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Taking Stock of the Timber Harvest Decision of Private Forest Owners: Some New Considerations

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Abstract

The conventional wisdom about the timber harvest decisions of nonindustrial private forest owners is that these owners forego some timber income to consume the nontimber goods of their forestland. Previous studies examining this trade-off did not consider the availability of such goods on neighboring land. In this paper we develop static and dynamic models of harvest behavior that explicitly recognize the role of neighboring forests. In both models, income maximizing harvest behavior is possible, especially in areas where the off-site prices of the nontimber goods of forestland are relatively low. A review of published regression results suggests that a simple income maximization model may be appropriate in the southeast. The analysis shows that the accessibility of private forestland for recreation is a matter of timber policy.

1.0 Introduction

A long-standing concern of forest economists is the nature and magnitude of the "problem" of forest management on land owned by individuals and corporations not directly involved in the manufacture of forest products. Generally the owners of these nonindustrial private forests do not practice the type of intensive forest management found on lands managed by the forest products industry. This disparity causes policy-makers some concern in light of recent timber supply projections indicating that at current management levels, softwood inventories will fall in the future and timber prices will rise (Adams, Haynes, Dutrow, Barber, and Vasievich [1], USDA [18], Brooks [5]). Nonindustrial private forest owners (hereafter, forest owners) hold about 60% of the nation's commercial forestland; possibly, more intensive management on these lands would reduce the future scarcity of timber. In an attempt to reconcile the low intensity of forest management on nonindustrial private forests with the presumption that forest owners behave rationally, recent research has focused on the behavioral aspects of timber supply from these forests. This research relies on the conventional wisdom that forest owners do not maximize net timber income because they derive satisfaction from the recreational and aesthetic outputs of their forests. This view is formally presented in the economic models of Binkley [2], Boyd [4], Max and Lehman [16], and Dennis [10]. The regression analyses of the Binkley, Boyd, and Dennis studies (BB&D) are generally believed to provide evidence that forest owners do indeed forego timber income to consume nontimber goods.

Unfortunately, a common result from these models is that the response of forest owners to various traditional forest policy instruments is weak and indecipherable. Concerning the effectiveness of reforestation cost-sharing, Boyd concludes that, "landowners with multiple objectives often react poorly to such incentives" (p. 103). Similarly, the analysis of Max and Lehman indicates that the effect on timber output of various tax structures is generally indeterminate, due to opposing income and substitution effects between timber and nontimber, and between time periods. More troubling still, the indeterminate results of Max and Lehman arise despite the assumption that recreation outputs are a positive function of the stock of timber. Although this assumption is reasonable for the forests examined by the authors --the Redwood forests of Santa Cruz County, California -- it is questionable in analyses involving the private forests of the eastern U.S.; many valuable wildlife species, for example, decline in numbers as the stock of timber increases (e.g. quail, deer, and rabbits; see Giles [11], and Calish, Fight, and Teeguarden [8]). Denied the analytical advantage of this assumption, the indeterminate effect of traditional forest policy instruments is compounded.

Whether traditional forest policy instruments are ineffective or even counterproductive provides reason enough to reconsider the empirical validity of these behavioral models. That is, before economists relinquish their role in the development of forest policy instruments on the grounds that the effect of such instruments is invariably indeterminate, and before they attempt rather unpromising efforts to overcome the indeterminacy of analytical results by developing empirical specifications of forest owner utility functions, it is worthwhile to consider again when these models are appropriate. This is done below. The analysis raises the possibility that traditional policy instruments are effective under conditions that may exist in some regions. The next section presents static and dynamic models of forest owner behavior in which the forest owner's harvest decision affects the (implicit) price of consuming a nontimber good on his own land. The models also explicitly consider the price of the nontimber good on neighboring lands. The upshot of the analysis is that conceivably, optimal harvest behavior involves the maximization of timber income; in other words, as a theoretical and a practical matter, a plain income maximization model of behavior may provide a better representation of forest owner behavior than the current crop of behavioral models. This result is a routine possibility in the static model, and arises under special -- albeit highly relevant -- circumstances in the dynamic model. In neither case does it rely on strong behavioral assumptions; it does not rely, for instance, on the assumption that forest owners gain no benefit from the nontimber goods of forestland. Rather, it reflects the possibility that the welfare loss arising from a marginal deviation from the income maximizing harvest policy may exceed the welfare benefit from the lower prices of the nontimber goods that such a deviation would bring. This is especially likely in areas where the price of consuming the nontimber good on neighboring lands is low.

The essential features of the analysis are best illustrated with an example. Suppose the value of a standing forest to a particular owner is derived solely from the opportunity it presents to observe a rare bird species. The difficulty of observing the species declines (gets cheaper) as the timber stand matures.

The forest owner must decide whether to clearcut his land at the income-maximizing rotation age, or to postpone harvest for one year. Will the forest owner postpone the harvest? Not necessarily; the loss of income from postponing the harvest normally implies fewer trips into the woods, so although observing the species is easier if the harvest is postponed, possibly the affordability of consumption (the affordability of hours of observation, perhaps) would decline. Moreover, the likelihood that the forest owner will harvest at the income-maximizing rotation age increases if he can observe the bird species on neighboring forestland as readily as he can observe the species in a mature forest on his own land. In this case the difficulty of observing the species after harvest depends not on the state of the forest owner's land, but rather on the state of neighboring forestland, and the relevant economic question is this: would the forest owner postpone harvest past the income-maximizing rotation age -- foregoing hundreds or perhaps thousands of dollars as a result -- if he can observe the species on neighboring land as easily as he can observe it on his own? The answer to this question has clear implications for the relevance of recreation policy to forest policy.

We do not argue that there are no goods and services of forestland unique to forest ownership. We do contend, however, that as a practical matter the income maximization model may be an appropriate model of forest owner behavior in the development of public policy for private forests. To this end, in section III we reexamine the regression results of BB&D to determine how well the income maximization hypothesis explains these results. To a surprising degree, the signs of coefficients in these regressions are consistent with a simple income maximization hypothesis. We conclude that an income maximization model of forest owner harvest behavior remains a viable alternative to the conventional wisdom, especially in the southeast. The implications of the analysis for forest policy are discussed in section 4.

2.0 Theoretical Considerations

The purpose of the following analysis is to identify the case where the harvest criterion of forest owners is income maximization. Some initial insights can be derived from a simple static model. In the model, the forest owner derives utility, u, by consuming a nontimber good, R, and all other goods, A. Let r represent the owner's consumption of the nontimber good on his own land, and let $\hat{r}$ represent the consumption of the good on neighboring lands. The (implicit) price of the former is p, and the price of the latter is q.[1] price p is a decreasing function of the timber stock remaining after harvest, $x = x_0 - h$, where x_0 is the initial stock of timber, and h is the harvest volume. Representing the impact of the harvest decision on utility as an indirect effect communicated through the price of the nontimber good is a critical departure from the household production models in previous studies, in which timber harvests serve to directly constrain the consumption of the nontimber good. The approach taken here is more general, in this sense: whereas the household production models of previous studies are not amenable to the case where the forest owner consumes the nontimber good on neighboring land, the solutions arising from these models can be obtained from models of the sort proposed here, by setting $q = \infty$, and choosing a price function $p(x)$ that is identically equal to the implicit price functions derived from these models.

The income available to the forest owner for consumption of A is the difference between income from timber sales, $G(h)$, and the income allocated to the nontimber good, $p(x_0 - h)r + q\hat{r}$.[2] Formally, then, the forest owner makes harvest and consumption decisions to solve the problem,

$$(1) \qquad \max_{h, r, \hat{r}} \; u(R,\; G(h) - p(x_0 - h)r - q\hat{r})$$

$$s.t. \quad h \leq x_0,$$

$$r + \hat{r} = R.$$

The solution of this problem is characterized by the Kuhn-Tucker conditions,

$$(2a) \qquad u_R - u_Y p \;\leq\; 0, \qquad r[u_R - u_Y p] \;=\; 0, \qquad r \geq 0;$$

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1 To a large extent, the price of consuming the nontimber good reflects the implicit price of the time used in consumption. A more explicit model employing both money and time budget constraints, and recognizing the effect of exogenous income on prices p and q, yields essentially the same results as this model, but with considerably less parsimony.

2 The price of A is 1.

(2b) $\quad u_R - u_Y q \;\leq\; 0, \qquad \hat{r}[u_R - u_Y q] \;=\; 0, \qquad \hat{r} \geq 0;$

(2c) $\quad u_Y G_h + u_Y p_x r - \mu \;\leq\; 0, \qquad h[u_Y G_h + u_Y p_x r - \mu] \;=\; 0, \qquad h \geq 0;$

where μ is the Lagrangean multiplier on the timber stock constraint in (1), and subscripts denote partial derivatives. From these conditions two conclusions can be drawn. The first is that if $p(x) > q$, $\forall x \in \{x: 0 \leq x \leq x_0\}$, then the forest owner will consume the nontimber good on neighboring lands only, regardless of the harvest decision. This reflects the perfect substitutability of r and $\hat{r}$. In this case the forest owner's production and consumption decisions are decoupled; the production decision is to maximize timber income $(h = x_0)$, and the consumption decision is to choose $\hat{r}$ and Y to maximize utility, subject to the budget constraint,

(3) $\quad G(x_0) - q\hat{r} \;=\; 0.$

The practical implication of this result is that in areas where forestland is homogenous with respect to the production of the nontimber good, and access to forestland is not difficult or costly, forest owners may choose simply to maximize their timber income.

The second, more striking, conclusion is that nothing in these conditions precludes the possibility that the forest owner maximizes timber income while consuming the nontimber good on his own forestland. From (2c) we know that if the forest owner maximizes timber income, the following inequality must hold,

(4) $\quad G_h(x_0) \;\geq\; -p_x(0)\, r.$

This condition clearly holds in the aforementioned case where it is cheaper to consume the nontimber good on neighboring land, because in this case $r = 0$. Note, however, that even when $r > 0$, timber income may be maximized, insofar as the marginal increase in income from harvesting the last unit of timber exceeds the corresponding marginal increase in the cost of consuming the nontimber good. This result differentiates this model from previous static models of forest owner behavior, in which maximizing timber income implies $r = 0$. In the present model, the primary consequence of maximizing timber income is not that the nontimber good is eliminated or unvalued, but rather the less dramatic result that the price of the good is relatively high.

2.1 Analysis in a Dynamic Setting

In a dynamic setting, the forest owner's problem can be separated into static and dynamic components. We proceed recursively by first dispensing with the static portion, which is to maximize utility at each point in time, *given* the allocation of income, y, and the prices of the nontimber good, $\{p,q\}$. Formally, the problem is,[3]

$$(5) \qquad u^*(p,q,y) = \max_{r,\hat{r}} \; u(R,\; y - pr - q\hat{r})$$

$$s.t. \quad r + \hat{r} = R,$$

where the definitions of terms are the same as in the static model; in particular, the second argument in $u(\cdot)$ is an expression of A, the composite good available at a price of 1.

The dynamic problem of the forest owner is to execute a timber harvest policy, and to allocate the resulting income over time, to maximize the net present value of his welfare. To examine whether the conclusions from the static model remain valid in a dynamic setting, we limit the forest owner's harvest decision to the matter of when to clearcut his timber stand. The net value of timber, G, is a twice continuously differentiable, nondecreasing concave function of the age of the timber stand, z. The price of the nontimber good on the forest owner's land is also a function of the age of the timber stand, as denoted by $p(z)$, and is also twice continuously differentiable.

Our objective is to examine the possibility that maximizing timber income serves to maximize the forest owner's welfare. To achieve this objective we represent the forest owner's welfare at time t with a money measure that is a monotonic transformation of the indirect utility function associated with the owner's intratemporal problem (5). Specifically, we use a compensation function, which measures the expenditure needed to achieve a reference-level of utility when prices differ from reference-level prices (see, for instance, [3], [14] and [19]). In the case at hand, the reference-level utility at time t is the utility obtained when the forest owner chooses the harvest policy S -- a sequence of harvest ages that are not necessarily all the same -- and allocates to time t the income, $y(t)$. Accordingly, the reference-level prices of the nontimber good are, $p(t,S)$ and q, where, $p(t,S) \equiv p(z(t,S))$. Note that in the analysis, q is fixed over

3 By expressing utility at each point in time as a function of only current consumption, we implicitly impose intertemporal separability on the utility function.

time. Although neighboring landowners harvest timber, the assumption of a fixed q is probably a good approximation of the usual case where an owner's forestland is surrounded by a patchwork of timber stands of various ages and ownerships, and so harvesting on any one plot has a negligible effect on q.

The alternative (non-reference) prices completing the specification of the compensation function are the prices of the nontimber good *when the harvest policy is to maximize timber income.* As we show below, casting the analysis in this manner permits a relatively straightforward comparison of the harvest rule guiding the forest owner's choice of S to the Faustmann rule associated with income maximization.

Let s' represent the optimal rotation age when the forest owner simply maximizes timber income. When the time horizon is infinite, this rotation age is constant over time because after each harvest, the problem solved by the firm is identical to the one solved after the previous harvest. In this light, we may refer to s' as the income-maximizing harvest policy, and moreover, we may denote the price of the nontimber good on the forest owner's own land at time t by, $p(t,s') \equiv p(z(t,s'))$. Formally, then, the compensation function is defined by:

$$(6) \qquad v(p(t,s'),\, q;\, p(t,S),\, q,\, y(t)) \quad \equiv \quad \min_{r,\hat{r},Y}\; p(t,s')r + q\hat{r} + A,$$

$$s.t. \quad u(r+\hat{r},\, A) \geq u^{*}(p(t,S),\, q,\, y(t)).$$

We assume that $v(\cdot)$ has the usual properties of a compensation function outlined in [18, p. 121-125]; we also assume $v(\cdot)$ is twice continuously differentiable in prices and income. In words, $v(\cdot)$ is the income needed under the income-maximizing harvest policy to make the forest owner as well off at time t as he is with reference-level utility u^*. Put another way, it is the income needed under the harvest policy s' to make the forest owner as well off at time t as he is with income $y(t)$ and the harvest policy S.

To reiterate, the compensation function (6) is a monotonic transformation of indirect utility function (5), and as such, is a money measure of the forest owner's welfare. We've chosen this particular formulation of the compensation function to facilitate the examination of income-maximizing behavior. Letting $y(t,s')$ denote the optimal allocation of income to time t, *given* the harvest policy s', we may conclude that if $v(\cdot) > y(t,s')$, the harvest policy s' does not achieve the level of utility at time t that is obtained with harvest policy S and income $y(t)$. In other words, $v(\cdot) - y(t,s')$ is the *net gain at time t* (equivalent variation) obtained by choosing the harvest policy S and income $y(t)$, *instead of* harvest policy

s' and income $y(t,s')$.

The dynamic production decision of the forest owner with bare forestland is to choose the harvest policy S and the income allocation rule $y(t)$ to maximize the net present value of his welfare. Equivalently, we may state the objective of the forest owner as choosing S and $y(t)$ to maximize the net present value of the expenditure (compensation) required to make the forest owner as well off under harvest policy s' as he is with S and $y(t)$. Letting i denote the discount rate, this objective may be stated,[4]

$$(7) \qquad \max_{S,\, y(t)} \int_0^{\infty} e^{-it} v(p(t,s'),q;\ p(t,S),q,y(t))\ dt.$$

The allocation of income over time is constrained by exogenous income and timber income,

$$(8) \qquad \int_0^{\infty} e^{-it} y(t)\ dt \ = \ W_0 + \pi(S),$$

where W_0 is the initial stock of income (which may include the present value of exogenous income), and $\pi(S)$ is the net present value of timber income associated with the harvest policy S.

Our efforts focus on the question of whether the income-maximizing harvest policy s' is the

4 The solution to this problem also solves the problem of choosing S and $y(t)$ to maximize the *net present value of the gain* from deviating from the harvest policy s' and income allocation rule $y(t,s')$. To see this, note that the solution to (7) also solves,

$$\max_{S,y(t)} \int_0^{\infty} e^{-it} v(p(t,s'),q;\ p(t,S),q,y(t))dt \ + \ Z,$$

where Z is a constant. Setting Z equal to the (constant) term

$$-\int_0^{\infty} e^{-it} y(t,s')dt$$

yields the problem,

$$\max_{S,y(t)} \int_0^{\infty} e^{-it} v(p(t,s'),q;\ p(t,S),q,y(t))dt \ - \ \int_0^{\infty} e^{-it} y(t,s')dt,$$

which can be restated,

$$(F1) \qquad \max_{S,y(t)} \int_0^{\infty} e^{-it}[v(p(t,s'),q;\ p(t,S),q,y(t))dt \ - \ y(t,s')]dt.$$

Now recall that the bracketed expression in (F1), $v(\cdot) - y(t,s')$, is the *net gain* in period t (equivalent variation) from choosing harvest policy S and income level $y(t)$ instead of harvest policy s' and income $y(t,s')$; accordingly, the objective function in (F1) is the *net present value of the gain* from deviating from s' and income allocation rule $y(t,s')$.

Boadway and Bruce [3] caution that using a compensation function in an intertemporal setting is not a straightforward exercise. They note that when prices change, households reallocate income over time, in response to the change. Thus, when determining equivalent variation from a price change, it is inappropriate to take income within each period as fixed. The intertemporal reallocation of income is explicit in our model; the "price change", $p(t,S)$, is accompanied by the optimal reallocation of income, $y(t)$.

optimal policy. We establish that in the general case it is not optimal. The method of proof is contradiction: we assume the forest owner does maximize timber income, and we use the principle of optimality to show that the first order condition concerning the initial harvest contradicts this assumption except under special -- albeit notably relevant -- circumstances.

We begin by denoting the date of the first harvest as time s, and restating (7) in the general dynamic programming formulation (where initially the land is bare),

$$(9) \qquad L^*(0,W_0) = \max_{\substack{s,y(t) \\ 0 \le t \le \tau}} \left[L(s,y(t)) = \int_0^s e^{-it} v(\cdot)dt + \int_s^\tau e^{-it} v(\cdot)dt + e^{-i\tau} L^*(\tau - s,\ W_\tau) \right],$$

where the first argument of $L^*(\cdot)$ is the state variable concerning the age of the timber stand, and so $L^*(\tau - s, W_\tau)$ is the solution to the forest owner's problem at time τ, beginning with a timber stand of age $\tau - s$. The purpose of τ in the analysis will become apparent momentarily; for now it is enough to note that a second harvest is not optimal in the interval $[s,\tau]$. For the sake of simplicity, in our analysis W_0 is zero, so W_τ is the net gain in income over the interval $[0,\tau]$,

$$(10) \qquad W_\tau = e^{i(\tau - s)} G(s) - \int_0^s e^{i(\tau - t)} y(t)\ dt - \int_s^\tau e^{i(\tau - t)} y(t)\ dt.$$

Implicitly $L^*(\cdot)$ incorporates the income constraint (8).

Deriving the harvest condition associated with $L(\cdot)$ in (9) is not a straightforward exercise. Normally the Kuhn-Tucker Theorem would be used to derive the harvest condition,

$$L_s(\cdot) = 0,$$

where the subscript denotes the derivative of $L(\cdot)$ with respect to the decision variable s. Note, however, that $p(t,s')$ is discontinuous at time s', as shown in figure 1.[5] Just before harvest at s', $p(t,s') = p(z) = p(t)$; immediately after harvest, $p(t,s') = p(t - s')$. The upshot of this discontinuity is that the derivative $L_s(\cdot)$ may not exist at the point of interest, s'. To circumvent this problem, we restate (9) as the two-sided control problem,

5 Although $p(z)$ is continuous, the function $p(t,s')$ is discontinuous because it includes as an argument the harvest policy s'.

(11) $\max L(\cdot) \quad s.t. \quad s \le s'$

$\max L(\cdot) \quad s.t. \quad s \ge s'.$

By the Kuhn-Tucker Theorem, if s' is the optimal harvest age, and right-hand and left-hand side derivatives exist at s', then the following conditions are satisfied,

$$(12) \qquad L_s(s',\cdot)=0, \quad \lambda \ge 0,$$
$$L_s(s',\cdot)=0 \quad \gamma \ge 0,$$

where λ and γ are the Lagrangean multipliers associated with the inequality constraints in (11).

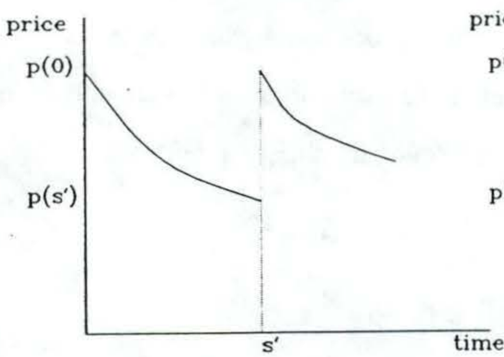

Figure 1a. $p(t, s')$, with $p_z < 0$.

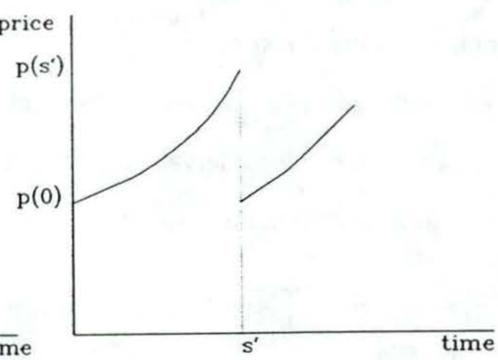

Figure 1b. $p(t, s')$, with $p_z > 0$.

Under the assumption that the forest owner maximizes timber income, two results relevant to the analysis must hold. First, the Faustmann condition for the optimal rotation age must be satisfied; formally,[6]

6 This is the necessary condition for income maximization.

$$(13) \qquad iG(s') + i\frac{e^{-i(s')}G(s')}{1-e^{-is'}} - G_z(s') = 0.$$

And second, $L^*(\cdot)$ is the net present value of income at time τ, given stand age $\tau - s$ and the income-maximizing harvest policy s':[7]

$$(14) \qquad L^*(\tau - s, W_\tau) = W_\tau + \left[\frac{e^{-i(s'-(\tau-s))}G(s')}{1-e^{-is'}}\right],$$

where the bracketed term is the net present value of timber income at stand age $\tau - s$, given that the harvest policy s' is executed after the first harvest.

In the analysis to follow, we examine whether s' solves a version of problem (11) that is modified by the imposition of result (14). To the extent it does not, a contradiction is established, and we know the forest owner does not simply maximize timber income.

After imposing result (14), and setting τ equal to s', we may state the Lagrangean associated with the first half of control problem (11) as,[8]

$$(15) \qquad L(s,y(t)) = \int_0^s e^{-it}[v(p(t),q\,;p(t),q,y(t)) - y(t)]\,dt \; + \; \int_s^{s'} e^{-it}[v(p(t),q\,;p(t-s),q,y(t)) - y(t)]\,dt$$

$$+ \; e^{-is}\left[\frac{e^{-is}G(s')}{1-e^{-is'}} + e^{i(s'-s)}G(s)\right] \; + \; \lambda(s'-s).$$

7 The derivation of (14) is straightforward. Note that under the assumption that income maximization is optimal, $v^*(\cdot) \equiv y(t)$ at every point in time, where $v^*(\cdot)$ is the optimal value of $v(\cdot)$. As a result,

$$(F2) \qquad \int_\tau^\infty e^{-it}v^*(\cdot)\,dt = \int_\tau^\infty e^{-it}y(t)\,dt,$$

The income consumed is constrained by the initial stock of income, and the present value of future timber income,

$$(F3) \qquad \int_\tau^\infty e^{-it}y(t)\,dt = W_\tau + \frac{e^{-i(s'-(\tau-s))}G(s')}{1-e^{-is'}}.$$

By definition we have,

$$(F4) \qquad L^*(\tau-s,W_\tau) = \int_\tau^\infty e^{-it}v^*(\cdot)\,dt.$$

Substituting (F3) and (F4) into (F2) yields (14).

8 Implicitly, we assume that at most one harvest is feasible in the interval $[0,s']$. As a result, we know that in the interval $[s,s']$,

$p(t,S) \equiv p(t-s)$.

This is a reasonable assumption which, though not necessary to obtain the results below, greatly simplifies the analysis.

In light of the smoothness assumptions about $v(\cdot)$, $p(z)$, and $G(z)$, $L(\cdot)$ is everywhere differentiable with respect to s in the closed interval, $[0,s]$; in particular, the left-hand side derivative of $L(\cdot)$ exists at s'. Consequently, necessary conditions for an optimum include (assuming $s>0$),[9]

$$(16) \qquad y(s) - v(p(s),q;p(0),q,y(s)) - \int_s^{s'} e^{-it} v_p p_z \, dt + \left[G_z(s) - iG(s) - i\frac{e^{-i(s')}G(s')}{1-e^{-is'}} \right] - \lambda = 0.$$

where the source of the derivative v_p is clear from (15). From (13), we know that at s' the bracketed term equals zero. Moreover, the integral term disappears and $\lambda \geq 0$. Thus, if s' is the optimal harvest age, the following condition must hold,

$$(17) \qquad y(s') - v(p(s'),q;p(0),q,y(s')) \geq 0.$$

We now turn to the second half of the forest owner's control problem (11), where $s \geq s'$. In this case, imposing condition (14) and setting τ equal to s yields the Lagrangean,

$$(18) \qquad L(s,y(t)) = \int_0^{s'} e^{-it}[v(p(t),q;p(t),q,y(t)) - y(t)] \, dt + \int_{s'}^{s} e^{-it}[v(p(t-s'),q;p(t),q,y(t)) - y(t)] \, dt$$
$$+ e^{-is}\left[\frac{e^{-is'}G(s')}{1-e^{-is'}} + G(s) \right] - \gamma(s'-s).$$

We know that $L(\cdot)$ is everywhere differentiable with respect to s in the interval, $[s',\infty)$; in particular, the right-hand side derivative of $L(\cdot)$ exists at s'. Necessary conditions for an optimum include,

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9 This condition represents the Kuhn-Tucker conditon, $L_s(\cdot) = 0$. To see this, note that taking the partial derivative of (15) with respect to s yields,

$$(F5) \qquad [v(p(s),q;p(s),q,y(s)^-) - y(s)^-] - [v(p(s),q;p(0),q,y(s)^+) - y(s)^+] - \int_s^{s'} e^{-it} v_p p_z \, dt$$
$$+ \left[G_z(s) - iG(s) - i\frac{e^{-i(s')}G(s')}{1-e^{-is'}} \right] - \lambda = 0,$$

where we differentiate income at harvest by $y(s)^-$ and $y(s)^+$, because the discontinuity of prices at s may warrant a discontinuity in the optimal allocation of income at s. Now note that by definition, the first bracketed term in (F5) is zero. Condition (16) is obtained by dropping this term, and also dropping the superscript on income, which is no longer needed to distinguish income levels.

$$(19) \qquad v(p(s-s'),q\,;p(s),q,y(s)) \; - \; y(s) \; + \left[G_s(s) \; - \; iG(s) \; - \; i\frac{e^{-i(s')}G(s')}{1-e^{-is'}} \right] + \; \gamma \; = \; 0.$$

Again, from (13) we know that at s' the bracketed term equals zero, and we also know that $\gamma \geq 0$. Thus, if s' is the optimal harvest age, the following condition must hold,

$$(20) \qquad y(s') \; - \; v(p(0),q\,;p(s'),q,y(s')) \; \geq \; 0.$$

In the general case, conditions (17) and (20) are contradictory. Suppose, for instance, that the price of the nontimber good on the forest owner's land is a strictly decreasing function of stand age; the older the timber stand, the lower the price of the nontimber good (it is less scarce). Then $p(0) > p(s')$, and in the general case, condition (17) is satisfied; the amount of income needed by the forest owner at price $p(s')$ to be as well off as he is with price $p(0)$ and income $y(s')$ is *less than* $y(s')$. On the other hand, condition (20) is *not* met; the amount of income needed by the forest owner at price $p(0)$ to be as well off as he is with price $p(s')$ and income $y(s')$ is *greater than* $y(s')$. Finally, if the price of the nontimber good on the forest owner's land is a strictly increasing function of stand age, so that, $p(s') > p(0)$, then following the same line of reasoning as above, we may conclude that in the general case condition (20) is met, and condition (17) is not.

Only under special circumstances are conditions (17) and (20) consistent with income-maximizing behavior. One is the trivial case where $p(0) = p(s')$. Another is the case where the price of the nontimber good on neighboring land is lower than $p(0)$ and $p(s')$. In this case the forest owner does not consume the nontimber good on his own land, and so we have,

$$v(p(0),q\,;p(s'),q,y(s')) \; = \; v(p(s'),q\,;p(0),q,y(s')) \; = \; v(q\,;q,y(s')) \; = \; y(s'),$$

in which case both (17) and (20) are satisfied. Quite simply, nothing is gained by a marginal deviation from the optimal harvest age s', because the nontimber good is readily available elsewhere.

At first glance, these restrictive circumstances for income-maximizing behavior seem paradoxical in light of our results for the static model in the previous section. Note, however, that whereas in the static model, income maximization is represented by a *corner* solution $(h = x_0)$, in the dynamic model this result is an *interior* solution $(0 < s < \infty)$. At the income-maximizing solution of the static model, the marginal change in income from an increase in the decision variable (the harvest volume h) is *positive*, and the argument used to suggest firms might maximize timber income is that this marginal gain is greater than the welfare loss associated with the corresponding increase in the price of the nontimber good. On the other hand, at the Faustmann rotation age of the dynamic model, the marginal change in income from an increase in the decision variable (the harvest age s) is *zero*, as expected for an interior solution, and so in the general case, the welfare gain from the increase in s which arises because of the reduction in the price of the nontimber good is sufficient for a net welfare improvement.[10]

In the general case, the results from the dynamic model reinforce the conclusion of Hartman [13], that when a standing forest has value, the Faustmann rule for harvesting timber is no longer optimal. Our model differs from the Hartman model in two important ways. First, our model emphasizes the role of neighboring forestland in the value of the recreational services provided by a parcel of forestland. Second, our model explicitly recognizes that the value of recreational services depends on timber income. The Hartman model does not recognize a budget constraint; it does not recognize, in other words, that the income from timber sales affects the wealth of consumers, and so indirectly, the value of the recreational services provided by the forest. For public forests, the Hartman model is perfectly appropriate, since for all practical purposes, the incomes of forest visitors are unaffected by timber revenues. On the other hand, one would expect that private forest owners understand that their opportunity to enjoy the recreational services flowing from a standing forest depends at least partly on the income the forest provides. Failure to recognize this relationship leads to a bias away from the income-maximizing harvest policy.

A more realistic view of forest owner behavior than presented in our dynamic model would recognize that forest owners confront the harvest decision only periodically -- perhaps once a year or once every few years. Reasoning by analogy with the continuous time case, we can develop a convincing albeit heuristic argument that in this case forest owners may indeed harvest timber in the income-maximizing period s', even when q is not lower than both $p(0)$ and $p(s')$. Suppose, for instance, that optimal harvest age s is no less than s', and sufficiency conditions are such that the decision to harvest at s' is

10 Obviously we assume $p_s < 0$. A comparable argument for moving away from the Faustmann rotation age can be made for the opposite case.

optimal if the cost from postponing the harvest to $s'+1$ exceeds the corresponding gain; in other words, if this marginal condition is met, we have a global maximum at s'. The crucial difference between this marginal condition and its counterpart in the continuous-time framework is that here the minimum length of postponement is positive, and so in the general case the income *loss* from a "marginal" (i.e., one-period) postponement is positive. The *gain* from postponing harvest arises from the difference between the price of the nontimber good when the timber stand is mature, and the price when it is recently cut. If q is less than $p(0)$, but greater than $p(s'+1)$, the point of comparison when discussing the immediate price advantage from postponing the harvest is not between $p(s'+1)$ and $p(0)$, but rather between $p(s'+1)$ and q; the lower the value of q, the smaller the price advantage of postponing the harvest. Intuition suggests that there exists a reservation price of the good on neighboring land, q^*, at which the forest owner is indifferent between harvesting timber at s' and postponing the harvest, and below which the forest owner harvests at s'. Quite simply, below q^* the price of the good on neighboring land is "low enough" that the welfare gain from postponing the harvest does not exceed the welfare loss of the foregone timber income. So, for instance, returning to the example of the rare bird species in the introduction, if the (implicit) price of birdwatching on neighboring land is lower than the reservation price, the forest owner harvests timber at the income-maximizing rotation age, despite the pleasure he gains from birdwatching. Moreover, if this off-site price lies between the on-site price at stand age s' and the on-site price at stand age 0, the forest owner does his birdwatching on his own land before harvest, and on neighboring land after harvest.

Extending the argument, let q^*_i denote the reservation price of the nontimber good on neighboring land, at or below which the forest owner with a timber stand of age $s'+i$ chooses to harvest. For the case under consideration, where $s \geq s'$, we might expect that under fairly general circumstances,

$$q^*_i \leq q^*_{i+1}, \quad i \geq 0,$$

at least in the right-hand neighborhood of s'. In words, the reservation price (below which the forest owner harvests timber) rises as the stand age increases. Accordingly, as q declines, the forest owner's harvest policy approaches the income maximizing harvest policy s'.

3.0 Review of the Regression Results of Previous Studies

The foregoing discussion establishes the circumstances under which the forest owner maximizes timber income. In the static model this possibility seems especially likely; in the dynamic model it arises under more restrictive but arguably prevalent circumstances. To the extent that forest owners manage their forests to maximize timber income, we should find evidence of such behavior in the published regression results of BB&D. Binkley and Dennis examined the harvest behavior of forest owners in New Hampshire. Boyd examined the harvest behavior of forest owners in North Carolina. In all three studies, the random variable of interest concerned whether a forest owner harvested timber in a particular year (coded "1" if harvest occurred, and "0" otherwise). Moreover, in all studies the implicit assumption underlying the explanations of coefficient signs is that the trade-off between timber income and nontimber goods induces the postponement of timber harvest.

Dennis used pooled time-series and cross-sectional data for the period 1973-83. In some regressions, Binkley used pooled time-series and cross-sectional data for the period 1947-73; in others, he used cross-sectional data for 1973 only. Boyd used cross-sectional data for 1980. Detailed accounts of the regression analyses can be found in the primary sources. Insofar as we examine previously published results, no statistical claims are made here. Rather, we simply ask the question, is an income maximization model refuted by the regression results?

Table 1 lists the explanatory variables used in the regression analyses. To a large extent, the ex ante and ex post explanations of coefficient signs provided by BB&D are at least partially consistent with an income-maximizing model. For instance, concerning the size of the forest holding and timber volume, Dennis observes, "A positive relationship was anticipated between both size of forest holding and per-acre timber volume and the probability of timber harvest *due to economies of scale*, and the assumption of decreasing marginal utility of timber reserved for amenities" (pg. 182, emphasis added). The former explanation of a positive expected sign is consistent with an income maximization model, though the latter is not. As another example, Boyd states, "The effect of education is not clearly described by our model, but to the extent that education increases awareness of technological and market opportunities its effect on both of our dependent variables should be positive" (p. 100).[11] Again, this explanation of the expected sign does not preclude income maximizing behavior.

For three variables, the ex ante or ex post explanations of coefficient signs offered by BB&D are clearly inconsistent with income maximization. Accordingly, we focus attention on these variables.

Table 1. Definitions of Explanatory Variables

PRICE	Index of stumpage prices
ACREAGE	Size of forestland, in acres (in Dennis, the logarithm of acreage)
DIST	Distance between the forest owner's residence and forest holding
INCOME	Exogenous income (in Dennis, a dummy variable coded 1 if income is greater than $30,000, and 0 otherwise).
AGE	Age of the forest owner
EDUC	Years of schooling
INT	The interest rate, based on 3 year Treasury bills
MBF	Timber stand volume in million board feet
PRO	A dummy variable coded 1 for forest owners with professional occupations, and 0 otherwise
RP	Proportion of forest stand in white pine
FARM	A farm vs. nonfarm dummy variable, coded 1 for farmer, 0 otherwise
TECH	A technology dummy variable coded 1 if the forest owner received technical advice from an extension forester, and 0 otherwise
FIP	A cost-sharing dummy variable coded 1 if the forest owner had knowledge of federal timber management cost-sharing opportunities, and 0 otherwise

<u>Technological Advice (TECH)</u>

Boyd included as a regressor a dummy variable concerning whether the forest owner received technical advice from an extension forester. He expected a positive sign, based on comparative static results indicating that an increase in "timber growing technology" shifts the timber-amenities production possibilities frontier in a manner favoring timber. However, the value of technical information is derived

11 The other dependent variable to which Boyd refers concerns timber stand improvements. Regression results for this variable are not examined here.

from the extent to which it allows the recipient to reduce uncertainty concerning the growing technology. In this light, the assertion that advice from a professional forester serves to increase the probability of harvest reflects the presumption that before receiving such advice, forest owners' subjective judgements concerning the growing technology are systematically biased towards a low rate of harvest. Such a presumption may be difficult to justify; essentially it must be argued that a lack of knowledge about timber growth is more likely to reduce the probability of harvest than increase it. Arguably the causal relationship between the harvest decision and the receipt of technical information is more complex than currently developed in the literature. An alternative reason to expect a positive sign on the technology dummy is that forest owners who have made a decision to harvest are more likely to seek the advice of a professional forester than are forest owners with no harvest plans. In other words, causality is not well-established for this variable.

Exogenous Income (INC)

The theoretical models of Binkley, Boyd, and Max and Lehman all predict that an increase in exogenous income reduces timber supply (and presumably lowers the probability of harvest in a given year), because nontimber forestland goods are normal goods. Under an income maximization model, the probability of harvest is not directly affected by exogenous income; both a wealthy forest owner and a poor one will execute Faustmann-type decision rules. To the extent forest owners find it difficult to borrow against their forestry investments, certain forest management activities involving large initial expenditures, such as reforestation, may be affected by exogenous income. Royer [17] found exogenous income increases the probability of reforestation in the South. In this case the harvest decision, which does not involve significant expenditures by the forest owner, would be indirectly affected by exogenous income, because forestry investments alter optimal rotation lengths. This indirect relationship between exogenous income and the probability of harvest is statistically controlled when stand characteristics are considered in regression analysis, as in Dennis.

Absentee Ownership (DIST)

Boyd extends his household production model to conclude that because timber is the relatively labor intensive production sector, and recreation is the relatively capital (timber) intensive sector, an increase in the distance between an absentee owner's residence and forestland results in a *decrease* in the probability of harvest. On the other hand, under the income maximization model absentee and resident forest owners alike maximize timber income, and so the distance variable would have no affect on the probability of harvest.

Interestingly, the theoretical models presented above suggest that if the variable concerning absentee ownership has any effect on the harvest decision, it *increases* the probability of harvest. An increase in the distance between a forest owner's residence and his forestland increases $p(z)$ relative to the price of consuming the forestland good elsewhere. Put another way, q is *lower* relative to $p(z)$ for absentee forest owners than for resident forest owners, so we would expect absentee forest owners to harvest more often. The intuition is fairly obvious: a forest owner residing one hundred miles from his forestland is quite likely to find the recreational services of his forestland within a one hundred mile radius of his residence, in which case he would have no reason to forego timber income by postponing harvest.

3.1 Regression Results

Table 2 reproduces regression results from BB&D. Two of the twelve regression equations derived by Binkley are presented; these are fairly representative of the full set of equations. In light of the discussion above, the variables of greatest interest are INC and DIST (Tables 1 and 2); significant coefficients on these variables serve to refute the income maximization model of harvest behavior. In the Binkley study, INC is significant at the .05 level in one regression and not in the other.[12] In the Dennis study, INC is significant at the .05 level, although the author notes that when forest owner education is included in the equation, INC is not significant. In the Boyd study, INC is not significant. Dennis

12 Overall, INCOME is significant at the .05 level in three of the twelve regression equations presented by Binkley.

eliminated from his analysis a variable concerning absentee ownership when he found it to have no significant effect on the probability of harvest. In the results presented by Boyd, DIST is not significant at the .05 level.

Table 2. Regression Results (Dependent Variable is Harvest/No Harvest)

	Binkley-1[a]	Binkley-2	Boyd	Dennis
	Coefficient Estimate (t-value)			
PRICE	.0686 (2.89)	.210 (3.41)	.0101 (1.96)	.040 (.93)
ACREAGE	.604 (6.90)	.889 (4.32)	.0071 (3.19)	.202 (1.14)
DIST	-	-	-.0025 (-1.45)	b
INCOME	-.0214 (-2.00)	-.00654 (-.311)	-.0002 (-.357)	-1.244 (-2.27)
AGE	-.00539 (-.702)	.0154 (.824)	-	-
EDUC	.00611 (.200)	.0357 (.438)	.0076 (.283)	-
INT	-	-	-	-.103 (-1.256)
MBF	-	-	-	.483 (2.166)
PRO	-	-	-	.883 (1.695)
RP	-	-	-	1.595 (2.176)
FARM	-	-	.7837 (2.993)	-
TECH	-	-	.862 (3.164)	-
FIP	-	-	.182 (.775)	

a Binkley-1 includes pooled time-series and cross-sectional data for the period 1943-73. Binkley-2 includes only observations for 1973.

b Dennis reports that in an alternative model, a dummy variable concerning absentee ownership was nonsignificant.

4.0 Policy Implications and Conclusions

The upshot of the foregoing analysis is that the matter of choosing the appropriate model of timber supply from nonindustrial private forests is not a settled issue. Insofar as the income coefficient was significant in the Dennis study, and significant in four of twelve regressions in the Binkley study (see footnote 12), these studies provide a somewhat weak refutation of the income maximization hypothesis. The regression results in Boyd seem consistent with income-maximizing behavior. As we demonstrated with the dynamic and static models of forest owner behavior, acceptance of the premise that forest owners attempt to maximize timber income *does not* imply rejection of the sensible view that forest owners benefit from the nontimber goods and services produced on forestland.

Perhaps the appropriate model of forest owner behavior depends on the region under study; arguably the conventional utility maximization hypothesis is appropriate in the northeast, and an income maximization model is appropriate in the southeast. A heuristic comparison of the northeast and southeast suggests why this might be so. For the most part, timber production is a more valuable land use in the southeast than in the northeast, so that postponing harvest is more costly in the southeast. Moreover, we would venture to guess that access to neighboring lands is less difficult --that is, the price of consuming nontimber goods on neighboring lands is cheaper -- in the southeast than in the northeast. The studies of Brown and Thompson [7], and Brown, Decker and Kelley [6], indicate that forestland accessibility is greatest in those areas where population density and annual income are low; where, more to the point, recreation demand is low. Landowners go to the trouble of closing their lands (by posting) when conflicts arise with recreationists. Conflicts arise relatively infrequently in areas with low recreation demand. Still, quite apart from the general level of recreation demand, in those areas where the social fabric of traditional rural society persists -- where forest owners consider it neighborly if not a community obligation to permit neighbors to recreate on their land -- private forests closed to the general public may remain open to neighbors.

The analysis and discussion above suggest amendments to the research agenda implied by the conventional wisdom about forest owners. For instance, it may prove fruitful to identify areas where private forestland remains an accessible resource with respect to nontimber forest outputs. In these areas the income maximization framework may well provide an adequate approximation of forest owner behavior, and so policy instruments to influence timber supply from private forests would need to focus primarily on the traditional barriers to intensive forestry, such as risk, lack of information, and capital constraints.

Finally, the analysis suggests that public policy concerning outdoor recreation on private forests is ultimately a matter affecting timber policy. Knowledgeable observers predict that the accessibility of forestland for recreation will decrease in the future (see, for instance, Gramann, Bonnicksen, Albrecht and Kurtz [12], and Cordell and Stevens [9]). Government efforts to keep private forests open for public recreation affect the economic scarcity of nontimber forest goods [15], and consequently may affect the timber supply from private forestland.

References

1. D.M. Adams, R.W. Haynes, G.F. Dutrow, R.L. Barber, and J.M. Vasievich, Private investment in forest management and the long-term supply of timber, *Amer. J. Agr. Econom.* 64, 232-240 (1982).

2. C.S. Binkley, "Timber Supply from Nonindustrial Forests: a Microeconomic Analysis of Landowner Behavior," Yale University Press, New Haven (1981).

3. R. Boadway and N. Bruce, "Welfare Economics", Basil Blackwell, Cambridge MA (1984).

4. R. Boyd, Government support of nonindustrial production: the case of private forests, *South. Econom. J.* 51, 89-107 (1984).

5. D.J. Brooks, Public policy and long-term timber supply in the South, *Forest Science* 31, 342-357 (1985).

6. T. Brown, D. Decker, and J. Kelley, Access to private lands for hunting in New York: 1963-1980, *Wildl. Soc. Bull.* 12, 344-349 (1984).

7. T. Brown, and D. Thompson, Changes in posting and landowner attitudes in New York State, 1963-1983, *New York Fish and Game J.* 23, 101-137 (1976).

8. S. Calish, R.D. Fight, and D.E. Teeguarden, How do nontimber values affect Douglas-fir rotations? *J. Forest.* 76, 217-221 (1978).

9. H.K. Cordell and J. Stevens, A national survey to determine public outdoor recreation opportunities on nonindustrial private forest and range lands, *in* "Nonindustrial Private Forests: a Review of Economic and Policy Studies" (J. Royer and C. Risbrudt, Eds.), Duke University Press, Durham (1983).

10. D.F. Dennis, A probit analysis of the harvest decision using pooled time-series and cross-sectional data, *J. Environ. Econom. Management* 18, 176-187 (1990).

11. R.H. Giles, "Wildlife Management," Freeman, San Francisco (1978).

12. J.T. Gramann, T. Bonnicksen, D. Albrecht, and W. Kurtz, Recreational access to private forests: the impact of hobby farming and exclusivity, *J. Leisure Res.* 17, 234-240 (1985).

13. R. Hartman, The harvesting decision when a standing forest has value, *Econom. Inquiry* 14, 52-58 (1976).

14. P. Johansson, "The Economic Theory and Measurement of Environmental Benefits", Cambridge University Press, Cambridge (1987).

15. L.L. Lagner, Demand for outdoor recreation in the United States: implications for private landowners in the eastern U.S., *in* "Conference Proceedings: Income Opportunities for the Private Landowner through Management of Natural Resources and Recreational Access" (W.N. Grafton, A Ferrise, D. Colyer, D.K. Smith, and J.E. Miller, Eds.), West Virginia University Extension Service, Morgantown, West Virginia (1990).

16. W. Max and D. Lehman, A behavioral model of timber supply, *J. Environ. Econom. Management* 15, 71-86 (1988).

17. J.P. Royer, Determinants of reforestation behavior among southern landowners, *Forest Sci.* 33, 654-667 (1987).

18. U.S. Department of Agriculture, "An Analysis of the Timber Situation in the United States, 1952-2030," Forest Service, Forest Research Report No. 23 (1982).

19. H. Varian, "Microeconomic Analysis", W.W. Norton and Co., New York (1984).