ECONOMIC ANALYSIS WITH SYSTEM DYNAMICS: A FORESTRY EXAMPLE

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ABSTRACT

It is important to begin any modeling attempt by determining the primary objectives of the decision makers in the field. In forestry there are two interests: production of multiple resources and profit (or cost). Conventional methods of analysis are incapable of handling the two foci adequately; one is always subsumed in the other. The DYNAST model, with the addition of an economic algorithm, provides a means of analyzing the system from both viewpoints without forcing one to dominate the other. This balance is achieved through using capital budgeting techniques such as net present value to represent both the multiple use and profit aspects of money. The economic algorithm can be used to analyze money as one of a host of multiple benefits in comparing management options, or as a method of estimating profitability independent of the context of the model. This latter application makes the algorithm potentially useful in many modeling contexts simulating business investment decisions.

The application of economic analysis techniques common in business transactions to the management of forest land is complicated by the multiple resources flowing from forests. It is difficult to isolate and evaluate individual investments and their resultant cash flows over several decades in a forest system. In addition, any silvicultural action produces a variety of effects or benefits including many non-monetary resources. Conventional project analysis based on the stream of dollar income and outflow generated by a single investment is inadequate for the complexity of forest resource management.

The dual role of money, as both capital and one of a host of benefits, is central to the analysis problem. The classic approach to this duality is to subsume multiple use within a capitalistic framework and attempt to express all benefits in terms of cash or "market" values. Methods which escape the most obvious limitation of this approach and use diverse units of measure to represent diverse benefits still fail to escape the limitations of the capitalistic paradigm; they merely see multiple kinds of capital [4].

The DYNAST simulation model, with the addition of an economic algorithm, provides a way of analyzing forest systems from both the multiple use and profit perspectives without forcing either to dominate. For purposes of capital analysis the entire forest management option being simulated is viewed as a single investment consisting of a series of silvicultural actions. A suite of benefits, including water, timber and wildlife, flows from this investment; money is another of these benefits which derive from the state of the forest. This ability to view money both as an investment to produce all benefits and as one of a set of "forest products" is crucial for adequate evaluation of forestry investments.

DYNAST (DYNamic Analytic Silviculture Technique) [1] is a computer simulation model of forest development; the production of benefits associated with this development is calculated with a set of "benefit" algorithms. Management, in the form of silvicultural actions, alters forest development and causes a shift in the production of all benefits. This type of management has two cost components: the cost of altering the system (over time) and the value resulting from the shift in production. A complete assessment of the utility of any management plan must evaluate these components jointly. The benefit algorithms of the current DYNAST model provide adequate measures of the second component but fail to address the investment portion [2]. To

remedy this shortcoming, an economic algorithm has been developed which serves two functions: it allows analysis of the investment involved in any series of silvicultural actions and it provides an improved measure of the value of money as a forest product.

Capital budgeting techniques provide a familiar methodological framework for investment analyses, particularly the value of cash flows. The techniques most commonly used in business are internal rate of return, average rate of return, net present value, payback period and benefit/cost ratio or profitability index [5]. We chose net present value and profitability index as the most appropriate of these indices for our purposes, as calculation of rates of return is inappropriate when sign changes in the cash flow occur [3]. Equivalent uniform annual cost or rent is also calculated as it is a useful means of comparing alternatives with relatively continuous cash flows.

Figure 1 and Table 1 show the model structure for calculating net present value, equivalent annual rent and profitability index in the conventional manner. The formulation is based on continuously compounded present worth and capital recovery factors [3, 6, 9]. The effects of individual investments cannot be separated within a biologic system, so the classic model for project evaluation was enlarged to encompass a series of silvicultural actions. Each simulation is treated as a single investment with a project life equivalent to the length of the simulation to date.

Conventional analytic techniques make six assumptions [3]: 1) the project and firm have the same risk; 2) the cost of capital is constant and independent of investment; 3) the investment opportunities are independent; 4)

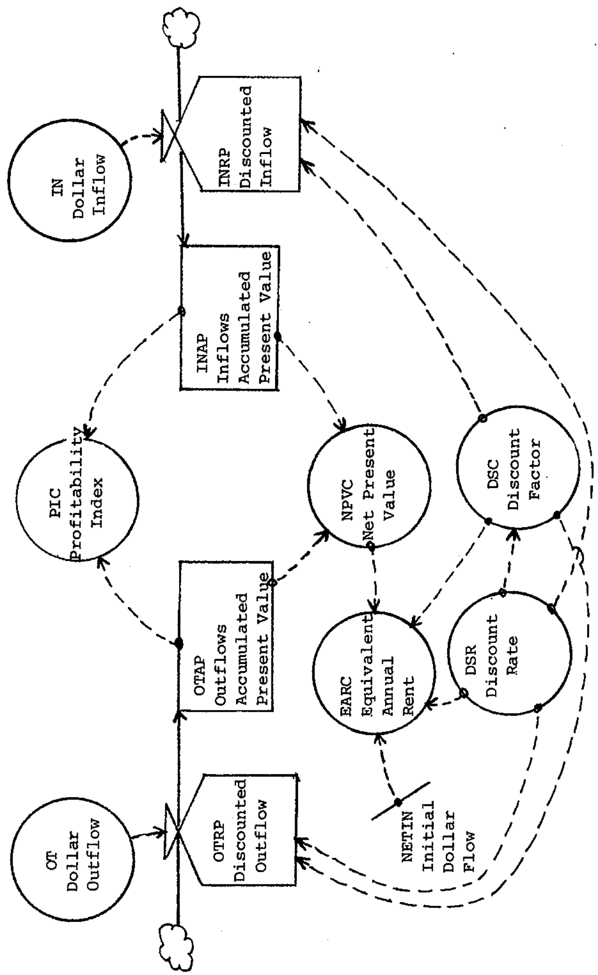

Figure 1. CONVENTIONAL ECONOMIC MODEL STRUCTURE

Table 1: Algorithm for calculation of conventional economic profitability measures.

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R    OTRP.KL = OT.K/FIFGE (DSC.K * EXP (DSR.K), DSC.K, TIME.K, 0)
L    OTAP.K = OTAP.J + DT * (OTRP.JK)
N    OTAP = 0
R    INRP.KL = IN.K/FIFGE (DSC.K * EXP (DSR.K), DSC.K, TIME.K, 0)
L    INAP.K = INAP.J + DT * (INRP.JK)
N    INAP = 0
NOTE
A    DSR.K = TABHL (TDSR, TIME.K, 0, 10, 1)
T    TDSR = .1/.1/.1/.1/.1/.1/.1/.1/.1/.1/.1
A    DSC.K = EXP ((MAX (0,TIME.K)) * DSR.K)
A    NPVC.K = INAP.K - OTAP.K
A    EARC.K = (NPVC.K - MAX (0,NETIN)) * (EXP (DSR.K) -1)/
             (1-(1/MAX (.01, DSC.K)))
S    PIC.K = INAP.K/MAX (OTAP.K,1)
N    NETIN = INAP-OTAP
```

where

OT = dollar outflow
OTRP = discounted outflow
OTAP = present value of outflows
IN = dollar inflow
INRP = discounted inflow
INAP = present value of inflows
DSR = discount rate
DSC = discount factor
NPVC = conventional net present value
EARC = conventional equivalent annual rent
PIC = conventional profitability index
NETIN = year 0 net cash flow
TIME = year

borrowing and lending rates are equal; 5) perfect capital markets exist; and 6) investment decisions are independent of consumption. Violations of these assumptions produce discrepancies between various methods of value analysis. The long-term nature of forestry investments renders it improbable that the full set of assumptions will hold over the planning period. In particular, it is unlikely that the cost of capital will remain constant and that borrowing and lending rates be equal.

The model structure for conventional capital analysis cannot handle violations of both cost of capital assumptions. Discounting on a year by year basis realistically accommodates variation in the discount rate, as a change in rate affects future cash flows only. Each year's income is subject to the rate current at that time. However, differences between borrowing and lending rates cannot be accounted for as all cash flows are simply discounted back to the present, with no provision made for reinvestment or lending.

The inability to represent differences between the discount and reinvestment rates can be a serious limitation [7, 8]. Forestry operations generate a large stream of intermediate revenue which may be reinvested at the lending rate; often the reinvestment is in another part of the company such as a mill or processing facilities, which generally earn higher returns than the land base. A discrepancy between borrowing and reinvestment rates creates inaccuracies in relative project ranking by different measures of profitabiity when projects differ in the timing of cash flows [3, 8].

Land management is subject to cash flows which decidedly vary both in timing and magnitude between management options, therefore we included

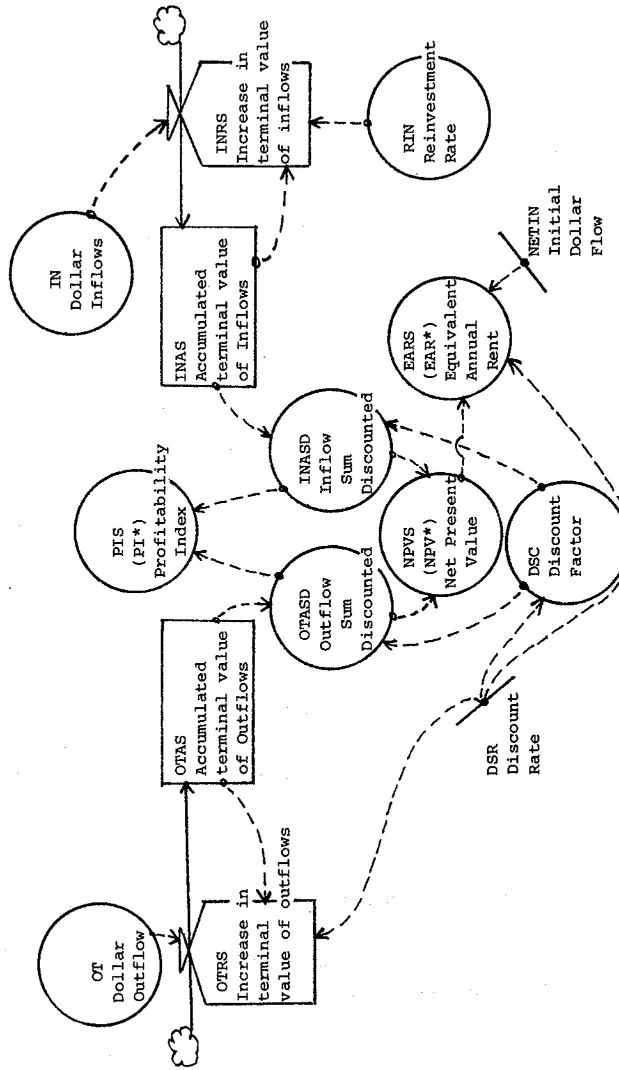

Figure 2. MODIFIED ECONOMIC MODEL STRUCTURE (after Clark et al., 1979)

Table 2: Algorithm for calculation of modified economic profitability measures.[1]

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R     OTRS.KL = FIFGE (OTAS.K * (EXP (DSR) -1, 0, TIME.K, 0) + OT.K
L     OTAS.K = OTAS.J + DT * (OTRS.JR)
N     OTAS = 0
A     OTASD.K = OTAS.K/DSC.K
R     INRS.KL = FIFGE (INAS.K * (EXP (RIN.K) -1), 0, TIME.K, 0) + IN.K
L     INAS.K = INAS.J + DT * (INRS.JK)
N     INAS = 0
A     INASD.K = INAS.K/DSC.K
NOTE
C     DSR = .1
A     DSC.K = EXP ((MAX (0,TIME.K)) * DSR)
A     RIN.K = TABHL (TRIN, TIME.K, 0, 10, 1)
T     TRIN = .1/.1/.1/.1/.1/.1/.1/.1/.1/.1/.1
A     NPVS.K = INASD.K - OTASD.K
A     EARS.K = (NPVS.K - MAX (0, NETIN)) * (EXP (DSR) - 1)/
               (1 - (1/MAX (.01.DSC.K)))
S     PIS.K = INASD.K/MAX (OTASD.K, 1)
C     NETIN = INAS - OTAS
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where

- OT = dollar outflow
- OTRS = increase in future value of outflows
- OTAS = accumulated future value of outflows
- OTASD = present value of outflows
- IN = dollar inflow
- INRS = increase in future value of inflows
- INAS = accumulated future value of inflows
- INASD = present value of inflows
- DSR = discount rate
- DSC = discount factor
- RIN = reinvestment rate for intermediate income
- NPVS = modified net present value, NPV*
- EARS = modified equivalent annual rent, EAR*
- PIS = modified profitability index, PI*
- NETIN = year 0 net cash flow
- TIME = year

1 Based on discussion in Clark et. al. (1979), pp. 78-84.

alternative measures of profitability in the economic algorithm. These alternative measures are based on a variant of net present value, NPV*, described in Clark [3]. This measure differs from the conventionally used NPV primarily in that with this approach intermediate income is compounded forward to the end year using the reinvestment rate before discounting back to the present using the discount rate. The two methods are equivalent if discount and reinvestment rates are equal. Cash outflows are compounded forward and discounted back using the discount rate in both directions since they are not subject to reinvestment. NPV* is the difference between the present values * of income and expenditure. The equations responsible for these calculations are presented in Table 2 (see Figure 2). Equivalent annual rent and profitability index are calculated as before (Figure 1).

The tradeoff between the two model structures is clear; each provides improved analysis under a single violation of the conventional assumptions. The choice of which set of profitability measures to use, conventional (Figure 1) or modified (Figure 2), will depend on the specific situation and the assumptions valid for that situation. If fluctuations in the future discount rate are expected to be significant, the measures based on annual discounting (NPV, EAR, PI) would be more appropriate than measures based on discounting the accumulated sum of cash flows all at once (NPV*, EAR*, PI*). Anticipated discrepancies between the discount and reinvestment rates would indicate the opposite choice.

This combined use of economic and multiple resource production simulations is best illustrated with an example. The Big Ivy is an upland hardwood forest in North Carolina producing timber, wildlife, water and money

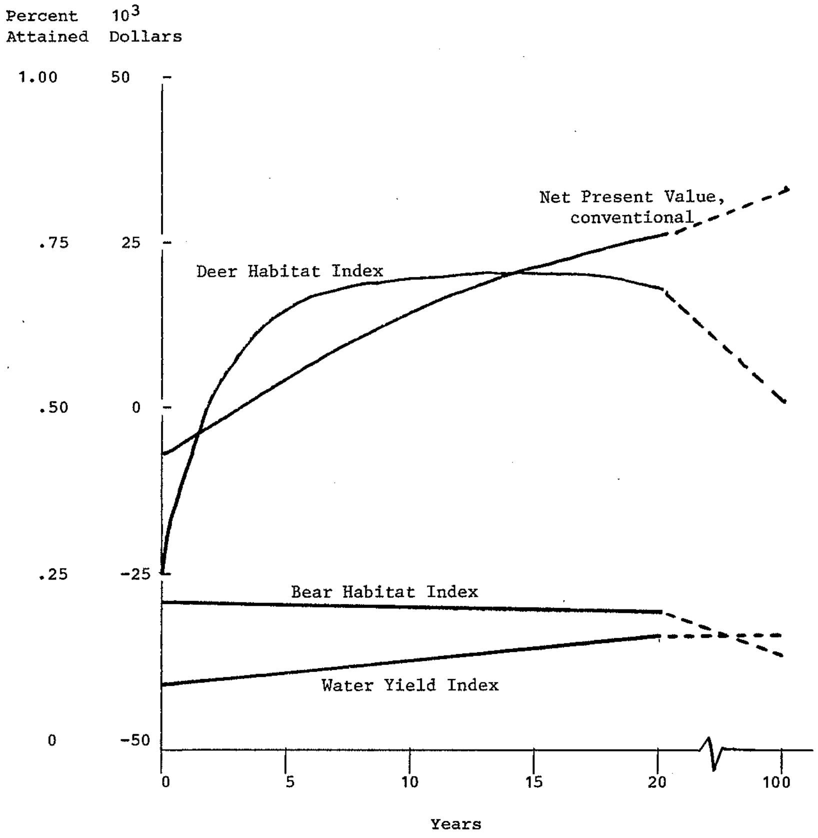

Figure 3. 80-year rotation, the Big Ivy forest, NC

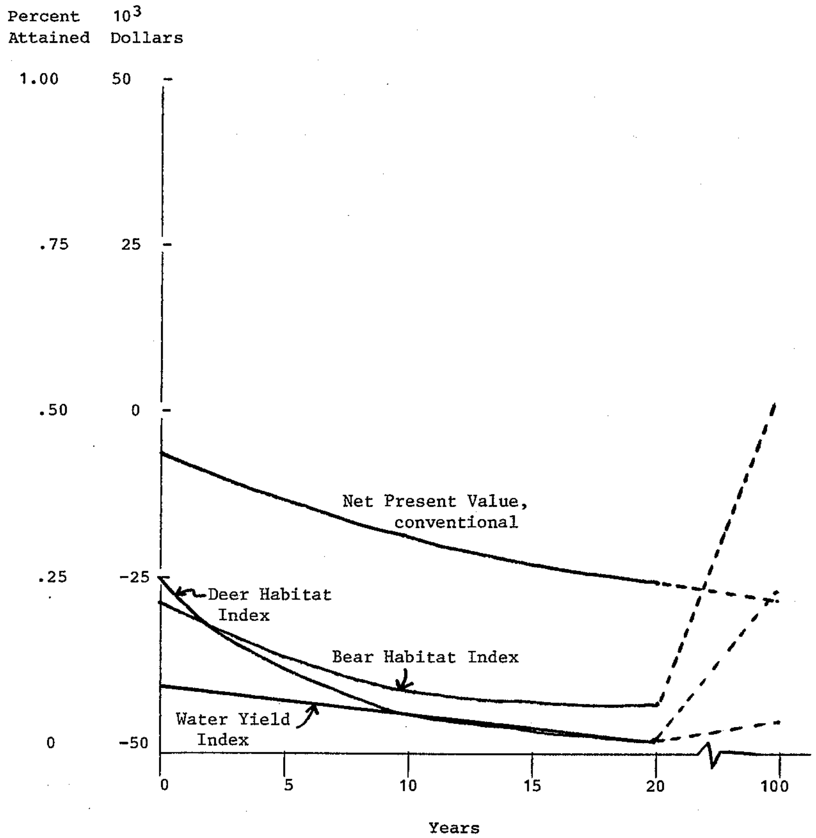

Figure 4. 200-year rotation, the Big Ivy forest, NC

benefits [1, 2]. An 80-year rotation (Figure 3) produces nearly optimal economic benefits (NPV) from timber production on a sustained yield basis in this forest. In the mid-term (20 years) this management regime produces water and deer habitat in substantial amounts but limits the quantity of bear habitat; in the long term both types of wildlife habitat illustrated decline. A longer rotation designed to produce the old growth stands preferred by species such as bear is economically discouraging (Figure 4); all indices are low during the extended period required to regulate the distribution of stand ages. Only bear habitat is highly favored on a sustained yield basis. It would be necessary to conclude from these projections that the joint production of timber and wildlife habitat is too costly for serious consideration.

This conclusion is based on regulating the forest with a single period of rotation; economic benefits rapidly decline to unacceptable levels as single rotation periods are moved away from the harvest age which maximizes production of marketable benefits. Single-length rotations limit the diversity of habitats by age, area and forest type; this produces an economic constraint on the joint production of non-marketable benefits that can be relaxed by creating a mosaic of stands with superimposed periods of rotation [1]. A balance between economic and non-economic considerations is achieve by apportioning land between two or more rotation periods (Figure 5). Wildlife habitat is enhanced in all cases by increasing the different types of stands, although the most noticeable response occurs with bear which achieves levels much higher than with either single rotation. Economic profits, as measured by net present value, are reduced by moving any portion of the land off an 80-year rotation; they do remain solidly in the profit category under the mixed rotation scenario, however. Adjustment of the flow through each

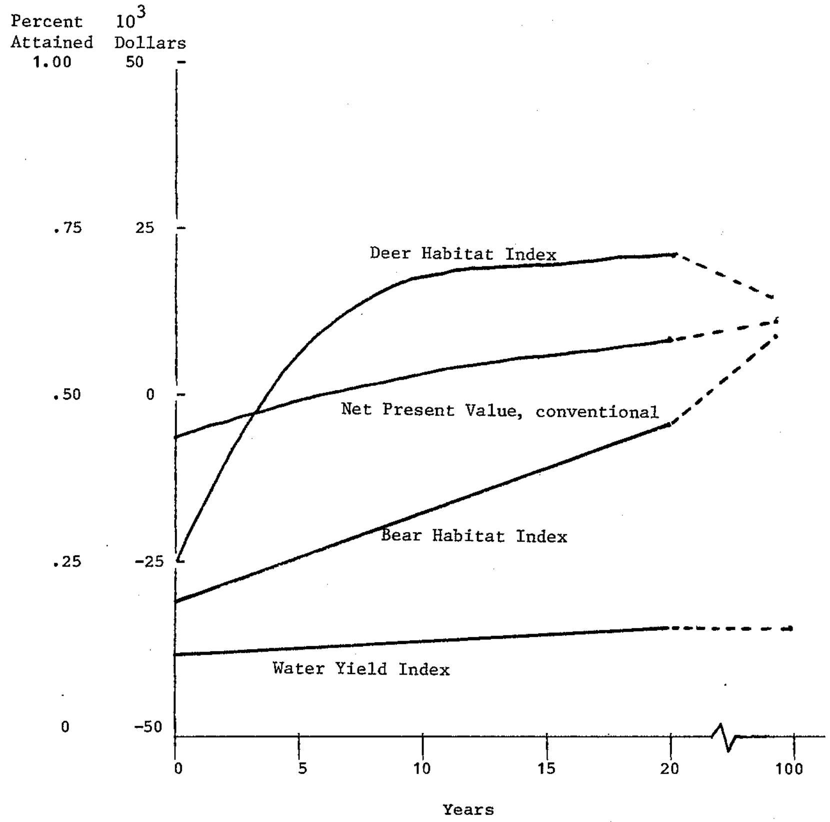

Figure 5. Multiple rotation lengths, the Big Ivy forest, NC*

*80 percent is rotated through an 80-year period and 20 percent through a 200-year period.

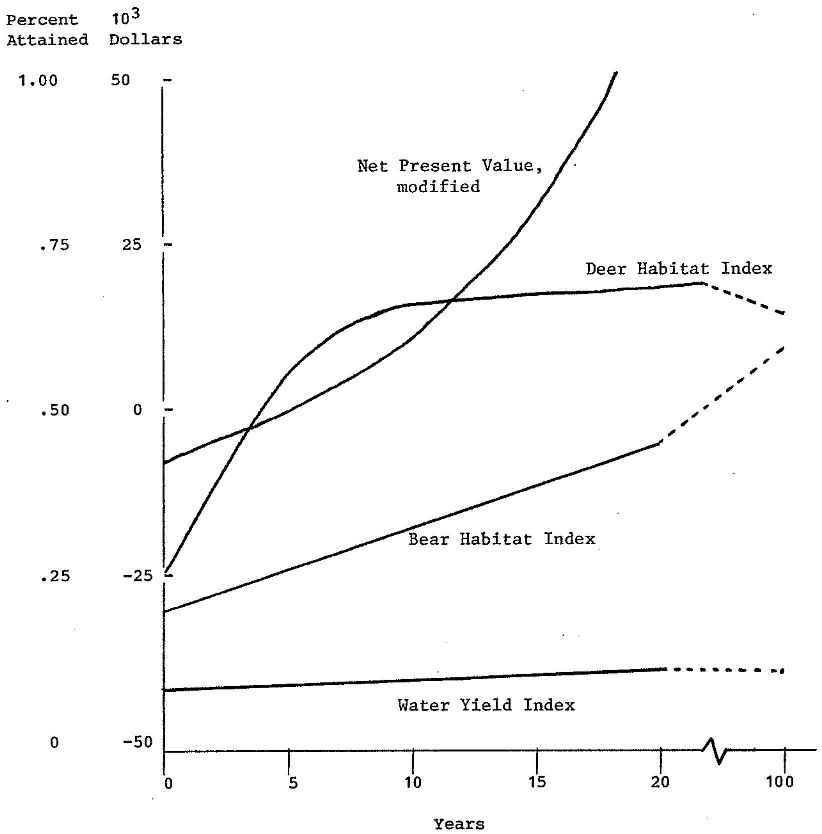

Figure 6. Multiple rotation lengths with modified economic factors, the Big Ivy forest, NC*

*80 percent is rotated through an 80-year period and 20 percent through a 200-year period.

rotation is a way of directing the production of non-monetary resources at a minimum cost; the result is enhanced production of a variety of resources with only moderate declines in economic profitability.

The exchange of money income for wildlife habitat is not a simple issue. The weights attached to each type of product will vary with the situation of the individual forest and the objectives of the owner. Additional complications are introduced when variations in economic parameters are considered; a reinvestment rate greater than the discount rate can appreciably alter the economic outlook of a project (Figure 6) without affecting production of any other benefits. Analysis must be based on sets of options with carefully considered, consistent assumptions in order to avoid biasing estimates of production of any resource.

Use of the economic techniques presented here improves the analyst's ability to compare options and assess the magnitude and nature of the tradeoffs between them. Forestry operations can be modified to produce the best combinations of benefits with minimal sacrifice of economic returns. This method also generates a set of objective, commonly understood measures of profitability that are useful for comparing the options under study with other types of investments.

The objectivity of these measures renders them independent of the immediate context of the model. This independence opens interesting possibilities for modeling. There are many situations where a real world business decision is simulated and evaluative critera that have significance outside the model would form sound input for the decision mechanism; the allocation of investment funds among a number of technololgies is a common example. Capital budgeting techniques could provide a more meaningful and accurate input into the funds allocation decision than more commonly used inputs such as marginal or average costs. This formulation would be especially applicable when modeling inter-company or interindustry investments.

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