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THE NON-TIMBER SERVICE VALUE OF OLD GROWTH FORESTS: THE MANAGEMENT OF U.S. NATIONAL FORESTS IN WESTERN WASHINGTON

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ABSTRACT

Over the past few decades the management of public old growth forest in the United States has been the focus of public debate. The tradeoffs between timber harvesting and amenity benefits of standing forests have been a key issue in this debate with national forest managers critiqued for both harvesting old growth forests too slowly or too quickly. To date there has been little analysis of the actual values placed on amenity benefits of old growth on national forests. The objective of this study is to analyze old growth forest management on U.S. national forests including the implicit amenity values of national forest managers. Using a data set from western Washington we estimate the implicit values of non-timber services by U.S. national forest managers. The average non-timber service changes during the study period, and increases as the stock of old growth forest decreases. The estimated value of per acre non-timber services is considerably higher than the values from previous studies. The results also suggest that national forest managers have at least partially recognized the non-timber benefits of old growth forests.

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I. Introduction

The stock of old growth forests in North America has decreased almost continuously since European settlement. During the 20th century much of the remaining stock of old growth was on U.S. National Forests. Due to harvesting of timber the public stocks of old growth forests on U.S. National Forests have declined dramatically since World War II.[1] Although diminished stocks have rendered old growth an unprofitable resource in many parts of the country, timber production from old growth forests is still profitable along the Pacific coasts of California, Oregon and Washington.

The unsustainable harvesting of old growth forests has long been a controversial issue with national forest managers critiqued for harvesting old growth forests too slowly, too quickly or at all. Critiques that public managers have harvested old growth stands too slowly have focused on financial losses incurred by conserving old growth stands (Clawson 1976). Critiques that public managers have harvested old growth too quickly have focused on the ecological values of old growth forests. Old growth forests provide habitats to many animal species, seedbeds to trees and shrubs, and supply other unique characteristics not supplied by younger second growth forests (Franklin et al. 1981; and Forest Ecosystem Management Team 1993).

Even though these opposing arguments regarding the public management of old growth forests have provoked seemingly endless debate, there has been little effort to evaluate the efficiency of management of old growth forests by public forest managers. The increasing importance of non-timber services

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[1] During this period national forests have been considered a very important timber supplier of softwood. Timber production from national forests increased rapidly after World War II and reached about 22 percent of the U.S. timber supply by 1962. 85 percent of timber production from the U.S. national forests in 1980 was from old growth areas (Nelson 1985)

requires more precise estimates of actual values placed on these services by public forest managers. The objective of this study is to analyze old growth forest management on U.S. national forests and simulate efficient management based on real data. This will allow us to evaluate the implicit non-timber values put on the old growth forests by public managers.

There are many previous studies that analyze the role of forest non-timber services. However, the primary focus of these studies is intensively managed forests, and not old growth forests (See Calish et al. 1978 for example). Economic analyses of old growth concentrate on the short-run influence of alternative management policies on local economic stability and timber industries (Satchell 1990; and Sample and Le Master 1992). The focus here is the efficient management of public old growth forests for both non-timber services as well as timber products. We extend the model of Berck (1981) to more fully describe the non-timber values of old growth. Using a data set unavailable to Berck, we compare the optimal harvesting paths under the assumption of private and public management. The difference between the two management regimes provides an implicit estimate of value placed on non-timber services by national forest managers.

The remainder of this paper consists of four sections. An optimal dynamic model of old growth forest management is presented in the next section. The third section contains a description of the data collected and estimated price and cost functions. The simulation procedure and results are included in the fourth section, while discussion and conclusions are offered in the last section.

II. Model

As mandated by the multiple use act of 1960 the U.S.D.A. Forest Service is charged with managing for both timber and non-timber services. To reveal public managers' non-timber service value, we compare total value of old growth forests between public managers and private owners. The private owners' harvest schedule of old growth stumpage produces the maximum profit of old growth forest from timber. Private owners' yearly profit becomes a benchmark by which to compare with the yearly profits from public management. Both private and public forest managers have a series of opportunities to make decisions on the old growth forests to maximize their objective including harvesting of old growth and silvicultural efforts for the second growth. Berck (1981) analyzes this process using a model for the optimal exhaustible resource management. Here we extend that model to include amenity benefits.[2]

We assume the land is initially covered with old growth forests. Since the non-timber service value is calculated based on the harvest volume difference between two management schemes, the exact value is revealed only when old growth trees are harvested. Let O(t) and y(t) be the volume of old growth stock and the harvest volume from the old growth stock at time t, respectively. The volume of the stock of old growth forest changes depending on the quantity of harvested volume. The equation-of-motion for the old growth stock is:

$$O(t+1) = O(t) - y(t) \quad \cdots\cdots (1)$$

After harvest of old growth, young second growth trees are planted or naturally regenerated and harvested for timber after a defined period. Let R(t) and h(t) be the regenerated area immediately after harvest and harvest volume from the second growth stock at time t respectively. The land constraint for the regenerated area is:

$$R(t) = \frac{y(t)}{\alpha} + \frac{h(t)}{\beta} \quad \cdots\cdots (2)$$

where α is the conversion factor of unit old growth volume into area, β is the conversion factor of unit second growth volume

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2 Over a very long time horizon forest managers also have the option of allowing second growth forests to mature into old growth forests.

into the area. α is assumed to be larger than β.

There are three distinct eras of harvesting. Since the land is covered by old growth, in the first era only old growth is available for harvest. After old growth is harvested, second growth occurs from natural or artificial regeneration. As second growth becomes mature, it is harvested too. During the second era both old growth and second growth are harvested simultaneously. A third era may occur, if old growth is no longer harvested or if the stock of old growth is depleted. To describe U.S.D.A. Forest Service behavior in the Pacific Northwest between 1963 and 1995, we use a framework provided by the second era.

The objective is to maximize the net present profit from all types of forest products including timber and amenity benefits from the old growth stock. The maximization problem combined with constraints can be written as

$$\underset{y,h,R}{Max}\,\pi = \sum_{t=0}^{T}\left(\frac{1}{1+r}\right)^{t}\left[-A(O_t)\times\frac{y_t}{\alpha} + p_t\times(y_t+h_t) - C(O_t, y_t) - w\times h_t\right] \quad \cdots\cdots\cdots \ (3)$$

$$s.t.\ O_{t+1} = O_t - y_t$$

$$R_t = \frac{y_t}{\alpha} + \frac{h_t}{\beta}$$

$$h(t)\ge 0,\ y(t)\ge 0,\ R(t)\ge 0,\ \mathrm{O(t)} < \mathrm{L}\quad for\ \ all\ \ t > 0$$

$$h(t) = 0 \quad for\ \ t \prec k$$

$$O(0) = L \ \text{ and } \ O(T) \text{ is constant}$$

where A is an average value function from non-timber services per area. The average non-timber service function is decreasing at an increasing or constant rate with respect to the old growth stock, O(t). pt is stumpage price, and C(·) is cost function of old growth harvest, which decreases at an increasing rate with respect to O(t) and increases at an increasing rate to y(t). The harvest cost of second growth is fixed at w.[3]

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[3] A sufficient condition for a maximum is: $\frac{y}{\alpha}A_{OO}C_{yy} + C_{OO}C_{yy} \ge (\frac{1}{\alpha}A_O + C_{yO})^2$.

To solve the problem we define the value function $J(O_t)$ as

$$J(O_t) = \max_{y,R}[-A(O_t)\frac{y_t}{\alpha} + p_t(y_t + R_t\beta - \frac{\beta}{\alpha}y_t) - C(O_t, y_t) - w(R_t\beta - \frac{\beta}{\alpha}y_t) + \frac{1}{1+r}J(O_{t+1})] \quad \text{.................. (4)}$$

where $R_t\beta - \frac{\beta}{\alpha}y_t$ from equation (2) substitutes for h_t.

Taking derivatives of the value function with respect to y and R, and setting these derivatives equal to zero provides:

$$\frac{\partial J(O_t)}{\partial y_t} = -\frac{1}{\alpha}A(O_t) + p_t - p_t\frac{\beta}{\alpha} - C_{y_t} + w\frac{\beta}{\alpha} - \frac{1}{1+r}J_{y_t}(O_t - y_t) = 0 \quad \text{............ (5)}$$

$$\frac{\partial J(O_t)}{\partial R} = p\beta - w\beta = 0$$

Since we know that y is the only variable that will affect future decisions in managing old growth, taking derivatives the value function at t+1 with respect to y_{t+1} and subtracting equation (5) we have:

$$-\frac{1}{\alpha}[A(O_{t+1}) - A(O_t)] + (p_{t+1} - p_t) - \frac{\beta}{\alpha}(p_{t+1} - p_t) - (C_{y_{t+1}} - C_{y_t}) + \frac{1}{1+r}[J_{y_t}(O_t - y_t) - J_{y_{t+1}}(O_{t+1} - y_{t+1})] = 0 \quad \text{...................... (6)}$$

The last term in bracket illustrates the change of marginal stock value over time. The last term, thus, can be simply written as

$$J_{y_{t+1}}(O_{t+1} - y_{t+1}) = (1+r)J_{y_t}(O_t - y_t) \quad \text{.. (7)}$$

Substituting equation (7) into equation (6) and rearranging terms, provides:

$$r = \frac{-[A(O_{t+1}) - A(O_t)] + (\alpha - \beta)(p_{t+1} - p_t) - \alpha(C_{y_{t+1}} - C_{y_t})}{-A(O_t) + (\alpha - \beta)p_t - \alpha C_{y_t} + w\beta} \quad \text{.............. (8)}$$

Old growth trees should be harvested when the rate of change of land rent for old growth equals the interest rate. The harvest decision for old growth depends on the existing stock and harvest of second growth, both of which may be zero. During the first era, when we have only old growth to harvest, $w\beta$ equals zero. If r is constant and equation (8) is always satisfied throughout the planning horizon, the zero value of w increases the right hand side value and results in faster depletion of old growth trees than in the second era, when we have second growth stumpage to harvest.

For private owners, if we rearrange equation (8) without the amenity function A, the harvest rule can be written as:

$$\frac{\alpha}{p_t}(C_{y_{t+1}} - C_{y_t}(1+r)) + \frac{r}{p_t}w\beta + (\alpha-\beta)r = (\alpha-\beta)\frac{p_{t+1}-p_t}{p_t} \quad \cdots\cdots\cdots\cdots\cdots (9)$$

If the increasing rate of marginal cost is larger than r, the harvest rate of old growth under private ownership is slower than the classical Hotelling's rule. The public managers' harvest decision rule can be written as:

$$\frac{1}{p_t}(A(O_{t+1}) - A(O_t)(1+r)) + \frac{\alpha}{p_t}(C_{y_{t+1}} - C_{y_t}(1+r)) + \frac{r}{p_t}w\beta + (\alpha-\beta)r = (\alpha-\beta)\frac{p_{t+1}-p_t}{p_t} \quad \cdots (10)$$

Under the exact same conditions as discussed for private ownership, we know that average non-timber service function is increasing faster than r. It is clear that public managers have a slower harvest rate than private owners.

III. Data and Estimation

For the prediction of prices, previous values of prices and volumes from 1963 to 1995 are used. The timber price on national forests is decided using several complicated steps (Adams and Haynes 1989). To avoid this complexity, the simple 'Average stumpage prices of timber sold on publicly owned or managed lands, Washington and Oregon' (USDA Forest Services 1963-1995) was selected for the timber price to be used in the estimation. This series of prices for stumpage on national forests are high bid values rather than harvest values. They are not necessarily equal to the market price of timber because auction and harvest do not take place simultaneously. High bid prices, however are sufficient to reveal the public managers' implicit value of old growth forest. Current timber prices are adjusted to the Producer Price Index of crude materials for further processing (Jacob 1998) to remove the influence of inflation.

Corresponding volume data, which are also sold volume rather than harvest volume, to the high bid prices are used for the same time period. Despite the difference between sold volume and harvest volume of national forest timber, the sold volume is always larger than the harvest volume, and is a good measure to reveal public managers willingness to sell old growth stock according to their non-timber service value as well as the timber price received.

Six years of data, from 1992 to 1997, on total cost and sold volume for a sample of three western Washington national forests were available to estimate a cost function for the simulation. The forests selected were Gifford Pinchot, Mt.Baker-Snoqualmie, and Olympic. The small number of observations forced pooling data. The statistics used in this study, which were reported to the U.S. Congress, contain the cost to operate the timber program and include expenses such as preparing and administering timber sales, and general administrative costs, etc. (U. S. General Accounting Office 1999). To make the timber program similar to a private owner's management, only harvest administrative cost and road related costs were selected from those expenses for the estimation. Similar to the estimated price function, the harvest volume of old growth, y, from the original model was substituted for the volume in the timber program. Estimates of the initial stock of old growth were assembled from timber inventory reports (Bassett and Oswald 1981, and Maclean, Ohmann, and Bassett 1991, and MacLean, Basset, and Yeary 1992), and the resulting series of stock was calculated by subtracting old growth harvest volume from the previous stock. State of Washington reports its harvest volume by old and young growth classes, which are divided at one hundred years of age.

The study is limited to National Forests in western Washington since 97 percent of old-growth-timber land in this area remains in national forests (Bolsinger et al 1997).

A simple process is used to forecast prices from the available time series. It is assumed that the expected price could be explained by present sold volume, sold volume of past periods, and previous prices. The explanation of this assumption is from the structure of timber sales by the U.S.D.A. Forest Service. Dramatic changes of timber harvest from national forests are often associated with an attempt effort to make up for a deficiency of timber supply from the private sector (Booth 1994). Sale volume suggested by Forest Service, hence, contains the information about timber markets and reflects expected timber price. To simplify the price equation, lagged prices and volumes are assumed to be the only variables that can influence current prices.

From the data we note, that the price of timber trends upward over time. The volume data, on the other hand, appears to have a downward trend. To analyze these types of time series data, which are assumed to be generated by stochastic processes, we need to test each series for stationarity. Table 1 contains the results of augmented Dickey-Fuller unit root tests, which are valid in the presence of serial correlation, for price and volume. The τ-test for $a_1 = 0$ does not reject at the 10% level, since test statistics for the price equation exceed the negative critical value. This eliminates the possibility of rejection of the unit root hypothesis. The unit root test, however, has low power to reject the null hypothesis, because it has a constant and a trend at the same time, as it is required to test if unnecessary regressors are included in the model (Enders 1995). Rejection of null hypothesis for the constant term without trend is illustrated in Table 1, and a unit root does not appear to exist in the price model presented.

TABLE 1. Dickey-Fuller Unit root tests for price and volume of timber sold on National Forest at Western Washington

Variable	Constant, No trend				Constant, Trend			
	Price[2]		Volume[3]		Price[2]		Volume[3]	
Test	Test Value	Critical Value[1]	Test Value	Critical Value	Test Value	Critical Value	Test Value	Critical Value
$Z(\alpha_1=0)$	-12.07	-11.2			-14.84	-18.2		
$\tau(\alpha_1=0)$	-2.768	-2.57	-0.986	-2.57	-2.982	-3.13	-1.868	-3.13
$\alpha_0=\alpha_1=0$	3.9496	3.78	0.9457	3.78				
$\alpha_0=\alpha_1=\alpha_2=0$					3.0889	4.03	1.5804	4.03
$\alpha_1=\alpha_2=0$					4.513	5.34	1.8846	5.34

1. The significance level for the critical value in parenthesis is 10%.
2. Price model does not use lagged difference.
3. Volume model uses one lagged difference.
4. The general test models for price and volume series are written as

$$\Delta P(t) = \alpha_0 + \alpha_1 y_{t-1} + \alpha_2 t + \sum_{j=1}^{m} \gamma_j \Delta P_{t-j} + \varepsilon_p(t)$$

$$\Delta V(t) = \alpha_0 + \alpha_1 V_{t-1} + \alpha_2 t + \sum_{j=1}^{n} \gamma_j \Delta V_{t-j} + \varepsilon_V(t)$$

where V(t)=y(t)+h(t).

TABLE 2. OLS estimation of Dickey-Fuller Test

Non-stochastic Regressor	Test Model
Constant, Trend for V	$\underset{(1.705)}{\Delta V_t = 0.0000004} - \underset{(-1.868)}{0.328}\, V_{t-1} - \underset{(-1.655)}{111734}t - \underset{(-1.598)}{0.283}\, \Delta V_{t-1},\ R^2 = 0.2992$
Constant for V	$\Delta V_t = \underset{(0.493)}{60468} - \underset{(-0.986)}{0.131} V_{t-1} - \underset{(-2.209)}{0.379} \Delta V_{t-1} \qquad R^2 = 0.233$
No Constant, No Trend for V	$\Delta V_t = -\underset{(-1.3)}{0.072} V_{t-1} - \underset{(-2.69)}{0.414} \Delta V_{t-1} \qquad R^2 = 0.2268$

Numbers in parentheses are t-statistics for each coefficient.

A stationarity test for the volume follows the same procedure as for price. Since the null hypothesis is not rejected in Table 1, and the hypothesis tests for significance of a trend and the constant term in Table 2 do not show any significance in this case, the final model that is composed with only stochastic variables decides the stationarity of volume variable. The last model in Table 2 shows t-statistic for unit root as -1.3 and this is higher than the critical value of -1.95 in 5% significant level. It may be said that sequence of sold volume, Vt, contains a unit root conclusively.

The estimated price model is

$$P(t) = \underset{(9.65)}{240.31} - \underset{(-0.29)}{0.000011}V_t - \underset{(-2.07)}{0.000076}V_{t-1} + u_t \ , \ R^2 = 0.2611 \quad \cdots\cdots\cdots (11)$$

where numbers in parentheses are t-statistics. Equation (11) is an Autoregressive Distributed Lag model with zero lags on price and one lag on volume. The price of timber that reflects the equilibrium point of supply and demand should be a function of timber quantity. Since the quantity of timber has a random walk, the price function can be expressed as a function of lagged quantity as well as the current quantity. The time trend is deleted since this variable decreases the performance of fit, as well as significance of each variable. The influence of present selling volume is not as big as lagged volume, but both have the expected negative impact on timber price, that is, a large quantity of timber sales will not only reduce the timber price in present year but also the price in future years.

Cost function estimation results for the dummy variable model and the error component model are illustrated in Table 3. In model selection, the low value of Hausmann test (1978) statistic, 0.154, allows us to use either model for cost function estimation. Since our interest lies in inferences about cost of all national forests rather than a specific forest, which are managed by U.S.D.A. Forest Service, it is appropriate to use error component model for the estimation. The estimation result of the selected error component model can be written as

$$C(t) = \underset{(10.96)}{4040400} + \underset{(5.238)}{1169.6} * \frac{[y(t)]^2}{O(t)} \quad \cdots\cdots (12)$$

where numbers in parentheses are t-statistics for each coefficients. The explanatory variable is consistent with the theoretical assumptions (Conrad and Clark model 1987). The positive value of the constant term reflects the size of timber program. The positive coefficient of the slope illustrates that cost increases for a larger volume of harvest for a fixed stock of old growth. Harvesting from the old growth area increases the development cost relative to the harvesting expense. Hence, equation (12) is used for harvesting old growth trees. For second growth harvest, the cost is assumed to be constant at \$31.49 per thousand board feet (TBF). Second growth serves as a backstop technology in this study (Nordhaus 1973).

TABLE 3. Results of cost equation estimation

Variable	Estimation of coefficient	
	Dummy variable model	Error component model
(Sold Volume)^2/Stock (y^2/O)	1132.2 (4.664)[i]	1169.6 (5.238)
Constant	-	4040400 (10.96)
Gifford Pinchot[ii]	4288300 (10.70)	-
Mt. Baker-Snoqualmie[ii]	4396200 (15.69)	-
Olympic[ii]	3485700 (12.47)	-
R^2	0.7818	0.6317

i. The numbers in parenthesis are t-ratio.
ii. Each national forest indicates its dummy variable.

IV. Simulation

The primary objective of the numerical simulation is to determine the values of the non-timber services for the old growth forests by determining the optimal paths that maximize the net present value (NPV) produced from multiple services. The difficulty of estimating a non-timber service function is complicated by the possibility of violating the assumption of convexity (Swallow, Parks, and Wear 1990). To avoid this difficulty, revealed non-timber service values that have been given by public managers will be calculated (Berck 1979), and the functional form of the non-timber service is estimated based on these values. The simulated non-timber service function combined with a real data set will determine the optimal path of decision variables such as annual harvest volume and the stock of old growth.

To find the non-timber service function in western Washington national forests it is required to go through a two-step procedure. First, the real paths of control variables will be compared with estimated private owners' paths to calculate the yearly profit discrepancy. Second, based on the differences between these paths, the non-timber service function is estimated.

Private owners, who do not include environmental values, are assumed to value only timber production. To maximize NPV from managing forestland occupied by old growth trees, private owners try to harvest existing old growth and second growth optimally. The specification of equation (3), the private owners' problem is

$$\underset{y,h,O}{Max} \sum_{t=0}^{N} \left(\frac{1}{1+r}\right)^{t} \times [P(t)\times(y(t)+h(t)) - C(O(t),y(t)) - wh(t)] \quad \cdots\cdots\cdots\cdots\cdots\cdots (13)$$

s.t. (1) and (2)

$$h(t)\geq 0,\ y(t)\geq 0,\ R(t)\geq 0,\ \mathrm{O(t)<L}\quad \textit{for all } t>0$$

$$h(t)\leq R(t-k)*\beta \quad \cdots\cdots\cdots\cdots\cdots\cdots (14)$$

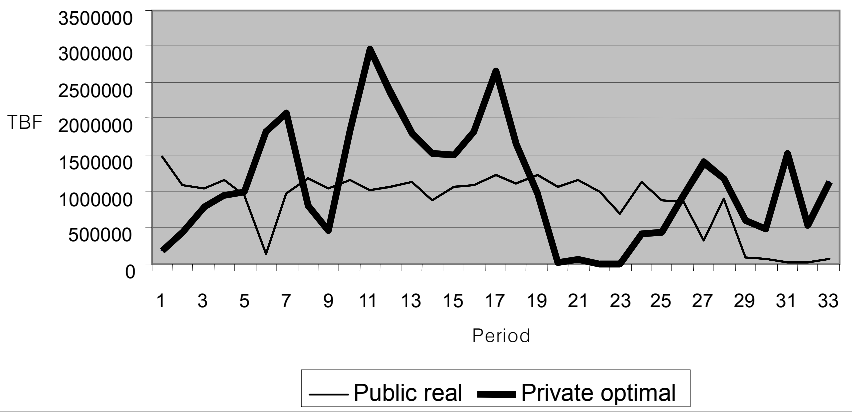
The relationship between second growth harvest and regeneration area is expressed in equation (14), and this is substituted for the constraint of h(t). The estimated price and the cost equation from previous section are used to maximize private owners' profit in equations (13), (1), (2), and (14). The General Algebraic Modeling System (GAMS) was chosen to assist in optimizing this non-linear model. To have a fair comparison with public managers' strategy, the planning horizon is set to 300 years, from zero to 299, and the initial price and old growth volume are given at $54.61/TBF and 49,269,761 TBF in Scribner scale, respectively, which are the real sale price and volume in 1963 (Bolsinger 1969 and Hazard 1965). The conversion factor of volume to the harvest acreage is calculated from the Washington Timber Harvest Report (Washington State Department of Natural Resource) for the periods of 1962-1978 and 1980, since in 1979 and after 1981 the report deleted harvest acreage from its category. Harvest acreage defines the acres sold as final harvest, not the actual harvest acres. Average timber production, which is set as the conversion factor, is 32,068 TBF per thousand acres for old growth forest, and 12,904 TBF per thousand acres for second-growth forest. A 5 percent rate of interest and a thirty-six year rotation period are selected to comply with previous studies (Calish et al. 1978).

Simulation results for the private owners' strategy are presented in Table 4. With given timber prices, the series of private owners' harvest volumes show significant difference, when compared to the series of public managers' harvest volumes. Also, the private owners' harvest volumes fluctuate more in response to a changing timber price (Figure 1). Throughout the study period public managers have harvested a consistent quantity of old growth timber regardless of timber price. This harvesting pattern is clear evidence of supplementary role of old growth forests in providing non-timber services. During the 1980's when National Forest Management Act was in effective, the pattern of old growth harvesting did not change and the volume did not decrease. The series of heavy harvests at the low timber price

TABLE 4. Simulation result of private management

Year	Time period	Old growth stock	Private managers' harvest volume	Public managers' harvest volume	Harvest difference	Profit difference	Regenerated area	Timber price
1963	0	49269760	186691	1474000	-1287309	-70299951.5	5.82	54.61
1964	1	49083070	439364	1079000	-639636	-42190398.9	13.70	65.96
1965	2	48643710	790665	1033000	-242335	-21284259.5	24.66	87.83
1966	3	47853040	951809	1167000	-215191	-20180596.3	29.68	93.78
1967	4	46901230	1001663	945000	56663.37	5907723.06	31.24	104.26
1968	5	45899570	1829646	144000	1685646	246812222	57.06	146.42
1969	6	44069920	2088919	981928	1106991	188498430	65.14	170.28
1970	7	41981000	816116	1176971	-360855	-37276320.9	25.45	103.30
1971	8	41164890	457289	1032697	-575408	-49968460.3	14.26	86.84
1972	9	40707600	1848901	1164403	684498.4	119609255	57.66	174.74
1973	10	38858700	2961339	1016283	1945056	474029497	92.35	243.71
1974	11	35897360	2369495	1068997	1300498	281362661	73.89	216.35
1975	12	33527860	1792280	1140604	651676.3	116376350	55.89	178.58
1976	13	31735580	1529956	883213	646742.9	110192058	47.71	170.38
1977	14	30205630	1492053	1066656	425396.5	80182994.6	46.53	188.49
1978	15	28713580	1820687	1097597	723089.5	151357097	56.78	209.32
1979	16	26892890	2653428	1222548	1430880	425815577	82.74	297.59
1980	17	24239460	1677661	1114024	563637.4	127742782	52.32	226.64
1981	18	22561800	967056	1224969	-257913	-42413862.6	30.16	164.45
1982	19	21594740	21090	1066085	-1044995	-64246294.7	0.66	61.48
1983	20	21573650	69581	1153819	-1084238	-81035961.6	2.17	74.74
1984	21	21504070	0	996173	-996173	-61075366.6	0	61.31
1985	22	21504070	0	699004	-699004	-46309015	0	66.25
1986	23	21504070	413621	1136822	-723201	-86653930.5	12.90	119.82
1987	24	21090450	438334	870743	-432409	-56100679.4	13.67	129.74
1988	25	20652120	952279	846309	105969.5	20620613.2	29.70	194.59
1989	26	19699840	1398803	313920	1084883	270146617	43.62	249.01
1990	27	18301040	1185493	913998	271495.5	64390578.5	36.97	237.17
1991	28	17115540	603935	91442	512493.3	90019449.9	18.83	175.65
1992	29	16511610	492452	71422	421030.1	70644633.1	15.36	167.79
1993	30	16019160	1524493	27296	1497197	471197788	47.54	314.72
1994	31	14494660	537509	21553	515955.8	97536293.1	16.76	189.04
1995	32	13957150	1137300	71432	1065868	317969700	35.47	298.32

FIGURE 1. Harvest Volume Comparision



periods, which have a negative profit difference, are deleted on the assumption that the value of non-timber services is always positive. Hence, non-timber service value of this period is unobservable during this period.[4] Similarly, the low timber price in period zero provided a very small volume of old growth timber by private owners, 186,691 TBF, but forced public managers to supply timber production of 1,474,000 TBF to balance the demand of timber.

The unit acre profit difference is calculated by dividing the profit difference with regenerated acreage and represents the average non-timber service value of the old growth forests with given old growth stock. The average profit difference is an increasing function of time period. This appears to illustrate the

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[4] This period reflects the early Reagan presidency, when pressure to use natural resources was high. The maximum (optimum) value of old growth forest with a given price is the upper limit to the profit under private management. Harvesting at a great rate violates the optimality condition, which would be an assumption in practice (see footnote 6). If those years with a negative profit differences are included to estimate the non-timber service value of old growth forests, we would underestimate public manager's true value of the non-timber services of old growth.

public managers' consideration of the value of old growth non-timber service. The profit difference decreases gradually as the sold volume of old growth increases, which means a smaller value of non-timber service is given when they decide to sell additional old growth earlier in the management period. The unit area profit difference ranges from \$189 to \$9,912 and averages at \$3,875. The public managers' non-timber service value on the old growth forests is much higher than in value of previous studies, which are \$1,890 per acre (Calash et al. 1978,) and \$1,155 per acre (Berck 1979) for the value of total non-timber services in second growth forests.

Unit acre profit differences and the stock of old growth stock for each period are utilized in estimating the non-timber service function. Before regressing the profit difference on the volume of old growth stock, it is required to test for the stationarity for both the stock and unit area profit difference. As in the previous section, augmented Dickey-Fuller unit root tests are applied to the variables, and the results are presented in Table 5. The overall procedure suggests that the unit acre profit difference

TABLE 5. Dickey-Fuller Unit root tests for unit area profit difference and volume of old growth stock on National Forests at Western Washington

Variable	Test	$\tau(\alpha_1 = 0)$	$\alpha_0 = \alpha_1 = 0$	$\alpha_0 = \alpha_1 = \alpha_2 = 0$	$\alpha_1 = \alpha_2 = 0$
Profit Difference[2] (A)	Constant No trend	-0.9732 (-2.57)[1]	0.7961 (3.78)		
	Constant Trend	-1.9056 (-3.13)		1.7078 (4.03)	2.1899 (5.34)
Old Growth Stock[3](O)	Constant No trend	-0.9364 (-2.57)	4.6635 (3.78)		
	Constant Trend	-1.5735 (-3.13)		3.9296 (4.03)	1.4348 (5.34)

1. The significance level for the critical value in parenthesis is 10%.
2. Profit difference model uses one lagged difference.
3. Old growth stock model does not use lagged difference.

has a unit root, and the stock volume does not have unit roots. The estimated equation for the non-timber service function is:

$$A_t = \underset{(2.9)}{7797.8} + \underset{(0.347)}{0.0871} A_{t-1} - \underset{(-1.983)}{0.000134} O_t, \qquad R^2 = 0.2596 \quad \ldots\ldots\ldots\ldots (15)$$

where A is a variable and defines profit difference per acre, which serves as non-timber service value. The numbers in parentheses are t-ratios of each coefficient. The large constant term with lagged term illustrates the maximum non-timber service value of the forests, since current stock is always less than or equal to the previous stock. The negative sign of old growth stock coefficient indicates that per acre non-timber service value increases as the old growth stock decreases.[5]

The estimated non-timber service function makes it possible to simulate the optimal path of old growth harvest volume. In the simulation we assume the same quantity of stock volume produces same profits between private and public managements. Under this assumption, the non-timber service value calculated from its function represents the opportunity cost of old growth timber harvest.[6]

The simulation results are depicted in Figure 2. As in the private manager’s problem, the old growth stock is initially set to the 1963 level. The harvest pattern is almost the same as the private manager's strategy, but the total volume saved for the non-timber services is less than the recorded volume by 7056

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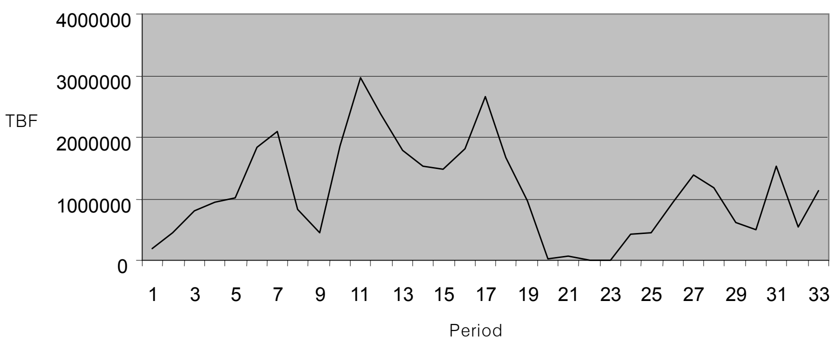
[5] Given the linearity of equation (15) in the old growth stock and the assumption of a non-linear non-timber value function in the old growth stock, the estimated equation does not perform well for small volumes of the old growth stock.

[6] Evaluating the sufficient conditions in footnote 4, we find that C_{OO}*C_{yy} =$(2339.2)^2$*y^2/O^4 ([(1/ α)(-0.000134)-2.339.2*$y/O^2]^2$ where A_{OO}=0 and α =32,068. This implies that the sufficient conditions are almost but quite not met. Fortunately, we can ignore this result, if we assume that the public managers are maximizing the NPV of the old growth stock, i.e. we assume that in practice, as opposed to theory, the public managers are operating on their optimal path.

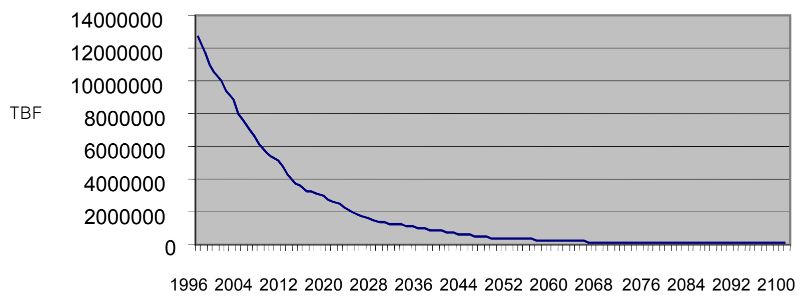
million board feet from 1963 to 1995. Under the given price series, if the non-timber service function fully reflects public managers' non-timber service value, the historical harvest volume is less than the optimal path, and public managers incurred $1.33 billion of timber revenue deficit in managing national forests compared to the optimal path.

FIGURE 2. Public Manager's Optimal Harvest Volume



To calculate the future optimal path of old growth timber harvest volume, the old growth stock and per acre non-timber service value are set at 12,834,220 TBF and $6482, which are observed in 1995, respectively. The pattern of harvest volumes illustrated in Figure 3 fluctuates depending on the timber price.

FIGURE 3. Optimal Stock Of Old Growth



Harvest volume decreases gradually throughout the planning horizon, and is depleted at year 2235.

V. Conclusions

The seemingly inexhaustible supply of old growth forest in the U.S. has been almost depleted. Remaining old growth forests are limited to very small areas of a few U.S. national forests. Continuous development has resulted in the destruction of the ecosystems of old growth forests, which may now be more valuable than that of intensively managed second-growth forests. The U.S. Forest Service, which manages the U.S. national forests, has been criticized for inefficient management of old growth forest by both preservationists and timber producers. These seeming endless debates on the harvest of old growth forests have not determined actual values placed on non-timber benefits by public forest managers. The results described here serve as a first step in addressing this omission.

We present a simple model to assess the historical placed on old growth forests by U.S. Forest Service Managers. Using historical data from western Washington national forests, we calculate timber prices and harvest costs. We use these functions to simulate a path of optimal timber harvesting. By comparing this optimal path of timber harvests with observed data, we estimate the value placed on non-timber services by U.S. Forest Service Managers. The average value is found to be evolving during the study period and increasing with the scarcity of resource. The estimated value of per acre non-timber services is considerably higher than the values from previous studies, and reveals that public managers have at least partially incorporated the non-timber benefits of old growth forests into management.

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