MODEL

USING RESOURCE ECONOMICS TO ANTICIPATE FOREST LAND USE CHANGE IN THE U.S. MID-ATLANTIC REGION

PETER J. PARKS[1], IAN W. HARDIE[2], CHERYL A. TEDDER[1] and DAVID N. WEAR[3]

[1]Department of Agricultural, Food, and Resource Economics, Cook College, Rutgers University, 55 Dudley Road, New Brunswick, NJ 08901-8520 USA; [2]Department of Agricultural and Resource Economics, University of Maryland, College Park, MD 20742 USA; [3]Economics of Forest Protection and Management, U.S. Forest Service, Post Office Box 12254 Research Triangle Park, NC 27709 USA.

Abstract. Demands for forest, farm, and developed land are evolving in the U.S. mid-Atlantic region. The demand for land in developed uses, as well as demands for various forest and farm products are changing in response to population growth, demographic shifts, and market forces. As demand factors change so do relative land values. Land area in future forest, farm, and developed uses may shift as landowners re-evaluate relative net benefits from land use alternatives. This study examines the effects of various land demand and supply factors on the determination of land use patterns in the mid-Atlantic region. Driving variables include costs and benefits from various uses, population density, and measures of land quality. Model parameters are estimated using a binomial logit procedure. Results from the study are used to estimate proportions of forest area on a county by county basis. Simulated forest landscapes under hypothetical future conditions are prepared and illustrated using geographic information system (GIS) techniques.

1. Introduction

Forests in the mid-Atlantic region[1] of the U.S. provide a wide range of benefits. These benefits may be lost when forest land is converted to other uses. The region, which includes some of the most densely populated counties in the U.S., is also subject to some of the most rapid changes in land demands in the country. The demand for land in developed uses, as well as demands for various forest and farm products, is changing in response to population growth, demographic shifts, and national and international market forces. As demand factors change, so do relative land values. Consequently, land area in future forest, farm, and developed uses may shift as landowners re-evaluate relative net benefits from land use alternatives. Anticipating potential changes in land use is essential for designing policies that sustain benefits from forests.

[1] The mid-Atlantic region includes 374 counties that are part of a multi-agency Mid-Atlantic Integrated Assessment (MAIA) research project. The MAIA region includes Delaware, Maryland, Pennsylvania, Virginia, West Virginia, the southern counties of New Jersey and New York, and the northern counties of North Carolina.

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This study develops a land use model of the Mid-Atlantic Integrated Assessment (MAIA) region, and examines the effects of various land demand and supply factors on land use patterns. Model parameters are estimated using a binomial logit model that relates proportions of land area to driving variables that measure demand and supply for land. The estimated model is used to anticipate potential future changes in forest land use. Forest areas that may be converted to other uses deserve further research to identify and simulate land policies that could help sustain benefits from forests that would otherwise be lost.

2. Conceptual Framework

Demands for forest, farm and developed land are all evolving in the mid-Atlantic region. The importance of remaining agricultural and forest areas as sources of open space and other environmental benefits is growing as population and urban land area increases. International economic development, growth in domestic population, and changes in international trade are increasing the demand for farm products.

The demand for developed land is increasing in parts of the mid-Atlantic region due to urbanization, immigration and new industrial production. As these demands evolve, relative land values change. Land area in agricultural and forest use within the region becomes more dependent on the relative land value tradeoffs being created by the evolving demands for land.

The general land allocation problem is that of a land user wishing to maximize net benefits obtained from an area by choosing the appropriate land uses. This section describes the problem faced by a user of L hectares who must allocate land between forest and non-forest uses. The land user's allocation decisions depend on the land's ability to provide benefits, the prices of outputs and inputs, and preferences for outputs. The area is divided into classes based on its ability to provide benefits (e.g., timber, recreation, crops). For discussion purposes, treat relevant land attributes (e.g., fertility, physiographic characteristics) as a composite commodity (Henderson and Quandt 1980) measured by a scalar, q, called land quality, that is defined so that higher quality land provides more benefits than lower quality land, Quality ranges from worst, q^-, to best, q^+, with $L(q)$ acres in each class. Thus the total area L is divided into tracts so that $L = L(q^-) + \ldots + L(q^+)$.

Maximizing net benefits from the land input requires the user to allocate uses to land classes. Land benefits consist of the present value of net benefits from forest and non-forest uses, $PVNB^{*F}(p,q)$ and $PVNB^{*NF}(p,q)$. The user determines these potential benefits by determining optimum forest or non-forest uses on land quality q when faced with price vector p for land benefits and nonland inputs. Given $PVNB^{*F}(p,q)$ and $PVNB^{*NF}(p,q)$, the user can obtain maximum benefits from the entire ownership by selecting $f(q)$, the proportion of land quality class q

that should be devoted to forest uses. If we allow the function $\phi(q)$ to describe the distribution of quality on the ownership, then the user's total net benefit from the entire ownership can be written

$$PVNB = \sum_{q=q-,q+}\{f(q)PVNB^{*F}(p,q) + [1-f(q)]PVNB^{*NF}(p,q)\}\phi(q)L.$$

The benefits that the user can obtain are subject to the available land distribution, the feasible land use choices, and the production possibilities implicit in $PVNB^{*F}(p,q)$ and $PVNB^{*NF}(p,q)$.

Length limitations prevent detailed representation of components of land use benefits in this manuscript. To simulate the effects of land policies, specific policy tools (e.g., subsidies, taxes) must be included in the land benefit functions. More detailed analyses are given in related studies. For example, Hardie and Parks (1997) quantify the effects of timber and agricultural revenues, as well as other variables, on southern U.S. forest land, Hardie and Parks (1996) evaluate the success of reforestation cost-sharing incentives in the U.S. south, Parks and Schorr (1997) evaluate performance of federal land use subsidies in metropolitan and nonmetropolitan counties in the northeastern U.S., Parks (1995) examines the effect of uncertainty on policy participation, Parks and Kramer (1995) simulate the costs and effects of national wetlands policies, Parks and Hardie (1995) simulate the cost of offsetting U.S. carbon emissions by storing carbon in U.S. forests.

Since $PVNB$ is linear in $f(q)$, the user will maximize benefits by solving $dPVNB/df(q) = 0$, which requires allocating land to forest uses until

$$PVNB^{*F}(p,q^*) - PVNB^{*NF}(p,q^*) = 0,$$

then selecting non-forest use. For qualities below the land quality margin q^*, forest benefits exceed non-forest benefits and the user maximizes total net benefit by allocating the land to forest (i.e., choosing $f(q)=1$). For hectares with quality above q^*, non-forest benefits exceed forest benefits and the user maximizes total net benefit by allocating the land to non-forest use (i.e., choosing $f(q)=0$). In the event benefits from one use exceed the other over the entire quality range, the user will obtain maximum benefits by selecting a single land use.

The optimal amount of land for the user to devote to forest use is $\Phi(q^*)L$, where Φ is the cumulative distribution function corresponding to ϕ. Because the attributes relevant to the user to characterize land quality may be spatial (e.g., distance to where land products are used) or nonspatial (e.g., soil fertility), the quality margin between land use alternatives may or may not be associated with a contiguous location. The land margin between forest and non-forest uses, defined above by q^*, provides an analytical basis for evaluating the potential for markets and market policy instruments (e.g., forest establishment cost-sharing, subsidized agricultural opportunity costs) to influence land use and supplies of land benefits.

The next section describes the data and empirical procedures used to quantify the influence of agricultural benefits, development benefits, and land attributes on forest land allocation in the region. The discussion of data and procedures is followed by a discussion of results and policy implications.

3. Data

Forest land estimates for 1982, 1987, and 1992 are constructed from observations of land use and characteristics collected by the U.S. Natural Resources Conservation Service (NRCS) in the 1992 National Resources Inventory. These data are merged at the county level with economic and land attribute data from the U.S. Bureau of the Census, Censuses of Agriculture and Population to form the complete dataset. Detailed empirical study of the role of timber and non-timber forest benefits on regional land allocation is prevented until regionally-consistent timber and non-timber production and valuation data are available. The proportion of forest land in a county corresponds to $\Phi(q^*)$, and county averages for land use benefits, costs, and land attributes correspond to measures of $PVNB^{NF}(p,q)$ and q, respectively.

3.1 COUNTY FOREST PROPORTIONS

Forest land proportions are computed for subregions of counties found in the MAIA region. Each county may contain land in one or more Major Land Resource Areas (MLRAs), a classification used by the NRCS for policy analysis (U.S. Department of Agriculture, Soil Conservation Service 1981, see also Parks and Hardie 1995). Each county-MLRA land use observation in the dataset represents the boundary of an MLRA found within a county. This increases the sample size from 374 counties to 509 county-MLRA analytical units.

The National Resource Inventories (NRIs) have been completed every five years since 1982. Data on ownership, land cover, and soil characteristics are observed on all NRI sample points. The forest area proportions, $\Phi(q^*)$, calculated for each county-MLRA unit include the proportion of privately-owned land that is grazed or ungrazed forest cover.

3.2 NON-FOREST BENEFITS

Key non-forest uses include developed (e.g., urban, right-of-way), and agricultural uses. As a proxy for benefits from developed uses, we include population density (measured in persons per square mile). Measures of agricultural benefits include benefits and costs from crops and livestock production. Agricultural data are drawn from the Census of Agriculture (U.S. Department of Commerce, Bureau of the Census). Revenues from crops and from livestock and livestock products were divided by areas in crop and livestock production, respectively, to obtain per acre statistics. Production expenses that were consistently recorded in each , Census (labor, machinery, fuel, seeds, feed, and livestock purchases) were summed to calculate a single measure of cost. These costs were then divided by land in crop production to obtain per acre figures for each county.

3.3 LAND QUALITY

Land quality is measured as the proportion of land in the county-MLRAunit that is in Land Capability Classes I and II. These better-quality lands are from a land classification system developed by the U.S. Department of Agriculture, Soil Conservation Service (198 1) to assess land suitability for agricultural production. Land with soil qualities of Class III or higher may be associated with significant limitations that restrict cultivation (See Parks and Hardie 1995 Appendix, for further details).

4. Estimation Methods

A class or tract of land will be allocated to non-forest use in county-MLRA[2] unit i at time t if land quality is above the critical threshold implicitly defined by $PVNB^{*F}(p_{it},q^*_{it}) = PVNB^{*NF}(p_{it},q^*_{it})$ for that unit and time (see above). Following Judge et al. (1985), let $q_{ijt} = g(x_{ijt}'\beta_t)$ be an unobservable index of quality for tract j in the unit. The index may be unobservable because (i) some components of the composite quality index q may not be observable, or (ii) land benefits cannot be precisely calculated from the available secondary data, or (iii) some components of benefits cannot be observed.

Observable data include x_{ijt}, a vector of attributes of the tract at time t (e.g., components of net benefit from competing uses, observable land attributes), and the outcome of the land allocation decision for the tract. For each tract in the county, if land quality is below the level q^*_{it}, the land in the tract is optimally allocated to forest; otherwise, it is allocated to non-forest use.

The index $g(x_{ijt}'\beta_t)$ is defined so that the probability that a tract drawn at random from the land base in county i at time t is forested is P_{ijt} = Probability $\{q^*_{it} \leq g(x_{ijt}'\beta_t)\}$. Since this probability is bounded by zero and one, and quality classes in this model are monotonically arranged from worst to best, the relationship be-

[2] By applying the model at the regional level, it is implicitly assumed that all land users in the region possess the same benefit functions and all nonindustrial forest land users are allocating land to maximize benefits. This "representative owner" assumption is statistically tested by evaluating the overall statistical significance of the model.

tween q_{ijt} and P_{ijt} can take the form of a cumulative distribution function (cdf), for example, the logistic cdf:

$$P_{ijt} = \Pr\{q^*_{it} \leq g(x_{ijt}'\beta_t)\} \approx 1/\{1+\exp[-g(x_{ijt}'\beta_t)]\}$$

To estimate the parameters β_t, the probabilities P_{ijt} are approximated with proportions calculated from grouped (i.e., land inventory) data.

A binomial model was selected because forest uses in particular are of interest. Specific non-forest uses to which forest land might be converted (e.g., developed uses, agriculture) can be addressed in a multinomial model with more land use choices, but were considered beyond the scope permitted by the special issue. Hardie and Parks (1997) provide an example of multinomial land use choice in a regional landscape. The logit model in particular was selected because 1) it is readily applicable to grouped data and widely used with these data, 2) the logit transformation of grouped data helps conform the dependent variable to statistical properties required by commonly used econometric procedures, and 3) procedures for correcting heteroscedasticity in a grouped logit model are well known.

The error e_{it} associated with the substitution of proportions for probabilities is heteroscedastic. The proportion of forest land for county i at time t is $\Phi(q^*_{it})$, and depends on the attributes of the county, x_{it}. The relationship between $\Phi(q^*_{it})$ and P_{it} is

$$\ln[\Phi(q^*_{it})\backslash(1-\Phi(q^*_{it})] \approx \ln[P_{it}\backslash(1-P_{it})] + e_{it}\, P_{it}\backslash(1-P_{it}) = g(x_{ijt}'\beta_t) + u_{it}.$$

When estimating the parameters β_t in 4), Maddala (1987) recommends a minimum chi-squared approach. The procedure amounts to recognizing and correcting for the heteroscedasticity of u_{it} by using $n_{it}P_{it}(1-P_{it})$ as weights; for our application, n_{it} is the area used to estimate forest area proportions in area i at time t, and P_{it} is the proportion of land in forest.

5. Results

Overall, the models fit the data very well: the adjusted R^2 statistics are .97 for the 1982, 1987, and 1992 time periods (Table I). The F statistics for overall significance of the regression jointly show the parameters as a group are significantly different from zero at well above usual levels of significance ($P<.01$). Higher costs of crop production, lower population density, and lower land quality, are associated with more land in forests ($P<.01$). Benefits from non-forest uses such as crops and livestock are not significantly related to forest cover, possibly due to colinnearity between the measures of benefit and the other variables included in the model.

Table I

Grouped Logit Parameter Estimate? for Forest Cover in the Mid-Atlantic Integrated Assessment (MAIA) Region for 1982, 1987 and 1992.

Variable	1982	1987	1992
Market Value of Crops Sold ($1000/acre)	-0.536 (0.685)	-0.691 (0.771)	-1.73 (0.900)
Market Value of Livestock (etc.) Sold ($1000/ac)	-0.00814 (0.0237)	-0.00336 (0.0316)	0.075 1 (0.0513)
Costs of Crop Production ($1000/acre)	3.26* (1.40)	5.43* (1.84)	6.98* (2.64)
Population Density (persons per square mile)	-0.00347* (0.000414)	-0.00388* (0.000405)	-0.00349* (0.000346)
Proportion of Land in LCC I and II	-10.5* (0.639)	-10.6* (0.659)	-10.8* (0.641)
Constant	3.34* (0.658)	3.26* (0.664)	3.35* (0.694)
Adjusted R^2	0.97	0.97	0.97
F[b]	695.*	693.*	683.*
N	495	478	474

[a] Estimates are corrected for heteroscedasticity. Numbers in parentheses are asymptotic standard errors.

*Indicates estimate is significantly different from zero ($P<0.01$). Estimates associated with 18 indicator (dummy) variables for Major Land Resource Area locations are not listed.

[b] ests the joint hypothesis that all coefficients are simultaneously zero. Degrees of freedom for the 1982, 1987, and 1992 F statistics are (24, 471), (24, 454), and (24, 450), respectively.

The grouped logit parameter estimates shown in Table I do not show the change in land proportion associated with these variables (such changes are referred to as marginal effects). Evaluating the marginal effects of variables in deter-, mining land area proportions is accomplished by deriving elasticities from the estimated logit equation. The elasticity in the land area proportion with respect to the kth element of x_{ijt} is defined here as the percentage effect of a one unit increase . in x_{ijtk} on the proportion of land in forests (suppressing the subscripts i, j, and t):

$$\&k(X) = \partial P(x)\backslash\partial x_k \cdot x_k\backslash P(x)$$

$$= -\partial g(x'\beta)\backslash\partial x_k \cdot \exp[-g(x'\beta)]/[1+\exp[-g(x'\beta)]]^2 \cdot x_k\backslash P(x)$$

It is clear that the elasticity of probability depends on the attributes of the county-MLRA land unit, x, and can be calculated using this formula for any value of x. Figure 1 presents a map of elasticities of 1992 forest area with respect to 1992 population for each county-MLRA unit.

The elasticity estimates show the potential sensitivity of forest cover to changes in population density. The elasticities range from 0 to -8.9, indicating that in the most sensitive parts of the MAIA region (near large cities such as Washington DC, Philadelphia and Baltimore), a 1% change in population might lead to as much as an 8.9% decrease in forest cover. In policy simulations, state level elasticities with respect to tax rates have been used by Parks and Quimio (1996) to evaluate the efficacy of farmland assessment to preserve agricultural land in New Jersey; county-level elasticities with respect to land subsidies have been used by Parks and Schorr and Parks and Kramer to evaluate the federal Conservation Reserve and Wetlands Reserve Programs, respectively.

Several caveats for these results arise from the data and estimation procedures. For example, the land use observations are several years apart (1982, 1987, and 1992), and it is possible that land use transitions could have occurred between surveys that are not reflected at the time the surveys are taken. In addition, while aggregating to the county level is perhaps the most straightforward way to link the NRI data with economic data from the Censuses of Agriculture and Population, it forces a representative owner assumption (see Footnote 2). Differences in land use objectives for various owners are to be expected; however, without supplementary surveys of individual owner objectives, these differences cannot be resolved using either the NRI plots or aggregated NRI statistics. The calculated land benefits ideally could be replaced with actual land sale prices; however, these are not readily available at the county level for the entire region and study period. Finally, there may be alternative explanations of the causes for land use allocation in the MAIA region: the decrease in private forest area shown in the NRI data occurred throughout most of the sample. Any variable which starts high (low) and then falls (rises) could appear to cause (mitigate) this conversion.

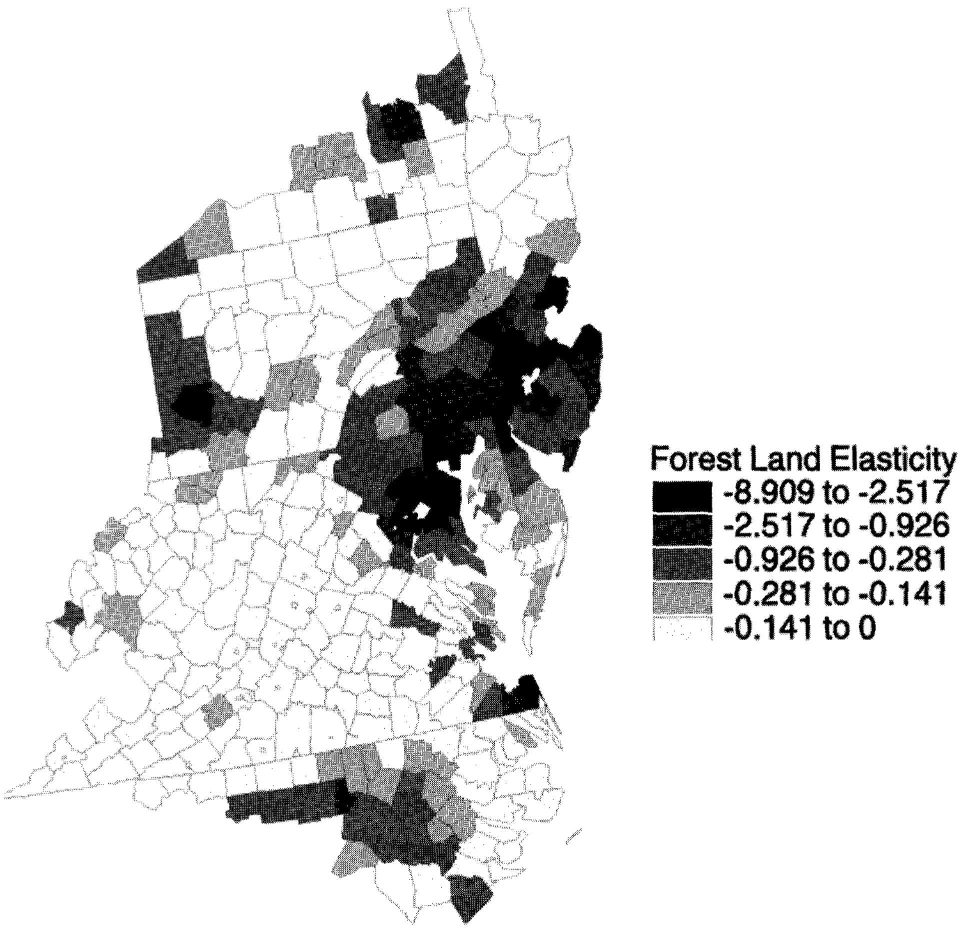

Figure 1.
in the mid-Atlantic integrated assessment region, U.S., 1992. (See text for a detailed definition of the region.)

6. Summary, Conclusions, and Policy Implications

This paper develops *a* model of benefit-maximizing forest land use decisions when forest land has heterogeneous attributes that influence the production of land products. Forest land area in the mid-Atlantic region of the U.S. is related to crop production costs, population density, and land quality. Increases in population density decrease the proportion of land in forests throughout the region. Although the response to changes in population density is inelastic for most of the region, subregions exist where more rapid (elastic) changes in forest cover may be anticipated.

Understanding the economic processes driving forest land use change facilitates the design of policies that affect land use and its environmental consequences (e.g., water quality, resource supplies, carbon storage). At a minimum, improving, the economic representation of forest land use processes in models of forested landscapes will make it possible to evaluate the sensitivity of the landscape to economic and other driving variables, and extrapolate trends in economic conditions to evaluate outcomes on the forest landscape. More ambitious applications include using land use models to help design and evaluate economic policies that are designed to accomplish specific land use or environmental outcomes (e.g., reforestation policies, Hardie and Parks 1996, wetlands policies, Parks and Kramer 1995, and carbon storage policies, Parks and Hardie 1995).

Land use choices at the state and local level may also be influenced by zoning, taxation, energy policy (gasoline taxes), and proximity to highways. Consideration of these types of policies often requires specific land parcels to be considered, by integrating economic analyses more closely with landscape ecological techniques. Studies that integrate both economic and landscape ecological techniques exist, but are relatively scarce (Parks 1990, Bockstael et al. 1996). These studies often rely on discrete choice (nongrouped) land use data, which permit econometric models to be more easily integrated with GIS-based ecological simulations. Parks et al. (1998) provide a detailed survey of of discrete choice and other models of forest land in temperate and tropical regions throughout the world.

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