Chapter 14

Timber and Amenities on Nonindustrial Private Forest Land

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Economic analyses of the joint production timber and amenities from nonindustrial private forest lands (NIPF) have been conducted for several decades. Binkley (1981) summarized this strand of research and elegantly articulated a microeconomic household model in which NIPF owners maximize utility by choosing optimal combinations of timber income and amenities. Most follow-up attempts have been limited to either simulations based on stylized characterization of joint production (Max and Lehman 1988) or to empirical representations hampered by data limitations—particularly with regard to measuring amenity production (Hyberg and Holthausen 1989). In attempting to redress this gap, Holmes (1986) was limited to binary representations of timber and amenities and did not get conclusive results. In this chapter, we use data from North Carolina that includes timber output and amenity indices to illustrate a method for empirically characterizing Binkley's household model.

By accounting for heterogeneous motives for forest ownership through explicit attention to amenity demand, the approach described in this chapter begins the process of developing more comprehensive forest management models that look beyond timber supply. Such efforts can improve the predictions of national and regional timber market models that have assumed timber profit maximization. Moreover, we can provide a clearer understanding of household production of socially desirable forest amenities that lie outside the reach of markets.

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1. TIMBER AND AMENITY MODELS

There are two major schools of timber supply modeling, optimal harvest age simulations and timber supply microeconometrics (Pattanayak et al. 2002). The optimal harvest age approach focuses on the timber harvesting decision for forest landowners who consider amenity benefits from standing forests. The main objective is to determine the optimal rotation length, given a set of parameters such as prices, biological technology, and preferences, and to simulate changes in the optimal length in response to changes in these given parameters (see chapter 8). Therefore, these studies are successors to Hartman's (1976) description of why and how amenity considerations lengthen optimal rotation. These studies draw their theory from Binkley (1981) or Hartman (1976). Simulations are based on assumed functional forms and parameters drawn from empirical studies, expert opinion, and informed conjectures regarding supply and demand of forest products.

A second set of literature uses microeconometrics to estimate parameters of timber supply behavior by private landowners. These positive analyses describe how landowners do behave instead of how they should or would behave. Binkley's (1981) work has been the starting point and conceptual template for this literature. A representative private landowner is assumed to maximize utility by consuming goods and amenities, where utility is separable over time and commodity space and is subject to an income and a production constraint. The technical production constraint links the landowner's scarce inputs, e.g., land or capital, to multiple products, e.g., timber and amenity. Amenity is conceptualized as self-produced recreation proxied by some form of forest inventory; most timber supply studies do not estimate amenity services. Timber supply is derived using first-order conditions of a typical constrained maximization problem to be a function of prices, interest rates, sociodemographics (income, occupation, and education) and biophysical factors (tract size, species mix, and inventory characteristics). Survey data are typically used to estimate the timber supply model with some direct or indirect accommodations for amenity services. A detailed description of these studies is presented in Pattanayak et al. (2002).

The strength of the optimal harvest age models lies in explicitly addressing the choice of forest age or structure. The major shortcoming of the optimal harvest age studies is the lack of empirical underpinnings. Moreover, the optimal harvest age studies tend to rely on Fisherian separation of consumption and production even in specifications with amenity services; therefore, attention to owner characteristics is inadequate. In comparison, the primary contribution of the microeconometric utility maximization tradition is the recognition of the role of owner characteristics on timber supply (because of uncertainty in prices and interest rates,

nontimber amenities, imperfect capital markets, and forest taxation). Their main problem is a lack of connection with the biological aspect of forests.

An approach that combines the strengths of the two traditions and fills the gap between theory and empiricism in timber supply modeling, is identified by Binkley (1987) and Wear and Parks (1994). This chapter develops an empirical nontimber index derived from the biological attributes of forest stands and integrates it with ownership characteristics as described in Pattanayak et al. (2002). Our interest is in the practical aspects of timber supply modeling, particularly measures of amenity flows. In the next section, we present a stylized household production model of timber supply and amenity demand that draws on the literature and previous data explorations to define the conceptual basis for our empirical analysis.

2. A CONCEPTUAL MODEL OF HOUSEHOLD JOINT PRODUCTION

The model presented in this section modifies Holmes's (1986) and Hyberg and Holthausen's (1989) interpretations of Binkley's (1981) household model in which owners produce amenities and timber income. A typical landowner maximizes utility comprising income (π) and amenities (a).[1] Acknowledging nonseparability, presumably due to incomplete amenity markets, utility will be conditioned by preference parameters θ that measure the shape of the utility curve and account for the risk characteristics and bequest motives of landowners. Studies by Kuuluvainen and Salo (1991), Kuuluvainen et al. (1996), and Dennis (1989) use sociodemographic data on age, occupation, and income to proxy for preferences.

As in Binkley (1981), utility is maximized subject to two constraints. The first constraint is a multi-input, multi-output production function that is twice-differentiable, continuous, and convex; y and a are vectors of timber and amenity outputs, and production possibilities will be conditioned by ecological factors, Z. This joint production function is the core of our analysis of simultaneous timber and amenity choices. Because amenities flow from the resulting forest condition, landowners are described as self-producing the amenities. The shape of the production function, including cross-effects, reflects increasing marginal productivity and decreasing second-order effects.[2] The second constraint is a budget constraint where income must be no greater than the sum of exogenous plus timber income. The Lagrangian for this problem, in which μ and λ are the Lagrangian multipliers, is presented in equation 14.1. μ is the marginal utility of jointly produced timber and amenities, and λ is the marginal utility of income.

$$\ell_{\pi,a,y} = U(\pi, a; \theta) + \mu[G(y, a; Z)] + \lambda[\pi_e + p \cdot y - \pi] \qquad 14.1$$

The first-order conditions of this utility maximization are presented in equations 14.2 to 14.4. Simultaneous solution of these first-order conditions determines optimal allocation of resources and consumption levels. Resources are allocated so that marginal opportunity costs are equal to marginal utility of consumption generated by that resource.

$$\ell_\pi = 0 = U_\pi - \lambda \quad \Rightarrow \quad \pi^*(p; \theta, \pi_e) \qquad 14.2$$

$$\ell_a = 0 = U_a + \mu \cdot G_a \quad \Rightarrow \quad a^*(p; \theta, \pi_e) \qquad 14.3$$

$$\ell_y = 0 = \lambda \cdot p + \mu \cdot G_y \Rightarrow \quad y^*(p; a^*, \pi_e, Z) \qquad 14.4$$

By manipulating equations 14.2, 14.3, and 14.4, we get

$$U_a = U_\pi p \cdot \frac{G_a}{Gy} \qquad 14.5$$

This implies that the marginal utility of amenity is equal to the marginal utility of the timber income forgone to self-produce amenity. In other words, at the margin, benefits equal the costs of self-producing amenities. By isolating the U_π in this same condition, we see that the marginal benefits of income equal the marginal cost measured in terms of forgone amenity benefits. We can totally differentiate equations 14.2 to 14.4 to obtain comparative static results for timber and amenities with respect to price (equations 14.6 and 14.7).

$$\frac{\partial a}{\partial p} = \frac{y \cdot U_{\pi a} \cdot {G_y}/{G_a} + y \cdot p \cdot U_{\pi\pi} + U_\pi}{U_{aa} \cdot {G_y}/{G_a} + U_a\left[{G_{ya}}/{G_a} - {G_y}/{G_{aa}}\right] + p \cdot U_{\pi a}} \qquad 14.6$$

$$\frac{\partial y}{\partial p} = \frac{y \cdot U_{\pi a} \cdot {G_y}/{G_a} + y \cdot p \cdot U_{\pi\pi} + U_\pi}{p \cdot U_{\pi a} \cdot {G_y}/{G_a} + U_a\left[{G_{yy}}/{G_a} - {G_y}/{G_{ya}}\right] + p^2 \cdot U_{\pi a}} \qquad 14.7$$

The signs of these expressions are ambiguous because the relative strengths of offsetting income and substitution effects of price changes are unknown. For example, consider a landowners' amenity choice in response to higher timber prices. From equation 14.5 we can see that higher timber prices raise the opportunity cost of consuming amenity and therefore impart a negative effect on amenity consumption (substitution effect). However, higher timber prices also increase the landowners' overall income through higher valued timber sales. Assuming amenity is a normal good, the landowner will wish to consume more amenities (income effect). In addition, the landowner must consider the timber production impacts of self-producing more amenities (G_{ya}) and declining marginal utility of amenities (U_{aa}) (equation 14.6). Similar considerations will influence timber supply responses to higher prices (see equation 14.7). For additional comparative statics, see Binkley (1981) and Hyberg and Holthausen (1989). The ambiguities created by the offsetting consumption and production responses strengthen our case for conducting empirical studies to determine how landowners actually behave.

There are three considerations in establishing an empirical timber supply model from these first-order conditions. First, because all consumption and production commodities are linked to the budget constraint either directly or indirectly (i.e., linked to market commodities through a joint production technology), all prices influence all consumption and production allocations, including self-produced/consumed amenities. Second, the supply of timber will depend on the actual level of amenities produced/consumed because there is no amenity price. That is, the quantity of amenity demand conditions the supply of timber. Third, in contrast to traditional timber production variables, landowner choice of amenity will be a function of prices and sociodemographic factors, not quantities of timber. The inclusion of timber prices in the amenity model accounts for the economic opportunity costs of producing amenities and, therefore, makes the inclusion of timber quantity redundant. See Ebert (1998) for a discussion of market and nonmarket choices of this nature. To the extent that sociodemographic factors proxy for preferences and attitudes and therefore influence the level of amenities chosen, they will be an argument of the amenity function. Although these factors are not in the timber production functions, they indirectly influence the timber allocations through their effect on amenity choice. The model presented in this section is a utility-theoretic characterization of supply of timber and amenity demand. We estimate amenity demand (equation 14.2) and timber supply (equation 14.3) to explore the tradeoffs between timber and amenity.

3. NORTH CAROLINA DATA

The primary data used in this analysis were obtained from USDA Forest Service plot surveys (USDA Forest Service, various years) and from Timber Mart-South price surveys (Norris Foundation, various issues). Neither the timber nor amenity data are collected directly; these values were calculated from the primary data (for details see Lee 1997). In addition, we used county-level sociodemographic data from the decennial census. Descriptive statistics are reported in table 14.1. Overall we have more than 4400 observations in this data set.

Table 14.1. Descriptive statistics for timber and nontimber data used in empirical model

Symbol	Variables	Units	Mean
a	Amenity index	See equation A-2	-0.002
H	Dummy for harvest	1 = harvest, 0 = not harvest	0.164
P	Timber price index	See equation A-1	3.288
D	Dummy for NIPF owner	1 = NIPF, 0 = otherwise	0.358
D	% of county with bachelor's degree	Percentage	12.22
D	Ln (median household income)	Ln ($)	10.04
Z	Dummy for operability	1 = no problems; 0 = otherwise	0.630
Z	Site class index	1= most growth to 6 = least growth	3.680
Z	Dummy for mountain ecoregion	1 = mountain, 0 = otherwise	0.162
Z	Timber inventory	See equation A-3	5.263

3.1 Timber Price and Quantity (P, y)

Timber harvesting information is collected at the plot and tree level and enables the determination of the product class and year of harvest. There are five product classes based on diameter of the tree and species class: pulpwood, chip and saw, and sawtimber in softwoods, and pulpwood and sawtimber in hardwoods. Although the details on the product class can be useful in measuring product substitution, our interest is in the broader timber-amenity tradeoff. Consequently we focus on the composite timber harvest data. Recognizing that there is no harvest for approximately 85% of the observations, our empirical tests use a discrete choice model of timber supply—that is, whether or not the owner-manager has harvested timber in any of the five product classes. We use the data on the year of harvest to match the relevant price information.

Price is the most critical variable in an economic model of timber and amenities. Our price data are from Timber Mart South (Norris Foundation, various years), which had three regions in North Carolina. The annual

stumpage price for each of five product classes is measured in U.S. dollars per cubic foot. We assign prices to plots based on the year of harvest; for plots that were not harvested at all, the 1990 price is used because that was the last price information considered by landowners in choosing not to harvest. We use principal component analysis (PCA) to construct a price index. The five prices are highly collinear, and we are interested in the overall opportunity cost of not harvesting (see equation A-1 in the appendix). PCA is a data reduction method that seeks patterns of variation among observed variables, and, therefore, simplifies subsequent analyses (see Hamilton 1992).[3] The first principal component of the five prices explains 72% of the price variance and has a reliability coefficient of 0.9.

3.2 Amenity Characteristics (a)

Amenity characteristics are classified as either indices or raw data. Because most of the ecology data underlying amenity characterizations are either in discrete measures or in complex estimates of cover, occupancy, and species, Lee (1997) developed several indices to measure the nontimber amenity attributes. Our interest is in modeling joint production of timber and nontimber broadly, and so we focus on the indices that comprise measures of tree diversity index, scenic beauty, and deer and bird habitat. The formulas for these indices are taken from the literature on ecology, wildlife, and scenic beauty.We use the Rudis et al. (1988) index to estimate scenic beauty, which has the highest values in the mountains and higher values on harvested (before harvest) than on nonharvested sites. An index of tree diversity was developed using the Shannon-Weaver index, which will weight rare species more heavily (Shannon 1948). Habitat suitability for deer is based on Crawford and Marchington (1989) and for wild birds on Sheffield (1981).[4]

To focus on the timber-amenity tradeoff, we develop a composite amenity index using PCA. We first create a faunal index that is based on the first principal component of the habitat indices for the deer and nine birds.[5] We then apply PCA to the faunal, tree diversity (Shannon-Weaver), and scenic beauty (Rudis) indices. We use only the first principal component that (1) is the only component with an eigen value > 1, (2) explains 61% of the combined variation, and (3) has a reliability coefficient of 0.67. For the amenity index or scores derived from this process (see appendix equation A-2), a positive value implies a site rich in faunal habitat, floral diversity, and scenic beauty. The computed scores range from –4.4 to 3.0.

3.3 Ecosystem Characteristics (*Z*)

Timber production is influenced by a number of site characteristics. Of the variables recorded in the Forest Inventory and Analysis (FIA) data set, we found four to be particularly relevant. The first is a measure of harvest operability. We code this as a dummy variable that is equal to 1 when the site is described as having "no problems." Sixty-three percent of our sites are in this category. The second is a measure of inherent capacity to grow crops of industrial wood using six site productivity classes that identify the average potential growth in cubic feet/acre/year and is based on the culmination of mean annual increment of fully stocked natural stands. Sites with the highest average potential growth are assigned a value of 1, and the lowest growth sites are assigned a value of 6. The percentage of the county covered by national forests is the third explanatory variable. To the extent that national forests are logged less frequently, there may be diseconomies of logging in counties that have a greater share in national forests. Finally, the volume of timber inventory can be a critical determinant of timber production. We have information on initial volume for five product classes and we use prices for the product classes to create a weighted average of the inventory.[6] We take the natural log of the weighted average to reduce scale differences (which can cause convergence problems in maximum likelihood estimation), improve linearity, and pull in outliers (see appendix equation A-3).

3.4 Sociodemographic Characteristics (D)

The final layer of data is socio-demographic information from census files. Although applying broad averages to plot-level ecological data is less than ideal, it is the closest we can get to measuring sociodemographic heterogeneity. See King (1997) for a discussion of inference from aggregated data of this nature. We use income and education at the county level as a first approximation. Income, proxied by the median household income in the counties, has a mean and standard deviation of $23,000 and $4000, respectively, in our data set. We use the log of the median household income. Education, proxied by the percentage of the population with a graduate degree, has a mean and standard deviation of 12 and 6. The FIA data provide us with the last bit of sociodemographic data: the owner type. We start with the simplest distinction, using a dummy variable to identify NIPF owners. Approximately 36% of our sample are other private owners.

4. EMPIRICAL MODEL

At the core of the joint production choice are equations 14.3 and 14.4 on amenity demand and timber supply.[7] We focus on this two-equation system as a first approximation of the tradeoffs of timber and amenity production.

4.1 Estimating Equations

We specify amenity demand as a function of timber prices and landowner sociodemographics (proxied by county aggregates). An innovation of this research is the characterization of amenity demand as an amenity index, which is constructed using the first principal component of three nontimber indices (see section 3). Because amenity is self-produced, we account for the associated endogeneity by regressing our amenity index on timber price and landowner sociodemographics, with the latter proxying the preference parameter θ from equation 14.3. The estimated form of amenity demand is

$$a = \beta_p P + \beta_d D + \varepsilon_a \qquad 14.8$$

where P is timber price; D is a vector of sociodemographics including education, income, and dummy variable for ownership; ε_a is the error term; and β is a vector of parameters to be estimated. The predicted value from this regression ($\hat{a}$) is used in the probability model of timber harvest, described in equation 14.9.

Timber supply is specified as a function of timber price, site characteristics, and amenity demand. Given that our data contain a large number of observations, approximately 85%, for which there is no timber harvest, we use limited-dependent variable methods to model timber supply. A probit model, which is based on a marginal utility discrete choice motivation, is employed to estimate the probability of a nonzero harvest.[8]

$$Prob(H = 1) = \Phi(\gamma_P P + \gamma_Z Z + \gamma_a \hat{a}) \qquad 14.9$$

where H is an indicator variable that is equal to 1 when $y^*>0$ and zero otherwise; $\Phi(\bullet)$ is the cumulative distribution function of the unobservable in the timber supply equation; P is timber price; Z is a vector of site characteristics such as site index, operability, timber inventory, ecoregion, and national forest percentage; and γ are parameters to be estimated.[9]

4.2 Estimation Results: Least Squares and Probit

The results from estimating equations 14.6 and 14.7 are reported in tables 14.2 and 14.3, respectively. Although the overall performance of our models is not very strong (R^2 = 0.06 and pseudo R^2 = 0.18), presumably because county aggregates serve as weak proxies for individual owner characteristics, we can detect some clear statistical signals in this otherwise noisy data set. Based on the signs and statistical significance of the estimated parameters, we find that both models generate plausible results.

Table 14.2. Amenity demand (index): robust least-square regression

Independent Variables	β (estimated coeff.)	p-value
Timber price index	-0.160	0.000
Dummy for NIPF owner	0.165	0.000
% of county with bachelor's degree	0.018	0.000
Log (median household income)	-0.324	0.020
Constant	3.491	0.011
R^2	0.06	
Root mean square error	1.31	
N = 4403		

Timber price has the expected negative influence on amenity demand, suggesting that the opportunity costs of preserving forests for nontimber uses (i.e., the substitution effect) dominate landowner choices. This finding also validates the utility-theoretic foundation of our approach. The coefficient of the ownership dummy indicates that NIPF landowners have a higher demand and self-production of amenities than other groups. That is, in comparison to other owners such as forest industry, NIPF landowners are less focused on timber management, with interest in a broad range of forest-based goods and services. We see higher amenity demand in counties with higher education levels, a result that is consistent with the logic that education is likely to be correlated with forest conservation or broader forest management goals. Finally, income is negatively correlated with the forest amenity index. One interpretation of this seemingly counterintuitive result is that the county level income variable is a proxy for urbanization such that more urban counties are positively correlated with poorer quality forests as measured by our habitat and scenic beauty index.

In the timber supply equation, we see the positive influence of timber prices. This finding that landowner-managers are more likely to harvest at higher prices is a critical piece of evidence in support of rational economic behavior and is consistent with our utility-theoretic model scenario in which the substitution effect dominates the income effect.

Table 14.3. Timber harvest: probit model

Independent Variables	γ (estimated coeff.)	p-value
Timber price index	0.272	0.000
Predicted nontimber index	-0.430	0.044
Timber inventory	0.314	0.000
Dummy for operability	0.562	0.000
Site class index (1 = most to 5 = least productive)	-0.054	0.115
Dummy for mountain region	1.236	0.000
% of county acres in national forests	-1.461	0.000
Constant	-4.025	0.000
Wald χ^2 (7)	567.59	0.000
Pseudo R^2	0.182	
N = 4403		

We find a positive coefficient on the timber inventory index, a positive coefficient on the operability dummy, and a negative coefficient on the site class index, which is significant only at the 11% confidence level. Collectively, these three results show a higher likelihood of harvests on sites with better silvicultural potential. We see lower harvests in counties with greater percentage of national forests, suggesting that there are some diseconomies of being in areas that are infrequently logged. The positive coefficient for the mountain region dummy indicates greater harvest in this ecoregion. While this may seem puzzling at first, we must recognize the multiple-regression nature of this result. That is, controlling for price, silvicultural potential, and externalities of national forests—which are typically cited as reasons for less logging in the mountains—the data suggest that there is a positive effect of being in the mountain region. Finally and most importantly, we see a negative coefficient on the predicted amenity index. This offers support for the hypotheses regarding the tradeoff between timber and amenities within a joint bioeconomic production process. The statistical significance of the amenity coefficient in the timber supply model is the core result of our study.

5. DISCUSSION

Using a data set from North Carolina that contains information on timber output and amenity indices, this chapter illustrates an approach to empirically characterize joint household production. At the heart of our model is a utility-maximizing NIPF landowner whose choices of timber and amenities depend on timber prices, site conditions, and individual preference characteristics. The unique features of this data set are the use of several nontimber indices to develop principal components to serve as measures of amenities. Census data is combined with the ecological and economic data to

proxy for landowner characteristics. We estimate a two-step probit model of amenity demand and timber supply. Based on the signs and statistical significance of the estimated parameters, we find that both models generate plausible results.

5.1 Methodological Contribution

Although formal economic modeling of multiple forest production by private agents is now 20 years old, we extend Binkley's (1981) logic by explicitly identifying timber and amenity outputs within a household production framework. In particular, we focus on the amenity demand function and offer insights on how to empirically specify joint amenity demand and timber supply models. In this context, the mix of plot-level ecological data, county-level sociodemographics, and market-level price data offer unique opportunities to test hypotheses on joint forest production. While the resolution of the sociodemographic data somewhat limits our ability to rigorously test hypotheses, it presents a useful step towards combining these kinds of information. Future studies could consider surveying a sample of households from the FIA study region to enrich the socioeconomic story. From an empirical perspective, our use of principal component analysis to summarize information on amenities as an amenity index illustrates a parsimonious method to identify the core issue of joint production—the tradeoff between timber and amenities. Finally, the two-step probit estimator used to model timber supply and amenity demand illustrates the application of an equation systems method to account for endogeneity arising out of the joint production nature of this problem. While these conceptual, data, or estimation methods are not individually unique to this study, collectively they constitute a useful kit of analytical tools to address forest economics questions of this kind.

5.2 Policy Implications

The statistical significance of the amenity index in the timber supply equation suggests that models that exclude nontimber outputs will generate biased timber supply parameters. In our data set, we found that in three specifications of the probit model, the model using the predicted value of amenities generates the smallest price coefficient. The three specifications are (1) excluding the amenity index, (2) including the amenity index, and (3) including the predicted value of the amenity index to account for its endogeneity. The mean elasticity of harvest probability with respect to price, defined as the percent change in harvest probability for a percent price change, is 1.88, 1.87, and 1.50 in the three models. While it is premature to

draw generalizations regarding the size and sign of this bias, this suggests the potential for errors and over-estimates in policy simulations that are based on timber supply characterization in which timber is the sole product.[10] In addition, we found that in two specifications of the probit model using amenity indices, the model using the predicted value of amenity generates the larger amenity coefficient.

Perhaps the more important policy contribution of the methods described in this chapter lies in providing a conceptual and empirical framework for better understanding how and why private agents manage forests. In particular, the model and the data allow us to investigate whether landowner-managers are jointly producing timber and amenities. Understanding how private agents can supplement public supply of forest amenities is of particular interest to policy makers because amenities (1) lie outside the purview of markets and (2) provide social benefits, in addition to private benefits to owner-managers. We can also identify the characteristics of owner-managers who are more likely to jointly produce amenities and timber. The empirical evidence supports the existence of joint production and its positive correlation with NIPF ownership and counties characterized by higher education and lower incomes. Clearly, future research that uses richer socioeconomic data can more fully characterize the socioeconomics of joint production. In the meanwhile, the methods and empirical results presented in this chapter provide a stepping-stone to the development of analytical tools for studying emerging forest policy questions such as the household joint production of timber and amenities.

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7. APPENDIX: FORMULAE USED

Price Index (*P*)

$$P = \left(\sum_{j}^{5} \kappa_j \cdot \left(\frac{p_j - \overline{p}_j}{\sigma_{pj}} \right) \right) + 3.297 \qquad \text{A-1}$$

where j product classes include three softwoods (pulp, chip-saw, and sawtimber) and two hardwoods (pulp and sawtimber); p_j is the per unit price; 2.96 is a scaling constant to ensure that the sum within the brackets is non-negative; and κ_j is the scoring coefficient generated by the first principal component. The coefficients are 0.37, 0.48, 0.52, –0.44, and –0.42,

respectively, suggesting that a positive factor score measures a plot with relatively high softwood prices and low hardwood prices.

Nontimber Index (*A*)

$$A = \sum_{i}^{3} w_i \cdot \left(\frac{A_i - \overline{A}_i}{\sigma_{Ai}} \right) \qquad \text{A-2}$$

where i includes fauna, tree diversity (Shannon-Weaver), and scenic beauty (Rudis); A_i is the amenity index; and w_i is the scoring coefficient generated by the first principal component. The coefficients are 0.66, 0.54, and 0.56, respectively, suggesting that a positive factor score measures a site rich in faunal habitat, floral diversity, and scenic beauty.

Timber Inventory Index (*I*)

$$I = Ln\left[\sum_{j}^{5} \frac{p_j}{\sum p_j} I_j \right] \qquad \text{A-3}$$

where j product classes include three softwoods (pulp, chip-saw, and sawtimber) and two hardwoods (pulp and sawtimber); p_j is the per unit price; and I_j the initial inventory.

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[1] The utility function is assumed to be concave, continuous, and twice-differentiable with the following properties: $U_a > 0$, $U_\pi > 0$, $U_{aa} < 0$, $U_{\pi\pi} < 0$, and $U_{\pi a} > 0$. The first four properties are usual assumptions (see Binkley 1981). The last condition cannot be extracted from standard assumptions. It says that a landowner will value amenities more at higher incomes than at lower incomes—the normal good argument for amenities. The validity of this can only be determined empirically.

[2] The production function is assumed to be convex, continuous, and twice-differentiable with the following properties: $G_a > 0$, $G_y > 0$, $G_{aa} < 0$, $G_{yy} < 0$, and $G_{ya} < 0$. The first four properties are usual assumptions (see Binkley 1981). The last condition says that it is more difficult to generate amenities at higher timber production than at lower timber production—a diseconomies of scale argument for amenities. The validity of this assumption can only be determined empirically.

[3] PCA can result in more parsimonious models, improved measurement of indirectly observed concepts, and may avoid multicollinearity. This method relies on the linear relationship among sets of measured variables using simple transformation of the data. That is, each variable is a linear transformation of the principal components using factor loadings. Alternatively, each principal component is the linear combination of the variables using score coefficients. Typically, the first principal component explains the most and represents the "best possible" (maximum variance) combination, and its contributions are evaluated in terms of a reliability coefficient or explained variance. The reliability

coefficient = $(k/k-1)*(1-1/\lambda_1)$, and the explained variance = (λ_1/k), where k is the number of variables combined and λ_1 is the eigen value. See Hamilton (1992) for details.

[4] White-tailed deer are ubiquitous in North Carolina, so deer habitat on an individual plot may have little impact on deer population in general or even on deer presence on that site. However, there are limited means to measure the quality of habitat other than suitability indices for a plot. Similar concerns and conclusions exist for the six species of wild birds.

[5] The species (and the associated scoring coefficient) included in this index are white-tailed deer (0.175), wood thrush (0.432), red-eyed vireo (0.451), pileated woodpecker (0.375), downy woodpecker (0.361), prothonotary warbler (0.133), brown-headed nuthatch (0.020), pine warbler (0.021), prairie warblers (–0.428), and eastern bluebird (–0.327). The first principal component has an eigen value of 2.8 and a reliability coefficient of 0.72, and is used as an index of faunal habitat.

[6] Price weights reflect the relative value of the types of inventory, which is appropriate in an economic model, and result in an inventory measure that is a value index.

[7] For the remainder of the chapter, we refer to the level of amenity self-produced or consumed as "amenity demand." As pointed out by Steve Swallow (personal communication), the level of amenities demanded or consumed is conditioned by what is available for the existing shadow price. To the extent that landowners manage their forest lands to obtain specific forest landscapes and structures, they self-produce amenity flows. This level of self-production is conditioned by the opportunity costs of creating these forest conditions or its shadow price, and therefore measures landowner amenity demand.

[8] Consider the choice facing a landowner-manager when deciding whether to harvest. The decision clearly depends on the net utility with and without harvesting (EU_i,*). This net utility is given by $EU_i* = \alpha_1 P_i, + \alpha_2 Z_i, + \alpha_3 a_i + e_i$, where e_i is a random disturbance and P_i, Z_i, and a_i are as defined in the text. Note that while EU_i* is not directly observable, the owner-manager's decision outcome is. Let H_i be an indicator of whether the owner *i* harvests or not. Then $H_i = 0$ if $EU_i* \leq 0$ and $H_i = 1$ if $EU_i* > 0$. The structural relationship presented above can be estimated using a probit model (Maddala 1983).

[9] We use a standard two-step estimator instead of more complicated methods (FIML and GMM) because Monte Carlo experiments (Bollen et al. 1995) and other studies (Norton et al. 1998) have shown no gain in performance in using more complicated methods.

[10] As suggested by Steve Swallow (personal communication), using the elasticity of harvest probability, we calculate the expected supply for a plot in response to a 10% increase in price. The expected supply is equal to the product of the plot timber inventory and the change in harvest probability associated with the 10% price change. Comparing the model without amenity indices (model 1) with the model with the predicted amenity index (model 3), we see that model 1 will over-predict expected timber supply by 14 feet^3 for a plot with the mean level of inventory. If we extrapolate to North Carolina levels using the volume expansion factors for each of the 4403 in our analysis, model 1 will over-predict supply by 220 million feet^3 of timber.