Forest Management and Nontimber Attributes:
A Graphical Approach

by

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ABSTRACT

Forest management from an economic perspective has sought to identify practices, (for example, cutting, thinning and insecticide applications), which promote financial maturity, often interpreted as the maximization of the present value of net revenues. While nontimber services such as habitat, flood control, and aesthetics are acknowledged to exist only a few authors have attempted to incorporate these values into a model of financial management and thus identify those practices that are "best" from the point of view of providing the desired mix of monetary and nonmonetary service flows. This paper presents a relatively simple graphical analysis for determining the underlying nature of the trade-off between revenue and a single nontimber attribute. The graphical analysis serves to highlight points made by earlier authors and can be used to assess the value of a more detailed multiobjective analysis.

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I. Introduction and Overview

Forest management by public agencies or small woodlot owners if often conducted so as to promote a diverse set of monetary and nonmonetary objectives. Forest economics has traditionally focused on practices which promote financial maturity, often interpreted as the maximization of the present value of net revenues. For even-aged stands the Faustmann equation has been regarded as the theoretically correct approach for determining the optimal economic rotation. If jointly-produced forest services such as recreation, flood control and wildlife habitat are deemed important, Hartman [6] has shown that management practices may logically depart from the Faustmann rotation.

In an empirical study of nontimber values in stands of Douglas-fir; Calish, Fight, and Teeguarden [2] developed seven nontimber, rotation-dependent, yield functions for Columbian black-tailed deer, Roosevelt elk, water, cutthrout trout, wildlife diversity, visual aesthetics, and mass soil movement. They identify optimal rotations for timber and each nontimber attribute where somewhat arbitrary unit values are assigned to deer, elk, trout, water, nongame diversity, visual aesthetics and soil loss per acre. Since each nontimber attribute has been assigned a value they can identify seven jointly optimal rotations when timber value is simultaneously considered with each nontimber attribute. The authors conclude: (1) the joint rotation may be shorter or longer than the Faustmann rotation depending on the shape of the nontimber yield function and unit values (assigned prices), (2) that the length of the joint rotation seemed relatively insensitive to the introduction and variation of nontimber values, (3) the opportunity cost (timber revenues foregone) of rotations that maximize a single nontimber value can be high, and (4) "just as there may be conflict between timber production and nontimber values, so is there conflict among nontimber values" (Calish, Fight, and Teeguarden [2, p. 221]).

This paper does not offer any new solutions to the problem of multiple objective forest management. Its value lies in a clarification of prevailing issues and in the development of a graphical construct which can identify the type of trade-off that exists between timber revenue and different nontimber attributes. The model does not require monetary evaluation of nontimber attributes; yet will provide information on the change in timber revenues per incremental change in the attribute. The graphics can provide a quick initial assessment on the nature of prevailing trade-offs and thus assist in determining whether a more detailed evaluation analysis would be in order.

The next section contains a brief review of the Faustmann model. This is followed by a section which presents four plausible shapes for nontimber attribute functions. The fourth section combines the Faustmann analysis with each of the attribute functions and derives a set of trade-off or transformation curves. The final section outlines how the analysis might be extended to a multiple objective framework permitting the simultaneous consideration of timber revenue and two or more nontimber attributes.

II. The Faustmann Model

The Faustmann model assumes a fixed amount of land will be used for timber production and that soil productivity, timber prices, and harvest costs remain constant into the foreseeable future. Under these assumptions the present value of net revenues or "stumpage value" would be calculated according to the infinite series:

$$V = \pi(T_1)e^{-\delta T_1} + \pi(T_2-T_1)e^{-\delta T_2} + \pi(T_3-T_2)e^{-\delta T_3} + \ldots \qquad (1)$$

where $\pi(\cdot)$ is net revenue from harvest and δ is the discount rate. With unchanging prices, costs, and soil productivity, however, the optimal rotation periods will be of equal length such that $T_k = kT$, and the present value of net revenues may be written as:

$$V = \sum_{k=1}^{\infty} \pi(T)e^{-k\delta T} = \frac{\pi(T)e^{-\delta T}}{1-e^{-\delta T}} = \frac{\pi(T)}{e^{\delta T}-1} \quad (2)$$

Maximization of V via selection of T requires

$$\frac{dV}{dT} = \frac{(e^{\delta T} - 1)\ \pi'(T) - \pi(T)\ \delta e^{\delta T}}{(e^{\delta T} - 1)^2} = 0 \quad (3)$$

Given that the denominator will be positive for $\delta T > 0$, the optimal rotation period, T^*, will equate the numerator to zero implying that

$$\pi'(T^*) = \frac{\delta\pi(T^*)}{1 - e^{-\delta T^*}} \quad (4)$$

or that

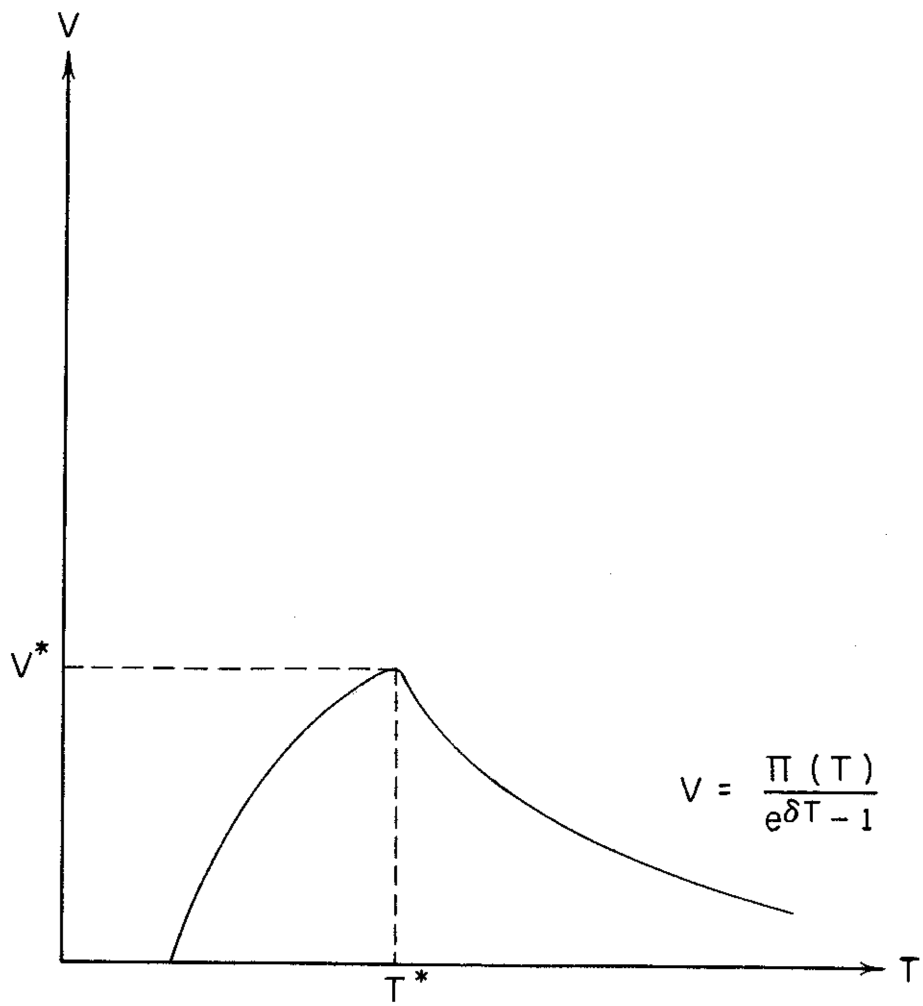
$$\pi'(T^*) = \delta\pi(T^*) + \pi'(T^*)e^{-\delta T^*} \quad (5)$$

Equation (5) is a management rule which says the optimal ortation should be one which equates the marginal gain in the value of standing timber, $(\pi'(T^*))$, to the sum of foregone interest payments if the current stand had been harvested earlier, $(\delta\pi(T^*))$, plus the cost of marginally postponing future harvests, $(\pi'(T^*)e^{-\delta T^*})$. This latter term is often referred to as "site value" or "soil rent." Thus equation (5) requires "that the forest be cut at an age T^*, when the marginal increment to the value of the trees equals the sum of the opportunity costs of investment tied up in the standing trees and in the site" (Clark, [3, p. 259]). A graph of the present value of net revenues, indicating a maximum at $T=T^*$ is shown in Figure 1.

III. Nontimber Attributes

The Faustmann model has been criticized not only on the basis of its assumptions about constant prices, costs, and soil productivity, but because it selects a rotation period based solely on present value considerations and ignores other forest services such as flood control, recreation, and wildlife habitat. For a

FIGURE I. OPTIMAL ROTATION WHEN MAXIMIZING THE PRESENT VALUE OF NET REVENUES



private woodlot owner, and most certainly a public agency charged with the management of collectively held timber lands, these joint-product or externality considerations should be taken into account. Samuleson sums it up nicely:

> Once a society achieves certain average levels of well-being and affluence, it is reasonable to suppose that citizens will democratically decide to forego some calories and marginal private consumption enjoyments in favor of helping to preserve certain forms of life threatened by extinction. It is well-known that clearcutting forests is one way of altering the Darwinian environment. Therefore, pursuit of simple commercial advantage in forest management may have as a joint product reversible or irreversible effects upon the environment. When information of these trade-offs is made available to the electorate, by that same pluralistic process which determines how much shall be spent on defense and other social goods, and how much shall be taxed for interpersonal redistributions of income, the electorate will decide to interfere with laissez-faire in forest management. This might show itself, for example, in forest sanctuaries of some size located in some density around the nation: the optimal cutting age there and indeed the whole mode of timber culture will have little to do with Faustmann copybook algorithm. Or, putting the matter more accurately, I would have to say the future vector of real costs and real benefits of each alternative will have to be scrutinized in terms of a generalization of the spirit and letter of the Faustmann-Fisher calculus. (Samuelson, [7, p. 486]).

These joint services have been formally introduced into a forest management model by Hartman [6]. In his analysis Hartman assumes that the value of recreational, flood control, and wildlife benefits can be measured and denoted by F(t). For a single rotation of length T the present value of such benefits would be calculated as

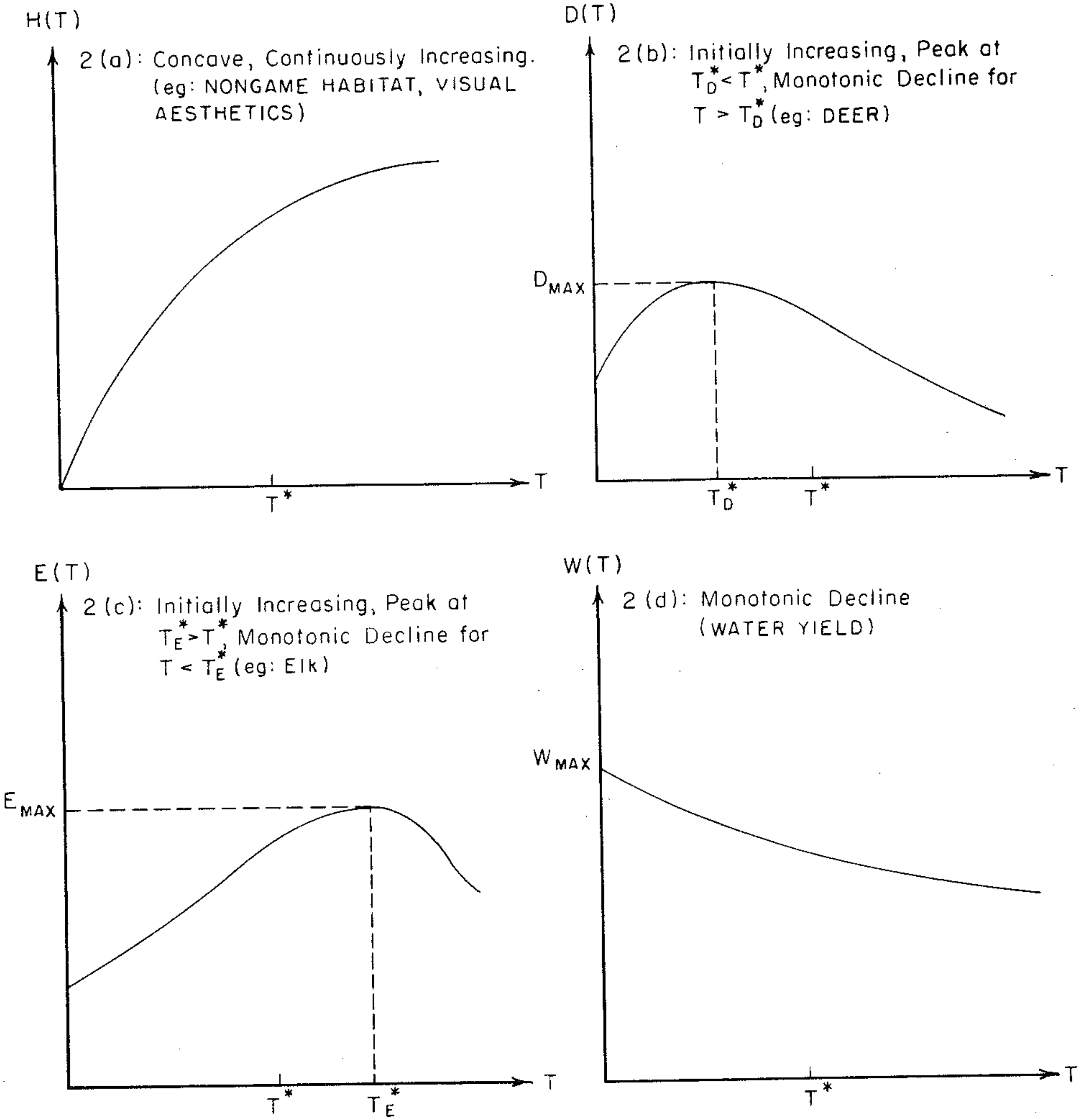
$$F = \int_0^T F(x)e^{-\delta x}\,dx \qquad (6)$$

Hartman then develops a modified Faustmann rule based on the maximization of the present value of net timber and joint service benefits.

The approach taken here is less presumptuous in the sense that it does not assume that the value, (in dollars), of joint-services can be measured. Rather, a slightly less demanding assumption is made that one or more of the joint-services can be measured in physical terms or by an index. For example, suppose the number of cavity and foraging trees per unit area could be counted and functionally related to the age of a forest stand. While it might be possible to measure the relationship between certain habitat characteristics and age of stand, it is usually much more difficult to take the next step and determine the monetary value associated with alternative levels of the characteristic or index. What seems more plausible is to provide the forest owner or manager with information on the nature of any trade-offs involved when he or she is concerned with two or more noncomparable objectives. If one of the objectives is the present value of net revenues, then the manager has the advantage of knowing what an additional unit of the habitat attribute is going to cost in terms of foregone present value.

Suppose that the yield per acre for certain species, (for example deer, elk, and trout), can be determined as a function of the rotation age adopted within a large "regulated" forest containing a mix of age classes in close proximity. Other attributes such as nongame diversity or visual aesthetics might be described by a per acre index. What might these yield and index functions look like? Figure 2 contains four functional relationships which would seem to cover most nontimber attributes. Figure 2(a) describes an attribute which is a concave, continuously increasing function of rotation length. Indices of visual aesthetics and wildlife diversity are thought to have this type of shape. Deer and elk will browse on new growth and can benefit from shorter rotations. Cover and habitat requirements for elk exceed those of blacktail deer and therefore they prefer a longer rotation. Figure 2(b) shows a yield function for deer where maximal yield per acre is actually achieved at a rotation shorter than that which would be adopted based on timber revenue considerations alone; that is, $T_D^* < T^*$. Figure 2(c) shows the presumed yield function for elk, which because of cover requirements peaks at $T_E^* > T^*$. Finally, figure 2(d) shows a gently declining water yield function implying that more mature forest stands will intercept some additional amounts of water within a watershed denying it to potential "downstream" users.

FIGURE 2. PLAUSIBLE FUNCTIONS FOR NONTIMBER ATTRIBUTES



IV. Revenue and Attribute Trade-Offs

If the only objective of forest management were to maximize the present value of net revenues, then the optimal rotation would be one satisfying Faustmann's formula given in equation (5) and occurring at $T = T^*$ in Figure 1. If revenue and a nontimber attribute are both important the analysis becomes slightly more complex and is portrayed in Figure 3, which derives a trade-off curve for revenue and habitat.

In quadrant I the relationship between present value and length of rotation had been rotated 270°. Note the maximum present value is still V^* occurring at T^*. Consider the rotation lengths capable of yielding $V_1 < V^*$. This level of present value can be achieved at T_1 and T_1'. Projecting these values up to the 45° line in quadrant II and across to the habitat curve, (identical to Figure 2(a)), in quadrant III one obtains two values H_1 and H_1'. These values are plotted with V_1 in quadrant IV. One could proceed in a similar fashion for other present values $V < V^*$. Each value could be achieved by two rotation lengths and would be plotted with the two corresponding habitat levels in quadrant IV. Connecting all such points would yield an H-V trade-off or "possibility" curve for the forest site in question. Moving along the trade-off curve from its intersection on the H-axis the forest manager would initially have the best of both worlds: increases in H <u>and</u> V. Beyond H^*, however, increases in habitat can only be achieved through reductions in present value.

Different attribute functions will result in different trade-off curves. Figure 4 shows the trade-off curves corresponding to the nontimber attributes in Figure 2. Figure 4(a) is the H-V curve derived previously. Assuming that both revenues and habitat are positively valued the trade-off interval would be the downward sloping segment where $T > T^*$. For blacktail deer the trade-off curve starts at the intercept on the D axis and is positively sloped until deer yield reaches a maximum at $D_{max}(T=T_D^*)$, whereupon any additional increase in revenue can only be obtained by a reduction in yield. The backward bending segment along which

FIGURE 3. DERIVATION OF A REVENUE-HABITAT TRADE-OFF CURVE

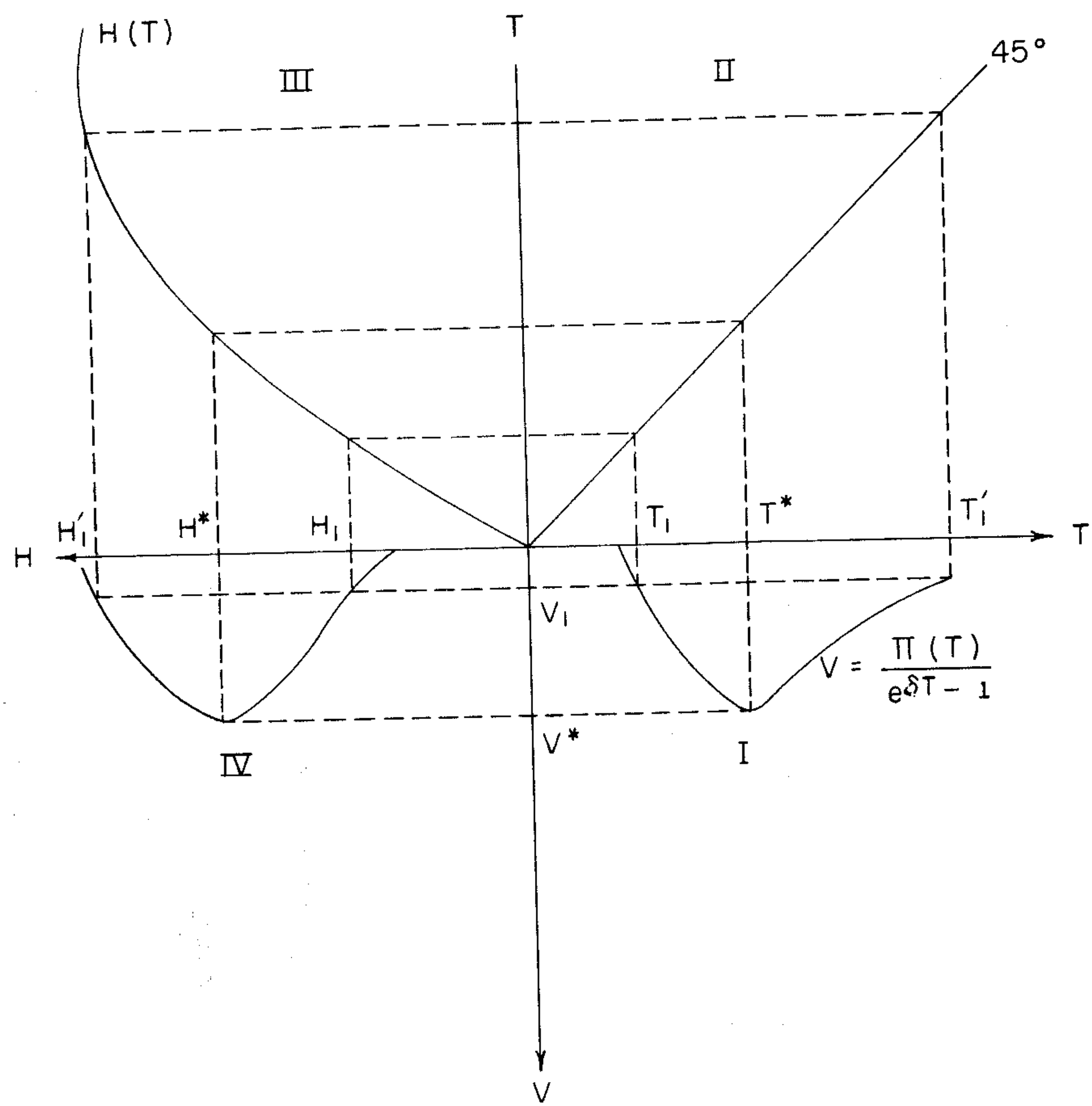
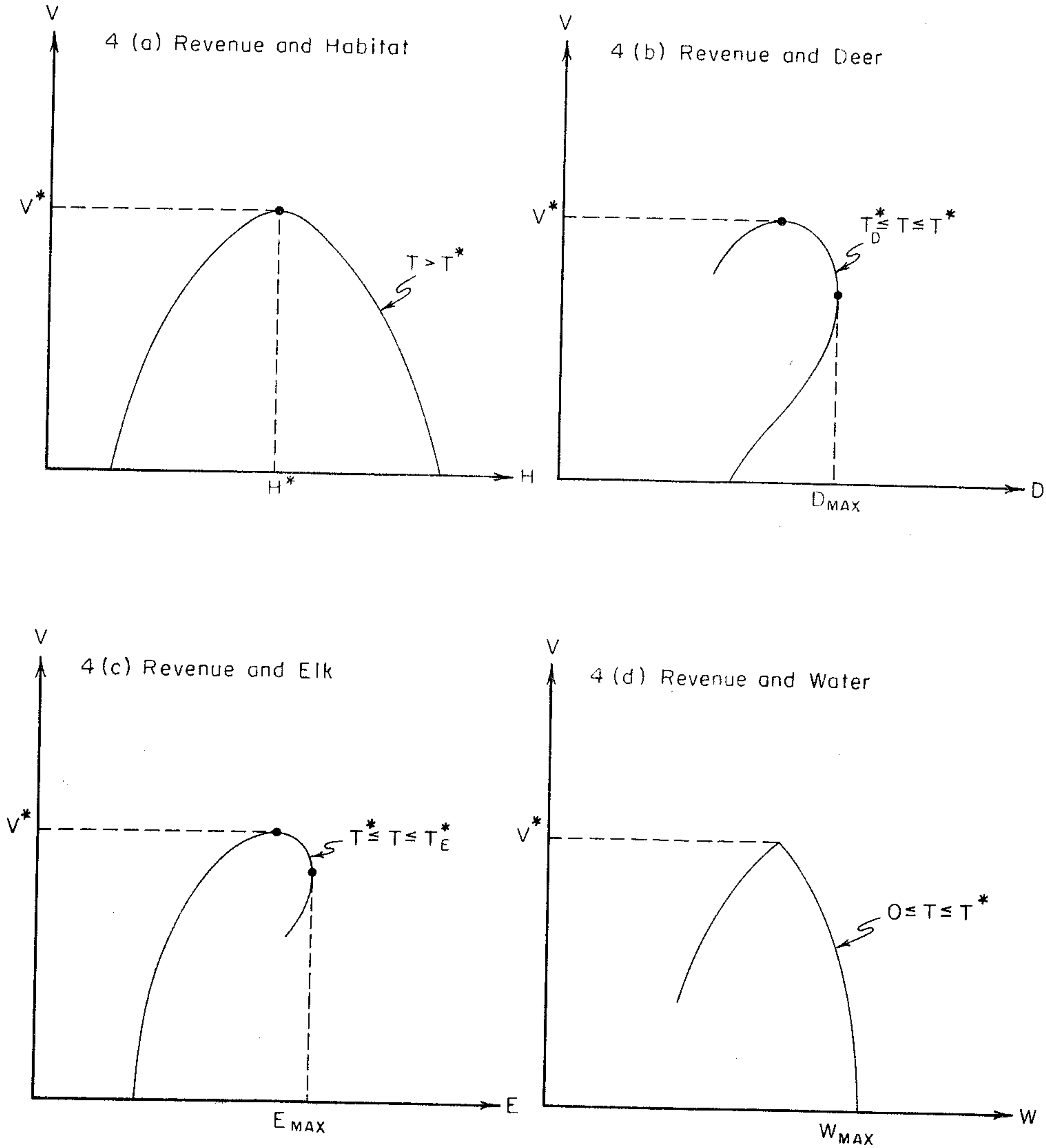


FIGURE 4. REVENUE AND ATTRIBUTE TRADE-OFF CURVES



$T_D^* \leq T \leq T^*$ becomes the relevant trade-off interval. In Figure 4(c) revenue and elk yield both increase until present value is maximized at V*. Increased elk yields may be obtained via reduction in V over the downward sloping segment for which $T^* \leq T \leq T_E^*$. Proceeding beyond E_{max} (where $T=T_E^*$) both elk yield and present value will decline. For water yield the trade-off interval is the initial segment from W_{max} to V* where $0 \leq T \leq T^*$.

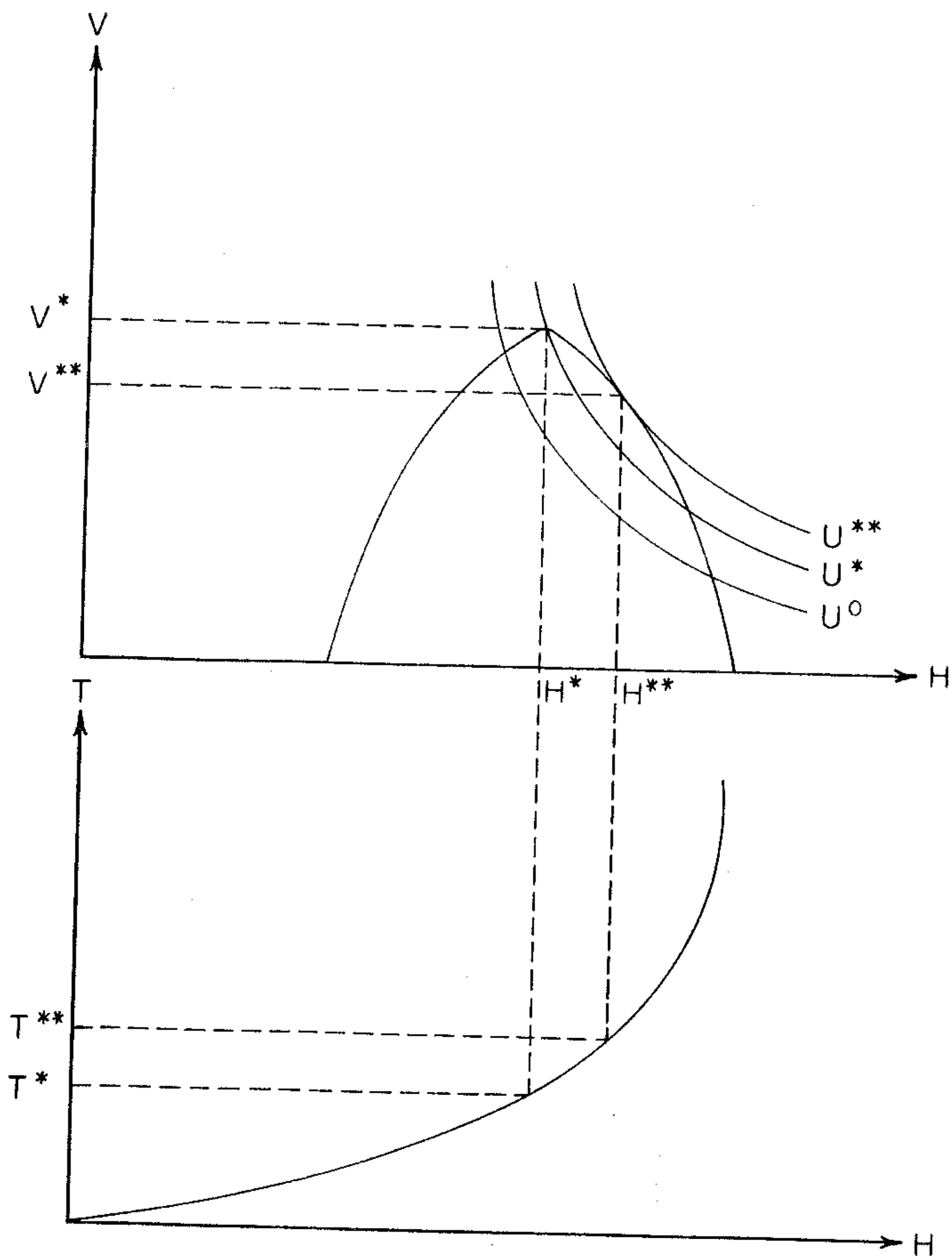
Three points about the nature of revenue and nontimber trade-offs might be noted. First, optimal joint rotations may be shorter or longer depending on the rotation length which maximizes yield or the attribute index. Second, in situations where the rotation which maximizes an attribute yield or index is "close" to the Faustmann rotation the trade-off segment will be compressed and "economic rotations may do a good job of providing for nontimber benefits" (Calish, Fight, and Teeguarden [2, pp. 221]). Third, in situations where the trade-off interval is extensive, (as in Figures 4(a) and 4(d)) an analysis which attempts to value incremental changes in the yield or index may be necessary to refine the appropriate range of choice.

To select a single preferred mix for revenues and a nontimber attribute (and thus the optimal joint rotation) it would be necessary to reduce the two dimensional problem to a scalar maximization problem by attaching a monetary value to the attribute or more generally by ordering attribute-revenue combinations through a value function. Suppose that the preferences habitat may be represented by the utility function U = U(H,V). In this case the problem would reduce to:

$$\max_{H,V} \; U = U(H,V) \text{ subject to } F(H,V) = 0 \qquad (7)$$

where F(H,V) = 0 is the H-V trade-off curve written in implicit form. Thus utility maximization problem is graphically portrayed in Figure 5. Indifference curves U^o, U*, and U** are superimposed on the trade-off curve. The administrator or owner seeks that mix of H and V which is feasible, (on or inside the trade-off curve), and

FIGURE 5. THE OPTIMAL JOINT V-H ROTATION



which allows him or her to reach the highest indifference curve. This occurs at the tangency between U** and the trade-off curve.

In comparing the solution values derived from present value maximization to the values derived from utility maximization we note: $T^{**} > T^{*}$, $V^{**} < V^{*}$ and $H^{**} > H^{*}$. In words, the optimal length of rotation is increased, reducing the present value of revenues, but increasing the average habitat level.

V. Forest Management and Multiple Objective Analysis

The graphical analysis of the preceeding sections is limited in its ability to simultaneously consider three or more objectives. Recall the trade-off curves in Figure 4 were derived by pairing each nontimber attribute function with the Faustmann equation for present value of net revenues. The decision variable for selecting a particular revenue-attribute mix was the rotation length T.

It was evident from the attribute functions that conflict existed among nontimber attributes; for example, shorter rotations promoting water yield and longer rotations promoting wildlife diversity. In its current form the model does not allow one to trade-off two attributes while holding the others fixed. Because net revenue and all nontimber attributes depend exclusively on rotation length the selection of an optimal mix for any two will automatically determine levels for the remaining attributes (or revenue). To fix the level for certain attributes while examining the trade-off between two others requires a model where the attributes of concern can be promoted by several decision variables or inputs.

Suppose forest attribute Z_j is affected the vector of decision variables $X = [X_1, \ldots, X_I]$ according to

$$Z_j = Z_j(X) \qquad j = 1,2, \ldots, J \tag{8}$$

where potential decision variables may be rotation length, thinning practices, soil stabilization activities, and fertilizer and pesticide application. These decision variables may be subject to a set of constraints written as:

$$g_h(X) \leq 0 \qquad h = 1,2, \ldots, H$$
$$x_i \geq 0 \qquad i = 1,2, \ldots, I \qquad (9)$$

Cohon and Marks [4] review the various weighting and constraint methods which can be used to generate a noninferior (trade-off) set for any two objectives. The constraint method would attempt to:

$$\max_X \; Z_j = Z_j(X)$$

$$\text{subject to:} \quad Z_k(X) \geq L_k \qquad \text{for all } k \neq j$$
$$g_h(X) \leq 0 \qquad (10)$$
$$x_i \geq 0$$

where L_k is a lower bound constraint on (J-1) objectives or attributes. By parametric variation of a particular L_k one can trace out a trade-off curve between Z_j and Z_k.

The generation of a trade-off curve in and of itself may provide the forest manager with information that could focus the area of concern and allow him or her to select the "best-compromise" solution in terms or a feasible decision vector X. Selection of a best-compromise solution requires (or implies) a preference weighting among conflicting objectives. In situations with three or more attributes, however, a decision maker may be hard pressed, even with trade-offs specified, to identify a preferred solution. In such cases a more formal approach to eliciting values may be needed. Keeney and Raiffa [5] describe techniques for representing perferences by a value function and conditions, specifically preferential independence, which will allow a value function to be assessed in terms of its component parts.

Extending the forest management problem to allow for a simultaneous consideration of present value and two or more nontimber attributes does not take into account two other important aspects: dynamics and stochastics. It will typically be the case that policies designed to alter the age structure of a forest stand will only achieve their results over an interval of time. Even if the new policies guide the system toward something akin to a steady-state the speed of approach and value of attribute variables along a time path will be important. A decision maker must now evaluate the vector of trajectories

$$Z_t = [Z_{1,t}, \ldots, Z_{J,t}] \qquad (11)$$

under alternative policies for some interval, say $t = 0, \ldots, T$. In addition to a preference weighting among objectives, time preserences are required to evaluate policies that lead to different time paths for one or more objectives. For example, if all objectives are positively valued over the relevant range then policy A would be unambiguously preferred to policy B if $Z^A_{j,t} \geq Z^B_{j,t}$ for all j,t, and $Z^A_{j,t} > Z^B_{j,t}$ for some j,t. Such Paretian superiority is not typically encountered and the decision maker will usually face intra- and inter-temporal trade-offs when evaluating alternative policies.

Finally, the problem may approach a complexity which defies valuation when it is acknowledged that the relationship between policies and objectives is stochastic; that is, the adoption of a particular policy will result in a particular vector of trajectories under certain circumstances, (states of nature), and an alternative vector under other circumstances. If the preferences of the decision maker can be shown to satisfy certain assumptions of preferential independence, value functions might still be derived. Bell [1] describes a study to characterize the preferences of a forest manager when faced with dynamic/stochastic policies for controlling the outbreak of spruce budworm in New Brunswick, Canada. An evaluation, however, of the marginal benefit derived from the thorough and painstaking work performed by Bell to assess the forest manager's objective function is itself difficult to make. The forest manager may have adopted the same policy with a less sophisticated probing of his preferences. What did emerge from the Bell study was the fact that the manager's preferences became better defined, (and may have even changed), as a result of the choices and preference ordering he was forced to consider in the process of identifying a suitable value function.

The graphical analysis of the preceeding sections has the advantage of simplicity, but it is limited in its ability to consider many complicating factors that arise naturally within a resource policy setting. This trade-off between simple and more complex models is not unique to resource economics. Within the forest management setting addressed in this paper, the construction of revenue-attribute trade-off curves may serve as a useful "first cut", (pardon the pun): identifying the range of conflict, and perhaps an a priori assessment of the value of a more sophisticated approach.

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