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Abstract

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Modeling Suburban and Rural-Residential Development Beyond the Urban Fringe

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ABSTRACT

This article investigates how land-use regulations differentially influence suburban versus rural-residential development. Particular emphasis is placed on how both the provision of municipal services (e.g., sewer and water) and zoned maximum density constrain higher-density residential development. We estimated a spatially explicit model with parcel data on recent housing development in Sonoma County, California. To account for heterogeneity in compliance with zoning regulations, we used a random-parameter logit model. The designation of sewer and water services was the most important determinant of suburban development. Meanwhile, it did not significantly affect the likelihood of rural-residential development, which actually leapfrogged into areas well beyond them. (JEL Q24, R14, R52)

I. INTRODUCTION

Prior studies have focused on the variation in housing densities among the metropolitan regions of the United States (Fulton et al. 2001), and considerable discussion has been generated regarding the causes and remedies for low-density urban and suburban development (Brueckner 2000; Nechyba and Walsh 2004). However, exurban development[1], particularly rural-residential properties located outside of large central cities and their associated edge cities, uses a great deal more land than urban and suburban development (Heimlich and Anderson 2001; Theobald 2002; Sutton, Cova, and Elvidge, in press). According to Heimlich and Anderson (2001), "…nearly 80 percent of the acreage used for recently constructed housing—about 2 million acres—is land outside urban areas. Almost all of this land (94 percent) is in lots of 1 acre or larger, with 57 percent on lots of 10 acres or larger [i.e., 10-22 acres]". Many of the undesirable characteristics used to define urban and suburban sprawl, such as low-density and noncontiguous development, are even more pronounced for rural-residential properties in the exurban area.

Exurban development has a large impact on farmland and habitat. Rural-residential development in exurban areas poses a greater challenge to farmland preservation efforts than urban and suburban development (Long and DeAre 1988; Heimlich and Anderson 2001). Native species have significantly reduced survival and reproduction in the vicinity of rural-residential homes, while populations of nonnative and some human-adapted species have often increased (Hansen et al. 2005; Maestas, Knight, and Gilbert 2003). The "zone of influence" on biodiversity from residential structures is much larger than the building footprint and often extends radially more than 100 meters because of domestic animals (e.g., cats and dogs) and disturbances from landscaping and rural roads that allow the establishment and spread of nonnative species (Odell, Theobald, and Knight 2003).

To mitigate these impacts, it is important to understand what factors influence the spatial pattern of residential development. Parcel-level models of residential land-use change have demonstrated the significance of spatial heterogeneity in the landscape and other factors (Bockstael 1996; Irwin and Bockstael 2002; Irwin, Bell, and Geoghegan 2003). These models use tax-assessment parcel records on individual landowner conversion decisions. Explanatory variables include spatially articulated data on parcel attributes, such as physical landscape features, access to public services, neighboring land uses, and land-use regulations. These models estimate the influence of these variables on the likelihood that undeveloped farmland or forest parcels will be converted to residential development.

The choice set in these residential land-use change models is specified as a binary dependent variable—developed or remain undeveloped. By lumping conversion events spanning a wide range of densities, binary choice models implicitly assume that the same development process operates for all types of residential conversion. However, land-use regulations may have different effects on different residential densities. For instance, limits on sewer and water service extension, the primary function of urban growth boundaries (UGB), may reduce suburban development outside of the boundary, but may have little or no influence on rural-residential development.

The purpose of this article is to investigate how land-use regulations differentially influence suburban versus rural-residential development. Particular emphasis is placed on how both the provision of municipal services (e.g., sewer and water) and zoned maximum density constrain higher-density residential development. To find these effects, we estimated a spatially explicit model with parcel data on recent single-family housing development in the unincorporated area of Sonoma County, California.[2] Using a random-parameter logit (RPL) model, we modeled the individual landowner's decision to convert an undeveloped land parcel to residential use as a function of parcel attributes. Our model uses four density classes for residential development and a fifth class to represent a parcel that remains undeveloped. The two higher densities, both with more than one house per acre, represent suburban development. Meanwhile, the two lower densities, both with less than one house per acre, represent rural-residential development. This distinction was made because this density is the typical limit on residential development serviced by septic systems. The explanatory variables are parcel attributes, which were extracted within a geographic information system (GIS), and include accessibility to highways and employment centers, physical land quality, neighboring land-use externalities, provision of sewer and water services, and zoned maximum-residential density.

Zoned maximum-residential density, often stated as the minimum-lot-size restriction, may constrain development at higher residential densities but allow development at lower densities. Thus, we determined to what extent recent residential conversion events occur at or below the zoned maximum density.[3] Prior studies have used zoned minimum-lot-size restrictions to explain the likelihood of residential development (Irwin and Bockstael 2002; Irwin, Bell, and Geoghegan 2003). But lot-size restrictions have a differentiated effect on different residential densities, most obviously restricting development of high-density development and not restricting low-density development. This distinction was not made because these prior studies specify residential development using a binary dependent variable.

The RPL model was used because maximum-density restrictions under the preexisting General Plan may not be applied uniformly. Maximum-density restrictions specified with random parameters measure unobserved heterogeneity in compliance with zoning designations, due to upzoning or variances. For instance, the local planning board may upzone in an area undergoing annexation but require housing development to comply with current zoned maximum-density restrictions in areas not intended for annexation. We therefore further differentiated the effects of maximum-density restrictions for four regions, defined according to the type of access to sewer and water service areas (SWSA).

In the next section, we describe how the RPL model is used to estimate the probability of residential development. The third section outlines the methods for the case study, including a description of land-use patterns and zoning regulations in Sonoma County, data on housing development and explanatory variables, and methodology to implement the RPL model. The fourth section discusses the main results of the residential land-use change model. We conclude by discussing policy implications for managing both suburban and rural-residential development.

II. RESIDENTIAL LAND-USE CHANGE MODEL

The landowner is assumed to be a utility-maximizing agent who makes a discrete choice in the current period on whether to convert an undeveloped parcel to residential use. A parcel is considered "undeveloped" if it currently has no residential use or extremely low residential density associated with extensive land uses (e.g., agriculture, forestry). There is a set of J alternatives, the J – 1 residential density alternatives and the alternative that the parcel remains undeveloped.

A random utility model is used to formulate the individual landowner's conversion decision. The utility that the owner of parcel n would obtain from the land being in alternative use j is U_{nj}, $j = 1, \ldots, J$. Conditional on the parcel being in the undeveloped alternative in the current period, the landowner will choose the residential density alternative in following period with the highest level of utility. That is, choose alternative i if and only if $U_{ni} > U_{nj}, j \neq i$. Let

$U_{nj} = V_{nj} + \varepsilon_{nj}$, where V_{nj} is an observable function of the parcel attributes that are hypothesized to influence the likelihood of conversion to residential density alternative *j* and ε_{nj} is an independently and identically distributed extreme-value error term.

For parcel *n*, the attributes Z_{nj} in relation to alternative *j* form a *K* x 1 vector that is categorized into two types of variables. The first type, of which there are *M* variables, vary over the alternatives. In this study, zoning regulations on maximum-residential density have this property. That is, the maximum-residential density restriction on parcel *n* can constrain the conversion to some higher-density alternatives, while it does not affect conversion to the lower-density alternatives. The other $K - M$ parcel attributes do not vary over alternatives. For instance, the slope of a parcel is the same regardless of whether the parcel is developed at a high or low density. For the *M* zoning variables, β^k is the corresponding parameter, $k = 1,..., M$. There are $J - 1$ alternative-specific coefficients that must be estimated for each of the remaining variables, $k = M + 1,..., K$. The parameter, β_j^k, corresponds to alternative *j* on variable *k*. Note that if the value of β_j^k were the same for all *j*, then variable *k* would cancel out and have no effect on the probability of residential development. One alternative must be omitted for model identification, and so the undeveloped state is chosen as the baseline alternative (i.e., $\beta_j^k = 0$ for all *k* in the undeveloped alternative). Hence, the index, V_{nj}, is expressed as:

$$V_{nj}\left(\beta\right) = \sum_{k=1}^{M} \beta^k Z_{nj}^k + \sum_{k=M+1}^{K} \beta_j^k Z_n^k \qquad [1]$$

The logit probability, L_{nj}, is:

$$L_{nj} = \frac{e^{V_{nj}(\beta)}}{\sum_{j=1}^{J} e^{V_{nj}(\beta)}} \qquad [2]$$

Zoning is an imperfect constraint since maximum-density restrictions may be applied with varying strictness. For instance, the maximum-density restriction may be increased (i.e., upzoning) for a given area, or the local planning board may also grant a variance for a given landowner's parcel, thereby permitting higher density than specified in the General Plan.

To account for heterogeneity in compliance with maximum-density restrictions, the RPL model is used. The RPL model, also known as "mixed logit," generalizes logit by allowing parameters to take on different values for different parcels. Our exposition below on the RPL model follows that in Train (2003). In this study, we let the parameters β^k for $k = 1,..., M$ on the zoning variables be randomly distributed. We take the density of β^k for $k = 1,..., M$ to be an independent normal distribution with mean b^k and variance w^k, such that the density for each parameter distribution is $f\left(\beta^k \mid b^k, w^k\right) \sim N\left(b^k, w^k\right)$. The alternative-specific parameters β_j^k for $k = M+1,..., K$ are taken as fixed parameters (i.e., $w_j^k = 0$). Hence, the parameter-density distribution $f\left(\beta_j^k \mid b_j^k, 0\right) = 1$ if $\beta_j^k = b_j^k$, and otherwise zero for $\beta_j^k \neq b_j^k$. This specification is just the standard logit for these variables with fixed parameters. Let b and w represent the respective K x 1 vectors of parameters b^k and w^k, and the joint density of parameters is $f\left(\beta \mid b, w\right)$. The RPL probability, P_{nj}, is the integral of the logit formula L_{nj} in equation [2] evaluated over the density of parameters $f\left(\beta \mid b, w\right)$:

$$P_{nj} = \int L_{nj}\left(\beta\right) f\left(\beta \mid b, w\right) d\beta \qquad [3]$$

The RPL models are known as mixed-logit models because the RPL probability is a weighted average of the L_{nj} evaluated at different values of β, where the weights are specified by the mixing distribution, $f\left(\beta \mid b, w\right)$. It is important to understand that RPL models have two sets of parameters. First, there are the parameters β that enters into L_{nj} and are specified to have a density $f\left(\beta \mid b, w\right)$. Second, there are the deep parameters that characterize the function, $f\left(\beta \mid b, w\right)$, such as mean *b* and variance w in the normal density as described above. The goal is to estimate the deep parameters, which are sufficient to describe the density function. Simulation methods are needed to estimate *b* and w because the integral in equation [3] does not have a closed-form solution. Maximization on *b* and w is thus done for the RPL model using the simulated log-likelihood function (Hajivassiliou and Ruud 1994).

For the empirical analysis, we used Ken Train's code for estimating RPL models.[4] The distribution of the zoning variables was specified as a normal distribution.[5] The mean on this normal mixing distribution was expected to be negative because, if the maximum-density restriction does act as a binding constraint, then it lowers the likelihood of development for those housing-density classes that exceed the designated zoned density. The standard deviation on the mixing distribution measured the unobserved heterogeneity in how strictly the density restrictions are applied to different locations. The left-hand tail of the mixing distribution provided the proportion of parcels for which the maximum-density restriction was not binding.

All other explanatory variables were estimated using fixed parameters. These other variables were tested for random-parameter specification using a likelihood-ratio test on the standard-deviation parameters. All these standard-deviation parameters were found to be insignificant, implying that fixed parameters for these variables were adequate. This occurred most likely because each of these variables already has $J - 1$ alternative-specific coefficients.

Here, we explain how the estimated parameters on $\hat{b}$ and $\hat{w}$ are used to simulate the choice probability, P_{nj}. Specifically, step 1 is to draw β randomly from the density $f\left(\beta \mid \hat{b}, \hat{w}\right)$. In step 2, L_{nj} in equation [2] is calculated for this value of β. Steps 1 and 2 are repeated Q times with each iteration, q, being a different random draw, labeled β^q. The average on L_{nj} is taken as the estimated-choice probability:

$$\hat{P}_{nj} = \frac{1}{Q}\sum_{q=1}^{Q} L_{nj}\left(\beta^q \mid \hat{b}, \hat{w}\right). \qquad [4]$$

The odds ratio is simulated by calculating the ratio of P_{nj}, in which L_{nj} in equation [4] is evaluated with and without a unit change in a given explanatory variable. For instance, the ratio of P_{nj} is simulated with and without a one-kilometer increase in the distance to nearest major highway for each parcel *n*, conditional on holding all other parcel attributes at their original values. The average odds ratio for alternative *j* is determined as the odds ratios averaged across all parcels.

III. DATA AND METHODS

Housing Development and Zoning Regulations in Sonoma County

Sonoma County spans a region between 30 and 100 miles north of San Francisco, California. As of 2000, over two-thirds of the 450,000 county residents lived within incorporated cities, such as Santa Rosa, Petaluma and seven smaller cities. While the majority of people live within incorporated cities, these cities cover only 4.0 percent of the County's land area. The unincorporated area, under the jurisdiction of the county government, covers the vast majority of the land area (4,112 square kilometers). Most land is devoted to agricultural and natural-resource uses, including grazing, timber, and vineyard use. Rural-residential development is also a significant type of land use. For instance, low density (1 unit per 1 to 5 acres) and very-low density (1 unit per 5 to 40 acres) residential development respectively occupy 3.5 percent and 9.4 percent of the land area, more than three times the incorporated area (Figure 1).

The Sonoma County General Plan, originally adopted in 1978 and updated in 1989, is the dominant regulatory regime within the unincorporated area. The General Plan specifies land-use designations and minimum-lot-size restrictions. Parcels located in designated areas for nonresidential uses (e.g., public land, commercial, and industrial areas), in addition to properties under easement contract or enrolled in the Williamson Act, were excluded from the analysis.[6] For zoning types in which housing development was allowed, the zoned maximum housing density was determined from the inverse of the zoned minimum-lot-size restriction.

The provision of sewer and water services acts indirectly as a zoning regulation. For public-health reasons, future development at greater than one housing unit per acre is restricted for areas without municipal water and sewer. There are two broad types of SWSA—those associated with the 9 incorporated cities and those associated with the 10 unincorporated rural towns. In 1989, these two types of SWSA covered only a small portion of the total land area in the County, 5.8 percent and 1.2 percent respectively. In comparison, the commutershed covers a much greater area and spans well beyond the extent of the 1989 SWSA. Approximately 59 percent of the total land area is located within less than a 40-minute commute time to either Santa Rosa or San Francisco. All SWSA existed prior to the adoption of the 1978 General Plan.

Subsequent expansion was contiguous to existing SWSA and built urban areas and was designated as part of the annexation process by incorporated cities.

Relative to boundaries of the SWSA in the 1989 General Plan, we define four mutually exclusive regions: (1) the “annexation region” which includes the areas outside of the 1990 incorporated city boundaries but located within the designated 1989 SWSA boundaries; (2) “unincorporated towns” with existing SWSA; (3) the “ring region” which includes the unincorporated areas without sewer service but located within one kilometer of any 1989 SWSA boundary; and (4) the “outside-ring region” which includes the unincorporated areas without sewer service and located farther than one kilometer from any designated SWSA boundary (Figure 2). Development at suburban densities was expected to be less likely for both regions outside of the SWSA, relative to the annexation region. The purpose of the ring region is to see whether parcels near a preexisting SWSA boundary have a higher likelihood for suburban development than those farther away.

In order to slow or stop the annexation process, eight of the nine cities in Sonoma County have now passed UGB.[7] The new legislation stipulates that the growth boundary is fixed for a 20-year horizon. These UGB were set to match closely with the existing sphere of influence and SWSA at the time of passage. No urban development is permitted beyond the boundary, defined as development that requires one or more basic municipal services such as water, sewer, or storm drains.

These UGB are often thought to create a sharp boundary between urban communities and farmland or natural-resource areas. In Figure 1, the actual residential density patterns are more varied for two reasons. First, the majority of the County’s housing units predate the original 1978 General Plan and, therefore, also the recent enactment of UGB in the 1990s. These historic housing-density patterns and other land uses strongly influenced the zoning designations within the unincorporated area. Second, rural-residential properties can be serviced by private well and septic systems and so can be built outside of the SWSA. Therefore, the important legal restriction outside of the SWSA is the current zoned maximum-density restrictions.[8]

Description of Housing Development and Parcel Subdivision Data

Land parcel records from the Sonoma County Tax Assessor's Office provided micro-level data on housing development and subdivisions. The assessor database contains lot size, date of last subdivision starting in 1993, number of single-family housing units, year built, and other characteristics for each current parcel. Parcel records were linked to a parcel map within a GIS. The data were then compiled to determine the undeveloped parcels in 1993 and to assess whether these undeveloped parcels were converted to one of several housing densities during the 1994-2001 period.

Data on parcel subdivisions and housing development were compiled in two stages. First, parcel boundaries in 1993 were determined from the date of last subdivision and adjacency between parcels. That is, the original 1993 parcel boundaries were reconstructed from adjacent current parcels that also have the same date of subdivision.[9] These parcel boundaries were then used to determine whether the parcel was recently developed in 1994-2001, conditional on being "undeveloped" in 1993. A parcel was considered undeveloped if either the parcel was vacant in 1993 or the existing housing density in 1993 was less than 1 unit per 40 acres. The data set contains 19,090 undeveloped parcels in 1993. For each parcel, the observed housing density was calculated as the number of housing units in 2001 divided by the 1993 parcel lot size. These observed housing densities were categorized into one of five density classes: very-high density

(≥ 4 units per acre), high density (1 to 4 units per acre), low density (0.2 to 1 unit per acre), very-low density (0.025 to 0.2 units per acre), and remain undeveloped (< 0.025 units per acre). The first two classes are suburban development, and the next two classes are rural-residential development.

Table 1 shows the numbers of parcels, housing units built, and land area developed by density class within the four SWSA regions. Consider the differences between the annexation region and outside-ring region. There were 1845 homes built at very-high density on 244 parcels in the annexation region, indicating that these housing developments were primarily large and dense subdivisions. In contrast, rural-residential homes built without subdivision were the dominant form of housing development located in the outside-ring region. There were 282 homes built at very-low density on 216 parcels. More importantly, rural-residential use consumed more than five times the land area of suburban use. In the annexation region, only 243 and 197 acres were developed at very-high and high densities, respectively, despite the fact that the majority of homes were built here. Meanwhile, 4372 and 775 acres were developed at very-low and low densities within the outside-ring region.

Description of Explanatory Variables

This section describes the construction of the explanatory variables. Data on zoned maximum-residential density were taken from the 1989 General Plan, which was predetermined relative to recent housing development in 1994-2001. To assess whether the maximum-density restriction acts as a binding constraint on parcel *n*, the zoned maximum-residential density, d_n, was compared to each of the five housing-density classes. Denote the lower bound of housing-density class *j* as h_j. "Bind" is a dummy variable that represents whether the lower bound for housing-density class *j* was greater than the zoned maximum density on parcel *n*, $h_j > d_n$. For example, consider a parcel located on a zoning designation with a 20-acre, minimum-lot-size restriction, indicating a zoned maximum density at 1 housing unit on 20 acres. Housing development would not be permitted for very-high, high, and low-density classes. For instance, the low-density class (1 unit on 1 to 5 acres) spans a range of housing densities at 0.2 – 1.0 units per acre. The lower bound on this range is 0.2 units per acre, which exceeds the zoned maximum density of 0.05 units per acre. Therefore, the bind variables for these three classes are equal to one. This zoned maximum density, however, would allow housing development at the very-low density class (1 unit on 5 to 40 acres) and, thus, the bind variable equals zero. Bind is always zero for the alternative to remain undeveloped.

Compliance with the 1989 General Plan may differ for these four respective SWSA regions in the degree to which maximum-density restrictions act as a binding constraint on housing development. Therefore, dummy variables were created to specify into which SWSA region each parcel centroid was located and, then, interaction terms were made between the bind variable and the four dummy variables on the respective SWSA regions. For the annexation region, we expect that compliance with the preexisting maximum-density restrictions is relatively low because this region is being provided municipal services in order to allow for higher-density development. We expect that recent development in the regions outside the 1989 SWSA boundaries typically has been constructed at housing densities built in accordance with the 1989 General Plan, which would indicate that maximum-density restrictions are binding for the vast majority of the area within the county. However, when density restrictions are not enforced outside of the SWSA boundaries, then upzoning or variances made by the local planning board are most often unobservable. Therefore, we expect that the mean and standard-deviation parameter estimates on the bind variable would be much larger for the two regions outside of the SWSA boundaries, as compared to the annexation region.

An important exception to maximum-density restrictions must be made for grandfathered lots. Grandfathering occurs when the preexisting lot size was already smaller than the zoned minimum-lot-size restriction. In this case, county planners said that the General Plan allows one house to be built, but no subdivision is allowed. That is, grandfathering takes into account both the actual lot size (*a*) and zoned minimum lot size (*s*), such that the maximum allowed density on parcel *n* is expressed as $g_n = \max\left(1/a_n, 1/s_n\right)$. A dummy variable, called "grandfather bind," was created for each alternative *j* to specify whether $h_j > g_n$. For example, consider again the parcel zoned with a 20-acre, minimum-lot-size restriction, and now assume that it was a 3-acre property. The maximum-allowable residential density with grandfathering is 0.33 (i.e., one housing unit on three acres), categorized into the low-density class. In other words, grandfather bind would not allow high and very-high density classes, whereas it would allow housing development for very-low and low-density classes. The grandfather-bind variable is thus slightly different from the bind variable because only the former would allow low-density development for this example. These grandfathered lots were very common within the unincorporated area located outside the 1989 SWSA.[10] Therefore, we created interaction terms between the grandfather-bind variable and each of the two regions outside of the SWSA.

Unlike the bind and grandfather-bind variables, all other explanatory variables were parcel attributes that do not vary over the housing-density alternatives. Hence, four alternative-specific coefficients are estimated for each of these parcel attributes (remain undeveloped is omitted as the baseline alternative). The distance from each parcel centroid to the nearest major highway in kilometers was calculated. This variable represents access to the local centers because all incorporated cities, and most unincorporated towns, are located along these transportation corridors (Figure 2). Minimum travel time from each parcel to San Francisco also was calculated.[11] Since poor accessibility to both regional and local employment centers lowers the returns to residential use and, hence, the profitability of development, we expect that the logit coefficients on the travel time and distance measures would be negative.

The average percent slope and elevation in meters were calculated for each parcel. Slope coefficients are expected to be negative because steeper slopes raise the site construction costs for all types of housing development. The expected sign on elevation parameters is ambiguous because higher elevation may afford better views or it may serve as another indicator for steeper slope. A dummy variable was used to represent whether a parcel is located in the 100-year floodplain. New housing construction is highly restricted in floodplain areas because of higher risk for structural damage and increased home-insurance rates. Therefore, all the floodplain coefficients were expected to be negative.

A set of explanatory variables was used to assess the amenities (or disamenities) created by neighboring land uses. The percentages of both protected open space (e.g., parks, reserves, and easements) and urban development (e.g., commercial, industrial, and residential use at greater than one unit per acre) within a 500 meter radius of the parcel were calculated. These variables were created from the 1993 land-use distribution and therefore are predetermined relative to the time period used to model land-use change.

IV. RESULTS AND DISCUSSION

Results from the RPL model of residential development are presented in Tables 2a and 2b. Table 2a shows the alternative-specific parameter estimates for the explanatory variables that do not vary over the residential density alternatives. Table 2b displays the parameter estimates on the mixing distribution for the zoning variables. In general, the parameter estimates in Table 2a are quite different between the density classes. To test this claim, we restricted the alternative-specific parameters in Table 2a to be equal across the four density-class alternatives. When comparing the full and restricted model, the chi-squared statistic is 1519.2 with 33 degrees of freedom ($p < 0.0001$). This indicates that residential development should be separated into several density classes, not solely a binary variable for develop or remain undeveloped. Zoning variables with parameter estimates on the mixing distribution in Table 2b also are different for the four SWSA regions. As expected, the two regions outside of the SWSA were found more likely to constrain higher-density residential development than either the annexation regions or unincorporated towns with existing SWSA (Table 2b). Below we first discuss the explanatory variables with fixed parameters in Table 2a, followed by a more detailed discussion on the zoning variables with random parameters in Table 2b.

Logit Results for Variables with Fixed Parameters

The first set of variables listed in the left-hand column of Table 2a includes the dummy variables for SWSA regions. The annexation region serves as the base region. For example, very-high and high density classes had negative and significant parameter estimates for the outside-ring region (Table 2a). These results indicate that housing development at very-high and high densities was much less likely to occur in the outside-ring region, relative to the annexation region. To determine the magnitude of the effects on the SWSA dummy variables, we computed the average odds ratios (Table 3). The steps in calculating the average odds ratios are described in the text following equation [4]. For the SWSA variables, the odds ratio is the ratio of the probability of development if the parcel were located in a given SWSA region (e.g., outside-ring region) to the probability if the same parcel were located in the annexation region. Calculating the average odd ratio over all parcels, the probability of development decreased on average by a factor of 0.056 and 0.149 for the very-high and high density classes respectively (Table 3). Specifically, the average odds ratio implies that the average probability of development at these density classes is only 5.6% and 14.9% for parcels located in the outside-ring region, with respect to the average probability on the same parcels when they are located in the baseline annexation region. These results are consistent with public-health regulations requiring municipal water and sewer services for development at very-high and high densities.

The corresponding parameter estimates in Table 2a were not significant for the very-low and low-density classes in this region. These two lower densities are typically serviced by private wells and septic systems and, thus, are not bound to SWSA. The fundamental implication for land use is that rural-residential development at very-low and low densities is more likely than suburban development at very-high and high densities to leapfrog into the vast region well beyond the SWSA boundary.

Similar results were found for the ring region (Table 2a). Both higher-density classes were negative and significant, and the average odds ratios were 0.085 and 0.149 respectively (Table 3). Meanwhile, neither lower-density class was significant. The ring region also has lower probability of very-high and high density development because only 1.7 percent of the ring region was designated as SWSA during 1989-2001.

The SWSA parameter estimate on unincorporated towns was not significant for the very-high density class, and the high density class was negative but much less significant than both regions outside of the SWSA. Specifically, development at high density was half as likely as compared to the annexation region, ceteris paribus. Hence, the unincorporated towns are much more similar to the annexation region than to the two regions outside of the SWSA. This result is interesting because annexation regions have both UGB and SWSA, whereas unincorporated towns only have the SWSA.[12] The likelihood of higher-density development is similar regardless of whether the parcel is situated inside the UGB associated with an incorporated city or located outside the UGB but within an existing rural town. The reason is that the UGB is only capable of limiting expansion of the SWSA into regions that have not already been serviced.

Several of the locational characteristics were found to be significant (Table 2a). Parameter estimates on distance to nearest major highway are negative and significant for very-high, high, and low-density classes. The average odds ratio was calculated under the two situations with and without a one-kilometer increase in distance to major highway for each parcel, ceteris paribus. The probability of development decreased with longer distance on average by a factor of 0.711, 0.667, and 0.873 for these respective density classes (Table 3). So households in higher-density development are more likely to be situated closer to local employment centers. This result was expected because approximately 80 percent of residents are employed within Sonoma County. Parameter estimates on travel time to San Francisco are negative and highly significant for very-low, low and very-high density classes. The probability of development decreased with an extra minute of travel time to San Francisco on average by a factor of 0.975, 0.969, and 0.986 respectively (Table 3). This result indicates that some households value being situated closer to San Francisco and the greater Bay Area to gain better access to the regional employment opportunities.

Physical land characteristics also were found to be significant (Table 2a). Parameter estimates on average percent slope were negative and significant for very-high, high, and low-density classes. According to the average odds ratios, a one-unit increase in slope would decrease the probability of development on average by a factor of 0.923, 0.939, and 0.970, respectively (Table 3). Steeply sloped parcels were less likely to be converted to higher-density development because site construction costs rise with increased slope. In fact, parameter estimates on slope were found to be most negative in the higher-density classes, indicating that the slope constraints have the largest influence on higher-density development. The parameter estimate on elevation was negative and significant for very-high density development, while estimates were positive and significant for the high and low-density classes. Parameter estimates on elevation have different signs because higher elevation has two effects with opposite expected signs. Elevation as an indicator of steeper slopes, and thus higher construction costs, appears to dominate for very-high density development, whereas the importance of better views was apparently the dominant factors for the lower-density classes. Parameter estimates on the 100-year floodplain were negative and significant for the very-high and high density classes. Parcels inside the floodplains, as compared to outside floodplains, had lower probability of development on average by a factor of 0.262 and 0.134, respectively (Table 3).

Spatial externalities from surrounding prior urban development have two effects. First, there is the nuisance effect from nearby industrial, commercial or other urban uses, which creates a negative externality. Second, the prior surrounding urban development implies that this area has been zoned for higher-density development or may be upzoned in the near future. If we assumed that higher-density development is more profitable, then prior surrounding urban development would decrease the likelihood of lower-density development, whereas it would increase the likelihood of higher-density development. Hence, the sign on the parameter estimate is expected to be negative for lower-density development, but it is ambiguous for higher-density development.

The results on spatial externality effects from prior urban development were negative and significant for all four density classes. A one-unit increase in the percentage of neighboring urban development would lower the probability of development on average by a factor of 0.993, 0.973, 0.950, and 0.845 (in order of highest to lowest density). The results indicate that the nuisance effect was influential for all four density classes. The second effect most likely resulted in decreasing the likelihood of lower density. The percentage of neighboring protected open space was not significant for all four density classes.

Logit Results for Zoning Variables with Random Parameters

Table 2b provides estimated mean and standard-deviation parameters on the normal mixing distribution for the zoning variables. Consider first the outside-ring region. The estimated mean on the bind variable was -6.73 and highly significant. Thus, for the majority of parcels in this region, zoning lowers the likelihood of development at housing densities that are not permitted under the zoned maximum-residential densities in the General Plan. However, the corresponding standard-deviation parameter estimate was 5.64 and significant, indicating variation in how strictly maximum-density restrictions were applied within this region. Similarly, the estimated mean and standard-deviation parameters on the grandfather-bind variable were -14.30 and 7.7 respectively. This indicates that grandfathering creates an additional zoning effect by further restricting development of more than a single home on the current lot.

Table 4 shows the average probabilities with and without the effect from zoning variables for the respective SWSA regions, conditional on holding all other parcel attributes constant. The average probabilities were calculated using only the parcels within a given SWSA region, since zoning variables are specific to the SWSA region. Because the zoning variables are dummy variables, the average probability without the effect from the zoning variables is calculated by setting Z_{nj} equal to zero for the bind and grandfather-bind variables. The effect of zoning on the probability of development is equal to the difference between the average probability of development with and without zoning. Consider again the outside-ring region. The average probability with zoning was less than the probability without zoning, particularly for the higher-density classes. For instance, the average probabilities with and without zoning at very-high density were 0.00099 and 0.00157, respectively. Hence, the effect from zoning is equal to –0.00058. That is, very-high density development already was unlikely for this region because there was no sewer service and maximum-density restrictions further decreased the average probability of very-high density development. Low-density development was more likely in this region because it does not require sewer service. But maximum-density restrictions decreased the average probability of low-density development from 0.01424 to 0.01167.

Now consider the ring region. For the bind variable, the estimated mean and standard-deviation parameters were –4.80 and 4.41 respectively (Table 2b). The mean and standard-deviation parameters on the grandfather-bind variable were not significant; however, they were approximately the same sign and magnitude, –12.63 and 6.99 respectively, as the corresponding parameters for the outside-ring region. In sum, the compliance with maximum-density restrictions were relatively similar for the two regions outside of the SWSA, especially when compared to the annexation region and unincorporated towns. For the annexation region, the estimated mean and standard-deviation parameters were only –0.542 and 0.089, respectively, because upzoning was widely implemented for this region transitioning from unincorporated land to the incorporated city. Nonetheless it is interesting that the mean parameter was negative and significant for the annexation region. The implication is that maximum-density restrictions lower the likelihood of development, albeit by a relatively small amount. Our result contrasts with the finding in Wallace (1988) that zoning designations on single-family residential use were not binding (i.e., zoning follows the market).

Policy Scenario on Expansion of the SWSA

Table 5 shows how the average probabilities of development would change as a result of expansion of the SWSA. Average probabilities of development were calculated only for those parcels currently located within the ring region, adjacent to the annexation region. The average probabilities were calculated as if these parcels were subject to the two zoning regimes, ceteris paribus. The first case was the current zoning regime for the ring region. The second case was the zoning regime for the annexation region (i.e., sewer service has been extended into the ring region and thus parcels have been annexed). When calculating the average probabilities, parameter estimates in Table 2a on land quality, neighboring land use, and locational characteristics are the same in both cases; however, the respective parameter estimates on SWSA variables are used in turn for the ring region and annexation region. Note that the annexation region was the base region in Table 2a and, thus, the SWSA parameter would be zero. Furthermore, the zoning parameter estimates in Table 2b for the ring region and annexation region are respectively used for the average probability calculations. The objective is to understand how extending sewer and water services to this region, which currently may be constrained by the existing UGB, would alter the average probability for each density class.

When the sewer and water service is extended, the average probabilities of development at very-high and high densities are much more likely (Table 5). For instance, the average probability of very-high density development would increase from 0.00277 to 0.05106. This increase may be attributed to two effects. First, the sewer and water service has a direct effect on the likelihood of very-high density development. Second, zoned maximum-density restrictions were less stringently applied within the annexation region, as compared to outside the annexation region. To see the direct effect of sewer service, consider the average probability outside versus inside the annexation region and, for the moment, ignore the second effect from density restrictions (i.e., probability without zoning). The average probability at very-high density development was estimated to increase by roughly an order of magnitude, 0.00809 versus 0.07935 respectively. When the second effect from density restrictions was taken into account, the average probability of development decreased from 0.00809 to 0.00277 outside the annexation region (i.e., a factor of 0.342), whereas it only decreased from 0.07935 to 0.05106 inside the annexation region (i.e., a factor of 0.643).

Development at very-low and low densities is largely unaffected by the sewer and water service extension. Low-density development decreased within the annexation region as compared to outside the annexation region, 0.01402 and 0.01749 respectively (Table 5). This indicates that lack of sewer service expansion would actually hasten low-density development outside the annexation region because these landowners are more constrained in constructing residential development at very-high and high densities.

V. IMPLICATIONS FOR RURAL-RESIDENTIAL AND SUBURBAN GROWTH MANAGEMENT AND CONCLUDING REMARKS

Suburban and rural-residential development respond differently to land-use regulations. The designation of SWSA is the most important determinant of suburban development at very-high and high densities. Suburban development was found to be approximately an order of magnitude less likely in regions outside of the SWSA, as compared to the annexation region. The land-use implication is that suburban development is largely constrained to the 7 percent of the County with designated SWSA, including existing incorporated cities, annexation regions, and unincorporated towns. Because rural-residential development at very-low and low densities requires only the installation of private groundwater wells and septic systems, it was not affected by the designated SWSA and actually leapfrogged into areas well beyond them. Zoning regulations on maximum-residential density also were found to significantly lower the likelihood of higher-density development, particularly in the vast majority of the landscape that was outside the designated SWSA. There was an additional zoning effect from grandfathered lots. As a consequence, most parcels developed outside of the SWSA consisted of a single home built on a large lot without subdivision. In contrast, the majority of homes built in the annexation region were in large dense subdivisions (Table 1).

The designation of SWSA boundaries and maximum-density restrictions both have strongly influenced the landscape-level patterns of residential development. Sewer and water service lines are extended physically from a central facility. Therefore, the designation of SWSA acts as a strong attractant force to guide the location of future suburban development. Large subdivisions on recently developed parcels within the annexation region were relatively contiguous. In contrast, most rural-residential homes were not built adjacently. These recent homes with septic systems do not require contiguity. Zoned maximum-density restrictions also do not provide an attractant force to guide rural-residential development but, rather, only repel higher-density development from certain areas. However, a major issue is that most rural-residential homes were built prior to the original 1978 General Plan. Therefore, the designations on maximum-density restrictions had to consider the existing rural residential land-use patterns that had already occurred under the low regulatory environment that prevailed before 1978. The result was that remaining farms intermixed with rural-residential areas were granted many development rights.

Land-use policies should be tailored to guide either suburban or rural-residential development. Priority funding for sewer infrastructure can be used to accommodate future suburban growth in designated target areas (Irwin, Bell, and Geoghegan 2003). Furthermore, UGB have been effective at restricting suburban development. Only minor amounts of suburban development occur outside the annexation region. However, rural-residential development converted more than five times the land area of suburban development in Sonoma County during 1994-2001, despite the enactment of the UGB. In fact, rural-residential zoning based on minimum-lot-size restrictions may encourage low-density sprawl because, when zoning is binding, future homeowners are required to consume more land than desired, thereby increasing the amount of habitat and farmland conversion.

In conclusion, this study demonstrates the necessity to consider multiple densities when modeling residential development. Indeed our parameter estimates in Table 2a are quite different for the four density classes, which shows that a binary model with one density class (i.e., develop or remain developable) provides inconsistent parameter estimates. As we have shown in Table 4, the average probabilities of development vary considerably by residential density class and

SWSA region. If policy makers utilize a binary model they would poorly predict differences in the likelihood of future suburban and rural-residential development. Furthermore, they may implement policies, such as UGB, that solely help redirect suburban development but would not address the potentially larger losses to farmland and habitat that result from rural-residential development.

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Endnotes

[1] Nelson and Sanchez (1997) define the exurban area as follows, "…exurbia extends beyond the built-up urban and contiguously developed suburban areas, but not into the true hinterlands beyond the commuting range of the city centers and their edge cities." Rural-residential properties located in the exurban area mainly are built on large lots and almost invariably are serviced by private wells and septic systems. Leapfrog development is common in exurban areas because these homes are not bound to existing sewer and water service areas. In this study, we define "rural residential" by the housing density at a parcel level (less than one house per acre), whereas "exurban" is defined as a conceptual region at a landscape level.

[2] The 1989 Sonoma County General Plan covers only the unincorporated area for the County. For this reason, we restricted our analysis to parcels in the unincorporated region outside 1990 city boundaries.

[3] Wallace (1988) found that zoning designations were not binding for urban development, including zoning categories for commercial/manufacturing, residential multiple uses, and residential family uses. Using very different methods, we examine zoning in the unincorporated area.

[4] See http://elsa.berkeley.edu/~train for more information.

[5] We also tried to specify the zoning variables with a lognormal distribution. A lognormal specification has the desired property of the same sign for the entire parameter distribution. Because the lognormal distribution is defined over the positive range and the coefficient on zoning is expected to have negative sign, the negative of the zoning variable enters the model. None of the model runs based on this lognormal specification was found to converge. The difficulty in convergence has been found in many other empirical studies, primarily due to the fact that the log-likelihood surface is highly nonquadratic when using a lognormal specification (Revelt and Train 1999).

[6] Development is restricted on properties with 10-year agricultural conservation contracts under the California Land Conservation Act of 1965, commonly known as the Williamson Act. Parcels enrolled in the Williamson Act are ultimately developable, but were not during the estimation period in 1994-2001.

[7] Incorporated cities and year of enacted UGB are as follows: Cotati in 1991; Santa Rosa, Healdsburg and Sebastopol in 1996; Petaluma and Windsor in 1998; Rohnert Park and Town of Sonoma in 2000. Seven city UBG were passed by voter initiative, while Cotati was decided by the City Council. Only Cloverdale, the most remote city, has not yet enacted an UGB.

[8] Federal regulations on development, including floodplain and Clean Water Act requirements, are largely incorporated into the General Plan.

[9] These 1993 parcel boundaries were visually checked with the exact date of subdivision for current parcels, and also using a separate 1999 parcel map, in order to assess the accuracy of this process. The process was verified to work well.

[10] In 1993, grandfathered lots represented 57 percent of the total remaining development rights outside the 1989 SWSA.

[11] An optimal routing algorithm within the GIS was used to determine the minimum travel time in minutes along the road network, utilizing weighted travel speeds of 55 miles per hour on major highways and 25 miles per hour on county roads.

[12] We utilized the SWSA variable for the annexation region, rather than UGB, because it was pre-determined relative to the 1994-2001 housing development. Most UGB were enacted between 1996 and 2000 and, thus, would be endogenous for this period of development.

TABLE 1: Parcels, Housing Units, and Acreage by Housing-Density Class within the Four SWSA Regions

Parcels developed in 1994-2001						
	Housing density class					
SWSA region	Very-high	High	Low	Very-low	Remain undeveloped	Total
Outside-ring region	12	62	237	216	10129	10656
Ring region	15	34	83	46	3356	3534
Unincorporated town	156	227	15	1	2268	2667
Annexation region	244	136	30	6	1817	2233
Total	427	459	365	269	17570	19090

Housing units built in 1994-2001						
SWSA region	Very-high	High	Low	Very-low	Remain undeveloped	Total
Outside-ring region	17	93	304	282	60	756
Ring region	21	61	120	62	2	266
Unincorporated town	204	296	16	1	0	517
Annexation region	1845	431	109	13	0	2398
Total	2087	881	549	358	62	3937

Acreage developed in 1994-2001						
SWSA region	Very-high	High	Low	Very-low	Remain undeveloped	Total
Outside-ring region	3	61	775	4372	395204	400415
Ring region	3	38	274	976	32752	34043
Unincorporated town	31	155	28	7	2915	3136
Annexation region	243	197	204	293	4061	4999
Total	280	451	1281	5648	434932	442592

TABLE 2: Random-Parameter Logit Estimation Results for Housing Development during 1994-2001 on Undeveloped Parcels in Sonoma County, California

Table 2a: Variables with Fixed Parameters

(Note to reviewers: Results from Table 2 are jointly estimated. The results would not fit on one page, so we had to report these results on separate pages in Tables 2a and 2b.)

	Housing-density classes [a]			
Variables with fixed parameters	**Very-high**	**High**	**Low**	**Very-low**
Sewer and water service areas (SWSA) [b]				
Outside-ring region	-2.9094**	-1.9335**	0.0652	-0.3059
	(0.5553)	(0.3229)	(0.2559)	(0.4541)
Ring region	-2.4877**	-1.9272**	-0.0346	-0.1197
	(0.4907)	(0.3862)	(0.2395)	(0.4668)
Unincorporated towns with SWSA	0.2315	-0.6555*	0.0214	-1.3535
	(0.2098)	(0.2457)	(0.3436)	(1.0922)
Locational characteristics				
Distance to nearest major highway	-0.3496**	-0.4126**	-0.1443*	0.0004
	(0.0903)	(0.0688)	(0.0579)	(0.0425)
Travel time to San Francisco	-0.0149**	0.0002	-0.0313**	-0.0256**
	(0.0039)	(0.0032)	(0.0050)	(0.0058)
Physical land characteristics				
Slope	-0.0811**	-0.0642**	-0.0325**	0.0092
	(0.0105)	(0.0088)	(0.0081)	(0.0072)
Elevation	-0.0051*	0.0045**	0.0039**	0.0007
	(0.0025)	(0.0014)	(0.0014)	(0.0008)
Floodplain	-1.3766**	-2.0443**	-0.9921	-0.8271
	(0.3198)	(0.4678)	(0.5391)	(0.6753)
Neighboring land uses in 1993				
% Urban	-0.0087*	-0.0296**	-0.0524**	-0.1702**
	(0.0039)	(0.0045)	(0.0069)	(0.0152)
% Protected land	0.0049	-0.0077	-0.0166	-0.0174
	(0.0064)	(0.0044)	(0.0089)	(0.0097)
Constant	0.8232*	-0.2069	-0.1762	-0.9459
	(0.3990)	(0.3560)	(0.4264)	(0.6448)
N = 19,090 parcels				
Log-likelihood = - 5721.1				

Note: Standard errors are in parentheses and significance at the 1 % and 5% level are represented by ** and *, respectively.

[a] Remain undeveloped is the baseline alternative.

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

Table 2b: Zoning Variables with Random Parameters by the SWSA Region

Variables with random parameters	Parameters on normal mixing distribution: Mean	Standard deviation
Bind variable by SWSA region		
Outside-ring region	-6.7368**	5.6400**
	(1.8111)	(1.1187)
Ring region	-4.8053*	4.4106**
	(2.2203)	(1.3559)
Unincorporated towns with SWSA	-1.6148	1.4487
	(1.1898)	(1.1759)
Annexation region with SWSA	-0.5417**	0.0888
	(0.1890)	(2.4012)
Grandfather-bind variable by SWSA region		
Outside-ring region	-14.3048**	7.7166**
	(3.8927)	(1.9370)
Ring region	-12.6398	6.9879
	(10.2165)	(5.0763)

Note: Standard errors are in parentheses and significance at the 1 % and 5% level are represented by ** and *, respectively.

TABLE 3: Average Odd Ratios for Variables with Fixed Parameters

	Housing-density classes			
Variables with fixed parameters	**Very-high**	**High**	**Low**	**Very-low**
Sewer and water service areas (SWSA)				
Outside-ring region	0.056	0.149	1.099	0.759
Ring region	0.085	0.149	0.995	0.914
Unincorporated towns with SWSA	1.273	0.524	1.032	0.261
Locational characteristics				
Distance to nearest major highway	0.711	0.667	0.873	1.009
Travel time to San Francisco	0.986	1.001	0.969	0.975
Physical land characteristics				
Slope	0.923	0.939	0.970	1.011
Elevation	0.996	1.005	1.005	1.002
Floodplain	0.262	0.134	0.386	0.455
Neighboring land uses in 1993				
% Urban	0.993	0.973	0.950	0.845
% Protected land	1.005	0.993	0.984	0.983

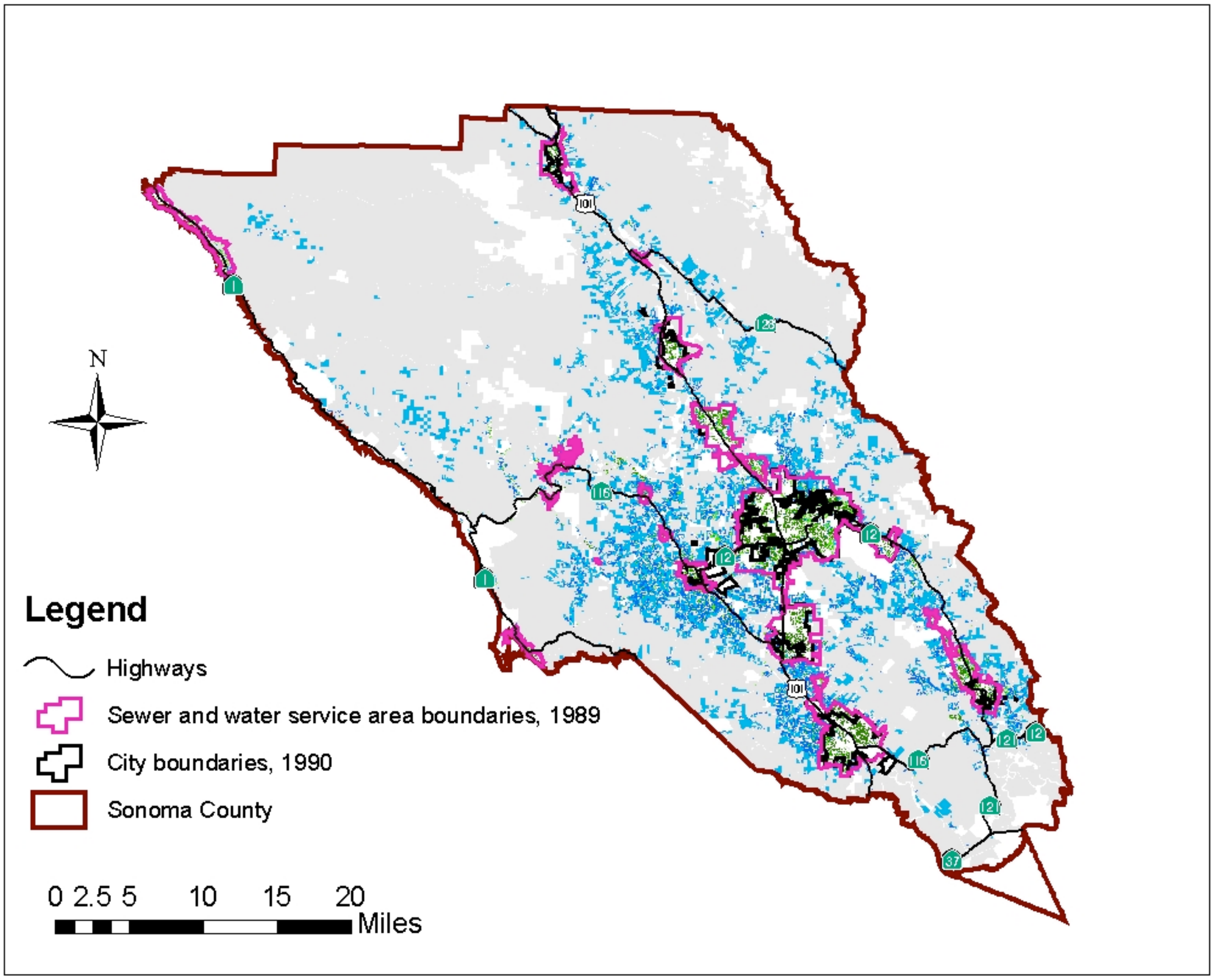
TABLE 4: Average Probabilities of Residential Development by Density Class for the Four SWSA Regions

	Density class				
SWSA region	**Very-high**	**High**	**Low**	**Very-low**	**Remain undeveloped**
Outside-ring region					
Probability with zoning	0.00099	0.00464	0.01167	0.01007	0.97264
Probability without zoning	0.00157	0.00623	0.01424	0.01056	0.96740
Ring region					
Probability with zoning	0.00240	0.00483	0.01102	0.00545	0.97630
Probability without zoning	0.00515	0.00883	0.01234	0.00542	0.96826
Unincorporated towns with SWSA					
Probability with zoning	0.02722	0.03602	0.00231	0.00015	0.93430
Probability without zoning	0.04149	0.03575	0.00230	0.00015	0.92031
Annexation region with SWSA					
Probability with zoning	0.04836	0.02653	0.00511	0.00115	0.91885
Probability without zoning	0.06383	0.03579	0.00621	0.00110	0.89308

TABLE 5: Average Probability of Residential Development by Density Class for Policy Scenario on Sewer and Water Service Expansion into the One-Kilometer Ring around the Annexation Regions

	Density class				
Zoning regime	**Very-high**	**High**	**Low**	**Very-low**	**Remain undeveloped**
Ring region					
Probability with zoning	0.00277	0.00749	0.01749	0.00753	0.96472
Probability without zoning	0.00809	0.01292	0.01900	0.00754	0.95245
Annexation region with SWSA					
Probability with zoning	0.05106	0.04776	0.01402	0.00747	0.87969
Probability without zoning	0.07935	0.07306	0.01662	0.00751	0.82347

FIGURE 1: Residential Density Patterns in 2001 for Sonoma County, California



Land use legend

Suburban

very-high density (≥ 4 units per acre) = Dark green

high density (1 to 4 units per acre) = Light green

Rural residential

low density (0.2 to 1 unit per acre) = Dark blue

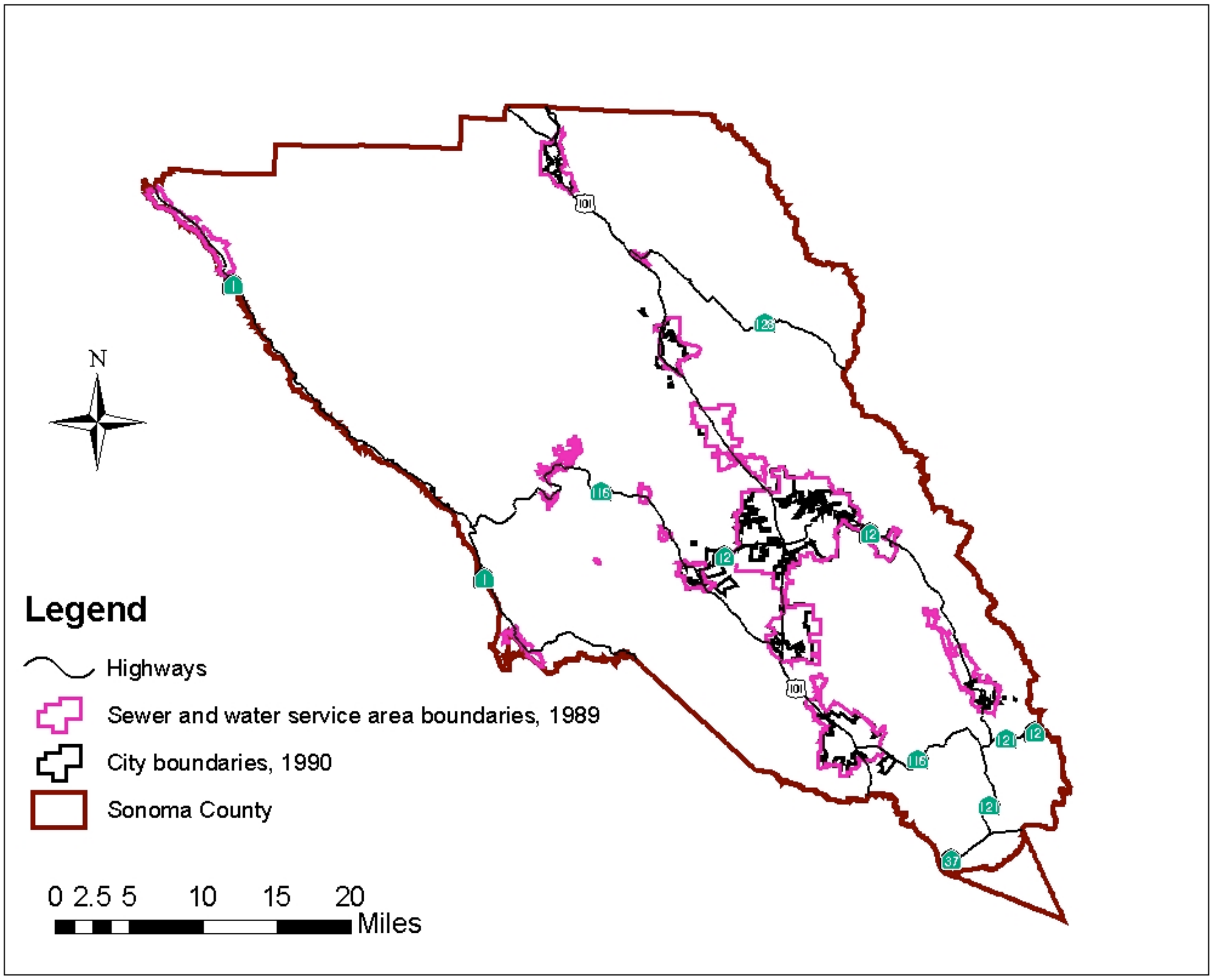
very-low density (0.025 to 0.2 units per acre) = Light blue

Remain undeveloped (< 0.025 units per acre) = Grey

Non-residential areas such as public lands and commercial = White

Note: Figures 1 does not show the 1 kilometer ring around the sewer and water service areas (SWSA) boundaries.

FIGURE 2: Sewer and Water Service Area Boundaries in 1989 and Incorporated City Boundaries in 1990 for Sonoma County, California.



Note: Figures 2 does not show the 1 kilometer ring around the sewer and water service areas (SWSA) boundaries.