MODEL

ASSESSING THE NON-TIMBER VALUE OF FORESTS: A REVEALED-PREFERENCE, HEDONIC MODEL

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ABSTRACT

Based on revealed preference theory, the value of non-timber goods and services obtained by forest owners, private or public, should be at least equal to the difference between the value of what they could have cut had they tried to maximize timber revenues, and of what they actually cut. This definition was applied to estimate the non-timber value (NTV) of Forest Inventory and Analysis plots in the Wisconsin maple-birch forest type, with a Markov decision model to predict the decision that would have maximized the timber income. Then hedonic regression was applied to determine how the biophysical characteristics of stands and the socioeconomic setting influenced NTV. In the Wisconsin maple-birch forests, the NTV was highest for national forests: about \$50 $ha^{-1}yr^{-1}$, ten times the timber revenues. The estimated NTV was similar for all non-national forests, at about \$20 to \$24 $ha^{-1}yr^{-1}$. For non-national public forests, NTVs were four times larger than timber revenues. They were almost twice as large as timber revenues for private non-industrial forests. Even for industry forests, NTVs were slightly higher than timber revenues. However, these NTVs could be biased due to constraints limiting the potential economic return from forest stands not reflected by the profit-maximizing model. The hedonic pricing model showed that stands with the same tree distribution had significantly higher NTVs for national forests, and similar NTVs for other ownership types. The marginal value of trees of various species and size was also different for national forests. At constant prices, from 1966 to 1984, the non -timber value of maple-birch forests in Wisconsin increased by 30% for national forests, and 55% for other forests.

Keywords: amenity, Markov model, multiple use, opportunity cost, ownership, price, recreation, timber supply.

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INTRODUCTION

Forests are valuable for timber production, and as sources of other goods and services: landscape aesthetics, wildlife habitat and preservation of biodiversity, carbon sequestration, ground water purification, production and conservation of topsoil, and oxygen release. Prices and quantities exchanged do not exist for most of these "non-market" goods. Yet, their value to consumers and producers can be high, and neglecting them would lead to inferior policies and decisions, due to the type of market failure analyzed extensively in the public good literature (Laffont, 1998). On the production side, the non-cash character of the services that the owner obtains from the stock of trees makes it difficult to incorporate them explicitly in timber supply analysis. Yet, the presence of recreational or other services provided by a standing forest has an important effect on when and whether to harvest (Hartman, 1976; Strang, 1983). The object of this paper is to try to derive non-timber values from "revealed preferences", that is actual choices of forest owners for different management outcomes. This approach is, then, symmetric and complementary of Hartman-Strang's. While they showed the theoretical consequences of non-timber values on when trees would be cut, we attempted instead to infer empirically the non-timber value from the way owners did or did not cut their trees.

Both revealed and stated preference methods of evaluating non-market goods have been researched extensively in the past twenty years (Freeman, 1993). In particular, the role of non-timber values has long been recognized in the theory of optimal harvesting decisions (Hartman, 1976; Bowes & Krutilla 1985). Some authors argue for enhancing these values from social equity considerations (Reiling & Anderson, 1985; Tomkins, 1990). Compelling empirical evidence exists supporting the relevance of these values to woodland owners. In their 1986 report on small private woodland owners in Wisconsin, Roberts et *al.* found that timber production only ranked 7th among the reasons to own woodland, while 69% of the responses ranked "scenic enjoyment" first or second and 74% gave the same rank to "wildlife habitat". A more recent survey of Wisconsin private forestland owners (Birch, 1994) found that amongst the reasons for woodland ownership, "recreation" and "aesthetic enjoyment", ranked consistently higher than timber production.

Much of the published work has been aimed at deriving non-timber values for benefit-cost analysis. Revealed preference methods, especially based on travel costs, have been used in a number of studies. The earliest estimated the effects of forest quality on demand for recreational activities such as camping, hiking, hunting, visiting resorts etc. (Michaelson, 1975; Moeller et *al.,* 1977; Leuschner & Young, 1978; Wilman, 1984; Crocker, 1985; Brookshire & Coursey, 1987). Sorg & Loomis (1984) review the early literature. McCollum et. al. (1990) investigated the recreational values of national forests, and Englin & Mendelsohn (1991) applied a travel cost hedonic pricing approach to value the recreational benefits of forest landscapes in the Pacific Northwest. Willis (1991) used travel cost functions to derive the recreational value of the Forest Commission estates in the United Kingdom, and Bateman et al. (1996) applied similar methods to Welsh forests and used the results to infer the non-timber values of reforestation activities in England. Dennis (1989) related harvesting behavior to forest characteristics in a theoretical model that can also accommodates non-timber values. Recently, Lee (1997) derived non-timber values for owners of even-aged forests in the southern United States, with hedonic discrete choice models.

Non-timber values have also been derived by contingent valuation. Walsh et al. (1989, 1990), and Loomis et al. (1994) estimated the public willingness to pay to protect forests from insects and fires. Similar techniques have been used to estimate the value of forest landscapes (Holms & Kramer, 1995; Mattson & Li, 1995) and of forest recreation (Scarpa et al., 2000). These studies corroborate the hypothesis that non-timber benefits are substantial, and may exceed timber revenues (Lockwood et *al.,* 1992).

The objective of this paper is to propose a method to estimate non-timber value, and its determinants based on revealed preferences. The method is then applied to maple-birch forests in Wisconsin. Maple-birch forests cover about one third of the 5.7 million hectares of commercial forest in this State (Smith, 1986). They are, therefore, a salient feature of the local landscape and economy. The forests are very diverse in terms of species and structure, containing more than 55 species of trees of various sizes (Lin et al., 1996). The premise of this paper is that the value of this diversity and of other forest traits to the owners can be inferred from their harvesting decisions. Specifically, non-timber value is defined as the difference between what owners actually cut from their stands, and what they could have gotten had they been profit maximizers. This non-timber value is estimated for each of 610 USDA Forest Service permanent plots in Wisconsin (Hahn & Hansen, 1985; Hansen et. *al.,* 1994), allowing for an assessment of the magnitude and distribution of non-timber value by ownership.

Then, hedonic pricing methods are applied to estimate the non-timber value of trees by species and size, conditional on other characteristics of the stand and of the owner that might influence non-timber value. Lastly, the hedonic price equations are used to estimate the non-timber rewards garnered by the owners of the stands measured in the 1966 and 1984 inventories.

THEORY

The unit under consideration is a forest stand: a homogeneous management unit of varying size but typically less than 10 ha. The theory involves two aspects. First, defining the monetary worth of the total non-timber value embedded in a forest stand, from the principle of revealed preference. Second, finding the contribution of each stand characteristic to this non-timber value, by hedonic pricing theory.

Harvest Choice and Timber versus Non-timber Values

Forest owners are assumed to prefer some combinations of forest stand states and timber revenues. For uneven-aged stands, the state is represented concisely by the number of trees of different size and species per unit of land, i.e. the tree distribution.

Let $\mathbf{Y}=[y_{ij}]$ be a (lxn) vector representing this tree distribution at the time of the harvesting decision, y_{ij} being the number of trees of species i and size j. Let $\mathbf{H}=[h_{ij}]$ be the number of trees to be cut from Y, and sold at prices $\mathbf{p}=[p_{ij}]$. Then, S = Y-H is what is left standing to produce current and future timber and other benefits. We assume that owners try to maximize their utility, over an infinite horizon. For each stand, observed over a given time length, this choice results in an actual harvest H^0, and an actual residual stand, $\mathbf{S}^0$.

Without markets for non-timber goods and services, if owners only cared about monetary returns, they would maximize the net present value of timber benefits by choosing $(\mathbf{H}^*,\mathbf{S}^*)$. But, most owners also enjoy non-timber benefits from the standing trees, and the observed vectors $(\mathbf{H}^0,\mathbf{S}^0)$ account for them. The observed decision reflects a trade-off between timber revenues and non-timber, usually non-monetary, rewards. For expected utility maximizers who benefit from both timber and non-timber we expect $\mathbf{H}^0 < \mathbf{H}^*$, and $\mathbf{S}^0 > \mathbf{S}^*$.

Lacking direct observations on what owners would have cut, had they tried to maximize timber revenues, these must be inferred with a model. For example, to derive an infinite horizon optimal timber-harvesting rule Lin & Buongiorno (1998) define N possible stand and market states. For every state i there is an optimal decision k^*, solution of N recursive equations (Ross, 1983):

$$V_i^{t+1} = \underset{k}{\text{Max}}\left[r(i,k) + d\sum_{j=1}^{N} p(j|k)V_j^t\right], \; i=1,\ldots N; t=1,\ldots,\infty. \qquad (1)$$

where V^t is the present value of the timber income over t years, i and k are combinations of stand and market states (price levels), $r(i,k)$ is the immediate timber return from cutting a stand from state i to state k, $p(j|k)$ is the probability of moving from state k to state j, and d is the discount factor. To each state i corresponds a price and a tree distribution Y. A decision means cutting the stand from state i to state k, corresponding to S = Y – H. The best decision is unique and depends only on the stand state and price level. Lin & Buongiorno (1998) give the decision matrix and the corresponding optimum rewards $r(i,k^*)$.

However, forest owners with utility for non-timber values would not solve problem (1), but one with a reward function that includes timber benefits $r(i,k)$ and non-timber benefits, $r'(i,k)$. Needed is a description of the non-timber benefits function $r'(i,k)$. We seek answers to two questions. First, how much are non-timber benefits worth in money terms, for a stand left in state *k*? Second, how much does each characteristic of the stand in state *k* contribute to non-timber value. Precisely, what is the marginal value, or implicit price, of each stand characteristic in terms of non-timber benefits?

Revealed-preference Measure of Non-timber Value

Let the utility derived by owners from their observed choice of post-harvest state k^0 be:

$$U^0 = U\left(\mathbf{S}^0, \mathbf{pH}^0\right), \tag{2}$$

a monotonically increasing function of its arguments, while the utility they would have gotten by maximizing net present value, choosing state *k* , is:

$$U^* = U\left(\mathbf{S}^*, \mathbf{pH}^*\right). \tag{3}$$

For owners who chose the bundle $(\mathbf{S}^0, \mathbf{pH}^0)$ when $(\mathbf{S}^*, \mathbf{pH}^*)$ was available we say that the first was "revealed preferred" to the second. Thus, by definition of the utility function:

$$U^0 \geq U^*. \tag{4}$$

The proposed measure of non-timber benefits is the timber revenue foregone for the sake of gaining the non-timber benefits associated with leaving $\mathbf{S}^0 - \mathbf{S}^*$ standing:

$$NTV = p\left(\mathbf{H}^* - \mathbf{H}^0\right) = p\left(\mathbf{S}^0 - \mathbf{S}^*\right) > 0. \tag{5}$$

That the state $(\mathbf{H}^0, \mathbf{S}^0)$ is revealed at least as good as $(\mathbf{H}^*, \mathbf{S}^*)$ implies that:

$$U\left(\mathbf{S}^0, \mathbf{pH}^0\right) \geq U\left(\mathbf{S}^0, \mathbf{pH}^0 + NTV\right). \tag{6}$$

Therefore, the NTV defined as the timber revenue foregone by the owner is a lower bound on the non-timber benefits expressed in monetary terms. This NTV is also a lower bound for the compensating variation (CV), the amount that would have to be paid to timber owners in addition to the timber income $\mathbf{pH}^0$ to compensate them for having to accept the state (S^*, $\mathbf{H}^*$) when $(\mathbf{S}^0, \mathbf{H}^0)$ was available.

In terms of the decision model (1) the timber-revenue maximizing return obtained by cutting from state i to state k^* is $r(i,k^*)$. Although few if any owner may use the specific model (1) to compute the profit-maximizing harvest, the maintained rational expectation hypothesis is that they use all the information they have optimally. They may make occasional mistakes, but not systematically (Gordon, 1993 p. 184). The NTV of the stand in pre harvest-state i, and post-harvest state k^0 is then:

$$r'\left(i,k^0\right)=r\left(i,k^*\right)-r\left(i,k^0\right), \tag{7}$$

which is the opportunity cost of choosing state k^0, rather than stand state k'. It is natural to assume that the non-timber (amenity) value of the stand depends mainly on the remaining trees, i.e. on the post-harvest state, k^0, so that $r'(i,k^0) = r'(k^0)$, independently of the pre-harvest state, i.

Given an estimate of the non-timber value of a stand state, the next step is to determine the marginal NTV of each stand characteristic. Thus, for each characteristic, we seek a price defining its contribution to the non-timber value. In particular, for each tree species and size, we seek a non-timber vector p' analog to the timber price vector p.

Determinants of Non-timber Value

Non-timber benefits of forests are heterogeneous goods tied to a bundle of forest characteristics X, defined in part by the residual stand state, k. In general, attributes such as accessibility of the forest, number, size and species diversity of trees may enhance non-timber benefits directly (large trees enhancing the aesthetics of a forest stand), or indirectly (diversity of tree size enhancing wildlife habitat and thus hunting, bird-watching, scenic beauty). Woodland owners are mostly price-takers with respect to stumpage price so, at the moment of the harvesting decision, they can be thought of as timber suppliers in a competitive environment. Forest owners also have a demand schedule for the forest attributes which includes non-timber benefits.

To be able to infer the values of forest stand characteristics to their owners, we assume that the timber market is in equilibrium, that is, that owners have made their utility-maximizing production choice given the price of timber and other goods and services, and that these prices clear markets. Under this assumption, the NTV of a stand is a function of its characteristics (Freeman, 1993 p. 371) which can be priced by hedonic methods (Rosen, 1974). The hedonic function is a regression of NTV on X that decomposes NTV into the contribution of each characteristic in X.

While amenity values depend partly on “intrinsic” attributes such as the species and size of trees, they also depend on the socioeconomic setting (Bockstael, 1996). For instance, other things being equal, in densely populated regions with wealthy households, the demand for recreational services of forests should be comparatively higher, making NTV higher. Especially critical is the forest ownership: The NTV on national forests should be much higher than on industry forests, because of markedly different management objectives. There, the NTV measures how much timber income the public has been willing to forego for other benefits. The concept of forest attributes was therefore extended to include such “extrinsic” indicators. The general hedonic model has the form:

$$NTV = NTV(\mathbf{X},\mathbf{Z}), \tag{8}$$

where **Z** is a vector of socioeconomic indicators. The coefficient of each forest attribute of the vector X, in the regression (8) is its hedonic price, while the coefficients of the socioeconomic attributes are shifters of the hedonic function.

ESTIMATING THE NON-TIMBER VALUE OF FIA PLOTS

The data were drawn from 610 plots representative of the entire maple-birch forest type in Wisconsin, obtained from the USDA Forest Service, Forest Inventory and Analysis (FIA) database (Hansen *et* al., 1994). A plot consists of a cluster of 10 sample points, uniformly distributed over 0.4 ha (Hansen & Hahn, 1992). Each plot was taken as representative of a stand, it had detailed data on the number, size and species of trees, type of terrain, and some data on location and ownership. The plots were measured twice between 1966 and 1984, at intervals between 6 and 16 years (average 13 years). The drawbacks of the FIA plots are their limited area, and incomplete information on the variables that might influence timber and non-timber values. The advantages are that there are many of them, measured in the same way, and that growth models and profit-maximizing rules have already been developed from the same plots (Lin & Buongiorno, 1998).

The first step was to estimate for each plot what the owners should have done, had they sought to maximize timber revenues. This was inferred from the optimal decision rule described in Lin & Buongiorno (1998), based on model (1). In Lin and Buongiorno's model, the forest stand states are defined by the basal area (high or low) of trees in each of three size classes (pole, small, and large sawtimber), in two species groups defined by shade tolerance. Altogether there are 64 possible stand states and 2 possible market states (high or low price). This makes for 128 stand-market states. For each state the decision rule indicates to which other state the stand should be cut to maximize the expected net present value of timber revenues, over an infinite time horizon. Applied to each FIA plot, this rule gave an estimate of the timber revenue ($ ha^{-1} yr^{-1}) that would be obtained by an owner acting to maximize timber revenue only, and who placed no value on non-timber benefits.

The FIA plot data also contain information on the trees that were actually cut by the owner between the two inventories. From these, we estimated the value of the harvest ($ ha^{-1} yr^{-1}), with the same prices used to find the decision that would have maximized the net present value of timber. Because the time of the harvest was unknown, the average price between the two inventories was applied.

Then, the difference between the value of the profit-maximizing harvest and that of the actual harvest gave the non-timber value ($ $ha^{-1}yr^{-1}$): our estimate of the monetary value of the flow of services generated by the stand of trees left after harvest. This is what the owner gave up, presumably to gain the amenity values inherent in the stand left after harvest.

Table 1 presents summary statistics for observed harvest, potential harvest and NTV, by type of ownership. The average potential harvest, i.e. the harvest that would have maximized revenues ranged from $25 and $55 $ha^{-1}yr^{-1}$. It was largest for national forests, and lowest for other public forests. It was intermediate, and about the same for in-

TABLE 1. POTENTIAL AND ACTUAL TIMBER REVENUE AND IMPLICIT NON-TIMBER VALUE.

Value	Ownership	Mean	S.D.	Median	Max.	Min.	Plots
(1) Potential ($ $ha^{-1}yr^{-1}$)							
	National	55.1”	53.6	35.6	230.1	0.0	106
	Other public	25.4	24.0	19.0	136.0	0.0	95
	Industry	39.3	41.7	25.4	165.9	0.0	95
	Other private	36.8	45.4	19.0	295.3	0.0	314
(2) Actual ($ $ha^{-1}yr^{-1}$)							
	National	5.4	17.8	0.0	130.6	0.0	106
	Other public	5.2	13.3	0.0	83.5	0.0	95
	Industry	18.6	35.2	0.0	162.7	0.0	95
	Other private	13.3	28.6	0.0	255.8	0.0	314
(3) Non-timber value =(1)–(2) ($ $ha^{-1}yr^{-1}$)							
	National	49.6*	51.5	28.9	210.9	-8.9	106
	Other public	20.2	23.5	12.3	136.0.	-5.2	95
	Industry	20.7	29.8	11.9	125.2	-25.4	95
	Other private	23.5	34.3	13.6	224.7	-55.6	314

(*) mean is significantly different from that of other owners at 5% significance level.

dustry and other private forests. These differences reflect the different management objectives, and also differences in forest productivity. In particular, other public forests (state, county and municipal) tend to be on poorer sites.

The actual harvest across ownership ranged from $5 to $19 $ha^{-1}yr^{-1}$. It was highest for industry forests, intermediate for other private forests, and lowest for national and other public forests. The non-timber value, defined as the difference between potential and actual timber revenues, was highest for national forests: about $50 $ha^{-1}yr^{-1}$, ten times the timber revenues’. The estimated non-timber value was similar in all non-national forests, at about $20 to $24 $ha^{-1}yr^{-1}$. For non-national public forests, non-timber values were four times larger than timber revenues. They were almost twice as large as timber revenues for private non-industrial forests. Even for industrial forests, non-timber values were slightly higher than timber revenues.

Figure 1 shows the distribution of forest area, harvest, and non-timber value in the entire maple-birch forest type of Wisconsin, based on the FIA plots weighed by the area

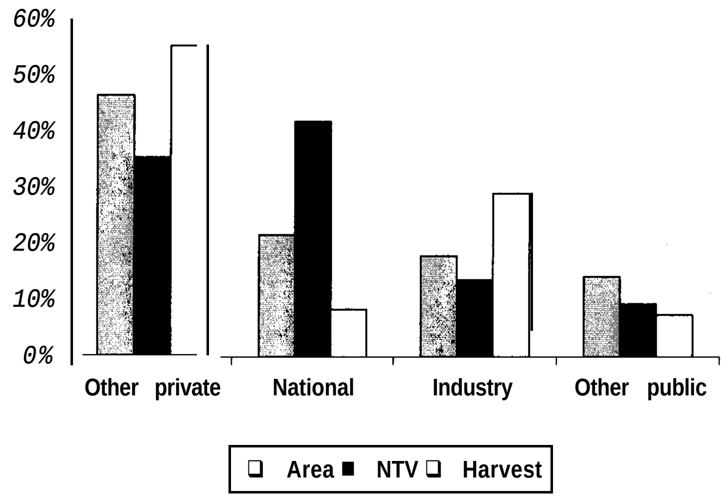

FIGURE 1. DISTRIBUTION OF NON-TIMBER VALUE (NTV), AREA AND HARVEST, BY OWNERSHIP.

that each plot is meant to stand for (its area expansion factor). Nearly half of the total area belonged to non-industrial private forest owners. They contributed more than half of the total harvest, and 35% of the estimated non-timber value. National forests that had 20% of the forest area contributed 40% of the non-timber value, as defined here, and less than 10% of the harvest. For industrial forest, the situation was reversed, contributing 30% of the timber harvest, and 15% of the non-timber value on less than 20% of the land area. Non-national public lands contributed equally to timber and non-timber values, less than 10% each, on 15% of the land.

The estimated NTVs of ten percent of the plots were negative: the cut was larger than what the net-present value-maximizing rule prescribed. However, negative NTVs were clustered near zero, in agreement with profit maximizing behavior (Figure 2). Slightly negative NTVs, or positive ones for that matter, may be due to a profit maximizer's imperfect knowledge, or/and different objective functions (for example, higher discount rates), or er-

[1] The difference in *NTV* estimates between national and other forests reflects largely differences in the utility functions. While public forest management should reflect the preferences of the entire citizenry, private forests tend to be managed more according to the preferences of their owners.

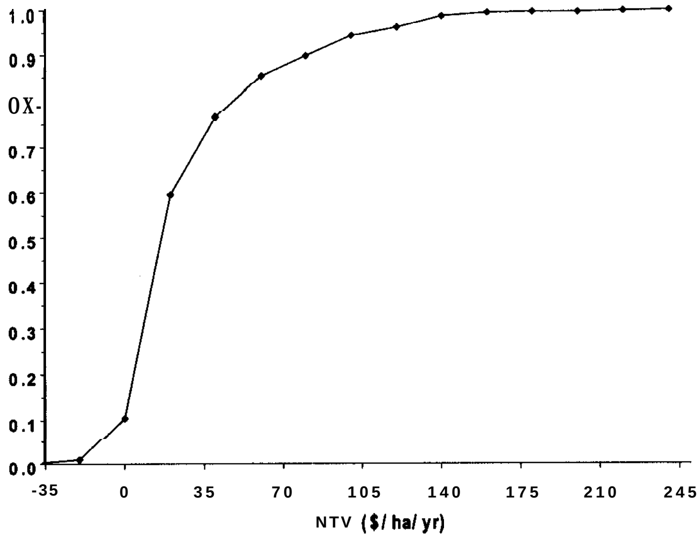

Figure 2. Cumulative Distribution of Non-timber Values (NTV) on FIA Plots.

rors in trying to maximize net present value. Also, there were stands that were not cut and for which the profit maximizing decision was not to cut. In those cases, 9% of the plots, the NTV was zero by definition, as the decision was consistent with maximizing timber profit. Therefore, the plots with NTV=O were maintained in the analysis. Still, for the few plots of zero NTV, this was clearly a lower bound because they could have some residual amenity values. In addition, the 19% of plots with NTV=O led to heteroskedastic residuals, which had to be recognized in estimating the hedonic price equation.

Potential Determinants of Non-Timber Value

The hypothesis is that three categories of variables influence the non-timber value of each forest stand represented by an FIA plot: the ecological attributes of the stand, its physical location, and its socioeconomic context. This led to the following potential explanatory variables:

Stand Structure and Diversity

Other things being equal, the NTV of a stand should depend on its ecological condition, after harvest since it is the residual stand that generates the amenity values. The stand was described by the number of trees in three species groups: Tolerant, mid-tolerant, and intolerant, and in three size classes: pole, small saw timber, and large saw timber (Lin et *al.*, 1996). We expected larger trees to have larger marginal NTV since they contribute greatly to the beauty and biological diversity of forests.

Another hypothesis was that NTVs would be influenced by the ecological diversity of stands. For lack of measures of total biological diversity, indices of tree diversity were used. Stands with high diversity of tree species and size can provide preferable wildlife habitat (Ambuel & Temple 1983; Hunter, 1990; Burton et. al., 1992). Diversity of stand structure also enhances the perception of scenic beauty (Ammer, 1994). Thus, high tree diversity should increase NTV. With Shannon's index (Pielou, 1975), we measured for each plot the diversity of species H_{sp} and of size H_{sz}, with 55 distinct species and 12 size classes (Lin et al., 1996). The average size diversity of stands in public forests was higher than in private forests, the size diversity of industry stands was particularly low, due to the absence of large trees. However, industrial stands had slightly higher average species diversity, but the difference across ownership was not statistically significant.

Because the striking colors of foliage in the fall is a feature of Wisconsin's north woods, we tried to quantify this with a Shannon index of color diversity H_{COL}, based on 4 chromatic classes (Little, 1995).

Site Characteristics

From the FIA database, four site and location variables were available. The site index *(SITE,* in meters for maple at age 50 years), was expected to have a positive effect on NTV since a high site index means the potential to grow large handsome trees of different species, with attendant biome. The distance of the stand from water *(DWATR,* in km) was expected to have a negative effect on its NTV, reflecting lower recreational value. The average percentage of the deviation from the horizontal over the plot *(SLOPE)* was to have a positive effect on NTV because hilly areas tend to be aesthetically pleasing. Roads could have different effects on NTV. Bostedt & Mattsson (1995) find that more roads increase non-timber values, plausibly by making forests accessible to more people. But, greater distance from roads (*DROAD*) could also make a stand more attractive for wilderness uses, thus increasing NTV. In addition, greater distance to road and slope could have decreased actual harvest, thus increasing NTV as computed here.

Socioeconomic Variables

Among the socioeconomic variables that might affect the NTV of a stand, ownership type is probably one of the most important, as suggested by the summary statistics in Table 1. The FIA database recognizes several ownership categories, which were grouped into four: National forests, identified by the dummy variable *NAT*, other public forests (i.e. state, county and municipal forests, PUB), industrial forests, *IND*, and other private forests, *OTH*. One would expect NTV to be lowest on industrial forests, corresponding to a more profit driven type of management,

Spatial socioeconomic interactions may affect environmental externalities (Bockstael, 1996). To describe the socioeconomic environment of a stand we used population density (POP, inhabitants km^{-2}) of the county in which each FIA plot was located, and the average household income of that county (INC, in thousands of 1976 $\$ yr^{-1}$). Both were obtained from The State of Wisconsin Blue Book (various years), for the middle year between the two inventories. Other things being equal, higher local income and population were expected to increase the demand for amenities from the forest (by the owner and by others), and thus to increase the non-timber value.

HEDONIC MODEL OF NON-TIMBER VALUE

The conditional mean NTV was estimated with a linear regression model:

$$NTV|\mathbf{X},\mathbf{Z} = \boldsymbol{\beta}'(\mathbf{X},\mathbf{Z}) + \varepsilon, \tag{9}$$

where ε is an uncorrelated, homoskedastic and i.i.d. error term with zero expected value. This model was meant to decompose the total expected NTV of a stand into linearly additive parts, the contribution of each stand variable. Each regression coefficient could therefore be interpreted as the marginal contribution to NTV of the variable, that is, the hedonic price of the characteristic that the variable measured (Rosen, 1974).

Model estimation began by including all of the theoretically relevant, and available, variables. This long regression was then "tested down" to a parsimonious model with only statistically significant variables (Kennedy, 1993). As noted above, the distribution of the NTV suggested that the residuals would be heteroskedastic, and this was confirmed by various tests (Glejser, 1969; White, 1980; Greene 1993). In the following results, the standard errors were estimated with White's estimators (1980), which is robust to a general form of unknown heteroskedasticity[2].

The results of estimation of model (9), with all the potential variables, are in Table 2. Among the stand variables, the number of trees of various sizes and species had the highest statistical significance, and most had the expected positive sign. Diversity of species or size did not seem to influence NTV, possibly because the information on diversity was already present in the data on number of trees by species and size. Of the site variables, the site index, distance to water, and distance from road had coefficients of plausible signs, but none was significantly different from zero. Among the socioeconomic variables, only the dummy variable indicating ownership to a national forest ***(NAT)*** seemed to matter. A stand in a national forest had an expected non-timber value \$22 $ha^{-1}yr^{-1}$ higher than stands in other types of ownership. There was no significant difference among the other ownership.

A parsimonious, more efficient, model of NTV was then estimated by eliminating the variables that were not significantly different from zero at the 5% level. The results (Table 2) gave a coefficient of determination about equal to that of the long regression. Moreover, an F-test on the restrictions of the parsimonious model gave $F(13,582) = 0.72$, P-value=0.75, so that the hypothesis that the omitted coefficients were zero was acceptable. The remaining coef-

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[2] **Full generalized least squares was also tried, with the following model of the residuals variance:**

$$\sigma^2 = \alpha + \beta H_{tot} + \gamma NAT, \qquad (10)$$

which assumed that the variance of the residuals was higher for stands of higher diversity, and on national forests. The results confirmed this expectation. However, the results for the *NTV* model (10) were very close to the OLS results, although they had smaller variance. OLS with White's heteroskedasticity correction was preferred because it did not require a specific form of the error function.

TABLE 2. EFFECT OF VARIABLES ON NON-TIMBER VALUE ($ $HA^{-1}YR^{-1}$).

	Long Regression		Short Regression	
Variables	Coef.	S.E.	Coef.	S.E.
Trees ha-‘:				
Shade tolerant:				
Pole	0.01	0.01		
Small saw	0.33***	0.05	0.32***	0.05
Large saw	1.18***	0.19	1.18***	0.19
Mid-tolerant:				
Pole	-0.00	0.02		
Small saw	0.51***	0.10	0.48***	0.10
Large saw	2.20***	0.34	2.21***	0.34
Intolerant:				
Pole	0.04***	0.01	0.03***	0.01
Small saw	0.23***	0.09	0.25***	0.09
Large saw	1.17***	0.32	1.02***	0.34
Diversity:				
H_{sz}	-6.78	4.90		
H_{sp}	-2.79	3.27		
H_{COL}	2.36	5.39		
Site:				
SITE	0.01	0.29		
SLOPE	-0.13	0.11		
DWATR	-0.02	0.24		
DROAD	0.13	0.22		
Socioeconomic:				
NAT	21.82***	5.01	22.74***	4.07
PUB	1.07	3.59		
OTH	-0.52	2.85		
INCOME	-3.73	2.19		
POPDENS	0.08	0.08		
Constant	12.29	12.22	-1.28	1.74
R^2	0.49		0.48	

***,** significant at 1% and at 5% level, respectively. S.E.= standard error. R^2=coefficient of determination, adjusted for degrees of freedom with 610 observations.

ficients were similar in the long and short regressions. There was a strong correlation between tree size and non-timber value. For example, the marginal contribution to NTV of a large sawtimber tree of shade-tolerant species was about $1.20 per year, four times that of a small sawtimber

TABLE 3. MODELS OF NON-TIMBER VALUE FOR NATIONAL AND OTHER FORESTS ($ $HA^{-1}YR^{-1}$).

	National Forests (N=106)		Other Forests (N=504)	
Variables	Coef.	S.E.	Coef.	S.E.
Trees ha-‘:				
Shade tolerant:				
Small saw	0.53***	0.16	0.26***	0.04
Large saw	1.59**	0.81	1.11***	0.17
Mid tolerant:				
Small saw	0.89**	0.42	0.38***	0.07
Large saw	0.80	1.45	2.37***	0.36
Intolerant:				
Pole	0.01	0.05	0.03***	0.01
Small saw	0.02	0.25	0.33***	0.08
Large saw	3.62**	2.82	0.86***	0.32
Constant	15.13***	2.75	0.05	1.52
R^2	0.40		0.50	

***, ** significant at 1% and 5% level.
R^2=coefficient of determination. adiusted for deerees of freedom.

tree. At equal size, trees of mid-tolerant species tended to have larger non-timber values than those of other species.

This and other interpretations of the results are subject to the caveat that the NTV computed should be a lower bound on non-timber value. Furthermore, these estimates of NTV may be biased due to the omission of important variables affecting owners' behavior. Keeping this in mind, the higher NTV on national forests suggested that the hedonic price of different trees might also be different. This was tested by estimating two models, for the plots in national forests, and for others (Table 3). A Chow test confirmed that the coefficients were significantly different, after allowing for a different constant. The model for non-national forests had a slightly better fit than that for the pooled data, and it confirmed the strong positive correlation between tree size and marginal *NTV*. But the model for national forests was worse, with imprecise hedonic prices for three tree categories.

TABLE 4. SOURCE OF THE CONTRIBUTION OF MAPLE-BIRCH STANDS TO HARVEST AND NON-TIMBER VALUE (NTV).

	National Forests			Other Forests		
Source:	**NTV 1966** ($ $ha^{-1}yr^{-1}$)	**Harvest 1966-1984** ($ $ha^{-1}yr^{-1}$)	**NTV 1984** ($ $ha^{-1}yr^{-1}$)	**NTV 1966** ($ $ha^{-1}yr^{-1}$)	**Harvest 1966-1984** ($ $ha^{-1}yr^{-1}$)	**NTV 1984** ($ $ha^{-1}yr^{-1}$)
Trees ha-':						
Tolerant:						
Pole	0.0	0.5	0.0	0.0	0.7	0.0
Small saw	15.8	1.2	23.5	4.2	2.0	9.1
Large saw	7.7	2.0	10.4	8.9	4.0	7.7
Mid tolerant:						
Small saw	7.2	0.2	9.1	2.7	0.5	3.0
Large saw	1.5	0.0	2.0	3.0	1.5	4.4
Intolerant:						
Pole	0.5	0.7	0.5	0.0	0.7,	2.5
Small saw	0.2	0.2	0.2	0.0	1.5	4.7
Large saw	2.0	0.2	3.7	1.2	1.7	1.5
Total from trees:	34.5	5.4	49.4	20.0	12.6	32.9
Other sources:	15.1		15.1	2.2		2.2
Total:	49.6	5.4	64.5	22.2	12.6	35.1

The hedonic price models of Table 3 were applied to compute the contribution of different tree categories to harvest and non-timber value in Wisconsin maple birch forests, during the time between the two inventories. The first column of Table 4 shows the non-timber value generated by the average hectare of national forests, at the time of the first inventory, circa 1966, net of the harvest taken between the two inventories. Of the NTV of \$50 $ha^{-1}yr^{-1}$, 70% came from the stock of trees, mostly shade tolerant and mid-tolerant, the rest from unidentified sources independent of the number of trees and reflected by the constant in Table 3. On non-national forests, 90% of the NTV of \$22 $ha^{-1}yr^{-1}$ could be attributed to the stock of trees. On national forests, the value of the average annual harvest was one-tenth that of the non-timber value. For other forests, it was about half. Between the two inventories, the non-timber value, at constant prices, increased by 30% for national forests, and by 55% for other forests. Most species and sizes of trees contributed to this increase.

SUMMARY AND CONCLUSIONS

The first part of this paper proposed as an aggregate measure of the non-timber value of a forest stand, the difference between what owners, public or private, could have gotten by maximizing timber revenues, and what they actually got. As theorized, this revealed willingness to pay should be a lower bound of the non-timber value. This definition was then applied to estimate the non-timber value of all FIA plots in the Wisconsin maple-birch forests, based on the actual harvest and on the result of a Markov decision model predicting the decision that would have maximized the timber income. The last part of the paper used hedonic regression to determine how the biophysical characteristics of stands, and the socioeconomic setting, influenced their non-timber value.

For the Wisconsin maple-birch forests, the non-timber value was highest on national forests: about \$50 $ha^{-1}yr^{-1}$, ten times the timber revenues, This is a lower bound on what the public has been willing to give up to enjoy the amenities provided by standing trees on national forests, exclusive of other direct public expenditures to manage them. Average non-timber values were similar in all non-national forests, at about \$20 to \$24 $ha^{-1}yr^{-1}$, four times the timber revenues. *NTVs* were almost twice as large as timber revenues for private non-industrial forests. Even for industrial forests, non-timber values were slightly higher than timber revenues. This may seem high, but non-timber values for industrial forests are varied and complex. They include the importance of the good public image that conservative management can bring to corporations, and the avoidance of litigation, with subsequent constraining laws, for the preservation of environmental values. Industry may find it cheaper to be its own regulator, for example by employing foresters with a strong land ethic who try to preserve non-timber values.

Still, these estimates of non-timber value are preliminary. They assume that owners would have harvested according to the revenue optimization model, had they been pure profit maximizers. It is possible, however, that constraints independent of amenity values could lead owners to harvest less or more. For example, industrial owners might harvest less than the land-rent maximizing amount to maintain a regular supply, or because of attitudes towards risks, or imperfect knowledge. Or, private owners with capital rationing constraints might harvest more than what the model predicts with a conservative rate of interest of 3% per year (Lin & Buongiorno, 1998).

The hedonic pricing model that predicted NTV from stand characteristics and socioeconomic variables had modest explanatory power. More variables on the owner characteristics could be used in future studies. Nevertheless, the present model gave plausible estimates of the marginal NTV of trees of different species and size, especially for non-national forests. Stands with the same tree distribution had significantly higher NTVs in national forests, but similar NTVs in other ownership. The marginal value of trees of various species and size was also different in national forests. With these hedonic prices, from 1966 to 1984, the non-timber value of maple-birch forests in Wisconsin increased by 30% in national forests, and 55% in other forests.

The revealed preference method proposed here could be useful in environmental accounting to derive lower bounds on non-timber value on a regional, and perhaps national scale. The method could be applied to other forest types and regions of the United States, since it uses almost exclusively the FIA data, available nationally, and updated regularly[3]. It does require a model to predict the timber-revenue maximizing decision, given current stand condition. But several models of this kind are available, and the model used here was itself developed from FIA data, so that it could be calibrated for other regions. Nevertheless, more must be learned about how the prescriptions of such profit maximizing models are affected by owners' specific circumstances, such as risk aversion and capital or timber-flow constraints. Somewhat paradoxically, this revealed-preference approach to non-timber valuation requires the best possible knowledge of the economics of pure timber production.

[3] The empirical part of this paper has dealt with the estimation of non-timber revenues and prices at a given point in time, but the method could be used to monitor changes in prices of non-timber benefits over time as well, in parallel with the updating of the FIA data.

Further improvements of the hedonic price function for non-timber values should be possible. It would be useful to get more detailed information on the socioeconomic characteristics of the owners and of their property, which may affect both the potential timber income, and the non-timber value. For example, information on whether or not owners recreate on their own land, the presence of peculiarly attractive scenery visible from the forests, and the amount of dead wood present to support biodiversity could all affect NTV's. The present method is grounded in the concept of revealed preference. But, what owners prefer depends critically on what they can do and who they are. Better quality data should ultimately better explain how owners choose between timber and other forest benefits. With these caveats, the approach seems worth pursuing as an alternative or complement to contingent valuation and related non-market valuation methods.

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