URBANIZATION AND TIMBER HARVEST PROBABILITY
IN MISSISSIPPI AND ALABAMA

Stephen A. Barlow, Ian A. Munn, David A. Cleaves, and Robert Moulton

Abstract: In the southern United States, increased development in traditionally rural areas is quickly reducing the land base currently used for forest management. This shift from rural to urban uses represents a long term removal of productive forest land. A complex landscape of residential and forestry uses in the same area results. This intermingling often spurs environmental concerns of neighboring landowners who perceive many aspects of forest management negatively. The impact of urbanization on timber harvesting in Mississippi and Alabama is investigated in this study. Distance to urbanized areas and population density are used as measures of urbanization. Data from the U.S. Department of Commerce, Bureau of the Census are combined with Forest Inventory and Analysis (FIA) data collected by the USDA Forest Service. These data were merged using Geographic Information Systems (GIS) to spatially reference the FIA plots to the demographic data. A binary logit model was estimated to provide a predicted harvest probability for each FIA plot. Distance to urbanized areas and population density are significant predictors of harvest probability. This study provides a methodology to combine available data sources to assist in the development of a state or regional timber availability model.

Introduction

Increased development in traditionally rural areas is decreasing the land base for forest management. This increased development creates the potential for conflict between the proponents of different land uses. Competition for land between residential and forestry uses creates a complex landscape where urban/suburban development occur in the same area (Vaux 1982). Neighboring landowners’ perceptions of forest practices as damaging to the environment may lead to enactment of local regulations that limit silvicultural practices (Cubbage 1995, Martus et al. 1995). Harvesting may only be reduced due to these factors. Eventually, however, urbanization may have an overall negative impact on timber harvesting as more of the forest lands near urbanizing areas are either permanently converted to urban uses or protected. There are many factors that influence the occurrence of timber harvesting (Dennis 1990, Newman and Wear 1993). This paper seeks to quantify the functional relationship between harvest on FIA plots between inventory periods and measures of urbanization such as distance to an urbanized area.

Two demographic factors that could have a significant negative influence on timber availability in the South are regional increases in population growth, and “urban sprawl.” Recently, population growth rates in the South and West have exceeded all other regions of the country. Between 1960 and 1991, the South’s population increased from 30.7 percent to 34.5 percent of the U.S. total, and the West’s

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1Respectively, Graduate Research Assistant and Assistant Professor, Department of Forestry, Mississippi State University, MS 39762; Principal Economist, USDA Forest Service, Southern Research Station, New Orleans, LA 70113; and Senior Economist, USDA Forest Service, Cooperative Forestry, Research Triangle Park, NC 27709. Paper presented at the 1996 Southern Forest Economics Workshop, Gatlinburg, Tennessee, March 27-29. Approved for publication as Journal Article No. FA-059-0696 of the Forest and Wildlife Research Center, Mississippi State University. Financial support for this research was provided by State and Private Forestry and the Southern Research Station, Law and Economics, USDA Forest Service.
from 15.6 percent to 21.4 percent (U.S. Department of Commerce (USDC), Bureau of the Census 1992). Patterns of development near the urbanized areas is also an important consideration (Lubka 1982). The percentage of U.S. land in metropolitan areas nearly tripled, from 5.9 percent in 1950 to 16.4 percent in 1990 (Shands 1991, USDC Bureau of the Census 1992). This increase in metropolitan land area indicates the spread of development beyond the core cities. Urbanization's impact on timber availability is potentially quite large. DeForest et al. (1991) found that metropolitan counties (populations of 250,000+) contain 26 percent of the Southeast’s timberland—about 28 million acres.

This study considers the impact that urbanization has on the probability of timber harvest. Our measures of urbanization are population density and distance to the center of an urbanized area, or a city with at least 50,000 people including its densely populated surroundings (USDC Bureau of the Census 1990).

Urbanization's impacts on harvesting in Mississippi and Alabama were explored by combining demographic and forest Inventory data. These data were merged in a GIS to spatially reference the plots to the demographic data. A binary logit model was used to estimate the probability of timber harvest on FIA plots.

Data and Methods

The two primary data sets used in this study are USDC Bureau of the Census, Census of Population and Housing Census Tract data, and USDA Forest Service, FIA plot level data. Census Tracts and Block Numbering Areas (the rural equivalent of Census Tracts) are county subdivisions established by the USDC Bureau of the Census and local governments that contain similar population characteristics. Census Tracts usually consist of 2,500 to 8,000 people and may vary widely in size depending on population density. Latitude and longitude coordinates were used to relate site characteristics to the population data. The combination of the two data sets links demographic data, such as population density and income levels, with USDA Forest Service plot-level data including net volume of growing stock trees, distance to a truck operable road, and other site and stand attributes.

Demographic Variables

A Census Tract base map of Mississippi and Alabama was created from USDC Bureau of the Census TIGER (Topologically Integrated Geographic Encoding and Referencing) Lines using the GIS software package ARC/INFO. Population data for each Census Tract were merged with FIA plot data. Census variables were population density in people per square mile (POPDENS), and median household income in 1989 dollars (MEDHINC). Another measure of urbanization, straight-line distance to an urbanized area (DISTMILE), was calculated using ARC/INFO. A squared version of DISTMILE was included in the model to explore a non-linear relationship.

Site Variables

The second data set is FIA data, which is collected and reported for each state periodically. These data consist of information collected from sample plots located on a three-mile grid pattern across each state (Kelly 1991). Factors shown by Binkley (1981) and Dennis (1990) to be significant determinants of past harvest choice include timber volume per acre, distance from the plot to the nearest road,

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ownership, and slope. In this study, other plot variables such as distance to built-up areas of ten acres or more, collected by the FIA, were considered.

The first FIA variable is net volume of growing stock in the previous inventory (NVGS), measured in cubic feet per acre. If the volume is high in the previous inventory, then the site is more likely to be harvested by the next inventory. Variables that represent cost of harvesting such as distance from the sample plot to the nearest truck operable road (DISR) and percentage slope (SLOPE) of the plot are also included. Four ownership categories were considered in this study: National Forest (OWNDUMNF), "other public" (OWNDUMOP), forest industry (OWNDUMI) and nonindustrial private (OWNDUMP). The category "other public" includes government owned forest land such as state forests and national parks. Three categories representing proximity to built-up areas of at least ten acres were considered for their impact on harvest probability: 1) within one mile of built-up areas (DSURBDUM1), 2) between one and three miles (DSURBDUM2), and 3) beyond three miles of built-up areas (DSURBDUM3).

**Empirical Model**

The probability of timber harvest was estimated using a binary logit model as follows:

\[
P(Y_i = 1 | X_i) = \frac{1}{1 + e^{-z}}
\]

(1)

where \(Y_i\) is the binary dependent variable:

- \(Y_i = 1\), if any harvest activity occurred since the last inventory (1987-1994 for Mississippi and 1982-1990 for Alabama). Harvests include partial cuts, shelterwood, seedtree, salvage cuts and clearcuts.
- \(Y_i = 0\), if no harvest has occurred during the seven years following the inventory.

\[
Z_i = \Sigma b_k X_{ik}
\]

\(X_i\) denotes the set of \(K\) independent variables.

\(b_k\) are the estimated parameters (\(k = 1, \ldots, K\)).

Equation (1) represents the cumulative logistic distribution function (Pindyck and Rubinfeld 1981). The probability of a timber harvest was modeled as a function of fourteen independent variables, and takes the following form:

\[
\text{Probability (Harvest)} = f (NVGS, DISR, SLOPE, OWNDUMOP, OWNDUMNF, OWNDUMI, OWNDUMP, DSURBDUM1, DSURBDUM2, DSURBDUM3, POPDENS, MEDHINC, DISTMILE, DISTMILE?)
\]

(2)

Note: OWNDUMOP and DSURBDUM3 were omitted from the model to allow inversion of the \(XX\) matrix. Partial cuts represented 58 percent of harvested plots while clearcuts were 37 percent of harvested plots.

**Results**

The null hypothesis that all non intercept coefficients are equal to zero was rejected using the test statistic -2 LOG L (Table 1). The estimated chi-square value, 673.97 with 12 degrees of freedom, was
Table 1. Parameter estimates and marginal effects for timber harvest on sampled sites in Mississippi and Alabama.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter Estimate</th>
<th>Standard Error</th>
<th>Marginal Effect*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT</td>
<td>-2.625</td>
<td>0.2969*</td>
<td>--</td>
</tr>
<tr>
<td>NVGS</td>
<td>0.000719</td>
<td>0.000033*</td>
<td>0.000157</td>
</tr>
<tr>
<td>DISR</td>
<td>-0.0120</td>
<td>0.00271*</td>
<td>-0.00262</td>
</tr>
<tr>
<td>SLOPE</td>
<td>-1.00295</td>
<td>0.00310</td>
<td>-1.000645</td>
</tr>
<tr>
<td>OWNDUMNP</td>
<td>-0.4596</td>
<td>0.2467</td>
<td>--</td>
</tr>
<tr>
<td>OWNDUMI</td>
<td>1.0089</td>
<td>0.2073*</td>
<td>--</td>
</tr>
<tr>
<td>OWNDUMP</td>
<td>1.0308</td>
<td>0.1994*</td>
<td>--</td>
</tr>
<tr>
<td>SDURBDUM1</td>
<td>-0.3987</td>
<td>0.0972*</td>
<td>--</td>
</tr>
<tr>
<td>DSURBDUM2</td>
<td>0.0159</td>
<td>0.0682</td>
<td>--</td>
</tr>
<tr>
<td>POPDENS</td>
<td>-1.00108</td>
<td>0.00044**</td>
<td>-0.000236</td>
</tr>
<tr>
<td>MEDHINC</td>
<td>-0.000000469</td>
<td>0.000006745</td>
<td>-0.000000103</td>
</tr>
<tr>
<td>DISTMILE</td>
<td>0.0127</td>
<td>0.00474*</td>
<td>0.00278</td>
</tr>
<tr>
<td>DISTMILE²</td>
<td>-0.00011</td>
<td>0.000038*</td>
<td>-0.0000241</td>
</tr>
</tbody>
</table>

-2 LOG L = 673.97  
df for X² = 12  
Number of observations = 6,622

* Marginal effects represent the change in the probability of harvest (evaluated at the mean probability of 0.323) for a one unit increase in each of the continuous independent variables.

** = Statistically significant at the 5 percent level.


statistically significant at the 1 percent level indicating that the model fits well. The chi-square test is analogous to the F-test in linear regression and tests the overall significance of the model. Table 1 contains the parameter estimates, standard errors, and marginal effects of each continuous variable. The estimated coefficients for NVGS, DISR, OWNDUMI, OWNDUMP, DSURBDUM1, DISTMILE, DISTMILE² are all significant at the one percent level. The coefficient on POPDENS is significant at the 5 percent level. Table 2 contains the classification table of the predictive model. The classification table categorizes the observations based on the probability of harvest. If the estimated probability of harvest is greater than or equal to 0.50, it is categorized as a "predicted" harvest, but if it is less than 0.50 it is categorized as "no predicted" harvest.

Overall the model correctly classifies 4,657 of the 6,622 observations or 70.3 percent. The proportion of observations correctly predicting a harvest is 20.3 percent. Of the 2,039 FIA plots that were actually harvested, the model correctly predicted 414 as harvested. The proportion of observations correctly predicting no harvest is 92.6 percent, or 4,243 of the 4,583 observed as not harvested are classified correctly. Therefore, the model is more effective at predicting "no harvest" than "harvest."

The parameter estimate for NVGS was statistically significant at the 1 percent level, indicating that timber volume has a positive impact on the probability of harvest. The estimated coefficients for the
Table 2. Classification table indicating category percentages correctly classified by the binary logit model.

<table>
<thead>
<tr>
<th></th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Harvest</td>
</tr>
<tr>
<td>Observed: No Harvest</td>
<td>4,243</td>
</tr>
<tr>
<td>Harvest</td>
<td>1,625</td>
</tr>
<tr>
<td>Total</td>
<td>5,868</td>
</tr>
<tr>
<td>Total</td>
<td>4,583</td>
</tr>
</tbody>
</table>

Total classification accuracy: 70.3%
Correctly classified as "Harvest": 20.3%
Correctly classified as "No Harvest": 92.6%

Ownership dummy variables OWNDUM1, and OWNDUMP were statistically significant at the 1 percent level and positive. These ownership variables indicate that industry and private landowners are more likely to harvest than "other public." Similar coefficients for industry and private ownership indicate little difference between the two in terms of harvest probability.

The dummy variable for National Forest ownership OWNDUMNF was negative. However, there was no significant difference in harvest probability between National Forest sites (OWNDUMNF) and the omitted category "other public." The "other public" category includes Sixteenth Section, state owned forest land in Mississippi, and federal wildlife refuges. State owned forest land in Mississippi is intensively managed and therefore more likely to be harvested than many lands in this category. The "other public" category is a catchall including lands both likely and unlikely to be harvested. Since the USDA Forest Service manages the National Forests for multiple uses such as timber, recreation, and wildlife, it seems reasonable that there would be no significant difference between National Forest and "other public."

The coefficient of DSURBDUM1 was negative and significant at the 1 percent level. The variable DSURBDUM2 was not significantly different from the omitted category DSURBDUM3 (Table 1). The negative sign on DSURBDUM1 indicates that harvest probability is lower on FIA plots within the one mile zone of "urban areas," as classified by the USDA Forest Service, than FIA plots beyond three miles (DSURBDUM3). Distance from the plot to the nearest truck operable road, represented by the variable DISR, has a negative and significant impact on harvest probability. DISR is a proxy for the harvesting costs associated with temporary road construction.

The marginal effects of the continuous independent variables are given by the following:

\[
\frac{dP}{dX} = b_i (1 - P) P
\]  

(3)

Therefore, the rate of change in probability with respect to X involves \( b_i \) and the level of probability from which the change is measured (Pindyck and Rubinfeld 1981). In this study marginal effects are presented at the mean values of the independent variables: on privately owned FIA plots (OWNDUMP = 1), and beyond three miles of built-up areas (DSURBDUM3 = 1). The mean probability of harvest is 0.323. The marginal effects are interpreted as the change in probability for a one unit increase in
Figure 1a. Probability of harvest as a function of population density (on private FIA plots beyond three miles of built-up areas).

Figure 1b. Probability of harvest as a function of distance from the center of an urbanized areas (on private FIA plots beyond three miles of built-up areas).

the independent variable. For example, holding the other variables constant at their means, if NVGS increases by 1,000 cubic feet per acre then the probability of harvest increases by 0.157.

The impact of an independent variable can be further illustrated by plotting the estimated probability of harvest over its observed range. Figure 1a illustrates the negative impact of population density on harvest probability. The influence of another measure of urbanization, distance from an urbanized area, is shown in Figure 1b.
Discussion

The results concur with previous research that site characteristics such as volume and accessibility help to predict the probability of timber harvest. In this study, slope did not significantly affect harvest probability. Ownership category affects harvest probability. Harvests are more likely on private and industry owned land. Probability of harvest on National Forests do not significantly differ from the "other public" category.

Level of urbanization influences the probability of harvest. An FIA plot that is within one mile of a built-up area is 0.08 less likely to be harvested than one that is beyond this one mile zone. Plots within this one mile zone of built-up areas are closer to urban influences such as conflicts due to increased development. This decrease in harvest probability may be due to conflicting land uses or may result simply because there is less land in forest management near built-up areas.

A more direct measure of urbanization, population density, is negatively related to harvest probability. Clearly, with increased population density there is a decrease in available land managed for timber. This may be due to a reduction in the proportion of land managed for timber and constraints on harvesting resulting from public opinion and conflicting land uses (e.g., residential and forest management).

Another measure of urbanization, distance from an urbanized area, aided in predicting harvest probability. The relationship between distance to an urbanized area and harvest probability is nonlinear. Holding other factors constant, the relationship between distance and harvest probability is positive between 0 and 115.8 miles and reaches a maximum at 57.8 miles (Figure 1b). Beyond 115.8 miles the impact of distance to an urbanized area on harvest probability is negative. A possible explanation for this relationship is that harvest is more likely, within the 57.8 mile zone, due to conversion of land from forest to "higher and better use" such as commercial or residential. This may contribute to short-term availability but mean reductions in the long-term as lands change use.

The FIA dummy variables measuring proximity to built-up areas is reinforcing the variable representing straight-line distance to an urbanized area. The FIA variables represent the occurrence of different land uses in an area or fragmentation of forest land. Decreased harvest probability within one mile of built-up areas, relative to the beyond three miles category, possibly represents the negative impact of forest fragmentation. However, the positive sign on DISTMILE likely reflects increased harvest probability due to conversion to commercial or residential uses within the urban/rural fringes. The negative sign on population density represents decreased harvest probability because less land is available for forestry uses in densely populated areas.

The strength of this study is that it provides the ability to map areas of high harvest probability (Wear and Flamm 1993). Mapping FIA plots with high harvest probability may aid planners and policy makers in identifying Census Tracts where conflicts due to competing land uses are likely to occur. Future research should focus on estimating the effects of urbanization, measured by population density and distance to urbanized areas, on available timber inventory (Wear and Flamm 1993). More accurate estimates of future timber availability are possible if the effects of urbanization are considered.
References


