.0044 (0.0027)	-0.0217** (0.0038)	-0.0253** (0.0044)
PHYSICAL LAND CHARACTERISTICS				
Slope	-0.0754** (0.0077)	-0.0542** (0.0056)	-0.0260** (0.0049)	0.0063 (0.0049)
Elevation	-0.0052** (0.0020)	0.0026** (0.0009)	0.0016* (0.0006)	0.0004 (0.0006)
Floodplain	-1.1990** (0.2750)	-1.7515** (0.4184)	-0.7219 (0.3470)	-0.6405 (0.5154)
NEIGHBORING LAND USES IN 1993				
% urban	-0.0057 (0.0031)	-0.0206** (0.0036)	-0.0490** (0.0058)	-0.1587** (0.0154)
Constant	0.4260 (0.3400)	-1.0174** (0.3131)	-0.9936* (0.3349)	-1.1106 (0.5158)
N = 19,090 parcels				
Log-likelihood = -5763.93				
Alternative-Specific Zoning Variables				
ZONING VARIABLES				
Outside-ring region	0.0024 (0.1035)			
Ring region	-0.1123 (0.2736)			
Unincorporated towns with SWSA	-0.7989** (0.2151)			
Annexation region with SWSA	-0.5111** (0.1286)			
GRANDFATHER ZONING VARIABLES				
Outside-ring region	-2.3257** (0.1551)			
Ring region	-2.6612** (0.1551)			

[a] "Remain undeveloped" is the baseline alternative.
[b] The annexation region is the baseline SWSA region, defined as outside 1990 incorporated city boundaries but within the designated 1989 SWSA boundaries for these incorporated cities.

Note: Standard errors are in parentheses. Significance at the 1 percent and 5 percent levels are represented by ** and * respectively.

different signs because higher elevation has two effects with opposite expected signs. Elevation may indicate steeper slopes, which appears to dominate at high density, but it also indicates better views in Sonoma County, which was apparently dominant for lower density development. The coefficient estimates on floodplain were negative and significant for development in the high and medium density classes.

Neighboring urban development significantly decreased the likelihood of lower density development, presumably because it is often viewed as a disamenity. Moreover, it indicates that a landowner is less likely to develop at lower density when higher density development may be imminent, as explained by the theoretical model in Newburn and Berck (2011). In fact, the coefficients on neighboring urban development are most negative for exurban development at very low and low density.

We now discuss the estimation results for the lower portion of Table 1 for the alternative-specific zoning variables x_{ij}. The zoning variables were interacted with the four SWSA regions to examine how strictly zoning regulations were enforced in these different regions. The coefficients on zoning variables for the annexation region and unincorporated town region were -0.51 and -0.80, respectively. This indicates that the General Plan zoning does somewhat constrain the density classes that are not permitted under the existing zoning designations for these two regions with sewer service. The coefficients on grandfather zoning variables were -2.33 and -2.66 for the ring and outside-ring regions, respectively. Hence, grandfathering rules were strictly enforced in these two regions located outside the SWSAs.

Simulations on Growth Management Policies

In this section, we examine how two sets of growth management policies affect the distribution of new households and developed acreage within the study region. The first set of policy scenarios analyzes regulations on municipal sewer and water infrastructure. Specifically, we compare the UGB policy that restricts SWSA boundaries versus the policy that allows SWSA expansion around the annexation region for each incorporated city. These two policy scenarios are analogous to the PFA expansion and baseline scenarios in Irwin, Bell, and Geoghegan (2003) because, according to DeGrove (2005), PFAs are typically designated based on existing and planned SWSAs. Our policy analysis, however, distinguishes between the relative effectiveness for managing development at suburban and exurban densities. The second set of policy scenarios analyzes changes to the General Plan zoning, including the effect of downzoning in designated agricultural and resource areas.

To investigate these scenarios, we use the estimated coefficients in Table 1 to predict the probability of residential development by density class for the 17,570 parcels remaining undeveloped in 2001. Since the estimation results in Table 1 are based on the development period in 1994–2001, the policy scenarios would therefore correspond roughly to the amount of predicted development over the following eight-year period. The locational and physical parcel attributes are held at their original values for all scenarios below. However, the percentage of neighboring urban development is updated to the amount in 2001. The developed acreage is calculated in expectation based on the estimated conversion probabilities from equation (3) on each parcel multiplied by the parcel lot size. The number of new households is determined for each density class based on the average density observed in the development period 1994–2001 multiplied by the developed acreage. Specifically, the average density observed in the actual 1994–2001 data for high, medium, low, and very-low density classes was 5.40, 2.38, 0.501, and 0.0948 units per acre, respectively.

Policy Scenarios on Urban Growth Boundaries

The baseline scenario uses SWSA boundaries restricted at their original location and the 1989 General Plan zoning designations. This policy scenario represents a UGB around each of the incorporated cities. UGBs in Sonoma County were set to match closely with the original 1989 SWSA boundaries and restricted municipal sewer and water infrastructure for a 20-year period. The 1989 General Plan was replaced with a major plan revision only recently, in late 2008. Because the 1989 General Plan had been largely unchanged over two decades except for minor amendments, we use these zoning designations in the baseline scenario.

Table 2 shows the predicted number of new households and developed acreage under the baseline scenario. The total population growth was predicted to be 8,069 new households, and the developed land area was 9,802 acres. Most of the population growth occurs at high and medium density development, with 3,531 and 2,887 new households, respectively. However, these two suburban density classes were responsible for only 654 and 1,213 acres of developed land. The majority of the land area developed occurs at very-low and low density, with 5,724 and 2,211 acres, respectively. Over 98 percent of the very-low and low density development occurred outside the SWSAs. The implication is that a relatively small number of households at exurban densities consume the majority of land, despite the adoption of UGBs to constrain residential development.

Figure 2 maps the predicted probability of exurban development at low density under the baseline scenario. This demonstrates the prevalence of exurban development in the regions outside the sewer service areas. Exurban development at low density is almost invariably on septic systems and does not depend on municipal sewer service; therefore, this large-lot development is able to leapfrog into the surrounding areas. In fact, the commutershed within close proximity to the larger incorporated cities is highly vulnerable to land fragmentation from exurban development (Figure 2). There is a lower likelihood of low-density exurban development in the regions that are more remote, steeply sloped, and designated with large minimum lot sizes greater than 100 acres. Figure 3 maps the predicted probability of suburban development at high density under the baseline scenario. Suburban development is more constrained to occur within the UGBs, which already have sewer service infrastructure provided by incorporated cities and unincorporated towns. This effect of sewer service on high density development is apparent from the estimation results in Table 1 because the SWSA coefficients are -3.40 and -2.04 for the ring region and outside-ring region, respectively.

The alternative policy scenario allows SWSA expansion around the annexation region for each incorporated city. Specifically, this scenario expands designated SWSA boundaries to include the one-kilometer ring region around each city. This represents the effect of relaxing UGBs, relative to the baseline scenario where SWSA boundaries are restricted. The General Plan zoning designations related to the zoning and grandfather zoning variables are unchanged. After SWSA expansion, the population growth at high and medium density in the ring region was 5,366 and 2,666 new households, respectively (Table 3). This substantial increase in suburban development occurs for two reasons. First, SWSA expansion has a direct effect on increasing the likelihood of suburban development. Second, although the General Plan zoning designations were unchanged, zoning is less strictly enforced after SWSA expansion into the ring region. The grandfather zoning coefficient is -2.66 for the ring region prior to SWSA expansion, whereas the zoning coefficient is -0.51 after the ring region has been encompassed into the annexation region. Taken together, these two effects result in over a twenty-fold increase in the amount of suburban development in the ring region after SWSA expansion.

Despite the increase in suburban development after SWSA expansion, exurban development still has a larger amount of acreage developed. Specifically, exurban development at very-low and low density accounts for 5,766 and 2,432 acres, whereas suburban development at high and medium density is only 1,642 and 2,289 acres (Table 3). In fact, the SWSA expansion for the one-kilometer ring region around each city is a relatively large area to service. The amount of suburban development would be lower under a more modest policy on SWSA expansion. Additionally, the SWSA expansion scenario in Table 3 basically makes an assumption of an "open city" model. That is, after SWSA expansion, the probability of suburban development increases, which results in an influx of households from surrounding areas (e.g., greater Bay Area). Note that the baseline scenario has 8,069 new households (Table 2), whereas the SWSA expansion policy has 16,080 new households (Table 3).

As a contrast to the open city model results in Table 3, we also perform the SWSA expansion scenario under the assumption of a "closed city" model (Table 4). The closed city model assumes that the number of new households is fixed within the study region. We perform the simulation for the closed city model by subtracting an equal amount from the partworth in equation (2) for each alternative, except the baseline alternative on remain undeveloped, until this yields the same

Table 2. Predicted Residential Development by SWSA Region under Baseline Scenario with Urban Growth Boundaries

	Housing-Density Classes					
SWSA Region	High	Medium	Low	Very-Low	Subtotal Developed	Total Acreage
			DEVELOPED ACREAGE			
Annexation region	356	277	76	44	753	4,048
Unincorporated towns	140	276	15	1	432	2,914
Ring region	6	44	167	412	629	14,227
Outside-ring region	152	615	1,954	5,266	7,988	411,570
Total	654	1,213	2,211	5,724	9,802	432,758
			NUMBER OF NEW HOUSEHOLDS			
Annexation region	1,925	659	38	4	2,627	
Unincorporated towns	754	658	7	0	1,420	
Ring region	31	105	84	39	259	
Outside-ring region	821	1,464	979	499	3,763	
Total	3,531	2,887	1,108	543	8,069	

total number of new households as the baseline scenario (i.e., 8,069 new households to correspond with the baseline scenario). Irwin, Bell, and Geoghegan (2003) similarly make a closed city model assumption when stating that 200 parcels are developed in their forecast period for their comparison of PFA expansion and baseline scenarios. The influx of new households would realistically be somewhere between these two extremes. Hence, the SWSA expansion scenarios under the open and closed city models in Tables 3 and 4, respectively, are intended to provide the upper and lower bounds on the predicted amount of development.

Table 4 shows that the SWSA expansion policy scenario under the closed city model results in a substantial decrease in the amount of developed acreage, relative to the baseline scenario in Table 2. Specifically, the total developed acreage was 5,752 acres under the SWSA expansion scenario versus 9,802 acres for the baseline scenario, even though both scenarios have the same number of new households. The reason is that the SWSA expansion policy causes an increase in the number of suburban households at high and medium density that, under a closed city model with a fixed number of new households, results in a corresponding decrease in exurban households at very-low and low density. That said, the SWSA expansion policy may cause an increase in suburban development; however, it does not solve the longer-term issue of remaining development rights in rural areas. In other words, it may only delay residential development in rural areas since there is still the excess zoned capacity for this development.

Policy Scenarios on General Plan Zoning

Before examining the policy scenarios on General Plan zoning, it is important to briefly discuss the actual number of remaining development rights according to zoning regulations in the General Plan. Figure 4 maps the excess zoned capacity for remaining development rights on undeveloped parcels in 2001. The number of development rights on each parcel is calculated from the lot size divided by the minimum lot size zoning. For example, a 75-acre parcel within a designated zoning of 20-acre minimum lot size would yield 3.75 units, which is truncated to three development rights. If there were already one house on this property, then the excess zoned capacity would be two remaining development rights. An

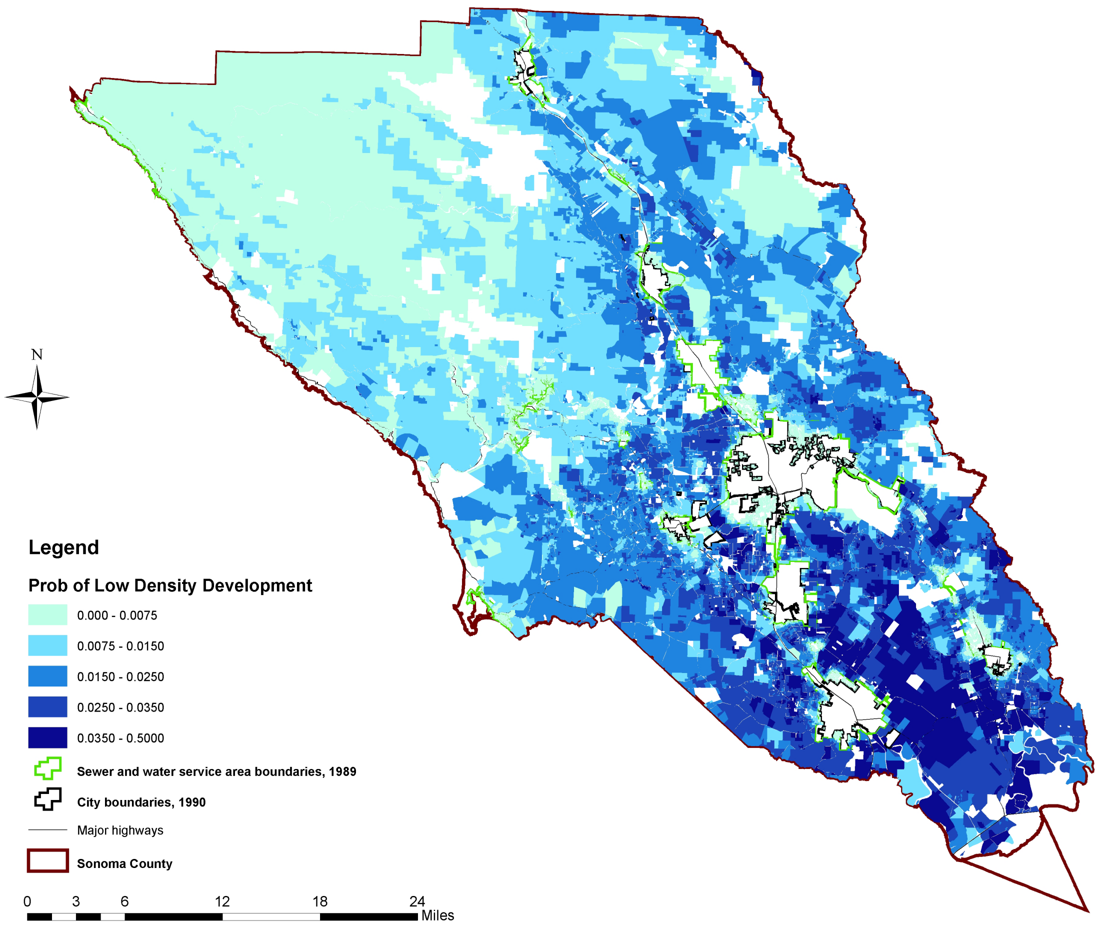

Figure 2. Predicted Probability of Low Density Exurban Development (0.2 to 1.0 units per acre) Under Baseline Scenario

eight-acre vacant parcel within this same zoning designation would be allowed one development right, due to grandfathering rules; however, it would not allow subdivision. Figure 4 shows that a large number of development rights remain outside the SWSA boundaries, despite the recent adoption of UGBs in Sonoma County. Specifically, there are 16,629 remaining development rights located outside the SWSA boundaries, and approximately 64 percent of these rights are due to grandfathering rules.

To further investigate the effect of zoning, we first perform the policy simulation to predict residential development under the baseline scenario (Table 5). This baseline scenario is exactly the same as in Table 2, except that Table 5 summarizes the predicted development according to the six zoning types allowing residential use in the General Plan. The alternative policy scenario here is to downzone the four zoning types designated as agricultural and resource areas (Table 6). Specifically, we assume that the General Plan has been revised such that the designated minimum lot size zoning exceeds 40 acres on all parcels within these four zoning types. Table 6 shows that the downzoning policy scenario does create a reduction in the acreage developed. Specifically, the baseline scenario has 9,802 acres developed (Table 5) compared to the downzoning scenario with only 7,626 acres developed (Table 6). The difference in acreage is almost entirely in the very-low density class. The reason is that the

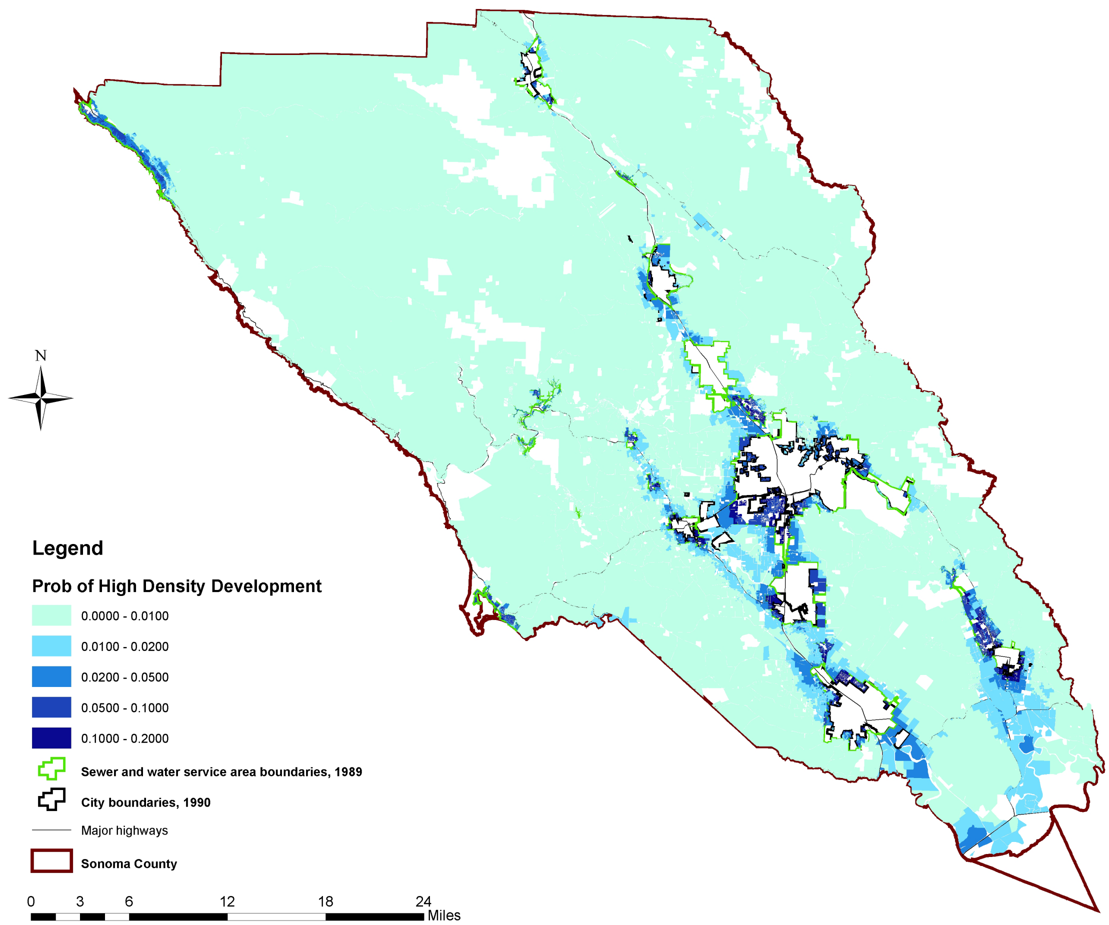

Figure 3. Predicted Probability of High Density Suburban Development (greater than 4.0 units per acre) Under Baseline Scenario

General Plan zoning for these four agricultural and resource types already had minimum lot sizes exceeding 10 acres. Hence, downzoning in these agricultural regions, if it has any effect, would be a reduction in very-low density development. In fact, it is notable to see how much development still occurs in these four zoning types even after the downzoning policy. There are two main findings that explain this persistence. First, the effect of grandfathered parcels would still be present and is significant in areas outside SWSAs. Second, although zoning is more strictly enforced in the ring and outside-ring region (Table 1), it is not absolutely binding, and variances in the General Plan zoning still occur.

Conclusions

The results from the empirical model of residential land-use conversion and policy simulations suggest that growth management strategies have different effects on development at exurban and suburban densities. In particular, growth management policies that focus on municipal sewer and water infrastructure, such as UGBs, are found to be more effective for managing suburban development than exurban development. Note that related studies used a binary model specification to analyze the effect of UGBs (Cho et al. 2006, Cunningham 2007) and PFAs (Irwin, Bell, and Geoghegan 2003, Shen and Zhang 2007) on resi-

Table 3. Predicted Residential Development by SWSA Region Under Scenario on SWSA Expansion into Ring Region (Open City Model)

	Housing-Density Classes					
SWSA Region	High	Medium	Low	Very-Low	Subtotal Developed	Total Acreage
DEVELOPED ACREAGE						
Annexation region	356	277	76	44	753	4,048
Unincorporated towns	140	276	15	1	432	2,914
Ring region	994	1,120	387	455	2,957	14,227
Outside-ring region	152	615	1,954	5,266	7,988	411,570
Total	1,642	2,289	2,432	5,766	12,129	432,758
NUMBER OF NEW HOUSEHOLDS						
Annexation region	1,925	659	38	4	2,627	
Unincorporated towns	754	658	7	0	1,420	
Ring region	5,366	2,666	194	43	8,270	
Outside-ring region	821	1,464	979	499	3,763	
Total	8,667	5,448	1,218	547	16,080	

Table 4. Predicted Residential Development by SWSA Region Under Scenario on SWSA Expansion into Ring Region (Closed City Model)

	Housing-Density Classes					
SWSA Region	High	Medium	Low	Very-Low	Subtotal Developed	Total Acreage
DEVELOPED ACREAGE						
Annexation region	182	139	38	22	381	4,048
Unincorporated towns	69	135	7	0	211	2,914
Ring region	527	577	197	226	1,528	14,227
Outside-ring region	69	276	887	2,399	3,632	411,570
Total	847	1,128	1,130	2,647	5,752	432,758
NUMBER OF NEW HOUSEHOLDS						
Annexation region	983	331	19	2	1,335	
Unincorporated towns	365	321	4	0	697	
Ring region	2,847	1,374	99	21	4,342	
Outside-ring region	372	658	444	227	1,702	
Total	4,567	2,685	566	251	8,069	

dential development, which assumes that these policies have the same effect for all residential densities. Hence, our analysis and simulations improve upon the binary model specification by considering the different effects of growth management policies on different residential densities.

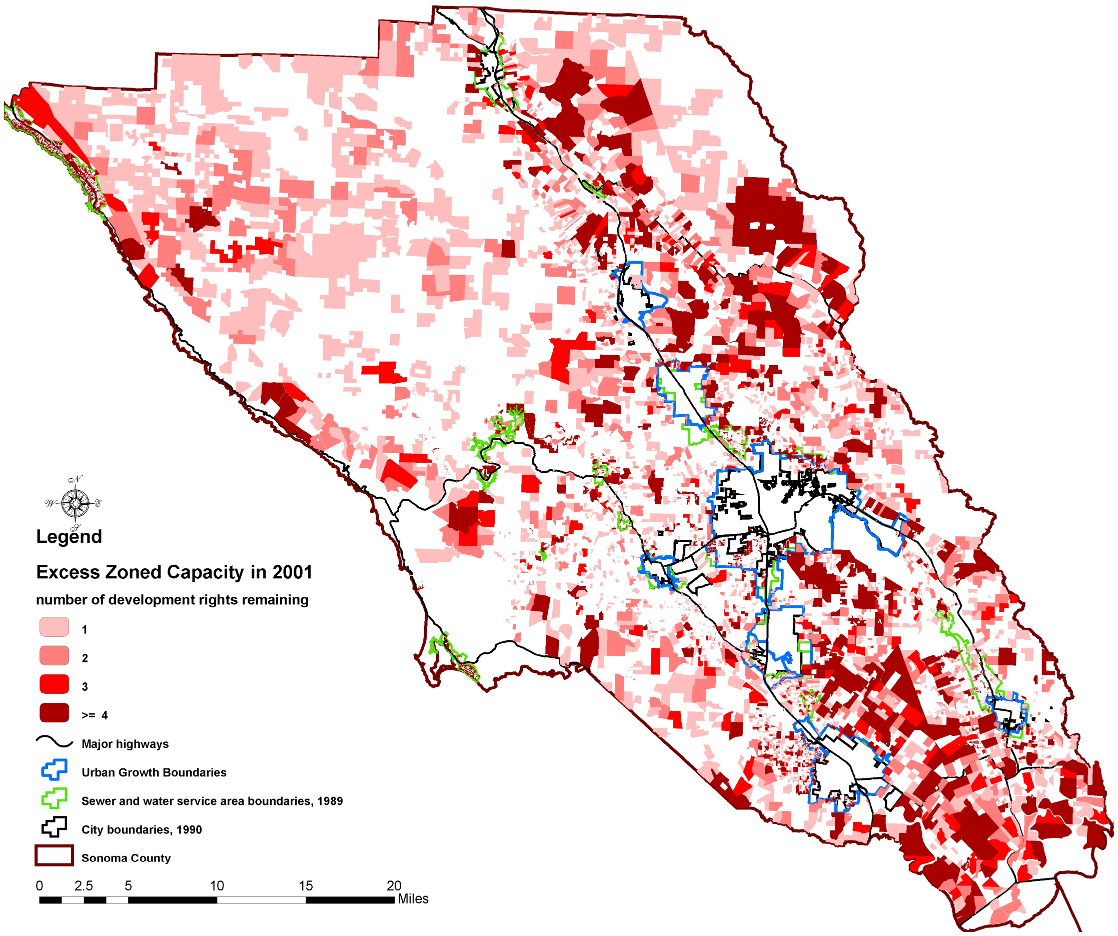

Figure 4. Excess Zoned Capacity on Number of Remaining Development Rights in 2001

Our empirical results indicate that suburban development at high and medium density is significantly less likely to occur outside the SWSA boundaries relative to the annexation region for incorporated cities. Hence, the UGB policy restricting SWSA expansion indicates that the acreage in suburban development is significantly reduced in the ring region around incorporated cities in comparison to the alternative policy allowing municipal SWSA expansion to annex this region. In contrast, exurban development at very-low and low density is typically built with septic systems and groundwater wells, and the empirical results indicate that it was not significantly affected by the provision of municipal SWSAs. Therefore, the UGB policy scenario restricting SWSA expansion has less influence on exurban development.

Zoning requirements in the General Plan are also found to significantly restrict higher density development, but the level of compliance varies by SWSA region. Minimum lot-size zoning requirements are somewhat restrictive within both the annexation and unincorporated town regions. The General Plan zoning is more strictly enforced in the region outside SWSAs, although properties with grandfathered rights are still allowed and are prevalent in this region. This is a primary reason to explain why the policy scenario to dramatically downzone agricultural and resource areas would only partially reduce the acreage in exurban development (Table 6).

It is important to understand which growth management strategies may be effective in managing exurban development. An effective strategy that has been used in Sonoma County has been to

Table 5. Predicted Residential Development by General Plan Zoning Under Baseline Scenario

	Housing-Density Classes					
SWSA Region	High	Medium	Low	Very-Low	Subtotal Developed	Total Acreage
			DEVELOPED ACREAGE			
Urban residential	128	73	15	2	218	1,542
Rural residential	270	435	598	598	1,901	23,413
Diverse agriculture	106	122	263	1,091	1,582	23,270
Land-intensive agriculture	49	87	148	588	872	22,473
Land-extensive agriculture	72	148	381	430	1,032	55,090
Resource and rural development	28	348	806	3,014	4,197	306,960
Total	654	1,213	2,211	5,724	9,802	432,748
			NUMBER OF NEW HOUSEHOLDS			
Urban residential	693	173	8	0	874	
Rural residential	1,459	1,036	300	57	2,851	
Diverse agriculture	572	291	132	103	1,098	
Land intensive agriculture	263	207	74	56	600	
Land extensive agriculture	391	352	191	41	975	
Resource and rural development	153	828	404	286	1,671	
Total	3,531	2,887	1,108	543	8,069	

combine General Plan zoning with a generously funded purchase of development rights (PDR) program. Because the creation of the original 1978 General Plan had to contend with existing residential development patterns, some designations (e.g., diverse agriculture, rural residential) have zoned minimum lot sizes that still allow exurban development at very-low and low density. However, the General Plan designated the vast majority of the land area into zoning types with minimum lot sizes predominantly exceeding 100 acres (e.g., rural and resource development, land-extensive agriculture). Because zoning is strictly enforced in these regions, there is a significantly lower likelihood of exurban development. Additionally, the county voters passed a ballot initiative in 1990 to create a PDR program, which has raised over $300 million during 1990–2010 from a sales tax increase. These funds have been used for easements or fee title purchases to clean up the countryside of the remaining development rights created in the original General Plan formation.

In conclusion, this study highlights that growth management strategies may have different effects on exurban and suburban development. Nonetheless, these findings must be qualified since they are derived from parcel data in a particular region, and growth management policies may be implemented differently in other regions. Further research is therefore needed to examine spatially explicit parcel-level development in other regions to determine the relative effectiveness of growth management policies for guiding future exurban and suburban development patterns. In particular, it is important to understand how growth management strategies may be used effectively to manage exurban development, which has been the leading cause of farmland loss in the United States (Heimlich and Anderson 2001).

Table 6. Predicted Residential Development by General Plan Zoning Under Downzoning Scenario in Agricultural and Resources Areas (Open City Model)

	Housing-Density Classes					
SWSA Region	High	Medium	Low	Very-Low	Subtotal Developed	Total Acreage
DEVELOPED ACREAGE						
Urban residential	128	73	15	2	218	1,542
Rural residential	270	435	598	598	1,901	23,413
Diverse agriculture	107	125	269	400	901	23,270
Land-intensive agriculture	49	88	150	265	553	22,473
Land-extensive agriculture	72	148	381	413	1,015	55,090
Resource and rural development	28	350	813	1,846	3,038	306,960
Total	656	1,219	2,227	3,524	7,626	432,760
NUMBER OF NEW HOUSEHOLDS						
Urban residential	693	173	8	0	874	
Rural residential	1,459	1,036	300	57	2,851	
Diverse agriculture	580	297	135	38	1,050	
Land intensive agriculture	266	210	75	25	576	
Land extensive agriculture	391	352	191	39	974	
Resource and rural development	154	833	407	175	1,569	
Total	3,544	2,900	1,115	334	7,894	

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