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A Spatial Model of Land Use Change for Western Oregon and Western Washington

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Abstract

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We developed an empirical model describing the probability that forests and farmland in western Oregon and western Washington were developed for residential, commercial, or industrial uses during a 30-year period, as a function of spatial socioeconomic variables, ownership, and geographic and physical land characteristics. The empirical model is based on a conceptual framework of landowners maximizing the present value of the future stream of net returns derived from various land uses. The empirical model is used to compute indices representing 50-year projections of future land use and timberland area change in western Oregon and western Washington for the Resource Planning Act assessment, and to identify counties in the study region where potential reductions in timberland area could be greatest. Results suggest that conversion of forest and farmland to urban uses will most likely occur on lands closer to existing population centers, and rate of conversion will increase with the size of those population centers. Relatively modest reductions in the area of timberland due to conversion to urban uses are projected for western Oregon and western Washington, with the greatest reductions occurring on nonindustrial private forest land.

Keywords: Land use change, urban sprawl, spatial models.

Summary

We developed an empirical model describing the probability that forests and farmland in western Oregon and western Washington were developed for residential, commercial, or industrial uses during a 30-year period, as a function of spatial socioeconomic variables, ownership, and geographic and physical land characteristics. Changes in land use, and particularly forest use, have important consequences for the future availability of timber, wildlife habitat, and other benefits provided by forests. The immediate purpose of preparing projections of land use described in this paper is to support a nationwide effort by the U.S. Department of Agriculture (USDA) Forest Service to assess future prospects for the Nation's forests resources, in accordance with the 1974 Resources Planning Act (for example, Haynes et al. 1995). The projections also support analyses of urban development pressures in the Pacific Northwest and studies of environmental and ecological processes at the landscape level.

Until recently, empirical land use models have relied on variations of the area-base approach, which describe the proportions of land in different use categories within defined geographic areas, usually counties, as a function of socioeconomic and land characteristics variables. However, the increasing availability of geographically referenced databases, coupled with growing interest in conducting interdisciplinary landscape-level analyses of ecological issues, has motivated the development of new empirical models with which to project the rate and location of land use change on relatively finer spatial scales by exploiting the additional information contained in spatially referenced land use data. We used geographically referenced historical land use data provided by the Forest Inventory and Analysis (FIA) Program of the USDA Forest Service to develop an empirical model describing the probability that FIA field plots in forest or farmland uses were converted to urban land uses in western Oregon and western Washington since 1961, as a function of several spatially explicit explanatory variables.

We estimated two versions of the empirical model: one assuming that land is developed when it is converted either to urban uses or roads, and another assuming that land is developed when it is converted only to urban uses. The explanatory variables used in the models include plot and county-level variables describing regional population pressures associated with existing cities in the region, potential rents earned from forest and farmland uses, household income, landownership characteristics, and geographic and physical characteristics of land. The empirical models were estimated by using probit and random effects probit. The estimated models are highly significant, and the signs of all explanatory variables are consistent with expectations. The statistical significance of the estimated coefficients for individual variables generally is superior in the probit and random effects probit models that exclude roads as a developed use.

We used the estimated model coefficients to project future land use change in western Oregon and western Washington, based on projected values of city populations and other explanatory variables. We used the estimated coefficients for the model that excludes roads as a developed use to compute the probability that FIA field plots currently in forest or farmland uses will convert to urban uses in the future. The computed probabilities are multiplied by the acreage expansion factors for each FIA field plot to estimate the area of land represented by each plot that is projected to be converted to an urban use over time. These estimates are aggregated for western Oregon and western Washington and are used to compute indices of land use and timberland area change for RPA summary years with the base year of 1997 equal to 100.

Projected total reductions in areas of forest land from the base year 1997 to 2050 are 1.0 percent in western Oregon and 1.0 percent in western Washington. Projected total reductions in farmland area are 4.1 percent in western Oregon and 13.2 percent in western Washington. Areas of land in urban uses in western Oregon and western Washington are projected to increase 17.7 percent and 22.5 percent. From 1997 to 2050, areas of timberland in western Oregon and western Washington are projected to decrease 0.3 percent and 0.0 percent for forest industry-owned timberland and 1.8 percent and 2.5 percent for nonindustrial private-owned timberland. The most significant reductions in forest area occur on land classified as other forest. From 1997 to 2050 forest land classified as other forest is projected to decline 7.5 percent in western Oregon and 8.9 percent in western Washington. Projected average annual percentages of changes in land use and timberland areas by projection period also are computed.

The projections suggest that urban land uses will continue to expand with increasing population in the Pacific Northwest, west-side region. Lands located closest to larger, more rapidly growing cities face the greatest likelihood of conversion to urban uses. Projected percentages of reductions in the areas of land in forest and farm uses are greatest on farmland, largely because farmlands tend to be located closer to existing cities. Most losses to urban uses are projected on timberland owned by nonindustrial private forest owners.

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Introduction

Changes in land use, and particularly forest use, have important consequences for the future availability of timber, wildlife habitat, and other benefits provided by forests. The immediate purpose of preparing projections of land use described in this paper is to support a nationwide effort by the U.S. Department of Agriculture (USDA) Forest Service to assess future prospects for the Nation's forests resources, in accordance with the 1974 Resources Planning Act (for example, Haynes et al. 1995). The projections also support analyses of urban development pressures in the Pacific Northwest and studies of environmental and ecological processes at the landscape level (see Kline and others 2001).

The increasing availability of geographically referenced databases, coupled with growing interest in conducting interdisciplinary landscape-level analyses of ecological issues, has motivated the development of new empirical models with which to project the rate and location of land use change. Until recently, empirical land use models have relied on variations of the area-base approach, which describes the proportions of land in different use categories within defined geographic areas, usually counties, as a function of socioeconomic and land characteristics variables (Alig 1986, Alig and Healy 1987, Alig and others 1988, Cropper and others 1999, Hardie and Parks 1997, Lichtenberg 1989, Parks and Murray 1994, Plantinga 1996, Plantinga and others 1990, Plantinga and others 1999, Stavins and Jaffe 1990, White and Fleming 1980). Although these models can be used to project future land use shares, and to estimate aggregate land use areas, their reliance on county-level data precludes projecting land use on any spatial scale finer than a county. Aggregation at the county level is unacceptable to meet some specific preferences of ecologists, who generally want land use projections provided on a spatial scale relevant to plant and animal habitats under study.

More recently, empirical models have been developed to project the rate and location of land use change, on a pixel-by-pixel basis, by exploiting the additional information contained in spatially referenced land use data increasingly available from geographic information systems. These models generally rely on discrete (point) land use data constructed from satellite imagery or aerial photographs and combined with other spatially referenced data describing socioeconomic factors and geographic and physical land characteristics. These data are used to estimate logit or probit models describing the probability of a given land use or land use change at a given location. Often, at least some explanatory variables are included to account for the spatial and socioeconomic factors hypothesized to affect land use, such as the distance to roads, markets, and population centers. Most models also incorporate some method for dealing with the autocorrelation inherent in spatial data. Such models have enabled analysts to examine various issues, including the effects of land ownership on land use change (Turner and others 1996), land use impacts on water quality (Bockstael 1996), causes of deforestation (Chomitz and Gray 1996, Nelson and Hellerstein 1997), urbanization of farmland (Bradshaw and Muller 1998), forest succession (Helmer 2000), and land use impacts on timber and ecological resources (Munn and Evans 1998, Wear and Bolstad 1998).

We used geographically referenced historical land use data to develop an empirical model of land use change in western Oregon and western Washington. Projected population growth throughout the region has motivated increasing interest in examining where land use changes are most likely to affect timber resources. The model describes the probability that forests and farmland have been developed since 1961 as a function of spatial socioeconomic variables, ownership, and geographic and physical characteristics. The model is used to project land use in the Pacific Northwest, west of the Cascade Range (west side) through 2050. The empirical model also provides analyses of urban development pressures in the Pacific Northwest, with implications for landscape-level environmental and ecological processes.

Land Use Data

Few sources provide a comprehensive and consistent depiction of historical land use change, so tradeoffs must be made among data quality, temporal coverage, and the availability of data describing specific land characteristics. A growing trend in land use modeling is to rely on remotely sensed data, such as satellite imagery or aerial photos, collected at one or two occasions in time. Although such data can provide a fairly comprehensive depiction of different land uses and can be merged with other spatially referenced data using geographic information systems, remotely sensed data often are limited in their temporal scope. This can hinder model estimation if too little change in land use is observed. In the Pacific Northwest, although some areas have experienced relatively rapid rates of growth in recent years, forest and farmland conversions to urban uses, for example, have occurred on a relatively small proportion of the total land base (Zheng and Alig 1999). Also, differentiating certain land uses, such as recently harvested forest from farmland, can be difficult.

A viable alternative to remotely sensed data is the work done by the Forest Inventory and Analysis (FIA) program of the USDA Forest Service's. The FIA program conducts periodic nationwide assessments of all nonfederal land, as authorized by the Forest and Rangeland Renewable Resources Research Act of 1974. Forest Inventory and Analysis inventory data are gathered by using photo-interpretation and ground-truthing on a systematic sampling of plots defined as pinpoints on the ground, and include land use and ownership characteristics of sample plots among other data. The plot-level data can be converted to acreage equivalents by using acreage expansion factors. The advantage of FIA data over remotely sensed data in this case is that FIA data available for western Oregon and western Washington span more than 30 years. Detailed discussion about FIA sampling and sampling error can be found in USDA Forest Service reports (Gedney and others 1986a, 1986b, 1987; MacLean and others 1991a, 1991b, 1991c).

The Forest Inventory and Analysis inventories sample a fixed set of field plots and provide data that can be used to examine actual land use changes on plots between successive inventories. Data are available from four inventories in western Oregon and provide three opportunities to observe beginning and ending land use. Data are available from three inventories in western Washington and provide two opportunities to observe beginning and ending land use. There are 1,466 field plots in western Oregon and 1,405 field plots in western Washington. We restricted the data set to privately owned forest and farmland plots and omitted those observations where beginning ownership was public or where beginning land use was urban, roads, or miscellaneous uses. In western Oregon, this yielded 1,241 observations of beginning and ending land use for the 1961-62 and 1974-76 inventories; 1,170 observations for the 1974-76 and 1985-86 inventories, and 1,164 observations for the 1985-86 and 1994-96 inventories. In western Washington, there were 1,009 observations for the 1963-67 and 1978-79 inventories and 966 observations for the 1978-79 and 1988-89 inventories. The complete data set includes 5,550 observations of beginning and ending land use during an average time step of 11 years (table 1).

Table 1–Number of FIA plot observations of beginning and ending land use from one inventory to the next, on private-owned forest and farmland in western Oregon and western Washington[a]

Initial land use	Ending land use: Forest	Farmland	Urban[b]	Roads[c]	Miscellaneous[d]
	Number				
Western Oregon:					
Forest	2,488	33	14	30	3
Farmland	42	928	29	6	2
Western Washington:					
Forest	1,581	14	25	25	2
Farmland	5	314	8	1	0

[a] Reports cumulative number of USDA Forest Service Forest Inventory and Analysis (FIA) program plot observations of beginning and ending land use between the inventories of 1961-62, 1974-76, 1985-86, and 1994-96 in western Oregon; and 1963-67, 1978-79, and 1988-89 in western Washington. Land use definitions are described in PRIME (1997).

[b] Includes townsites, clustered suburbs, and residential and industrial buildings.

[c] Includes constructed roads, powerlines, pipelines, and railroads.

[d] Includes barren rock, sand, glaciers, marshes, lakes, streams, and reservoirs.

We restricted our analysis to conversions of forest and farmland to urban uses and ignored conversions of forest to farmland and farmland to forest. Although historically in western Oregon and western Washington land has moved between forest and farm uses, such shifts are difficult to measure. For example, recently harvested forest land sometimes is mistaken for grazing land and misclassified as agricultural. Grazing land with sparse tree cover sometimes is misclassified as forest. Also, conversions between forest and farmland during the period under study have not significantly changed the total area of land in either use relative to the conversion of forest and farmland to urban uses. The FIA plot data for western Oregon show that net conversions between forest and farmland since 1961 total 9 plots (42 - 33) converting from farmland to forest, while 43 plots (14 + 29) in forest and farm uses converted to urban uses (table 1). Net conversions between forest and farmland in western Washington total 9 plots (14 - 5) converting from forest to farmland, whereas 33 plots (25 + 8) in forest and farm uses converted to urban uses. When data for western Oregon and western Washington were combined, net conversions between forest and farmland totaled zero. Further justification for restricting the empirical model to conversions of forest and farmland to urban uses stems from the traditional treatment in land economics literature of "development" uses as a permanent state (see for example, Fisher and others 1972, McConnell 1989). Conversions between forest and farmland tend to be more reversible.

Conceptual and Empirical Framework

Previous empirical models of the conversion of forest or farmland to urban uses are based on a conceptual model of landowners choosing to develop land when the present value of the future stream of net returns generated by land in an urban use rises above the present value of the future stream of net returns generated by the land remaining in its current nonurban use (Bockstael 1996). Anticipated population growth in western Oregon and western Washington is expected to place increasing conversion pressure on existing forests and farmland as demands for land in residential, commercial, and industrial uses increase the value of land in these urban uses relative to the value of land in forest or farm use. Assume that a landowner develops a land parcel i when the present value of the future stream of net returns of the parcel in a developed use less conversion costs V_{iD} equals or exceeds the present value of the future stream of net returns of the parcel remaining in forest or farm use V_{iF} as

$$V_{iD} \geq V_{iF} \quad , \tag{1}$$

where the subscript D denotes a developed use, and the subscript F denotes an existing, undeveloped, forest or farm use. Letting v represent the observed portion of V and μ represent the unobservable random portion, we expressed the probability that parcel i, which is observed in an undeveloped land use at t-1, will be observed in a developed land use at time t as

$$\begin{aligned} P(develop) &= P(\, v_{iDt} + \mu_{iDt} \geq v_{iFt} + \mu_{iFt}\,) \\ &= P(\, v_{iDt} - v_{iFt} \geq \mu_{iFt} - \mu_{iDt}\,)\,. \end{aligned} \tag{2}$$

Empirically estimating the model in equation (2) required us to specify appropriate explanatory variables describing v_{iDt}- v_{iFt}, and to choose a distribution for the error term μ_F - μ_D (Bockstael 1996).

Land use data for FIA plots consist of discrete observations of land use on each plot at several occasions in time. These occasions have occurred at relatively regular intervals of about 11 years. From the data, we constructed a dummy variable y_i equal to 1 for plots i observed in a forest or farm use at one FIA inventory occasion and in an urban use at the following occasion, and equal to 0 for plots observed in a forest or farm use at both the initial and following inventory occasions. A structural model of equation (2) can be written as

$$\begin{aligned} y_i^* &= \beta' x_i + \in_i \\ y_i &= 1 \; if \;\; y_i^* > 0, 0 \; otherwise \quad , \end{aligned} \tag{3}$$

where x is a vector of explanatory variables used as proxies for the conceptual parameters v_{iDt}- v_{iFt},$\in$ is an error term accounting for μ_F - μ_D, β is a vector of estimated coefficients, and i = 1, . . . , n.

If we assume that the error term $\in$ in (3) is normally distributed, the dummy variable y_i can be used to estimate a probit model describing the likelihood that FIA plots were converted from forest or farmland to urban uses from one inventory occasion to the next as

$$P(\, y_i = 1) = \Phi(\beta' x_i) \quad , \tag{4}$$

where Φ is the standard normal distribution (Greene 1997). Alternatively, if we assume that the error term $\in$ is logistically distributed, we can estimate a logit model as

$$P(y_i = 1) = \frac{e^{\beta' x_i}}{1 + e^{\beta' x_i}}, \tag{5}$$

where e is the base of the natural logarithm. Initially, we have no definitive reason to prefer one estimation procedure over the other.

In our particular case, the dependent variable y_i was constructed from multiple observations of beginning and ending land use on individual plots on several occasions through time. For example, if land use observations exist for a plot at four successive occasions, we have three observations of beginning and ending land use for that plot. If land use observations exist for a plot at two successive occasions, we have only one observation of beginning and ending land use for that plot. Because the data vary cross-sectionally through time, there is the potential for correlation among observations across time to deflate standard errors and bias estimated coefficients. Two ways to account for the time-series nature of the data in empirical estimation are fixed-effects logit and random-effects probit (Greene 1997).

Fixed-effects logit accounts for potential correlation among observations across time by estimating an individual intercept term for each cross-sectional set of time-series observations. In our case, each FIA sample plot is a cross-sectional set for which we have time-series observations of beginning and ending land use observed during successive inventory occasions. For plots that converted to urban or other miscellaneous uses during early occasions, however, we may only have one observation of beginning and ending land use. Once plots convert from a forest or farm use to an urban or other miscellaneous use, they are no longer included in the data set. The presence of some plots comprising just one observation of beginning and ending land use prevented us from estimating a fixed-effects logit model.

Alternatively, the random-effects probit model assumes that correlation between successive disturbances for individual plots can be reduced to a single constant ρ (Butler and Moffitt 1982). The structural model (3) is modified to account for multiple periods t as

$$y^*_{it} = \beta'_* x_{it} + \in_{it}, \tag{6}$$

where $t = 1, \ldots, T$, $\in_{it} = \varepsilon_{it} + \upsilon_i$, and $\beta = \beta_*/\sigma_\varepsilon$, and

$$Var[\varepsilon_{it} + \upsilon_i] = Var[\in_{it}] = \sigma^2_\varepsilon + \sigma^2_\upsilon. \tag{7}$$

The correlation across time is estimated as

$$Corr[\in_{it}, \in_{is}] = \rho = \sigma^2_\upsilon / (\sigma^2_\upsilon + \sigma^2_\varepsilon) \tag{8}$$

and can be evaluated by using a simple t-test (Greene 1995, p. 427).

Empirical Model

There are two ways to define development in the empirical model. One approach includes as developed only those lands being converted to urban uses, and excludes lands being converted to roads. Forest Inventory and Analysis classifies townsites, clustered suburbs, and residential and industrial buildings as urban, whereas constructed roads, powerlines, pipelines, and railroads are classified as roads. This approach assumes that the conversion of forests and farmland to “roads” either maintains or enhances rather than diminishes their resource value. Much of the land classified by FIA as roads consists of roads built by the forest industry to provide access for timber harvesting. A second approach includes both roads and urban uses as developed uses. This approach assumes that the conversion of forests and farmland to roads diminishes their resource value by precluding timber and agricultural production. Changes over time in the definition of roads FIA confounded our choice. The 1961-62 western Oregon inventory classified forest roads less than 37 meters wide as forest, whereas later inventories classified all forest roads, regardless of width, as roads (MacLean 1990). Some conversions of forest to roads from the 1961-62 to the 1974-76 inventory may be due to this change in definition. In light of these difficulties, we tested two models: one assuming that land is developed when it is converted either to urban uses or roads, and another assuming that land is developed when it is converted only to urban uses.

Detailed data describing the present value of the future stream of net returns of forest and farm uses on FIA plots are unavailable. We can, however, construct a set of proxy variables with which to describe potential returns in terms of specific land quality characteristics, as hypothesized by Ricardo, or proximity to commodity markets, as hypothesized by von Thunen. Empirical specifications commonly include explanatory variables hypothesized to affect rents derived from different land uses, such as variables measuring forest and farm revenues and costs (Alig 1986, Alig and others 1988, Hardie and Parks 1997, Kline and Alig 1999, Lichtenberg 1989, Parks and Murray 1994, Plantinga and others 1999, White and Fleming 1980) and distances to commodity markets (Chomitz and Gray 1996, Cropper and others 1999, Nelson and Hellerstein 1997, Turner and others 1996). Many specifications also include land characteristics, such as slope or soil quality, which measure the suitability of land for forest and farm uses.

Conceptually, urban rents have been viewed as a function of the spatial proximity to city centers (Capozza and Helsley 1989, Fujita 1982, Mills 1980, Miyao 1981, Wheaton 1982). Although von Thunen viewed spatial proximity as influencing primarily the costs associated with transporting forest and farm commodities to market, modern society associates spatial proximity more with maximizing the difference between quality of life factors, such as housing and neighborhood amenities, and commuting costs. Empirical specifications generally have described urban rents by using population density (Alig 1986, Alig and Healy 1987, Alig and others 1988, Cropper and others 1999, Hardie and Parks 1997, Kline and Alig 1999, Parks and Murray 1994, Plantinga and others 1990) or the proximity of land to cities likely to influence the conversion of undeveloped land to urban uses (Bockstael 1996, Munn and Evans 1998, Plantinga and others 1990). Data for computing population density variables, however, rarely are sufficiently disaggregated geographically to adequately describe the spatial heterogeneity inherent in population growth. Variables that simply measure the proximity of land to select cities do not describe how the impact on each city changes as its population grows or declines. One way to describe population growth and its spatial distribution is with a gravity index that integrates both population and proximity.

Gravity models initially were developed by Reilly (1929) to describe the degree to which cities attract retail trade from surrounding locations (Haynes and Fotheringham [1984] provide a thorough discussion). A common gravity index specification is

$$Gravity\ index = \frac{Population}{(Distance\ )^2}\ , \tag{9}$$

which is directly proportional to the population of the city and inversely proportional to the square of the distance between the city and the specific location of interest (Haynes and Fotheringham 1984). Gravity indices also have been used to account for the combined influence of population and proximity as forces of economic change affecting land use. In a recent example, Shi and others (1997) include a gravity index as an explanatory variable in a county-level hedonic model of farmland prices to account for urban influences. Their "urban influence potential variable" is constructed as the sum of the gravity indices computed for each of the three major cities nearest to each county, and is a statistically significant variable in their empirical model of farmland value.

Other mathematical specifications of gravity indices are possible by varying the exponents on population and distance, to adapt the index to the specific conditions or "social context" of the geographic region under study (Haynes and Fotheringham 1984, p. 12-16). For example, the specification described in equation (9) tends to compute relatively high index values for large cities and gives significantly less weight to smaller cities. We tested several gravity index specifications by varying the exponents on population and distance, and the number of cities included. The specification that consistently performed best in terms of its *t*-value and log-likelihood ratio tests is

$$Gravity\ index_i = \sum_{k=1}^{3} \frac{(\ Population_k\ )^{0.5}}{Distance_{ik}}\ , \tag{10}$$

where *k* represents the three cities having the greatest urban influence potential, as measured by the individual gravity index computed for each city. Although our inclusion of only the three most influential cities is somewhat arbitrary, the specification seems to describe the development pattern in the Pacific Northwest west side. To reduce the total potential number of cities in the analysis, we included only those 95 cities in the Pacific Northwest west side with a population greater than 5,000 (U.S. Bureau of the Census 1992). Although this cutoff does not capture the influence of every single city, it captures the impact of those most likely to influence land conversions. We computed distance as the Euclidian distance between sample plots and each city center in the analysis.

A final estimation issue arises from our use of spatial data. Spatial autocorrelation can result from omitted spatial variables that influence the land use decisions of landowners, such as weather-related variables, and spatial behavioral relations, such as common ownership of neighboring land use observations. The first source leads to inefficient, but asymptotically unbiased estimated coefficients, whereas the second source can lead to inefficient and biased estimated coefficients (Nelson and Hellerstein 1997). Although no standard statistical protocols exist with which to treat spatial autocorrelation in land use analyses, methods have been devised and tested (table 2). One method is to include spatial lag (or neighborhood) variables based on the land use of neighboring

Table 2—Studies modeling land use or land use change using spatial variables

Study	Spatial variables	Estimation technique	Treatment of spatial autocorrelation
Studies examining the probability of a given land use:			
Chomitz and Gray (1996)	Distance to market center	Multinomial logit	Bootstrapping procedure
Turner and others (1996)	Distances to roads and market center	Multinomial logit	Spatial lag variable
Nelson and Hellerstein (1997)	Distances to roads, towns, and villages	Multinomial logit	Spatial lag variable and sampling
Helmer (2000)	Distances to roads	Multinomial logit	Sampling
Studies examining the probability of a change in land use:			
Bockstael (1996)	Distances to large cities and the Chesapeake Bay	Binomial probit/hedonic regression	Spatial lag and land use frag-mentation variables
Bradshaw and Muller (1998)	Distances to cities	Binomial logit	NA
Munn and Evans (1998)	Distance to nearest road and city	Multinomial logit	NA
Wear and Bolstad (1998)	Distances to roads and market centers	Binomial logit/poisson regression	Spatial lag variable

NA = not applicable.

pixels. Another method is to purposefully sample (Fortin and others 1989, Haining 1990) to reduce the presence of autocorrelation arising from spatial behavioral relations. For example, if autocorrelation is thought to arise from multiple observations falling under common landowners, the entire set of observations can be sampled at a spacing purposefully selected to reduce the likelihood that any sampled observations fall under the same ownership. In our case, FIA data are based on a systematic sampling of plots roughly spaced on a 5.5-kilometer grid. We were unable to construct a spatial lag variable because information about land use in between plots was unavailable. With a 5.5-kilometer average spacing, each plot represents an average of 2995 hectares, which exceeds the land holdings of most private landowners in the study region. We assumed that the likelihood that plots fall under the same ownership is minimal.

Empirical Results

The explanatory variables *x* include plot-level and county-level variables describing rents associated with urban (GRAVITY INDEX), forest (FOREST RATIO), and farm (FARM RATIO) land uses (table 3). We expect the variable GRAVITY INDEX, as a measure of urban influence potential, to have a positive influence on the likelihood of development, and the variables FOREST RATIO and FARM RATIO, as measures of forest and farm rent-earning capacity, to have a negative influence on the likelihood of development.

Table 3—Descriptions of explanatory variables tested in the probit models

Variable	Description
GRAVITY INDEX	Index computed following equation (4) and equal to the average of the 3 largest values of individual city indices, each computed as the ratio of the square root of a population of the city (U.S. Bureau of the Census 1992) divided by the proximity of a city to the plot measured as the shortest Euclidian distance in kilometers. The 95 largest cities located in western Oregon and western Washington, each having a population greater than 5,000 in 1990, are included. Population for FIA inventory years is derived by interpolating between census years.
FOREST	Variable equals 1 if plot is timberland or other forest (PRIME 1997); 0 otherwise.
FOREST RATIO	Five-year average of sold stumpage price per 1,000 board feet (1992 dollars), Pacific Northwest, west-side region (Sohngen and Haynes 1994), weighted by the ratio of plot site index to average site index for all plots, divided by a 5-year average of logging and hauling costs for saw and veneer logs per 1,000 board feet (1992 dollars), Pacific Northwest west-side region (Adams and others 1988), weighted by the ratio of county average forest land slope to the average forest land slope in western Oregon and western Washington, times FOREST.
FARMLAND	Variable equals 1 if plot is cropland, pasture, or range (PRIME 1997); 0 otherwise.
FARM RATIO	Five-year average of annual value of agricultural products sold per hectare (1992 dollars), by county (U.S. Bureau of the Census 1994), divided by 5-year average of annual production expenses per hectare by county. Value and cost figures for noncensus years derived by interpolation between census years, times FARMLAND.
INCOME	Five-year moving average of median annual household income ($1,000s) by county (U.S. Bureau of the Census 1992), adjusted to 1992 dollars. Income for noncensus years derived by interpolating between census years.
FOREST INDUSTRY	Variable equals 1 if plot is forest industry-owned or corporate-owned, including individuals or companies operating wood-using mills or managing forests for timber production (PRIME 1997); 0 otherwise.

Table 3—Descriptions of explanatory variables tested in the probit models (continued)

Variable	Description
NIPF OWNER	Variable equals 1 if plot is nonindustrial privately owned, including individuals or corporations that produce agricultural products, and miscellaneous private owners not otherwise classified (PRIME 1997); 0 otherwise.
COASTAL LOCATION	Variable equals 1 if plot is located within 4 kilometers of the Pacific Ocean; 0 otherwise.
INTERSTATE 5	Variable equals the shortest, straight line distance (100s of kilometers) between plot and Interstate 5.
ELEVATION	Variable equals plot elevation (1000s of meters).
OREGON	Variable equals 1 if plot is located in Oregon; 0 otherwise.

NIPF = nonindustrial private forest.

Household income (INCOME) also is included and is expected to have a positive influence on the likelihood of development. We expect that land in urban uses is a superior good. Additional plot-level variables (FOREST INDUSTRY and NIPF [nonindustrial private forest] OWNER) provide a test of differences across owner types.

Geographic and physical characteristics (COASTAL LOCATION, INTERSTATE 5, and ELEVATION) may influence the rent-earning capacity of land in different uses. For example, land near the Pacific Ocean or closer to Interstate 5 may increase the potential value of land in residential and other urban uses. Land at higher elevations may exhibit reduced urban use potential due to poor access or steep slopes. A variable specifically describing the slope of sample plots would be desirable but is not included because FIA inventories do not record slope for nonforested sample plots. The variable OREGON provides a test of differences between the rates of development in western Oregon and western Washington.

The estimated probit models are highly significant ($P < 0.01$) with chi-squared values of 167.58 and 188.58, each with 9 degrees of freedom (tables 4 and 5). The signs of all explanatory variables are consistent with expectations in both models. Random-effects probit models for "urban uses" and "urban uses and roads" yield a similar set of estimated coefficients (tables 4 and 5), and ρ values of 0.389 and 0.398, respectively, with t-statistics of 0.70 ($P > 0.40$) and 1.00 ($P > 0.30$), respectively. Log-likelihood ratio tests of the ρ coefficient yielded χ^2 values of 1.96 ($P < 0.20$) and 3.14 ($P < 0.10$), respectively, suggesting that random effects probit estimation is only marginally superior in either version of the model.

The statistical significance of the estimated coefficients for individual variables generally is superior in the probit and random-effects probit models that exclude roads as a developed use (table 4). Because most observations of road-building involve the construction of forest roads rather than new highways and other roads associated with new urban development, the empirical models that exclude roads as a developed use likely are more consistent with our conceptual model of urban development. Also, it seems reasonable to assume that the rate at which forest roads are constructed in the Pacific

Table 4—Estimated coefficients of probit and random-effects probit models describing the probability that private land is converted to urban uses in western Oregon and western Washington

	Probit		Random-effects probit	
Variable	Estimated coefficient	Marginal effect	Estimated coefficient	Marginal effect
Intercept	-2.826*** (-5.92)	-0.0199	-3.465*** (-3.35)	-0.0019
GRAVITY INDEX	.024*** (5.64)	.0002	.035** (2.42)	.0000
FOREST RATIO	-.624*** (-6.38)	-.0044	-.809*** (-3.34)	-.0004
FARM RATIO	-.593*** (-5.18)	-.0042	-.792*** (-2.78)	-.0004
INCOME	.040*** (2.95)	.0003	.046** (2.55)	.0000
NIPF OWNED	.433** (2.33)	.0030	.575* (1.75)	.0003
COASTAL LOCATION	.331* (1.82)	.0023	.412 (1.55)	.0002
INTERSTATE 5	-.423 (-1.51)	-.0030	-.528 (-1.42)	-.0003
ELEVATION	-1.534*** (-3.40)	-.0108	-2.028** (-2.14)	-.0011
OREGON	-.120 (-.99)	-.0008	-.151 (-.86)	-.0000
Rho (ρ)	N/A	N/A	.389 (.70)	N/A
Summary statistics:	N = 5,550 Log-likelihood = -307.29 χ^2 = 188.58, df = 9, P < 0.01 Pseudo R^2 = 0.48		N = 5,550 Log-likelihood = -306.31 χ^2 = 1.96, df = 1, P < 0.20 Pseudo R^2 = 0.62	

Notes*:* The *, **, and *** indicate that the probability of the t-statistic (in parentheses) for each coefficient exceeding the critical t value is greater than 90, 95, and 99 percent, respectively. Pseudo R^2 values are computed following Zavoina and McElvey (1975).

NIPF = nonindustrial private forest.

NA = not applicable.

Table 5—Estimated coefficients of probit and random-effects probit model describing the probability that private land is converted to urban uses and roads in western Oregon and western Washington

	Probit		Random-effects probit	
Variable	Estimated coefficient	Marginal effect	Estimated coefficient	Marginal effect
Intercept	-2.067*** (-6.08)	-0.0704	-2.614*** (-3.88)	-0.0192
GRAVITY INDEX	.022*** (5.72)	.0007	.033*** (3.30)	.0002
FOREST RATIO	-.568*** (-8.25)	-.0194	-.751*** (-4.64)	-.0055
FARM RATIO	-.605*** (-6.54)	-.0206	-.818*** (-3.89)	-.0060
INCOME	.025** (2.43)	.0009	.031** (2.38)	.0002
NIPF OWNED	.156 (1.48)	.0053	.198 (1.30)	.0014
COASTAL LOCATION	.336** (2.48)	.0115	.438** (1.96)	.0032
INTERSTATE 5	-.145 (-.79)	-.0049	-.180 (-.78)	-.0013
ELEVATION	-.288 (-1.54)	-.0098	-.368 (-1.41)	-.0027
OREGON	-.239*** (-2.76)	-.0081	-.293** (-2.50)	-.0022
Rho (ρ)	N/A	N/A	.398 (1.00)	N/A
Summary statistics:	N = 5,550 Log-likelihood = -562.29 χ^2 = 167.58, df = 9, $P < 0.01$ Pseudo R^2 = 0.35		N = 5,550 Log-likelihood = -560.72 χ^2 = 3.14, df = 1, $P < 0.10$ Pseudo R^2 = 0.48	

Notes: The *, **, and *** indicate that the probability of the *t*-statistic (in parentheses) for each coefficient exceeding the critical *t*-value is greater than 90, 95, and 99 percent, respectively. Pseudo R^2 values are computed following Zavoina and McElvey (1975).

NIPF = nonindustrial private forest.

NA = not applicable.

Northwest in the future will be substantially less than the rate at which they were constructed during the past 30 years—the period described by the present data. For these reasons, we focused our discussion on the empirical results produced by the models that exclude roads as a developed use (table 4).

Estimated coefficients for the variable GRAVITY INDEX, describing urban influence potential, are positive, statistically significant ($P < 0.05$), and consistent with a higher likelihood of development on land located closer to population centers, and increasing with the size of those population centers. Estimated coefficients for the variables FOREST RATIO and FARM RATIO are all negative, statistically significant ($P < 0.01$), and consistent with a lower likelihood of development on land that is earning substantial rents in forest or farm uses. Estimated coefficients for INCOME are positive ($P < 0.05$) and suggest a greater likelihood of development on land located in counties with higher household income. The variable FOREST INDUSTRY is omitted from both models to avoid perfect collinearity among the ownership variables. Estimated coefficients for NIPF OWNER are positive ($P < 0.10$) and suggest that forest land owned by nonindustrial private owners is more likely to be developed to urban uses than is forest industry land (table 4).

Estimated coefficients for COASTAL LOCATION are positive ($P < 0.15$) and consistent with a greater likelihood of development on lands located within the Pacific coastal strip. Estimated coefficients for INTERSTATE 5 are negative ($P < 0.15$) and consistent with an expected increase in the likelihood of development as distance to Interstate 5 decreases. Estimated coefficients for ELEVATION are negative ($P < 0.05$) and suggest a diminishing likelihood of development as elevation increases. Because elevation and slope often are correlated, negative ELEVATION coefficients could indicate a lower likelihood of development occurring on sample plots having steeper slopes (table 4).

Estimated coefficients for OREGON are negative but not statistically significant ($P > 0.30$), thereby suggesting no discernable statistical difference between the rates of development in western Oregon and western Washington as defined in the empirical model (table 4). The empirical model does not explicitly account for land use laws and policies that likely could impact the rate and pattern of land use change. Oregon's land use planning program has served as a national model in land use planning and growth control (Abbott and others 1994). It could therefore be expected to account for measurable differences in the rate and pattern of land use change occurring in western Oregon and western Washington. Previous research suggests, however, that Oregon's land use planning program has had little measurable impact on the land use change described by FIA data (Kline and Alig 1999). Explanatory variables accounting for land use zoning adopted under Oregon's land use planning program initially were included in the current analysis, but estimated coefficients for these variables consistently were found to be statistically insignificant.

Validating the forecasting performance of an estimated empirical model is useful in determining if projected outcomes are reasonable. Validation refers to evaluating the structure of a model behavior relative to the structure and behavior of the system under study to increase confidence in the ability of the model to provide reliable information for policy analysis. A feasible method of model validation is to reserve a portion of the data sample from empirical analysis for validation purposes. Projected outcomes resulting from the estimated empirical model then can be compared to actual outcomes described by the reserved data sample (see Wear and Bolstad 1998). This validation method necessitates that sufficient data exist to both estimate and validate the model.

Although the complete data sample includes 5,550 observations, only a small proportion of these comprise conversions of forest or agricultural land to urban uses. Consequently, we do not have a sufficient number of observations of land use change to both estimate and validate the empirical model. The statistical significance of the empirical model and many of the explanatory variable coefficients suggest a good fit with available data.

Projecting Future Land Use

Model coefficients can be used to project future land use change in western Oregon and western Washington, based on projected values of population and other explanatory variables. Population projections for all 95 cities used in the analysis are based on county-level projected population growth through 2010 (McGinnis and others 1996, 1997), state-level projected population growth for 2010 to 2025 (U.S. Bureau of the Census 1999), and extrapolation from 2025 to 2050 (fig. 1). Stumpage prices used to compute FOREST RATIO are assumed to increase annually by 1.5 percent through 2010, by 1 percent from 2010 to 2020, and by 0.5 percent from 2020 to 2050. All other explanatory variables are assumed to remain constant since the latest FIA inventory.

We used the estimated random-effects probit coefficients for the model that excludes roads as a developed use (table 4) to compute the probability that each FIA sample plot will convert to an urban use at each 11-year time step. The computed probability is multiplied by the acreage expansion factor for each plot to estimate the area of land represented by each plot that is projected to be converted to an urban use at each time step. These estimates are aggregated for western Oregon and western Washington and are used to compute interpolated indices of land use and timberland area change for summary years with the base year 1997 equal to 100 (table 6). Because land use projections are based on data describing historical land use changes subject to past development density patterns, the projections necessarily are based on the assumption that historical development patterns will continue.

The current composition of land uses on private land in the Pacific Northwest west side is 46 percent forest industry-owned timberland, 19 percent nonindustrial private-owned timberland, 3 percent other forest, 23 percent farmland, and 9 percent urban for western Oregon; and 48 percent forest industry-owned timberland, 23 percent nonindustrial private-owned timberland, 1 percent other forest, 16 percent farmland, and 12 percent urban for western Washington (fig. 2). Areas of land in forest and farm uses are projected to decrease as they are converted to urban land uses. Projected reductions in areas of forest land from the base year 1997 to 2050 are 1 percent in western Oregon and 1 percent in western Washington (table 6). Projected reductions in farmland area are 4.1 percent in western Oregon and 13.2 percent in western Washington. From 1997 to 2050, areas of timberland in western Oregon and western Washington are projected to decease 0.3 percent and zero percent, respectively, for forest industry-owned timberland; and 1.8 percent and 2.5 percent, respectively, for nonindustrial private-owned timberland. The most significant reductions in forest area occur on land classified as other forest. From 1997 to 2050, forest land classified as other forest is projected to decline 7.5 percent in western Oregon and 8.9 percent in western Washington (table 6). Projected average annual percentages of changes in land use and timberland areas by projection period also are computed (table 7).

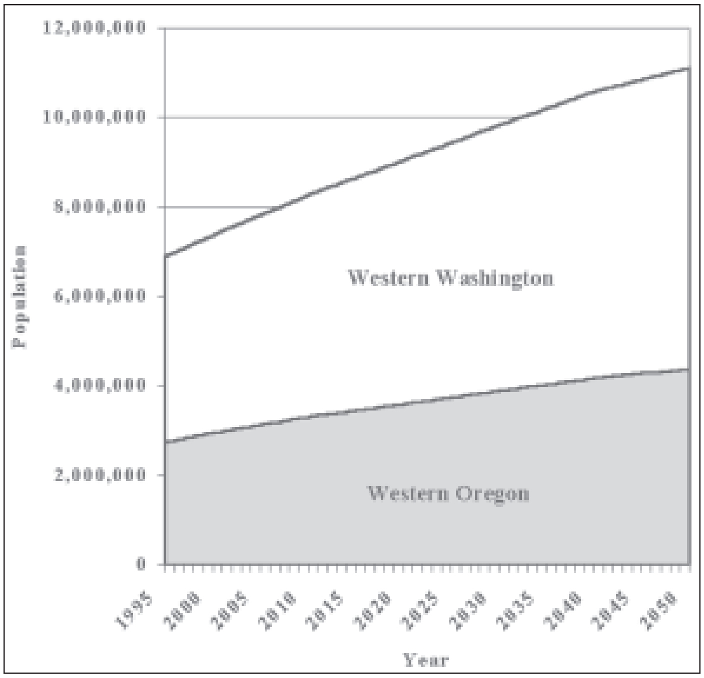

Figure 1—Projected population, Pacific Northwest west side.

Table 6—Projected land use change indices (1997 = 100) for nonurban private land in western Oregon and western Washington[a]

	Year					
Land use	**1997**	**2010**	**2020**	**2030**	**2040**	**2050**
Western Oregon:						
Timberland[b]—						
Industry[c]	100.0	99.8	99.8	99.8	99.7	99.7
NIPF[d]	100.0	99.2	98.9	98.6	98.4	98.2
Other forest	100.0	97.8	96.2	94.9	93.5	92.5
Total forest	100.0	99.6	99.4	99.2	99.1	99.0
Farmland	100.0	99.1	98.3	97.5	96.7	95.9
Western Washington:						
Timberland[b]—						
Industry[c]	100.0	100.0	100.0	100.0	100.0	100.0
NIPF[d]	100.0	99.2	98.7	98.2	97.8	97.5
Other forest	100.0	96.6	95.5	93.8	92.6	91.1
Total forest	100.0	99.7	99.5	99.3	99.2	99.0
Farmland	100.0	96.5	94.0	91.5	89.1	86.8

[a] Projected based on random effects probit model coefficients (table 4).

[b] Timberland comprises forest capable of producing at least 0.57 cubic meter per hectare per year of industrial wood (PRIME 1997).

[c] Industry includes individuals or companies operating wood by using mills or managing forests for timber production.

[d] Nonindustrial private forest (NIPF) owners include farmers and all other miscellaneous private owners not otherwise classified.

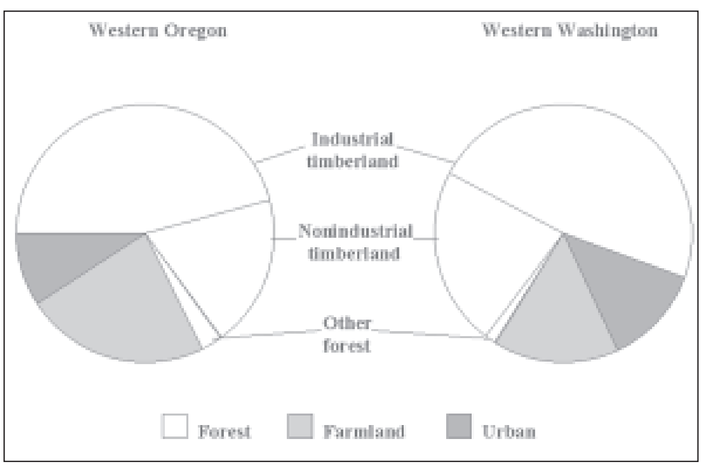

Figure 2—Current composition of land uses of private land, Pacific Northwest, west side.

Table 7—Projected average annual percentage of changes in nonurban land uses on private land in western Oregon and western Washington, by projection period[a]

	Projection period				
Land use[b]	**1997 to 2010**	**2010 to 2020**	**2020 to 2030**	**2030 to 2040**	**2040 to 2050**
Western Oregon:					
Timberland—					
Industry	-0.01	0.00	0.00	0.00	0.00
NIPF	-.06	-.03	-.03	-.03	-.02
Other forest	-.17	-.16	-.14	-.14	-.11
Total forest	-.03	-.02	-.02	-.01	-.01
Farmland	-.07	-.07	-.08	-.08	-.08
Western Washington:					
Timberland—					
Industry	.00	.00	.00	.00	.00
NIPF	-.06	-.05	-.05	-.04	-.03
Other forest	-.26	-.12	-.18	-.13	-.16
Total forest	-.03	-.02	-.02	-.02	-.01
Farmland	-.27	-.27	-.27	-.26	-.25

NIPF = nonindustrial private forest.

[a] Projected based on random effects probit model coefficients (table 4).

[b] Land use definitions provided in table 6.

Projected percentage of losses of timberland to urban uses in individual counties by projection period are greatest (>2 percent) for Marion and Washington Counties in western Oregon and for King, Kitsap, and Whatcom Counties in western Washington (fig. 3). Projected percentage of losses of timberland to urban uses also are relatively high (1 to 2 percent) in Lane and Multnomah Counties in western Oregon, and Clark, Cowlitz, and Thurston Counties in western Washington. Counties accounting for the greatest share of projected timberland losses for the entire Pacific Northwest west side (>0.1 percent) are Washington County in western Oregon and Kitsap County in western Washington (fig. 4). Douglas, Lane, and Marion Counties in western Oregon, and Cowlitz, Kitsap, Thurston, and Whatcom Counties in western Washington also are projected to account for a relatively high share of timberland loss (0.02 to 0.1 percent) in the study region.

Summary and Conclusions

Projections based on probit models describing the likelihood of urban development on land currently in forest and farm uses in western Oregon and western Washington suggest that urban land uses will continue to expand with increasing population in the region. Lands closest to larger, more rapidly growing cities are more likely to be converted to urban uses. Projected percentages of reductions in the areas of land in forest and farm uses are greatest on farmland, largely because farmlands tend to be closer to existing cities. Projected reductions in the area of timberland are minor, with most losses

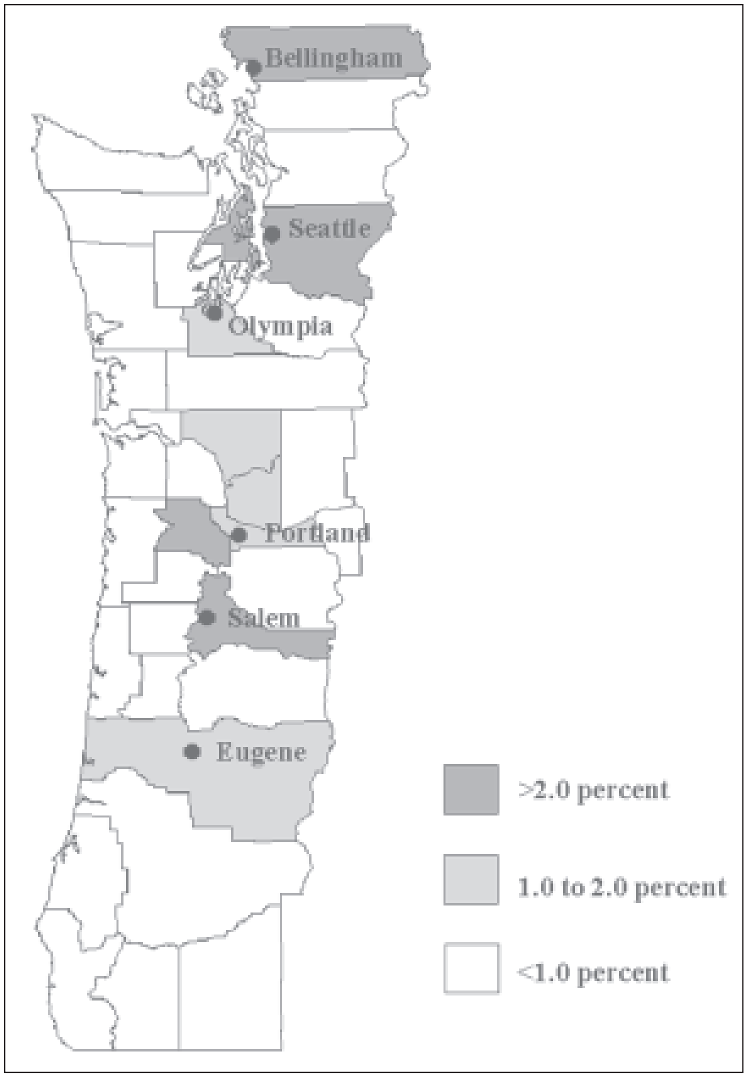

Figure 3—Projected percentage of timberland base of counties lost to urban uses by 2050, Pacific Northwest west side.

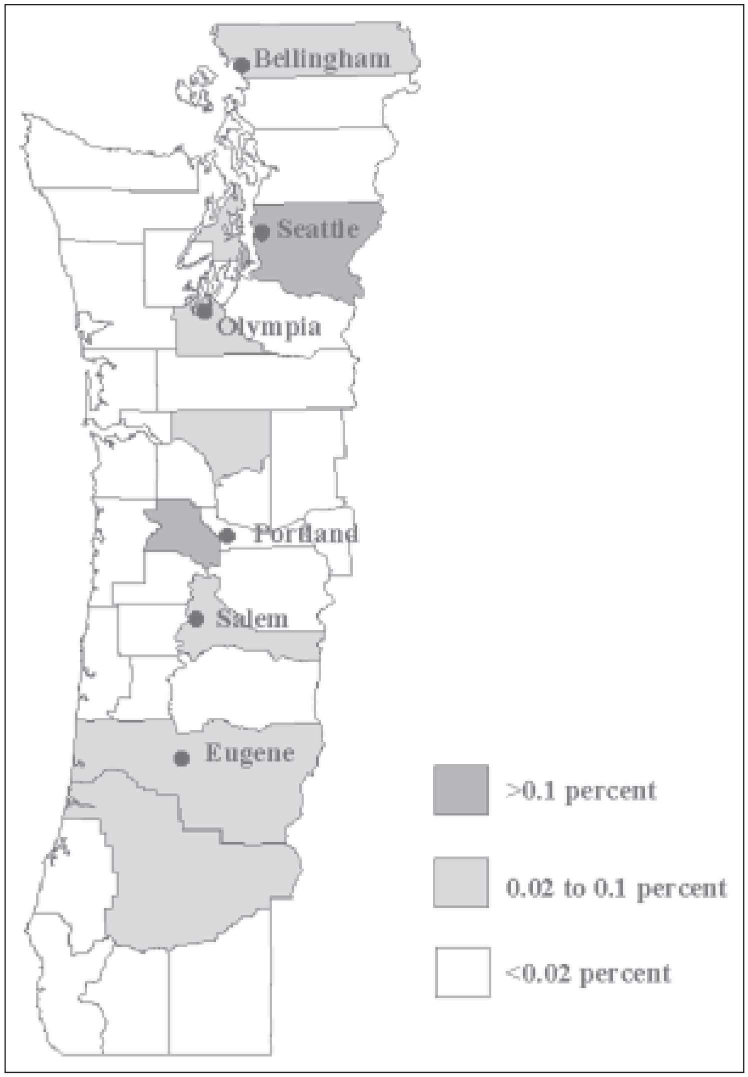

Figure 4—Projected county share of Pacific Northwest west-side region timberland converting to urban uses by 2050.

to urban uses projected on timberland owned by nonindustrial private forest owners. This analysis describes only shifts from forest and farm uses to urban uses. Although land in western Oregon and western Washington shifts between forest and farm uses, historical data for the past 35 years suggest that the total area of land in either use has not changed significantly because of such shifts.

The land use projections are based on the assumption that land use programs and policies, such as Oregon's Land Use Planning Program, remain unchanged. This trait enables policymakers to examine likely future land use scenarios if current land use programs and policies continue unchanged. In western Washington, FIA data reflect land use changes occurring in the absence of statewide planning. Statewide planning in Washington was only recently initiated with the Growth Management Act in 1990 (Baker 1992). Beyond the scope of this study, alternative land use scenarios resulting from new or evolving land use programs and policies could be simulated with the empirical models presented. Such simulations could portray behavioral effects induced by different policy instruments.

New empirical land use models present new opportunities for analyzing and projecting land use change by exploiting the additional explanatory information provided by spatial data. Tradeoffs encountered when using more spatially disaggregated data include frequent unavailability of economic data at finer spatial scales at which ecological data commonly are available. Although empirical issues remain unresolved, spatial land use models potentially have applications to a wide range of ecological and natural resource policy issues. In the short term, use of spatial land use models may be limited by available land use data and the expense of processing spatial data. Satellite imagery often is limited in its temporal scope, and aerial photos may be expensive to digitize. Existing national land use inventories, such as the National Resource Inventory and the FIA program, are designed to document specific agricultural and forest resources and may not provide a detailed and comprehensive depiction of all potential land uses in a given region. Improved land use data and greater collaboration between existing national land use inventories would benefit future land use modeling efforts.

The inclusion of explanatory variables based on gravity models of urbanization show promise as a means to capture the spatial impacts of population growth on land use change in rural areas. Extensions to the conceptual framework for analyzing the spatial variability of urban rents also could include greater consideration of the role of technology, transportation systems, and differences in quality of life factors. Better information also is needed about land use changes resulting from the location of homes in predominantly rural areas. Such land use changes have implications for both commercial timber production and nontimber forest outputs such as wildlife habitat. In Oregon, areas of preexisting rural development are considered "exception areas" in statewide land use planning. These areas total about 323 750 hectares and are equal to all of the land located within urban growth boundaries in the state (Liberty 1997). Population densities in most exception areas are relatively light, and commercial timber production is common. Increases in population density, however, likely could impact existing commercial timber production, as well as nontimber forest outputs. For example, forest owners possessing small parcels often are not interested or engaged in commercial forestry (Johnson and others 1997). Future analysis could reveal whether forest home sites will have a significant impact on future commercial timber production or nontimber forest outputs.

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