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Ranking Independent Timber Investments by Alternative Investment Criteria

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A sample of 231 independent timber investments were ranked by internal rate of return, present net worth per acre, and the benefit/cost ratio—the last two discounted by 3, 6.4, 7.5, and 10 percent—to determine if the different criteria had a practical influence on timber investment ranking. The samples in this study were drawn from a group of timber investments partially financed by Forestry Incentives Program cost-share funds. The investment rankings were quite similar among the three criteria. Under constrained investment budgets, the benefit/cost criteria produced the investment selection with the greatest cumulative present net worth. Under less severe budget constraints, all three criteria produced investment selections with essentially the same cumulative present net worth.

Retrieval Terms: internal rate of return, present net worth, benefit/cost ratio, marginal investments, perpetual rotations, multiple rates of return

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Retrieval Terms: internal rate of return, present net worth, benefit/cost ratio, marginal investments, perpetual rotations, multiple rates of return

Commonly applied criteria for ranking investments can lead to the same investment selections. The investment scale, reinvestment rate, and investment period should be comparable among competing investments. In analyzing timber investments, these comparability adjustments are often not made.

In this study, three investment criteria were applied to a set of 231 independent timber investments to determine how significant the theoretical considerations are in empirical analyses of independent timber investments. The sample investments were drawn from a group of timber investments partially financed by the Forestry Incentives Program cost share funds in 1974. The three criteria tested were internal rate of return (IROR), present net worth (PNW) per acre, and benefit/cost ratio (B/C)—the last two discounted at 3, 6.4, 7.5, and 10 percent.

When the sample of 231 investments were ranked by these three criteria, individual investments were often only displaced by a few rank positions between the several criteria. When the investment budget was severely constrained, the B/C criterion consistently selected investments with the highest cumulative PNW, but the B/C criterion advantage quickly dissipated as the budget constraint was relaxed. An error in the selection of the discount rate to use in the PNW calculation led to greater differences in investment ranking by PNW per acre than were found in comparisons of the IROR ranking with the PNW per acre ranking. Multiple IROR's, a source of ambiguity, occurred so infrequently as to be of little importance.

These empirical results suggest that certain practical aspects of the timber investment analysis situation, such as the certainty of the input data, must be considered along with the theoretical factors when an investment criterion is chosen.

The two most commonly compared criteria for rating the desirability of alternative investments are present net worth (PNW) and internal rate of return (IROR). Each criterion is described in a number of forms in the literature. The benefit/cost ratio (B/C) formulation of the PNW criteria is a common example. The economics literature contains works by Fisher (1930), Lutz and Lutz (1951), Boulding (1955), McKean (1958), Solomon (1959), Hirshleifer (1958, 1970), Mishan (1976), and Bierman and Smidt (1980). Examples in the forestry literature include works by Gaffney (1960) and Bentley and Teeguarden (1965).

A theoretical discussion about the relative merits of the investment criteria has practical relevance since different criteria can lead to dissimilar investment rankings and, therefore, investment selection. As is typical in long-standing debates, much of the difference in rankings lie in the assumptions underlying each criterion.

This paper applies three commonly used criteria to a sample of 231 independent timber investments to determine if they had any practical influence on investment ranking. It also discusses some practical aspects of their use in timber investment analysis.

CRITERIA ASSUMPTIONS AND AMBIGUITIES

This study had four objectives. One was to determine the frequency and severity of ranking differences among independent timber investments. The investments were ranked by three criteria: PNW per acre, IROR, and B/C. PNW per acre was used rather than total PNW for the investment because it partially standardizes for the investment scale, and is also more commonly used in timber investment guides.

Another objective was to determine how much the investment ranking differences are influenced by the discount rate, since the discount rate is seldom known with certainty. This objective also addresses how much ranking differences are influenced by investment diversity and how much the impact of ranking differences is affected by the size of a fixed investment budget.

The third objective was to determine how often multiple IROR's exist for the same investment. The fourth objective was to determine how much the inclusion of perpetual rotations in the analysis, rather than just first rotation results, affects the estimated financial return. Perpetual rotations standardize the investment period among competing investments, but perpetual rotation data are often less accurate than first rotation data, and the extra data collection adds cost to the analysis.

Assumptions

The ranking criteria commonly found in the literature are based on certain assumptions. Assumptions which relate to access to factor markets have been examined by Bentley and Teeguarden (1965). The IROR rule assumes there is no access to the capital market—the total pool of investment capital is fixed. The selection of investments which maximizes the IROR responds correctly to that assumed situation by maximizing the return or "rent" on the limited capital. Similarly, the general PNW criterion assumes that the management factor is fixed so selection based on the PNW criterion maximizes the return to management. The Faustmann or soil-rent PNW formulation maximizes the return to land.

Other important assumptions concern the scale of investment and the return on reinvested intermediate returns. Investment selection based upon PNW and IROR estimates implicitly assumes either that all investments are of the same scale or that they are infinitely divisible and expandable. The PNW criterion assumes that all intermediate net returns prior to the investment maturity date can be reinvested at the rate of discount. The IROR criterion assumes that they can earn the same return as the parent investment from which the net intermediate returns originated.

If the choice among the criteria is based on theoretical considerations only, the analyst's choice should rest on which assumptions are valid in the particular situation being analyzed. If the assumptions for the investment situation meet the conditions underlying criterion A, then criterion A will yield the correct investment selection for that situation.

McKean's (1958) advocacy of the IROR criterion, for example, may very well have arisen from his focus on public investments where the fixed capital assumption is valid in the short run. Annual budgets are generally fixed in public agencies by the annual appropriation process. It can hardly be argued, however, that an annually fixed budget is the same as an absolutely fixed pool of investment capital. Public investments which are not funded this year can be funded from next year's budget and a 1-year delay is trivial when the maturity period for public timber investments typically exceeds 50 years. The fixed capital assumption may be valid for public agencies in underdeveloped countries, but it is difficult to support in the United States

(Gregory 1972), as is apparent from the magnitude of government borrowing in this country.

Ambiguities

In addition to analyzing the validity of underlying assumptions, the analyst should also study the criteria for possible ambiguities. The possibility of multiple IROR's for a single investment, for example, has been cited as an ambiguity of the IROR criterion (Hirshliefer 1970, Mishan 1976). In applying Descartes' rule of signs, there are as many potential IROR's as there are sign reversals in the time stream of net benefits.

We believe that the multiple IROR's are a signal of the ambiguity of the investment itself rather than of the IROR criterion. The multiple IROR's display the ambiguity underlying a particular investment, whereas the same ambiguity remains hidden in the PNW calculation. The estimated PNW yields equally ambiguous results when the discount rate is varied.

Using Gansner and Larsen's (1969) example investment, which could correspond to an increment in timber management intensity, a net benefit time stream of:

year 0 = -$ 25.00
year 10 = + 112.25
year 20 = - 169.96
year 30 = + 80.78

produces IROR's of 2, 4, and 6 percent. A PNW which is positive at discount rates of 0 to 2 percent, negative at rates of 2 to 4 percent, positive at rates of 4 to 6 percent, and negative at rates above 6 percent is no less ambiguous than the multiple IROR's. If the correct discount rate were known with certainty, the PNW variability for this example investment would not create ambiguity because there is a single PNW for a single discount rate. Perfect information is a harsh assumption, however, as is evident from the long-standing debate over the appropriate discount rate for public sector investments. The continuing debate over discount rates for long-term forestry investments also shows that the question is not likely to be answered with finality in the near future (Row and others 1981).

The multiple IROR can be solved by (a) compounding all positive intermediate net benefits to the end of the investment period, using the "lending" rate or alternative rate of return, and (b) all negative intermediate net benefits to the beginning of the period, using the "borrowing" rate (Marty 1970). The IROR calculated from this simple time stream of one positive and one negative net benefit, which is called a composite internal rate of return by Marty, always yields a single IROR. Use of the composite IROR avoids the problem of the more commonly applied form of IROR, which assumes that intermediate net benefits from different investments earn different rates of return when they are in turn reinvested. The composite IROR calculation forces inclusion of an explicit reinvestment rate, thus permitting its standardization among competing investments. An explicit reinvestment rate can lead to substantially different IROR estimates if the reinvestment rate is much different from the IROR (Schallau and Wirth 1980).

The IROR criterion can be ambiguous when net disinvestment actions are being evaluated. The IROR is infinite when there are no negative net benefits in the investment time stream, as in alternative commercial thinning regimes. The IROR may also be very high for low-cost precommercial thinnings which increase yields substantially.

It is generally conceded that all three commonly employed investment criteria used in this study bisect the ranking of investments at the same alternative rate of return or discount rate threshold *if* the competing investments are independent and *if* the investment budget is not fixed. The same subset of investments is accepted and the same subset is rejected by all three criteria. Investments are independent if the undertaking of one does not materially affect the net benefit time stream of another or exclude another investment from consideration altogether. Although not completely independent, timber investments can generally be treated as such as long as they are treatments of separate pieces of land. Alternative investment or treatment designs on the same piece of land are not independent investments.

Unfortunately, as they are conventionally applied, the three selection criteria may rank investments differently. The three criteria need not, therefore, produce the same selection of investment cases when the investments are mutually exclusive or when the pool of investment capital is fixed at a less than optimum level.

These theoretically possible ranking differences disappear if the investments are all "normalized" (Mishan 1976). The three conditions of normalization are standardization of (1) the reinvestment return on intermediate positive net benefits, (2) the scale of the investment, and (3) the investment maturity period. One way to standardize the reinvestment rate in the IROR criterion has already been explained—calculation of Marty's (1970) composite IROR. One way to standardize for the time horizon among timber-growing investments is to follow the first rotation investment with successive rotations into perpetuity. Standardization for scale is more cumbersome, but the same end can be achieved by identifying, from among the set of all possible investment combinations, the investment subset that maximizes the value of the selected investment criterion (Mishan 1976).

All of these normalization steps are seldom used in practice, especially the standardization of investment scale. Most timber investment guides use unnormalized PNW per acre (Beuter and Handy 1974) or IROR (Manthy 1970). If we fail to take the normalization steps and choose a criterion on the basis of theoretical considerations alone, then the selection among criteria must be based upon the soundness of the respective assumptions for the particular investment decision being evaluated. We feel that the assumptions underlying the PNW criteria are generally

more sound for public sector timber investment situations than are the IROR assumptions, but the failure to adjust for scale differences may cause serious errors.

What if all the criteria produce the same investment selections? If the investment selections are the same in a particular evaluation, or substantially so, then the theoretical distinctions are not very relevant in practical applications. It is our thesis that if the ranking results are similar, the selection of an investment criterion should be swayed by practical considerations, such as the relative sensitivity of the criteria to data variability.

METHODS AND RESULTS

The timber investments analyzed in this study were drawn from the 1433 sample investments evaluated by Mills and Cain (1978) from the 1974 Forestry Incentives Program. The investments are independent and structured in a marginal analysis format. Each criterion estimates the financial return on the increment of management activity applied to the timber stand rather than the entire management activity. The first rotation was followed by a second rotation and the second was repeated into perpetuity. All costs and prices were expressed in real dollars. The initial investment cost includes both the private and public cost share, which in combination equal the direct cost.

A single time stream of net benefits was constructed for each investment. The IROR, PNW per acre, and B/C were calculated from each time stream, the latter two criteria at 3, 6.4, 7.5, and 10 percent discount rates. No normalization of investment scale nor reinvestment rate was made, but the perpetual rotations normalize for the investment period.

The 3 percent rate was an arbitrarily low rate which coincidentally is close to the 4 percent rate proposed for land management planning analysis on Forest Service lands (U.S. Dep. Agric., Forest Serv. 1980; Row and others 1981). The 6.4 percent was the Water Resource Council rate at the time the calculations were made (U.S. Dep. Agric., Soil Conserv. Serv. 1973), 7.5 percent was similar to the long-term borrowing rate of government bonds, and 10 percent was the rate that the Office of Management and Budget (U.S. Office of Manage. and Budget 1972) estimated was the real rate of return on investments in the private sector.

Different subsets of the total 1433 investments were evaluated to fulfill each of the four study objectives. Because of the similarities among some of the 1433 cases, a subset of the 231 investments was selected to determine the frequency and impact of ranking differences (objective 1). The 231-investment subset contained examples of most of the major silvicultural practices commonly encountered throughout the country. Investment cases in southern pine, northern pine, other northern conifer, central hardwoods, northern hardwoods, and western conifer species groups were represented. The silvicultural practices represented included planting on bare land, site preparation and planting, understory release, precommercial thinning, intermediate treatments, pruning, and pruning and intermediate treatments together. The mean financial returns on the sample cases were higher than has generally been estimated for timber investments. The mean IROR of the 231 cases was 16.7 percent, the mean PNW per acre at the 7.5 percent discount rate (at 7.5 pct) was $311, and the mean B/C (at 7.5 pct) was 7.8.

These 231 investments were subdivided into six similar groups to determine if investment diversity influenced the ranking results (objective 2). The entire 1433 investments were searched for multiple IROR's (objective 3). A subset of 90 investments was evaluated to determine the impact of removing second rotation data (objective 4).

The rankings of 231 investments were compared two ways. The first comparison was made by measuring the percentage difference in investment rank. The percentage rank difference is a convenient descriptive device for identifying ranking patterns even though rank differences themselves do not measure the cost of any investment selection errors. The rankings were then compared by measuring the total PNW of the program of investments that would be selected from the different rankings to fulfill each of several fixed investment budgets. The difference in the total PNW of the selected investment programs provides an estimate of the financial return foregone if the wrong investment criterion is selected.

The use of the PNW of the total program of investments as a yardstick for comparison implicitly assumes that total PNW is the best investment criterion. Total PNW was used because we judged its underlying assumptions to be more commonly valid in public sector timber investment situations than those underlying IROR. The total IROR or B/C could also have been used as a common measurement for comparison.

Influence on Rank Position

The first method for quantifying the rank position differences—the percentage rank difference—is the absolute percentage difference in rank position of an individual investment when ranked by one financial return criterion as opposed to another. It was calculated as follows:

$$\text{percentage rank difference} = \left| \frac{R_i - R_j}{n} \right| (100 \text{ percent})$$

in which

R_i = rank position by criterion i

R_j = rank position by criterion j

n = number of investments in the rank (231 cases)

For example, if case A is in rank position 93 in the IROR rank and in position 115 in the PNW per acre (at 7.5 pct) rank, the percentage rank difference is 9.6. Case A is

ranked 9.6 percent higher on the investment list developed from IROR than the one developed from PNW per acre (at 7.5 pct).

The percentage rank differences for individual cases were then grouped into percentage rank difference classes. For example, if 35 cases had percentage rank differences between 0 and 5 percent, they were grouped. The number of cases in the class was then expressed as a percentage of the total number in the list. In the example, 15 percent of the cases (35/231) have rank differences of 0 to 5 percent. The mean percentage rank differences for all the cases were calculated for all of the 36 paired comparisons possible from the financial return criteria tested here: IROR, PNW per acre, and B/C at 3, 6.4, 7.5, and 10 percent discount rates.

Several ranking patterns were apparent. First, roughly half (42 to 53 pct) of the investments had ranking differences of 5 percent or less when IROR, PNW per acre (at 7.5 pct) and B/C (at 7.5 pct) were compared (*table 1*). Less than one-quarter of the investment cases (10 to 23 pct) had rank differences of more than 20 percent. The mean difference varied from 8 to 13 percent for these three comparisons.

Second, the IROR ranking of investments was more different from the PNW per acre (at 7.5 pct) and the B/C (at 7.5 pct) rankings than the latter two were from each other. The closeness of the IROR rank to the PNW per acre and B/C ranks increased dramatically, however, as the discount rate was increased. For example, the mean percentage rank difference decreased from 21 percent when IROR was compared to PNW per acre (at 3 pct) to 10 percent when IROR was compared to PNW per acre (at 10 pct). PNW per acre and B/C rankings were constructed with higher discount rates to determine if this convergence with the IROR rank continued, but most of the convergence had occurred by the 10 percent discount rate.

Third, the investment rankings constructed from the same investment criterion calculated at different discount rates sometimes differed more than the ranks constructed by different criteria. For example, when the PNW per acre rank at 3 percent was compared to the PNW per acre at 10 percent, only 24 percent of the cases had percentage rank differences of 5 percent or less. The IROR and PNW per acre (at 10 pct) rankings show more agreement than that; 50 percent of the cases had ranking differences of 5 percent or less. This discount rate effect is unimportant if the correct discount rate is known with certainty, but that is an heroic, and generally invalid, assumption in the public sector.

Impact under Constrained Budgets

The IROR criterion should be used if the total pool of investment capital is fixed. The B/C criterion is probably more appropriate in constrained budget conditions than PNW unadjusted for investment scale differences because B/C more closely corresponds to maximizing the added PNW per dollar of constrained budget. In actual practice, all three criteria have been used in fixed budget situations in the past.

Budget levels from $20,000 to $140,000 were tested in $20,000 increments. Only the first-year investment cost was considered constrained by the budget. The total PNW of each investment was calculated by multiplying the acreage of the investment case by the PNW per acre. The total PNW of the investments selected to fulfill each fixed budget level is the sum of the total PNW for each investment case. This total PNW of the program of investments is termed the "program PNW." The program PNW was always calculated using the same discount rate that was used to construct the PNW per acre and B/C ranks. We prorated investment cases at the budget margin by using average costs per acre, so that the budget level was met exactly.

To facilitate comparison, the program PNW that ranked highest among the criteria being compared at that budget level was specified as 100 percent. The PNW of the investment program selected from other financial return criteria was then recorded as a percentage of that highest program PNW. For example, if the program PNW's at a $40,000 budget level were $36,000, $43,000, and $54,000 for IROR, PNW per acre (at 7.5 pct), and B/C (at 7.5 pct), respectively, the B/C criterion was shown at 100 percent. The program PNW for IROR was 67 percent and for PNW per acre was 80 percent of the maximum. The fall down in program PNW is a direct measure of the cost of selecting an incorrect investment criterion.

At low budget levels, the B/C criterion consistently produced the largest program PNW of the three financial return criteria tested at all four discount rates. The PNW per acre consistently provided the next highest program PNW and the IROR provided the lowest program PNW. The B/C selection was probably superior to that of PNW per acre because the B/C ratio more closely approximates added PNW per dollar of constrained budget than does PNW per acre. The B/C criterion is also more neutral to investment scale than unnormalized PNW per acre. A direct criterion of PNW per dollar of constrained budget would probably have performed better than B/C (Lorie and Savage 1959).

The program PNW shortfall resulting from application of the PNW per acre and IROR criteria declined as the budget constraint was relaxed. For example, the IROR's program PNW at the first budget level was 26 percent below the maximum program set by the B/C (at 7.5 pct), but the IROR's program PNW was only 5 percent below at the third budget level (*table 2*). The program PNW from the IROR criterion was at least 90 percent as large as the maximum program PNW by the third budget level for all discount rates except 3 percent. The program PNW for the PNW per acre criterion was at least 95 percent of the maximum by the third budget level for all discount rates.

Table 1—*Differences in rank position of 231 forestry investment cases in paired-rank comparisons using criteria of internal rate of return (IROR), percent net worth (PNW) per acre, and benefit/cost (B/C) ratio.*

Criteria (and discount rate) compared	Difference (pct) in rank position							Mean difference
	0–5	6–10	11–20	21–30	31–40	41–50	51+	
	Percent of Cases							*Percent*
IROR and . . .								
PNW per acre (3)	19	17	22	13	11	8	10	21
PNW per acre (6.4)	37	17	18	10	10	5	3	15
PNW per acre (7.5)	42	18	17	11	5	6	2	13
PNW per acre (10)	50	17	18	6	5	4		10
B/C (3)	25	12	23	16	8	9	7	20
B/C (6.4)	42	13	20	13	7	4		12
B/C (7.5)	47	16	14	16	4	3		11
B/C (10)	54	20	18	7	1	1		7
PNW per acre (3) and . . .								
PNW per acre (6.4)	34	27	25	7	3	3		10
PNW per acre (7.5)	30	23	30	8	5	2	1	12
PNW per acre (10)	24	16	29	18	6	4	3	16
B/C (3)	50	25	19	3	2	1		7
B/C (6.4)	27	19	28	15	6	4	1	14
B/C (7.5)	23	17	28	18	7	5	2	16
B/C (10)	19	17	26	18	10	4	6	19
PNW per acre (6.4) and . . .								
PNW per acre (7.5)	86	11	3					3
PNW per acre (10)	47	28	19	5				7
B/C (3)	37	17	27	9	6	2	1	12
B/C (6.4)	50	24	16	8	2			8
B/C (7.5)	50	21	8	7	1	2		8
B/C (10)	39	23	20	11	4	2	1	11
PNW per acre (7.5) and . . .								
PNW per acre (10)	64	25	9	1				5
B/C (3)	34	18	28	9	7	2	2	13
B/C (6.4)	52	20	19	6	2			8
B/C (7.5)	53	20	17	6	2	1		8
B/C (10)	45	28	15	6	4	2		9
PNW per acre (10) and . . .								
B/C (3)	28	19	24	16	6	4	3	15
B/C (6.4)	45	21	23	9	1	1		9
B/C (7.5)	52	22	18	8				8
B/C (10)	57	23	11	6	3			7
B/C (3) and . . .								
B/C (6.4)	34	19	28	12	5	1	1	12
B/C (7.5)	31	17	27	14	7	1	1	14
B/C (10)	25	17	24	16	12	3	3	17
B/C (6.4) and . . .								
B/C (7.5)	84	15	2					3
B/C (10)	47	26	22	5				7
B/C (7.5) and . . .								
B/C (10)	66	22	11					5

Table 2—*Percent of the largest program present net worth[1] achieved when investments are selected from 231 investments ranked by internal rate of return (IROR), present net worth (PNW) per acre, and benefit/cost (B/C)*

Constrained budget level (thousand dollars)	IROR	PNW per acre[2]	B/C[2]
	Percent		
20	74.4	89.1	100.0
40	83.2	92.7	100.0
60	94.5	95.7	100.0
80	98.2	97.9	100.0
100	100.0	99.5	100.0
120	100.0	100.0	100.0
140	100.0	100.0	100.0

[1]Program PNW is defined as the accumulated PNW of the entire program of investments that are selected from the various rankings to fulfill each of the fixed investment budgets.
[2]Discount rate of 7.5 percent.

The program PNW's for the various criteria converged rapidly because individual investments were often displaced by only a few rank positions from one criterion to another. This displacement was demonstrated by the percentage rank difference measurements. If the constrained budget were large enough to finance the top 75 investments, it made little difference if an investment's rank was 25 or 45.

The program PNW from the IROR rank was much further behind the B/C criterion maximum at low discount rates than at high ones. The IROR's program PNW at the first budget level was 38 percent of the maximum set by B/C (at 3 pct). The shortfall gradually declined as the discount rate increased. At the 10 percent discount rate, the IROR's program PNW was 87 percent of the maximum at the first budget level. This difference was probably related to the convergence of the discount rate and the mean IROR for the investment sample.

The 231 sample investments represent a diversity typical in the development and evaluation of national-scope timber investment programs. The six subsets of silviculturally similar investments were constructed to determine

whether investment diversity affects ranking differences. These silviculturally similar groups are more typical of the timber investment diversity faced by a small landowner.

The constrained budget results from the subsets of similar investments were consistent with the results from the more diverse set of 231 investments in two respects (*table 3*). The B/C criterion almost invariably yielded the greatest program PNW, and the program PNW's from the different criteria converged as the amount of the fixed budget increased. Although the budget levels are not directly comparable, it appears that the program PNW's converged faster for the more similar investment subsets than they did for the full sample.

Contrary to the results from the 231-investment set, however, the IROR's program PNW was consistently greater than that of the PNW per acre criterion. The shortfall of the IROR's program PNW below the maximum established by the B/C criterion was negligible in all situations except the first budget level in two subsets. There is no readily apparent reason for this relative change.

Table 3—*Percent of the largest program present net worth (PNW)[1] achieved when investments are selected from alternative rankings of six similar investment groups, by budget level and investment criteria applied*

Investment group[1]	Budget level (thousand dollars)	Internal rate of return	PNW per acre[2]	Benefit/cost[2]
		Percent		
Planting of southern pine (41)	2.5	81.9	62.3	100.0
	5.0	99.9	77.3	100.0
	7.5	100.0	83.5	97.6
	10.0	100.0	92.8	100.0
	12.5	99.6	96.5	100.0
	15.0	99.9	95.8	100.0
	17.5	100.0	93.5	100.0
	20.0	99.9	98.3	100.0
Planting of northern conifers (20)	2.5	100.0	100.0	100.0
	5.0	100.0	100.0	100.0
	5.0	100.0	100.0	100.0
	7.5	100.0	100.0	100.0
Planting of western conifers (13)	2.5	100.0	79.3	100.0
	5.0	100.0	99.8	100.0
	7.5	100.0	99.8	100.0
Understory release of southern pine (14)	2.5	89.9	100.0	100.0
	5.0	100.0	99.6	99.2
	7.5	100.0	100.0	100.0
Intermediate treatment in oak-hickory and cove hardwood (15)	2.5	98.3	92.6	100.0
	5.0	98.7	99.8	100.0
	7.5	100.0	100.0	100.0
	10.0	100.0	100.0	100.0
Intermediate treatment in northern hardwoods (23)	2.5	94.2	86.4	100.0
	5.0	98.2	94.6	100.0
	7.5	98.8	95.4	100.0
	10.0	100.0	100.0	100.0

[1]Values in parentheses show number of investments.
[2]Discount rate of 7.5 percent.

Frequency of Multiple Internal Rates of Return

Silvicultural practices analyzed as marginal investments usually contain more than one sign reversal in their time stream of net benefits. The time stream of net benefits often starts then with a treatment (negative net benefit), followed by a harvest of the treated stand (positive net benefit), and followed in turn by the foregone harvest of the timber stand that would have occurred if the stand had not been treated (negative net benefit). A time stream with two sign reversals has the potential for two unique IROR's.

All 1433 investments originally sampled from the 1974 Forestry Incentives Program were searched for multiple IROR's. Only two had more than one IROR. One was a Douglas-fir planting investment with IROR's of 2.7 and 12.9 percent. The other was a ponderosa pine pruning investment which had 3.7 and 7.8 percent IROR's.

Effect of Perpetual Rotations

All timber investments analyzed to this point included a second timber rotation which was repeated into perpetuity. Ninety investments were drawn from the original 1433 investments to test the impact of removing the second and perpetual rotations. These 90 were then combined into 5 subsets of similar investments (*table 4*). The length of time between the treatment and the end of the first rotation was 40 to 50 years for most of the sample cases. The mean IROR, PNW per acre (at 7.5 pct), and B/C (at 7.5 pct) were calculated for the investments in each subset, both with and without the second and perpetual rotations.

The impact on IROR of removing the perpetual rotations was very low. The greatest IROR reduction was 0.13 percentage points of interest or a 0.01 percent decline. The mean B/C ratio was affected more, but the mean change was still small. The greatest impact was on the PNW per acre criterion. The average PNW per acre reduction was $11/acre or 11.45 percent.

Perfect knowledge is usually assumed in theoretical discussions of the several investment criteria, yet it never exists in reality (Hirshleifer 1958). This is especially relevant in forestry investments with their very long maturity periods. The relative effect of input data uncertainty on the performance of the several investment criteria should be considered.

This relatively lower sensitivity of IROR to the analysis simplification of removing the perpetual rotations is similar to the results derived by Mills and others (1976) in their analysis of financial return sensitivity to the possibility of data errors. They estimated the percentage change in input data required to yield an IROR which was 1 percent of interest higher or lower than the IROR using the base data. A comparable threshold for the effect of input data changes on estimated PNW was then calculated to deter-

Table 4—*Estimated mean financial return with and without the second and perpetual timber rotation for five groups of similar investments, by investment criteria applied*

Investment group[1]	Average first rotation	Internal rate of return	Present net worth per acre[1]	Benefit/cost[1] ratio
	Years	*Pct*	*Dollars*	
Site preparation and plant southern pine, Alabama (20):	44.2	–	–	–
With perpetual rotations	–	11.37	155.25	3.88
With first rotation only	–	11.33	139.69	3.78
Intermediate treatment of southern pine and oak-pine, Louisiana (19):	44.4	–	–	–
With perpetual rotations	–	13.16	150.47	5.82
With first rotation only	–	13.15	131.80	5.69
Plant northern conifers, Michigan (25):	116.8	–	–	–
With perpetual rotations	–	8.19	6.72	1.58
With first rotation only	–	8.19	6.66	1.57
Intermediate treatment of oak-hickory, Pennsylvania (5):	50.6	–	–	–
With perpetual rotations	–	15.75	187.09	5.10
With first rotation only	–	15.75	181.94	5.01
Intermediate treatment of northern hardwoods, Michigan (21):	48.0	–	–	–
With perpetual rotations	–	12.67	50.81	2.97
With first rotation only	–	12.54	35.20	2.47

[1]Values in parentheses show number of investments.
[2]Discount rate of 7.5 percent.

mine if the estimated IROR was more or less sensitive than estimated PNW to input data changes.

Their results showed that the estimated IROR was far less sensitive to input data changes than was the estimated PNW for investments which had an IROR that approached the discount rate. Those investments are the very ones in which the decisionmaker wants the most confidence, because they are near the acceptance-rejection threshold. The lower sensitivity of the IROR criterion to input data uncertainty translates directly into reduced data collection costs because data standards can be less stringent. The costs of data collection are just as important as the costs of errant investment selections.

DISCUSSION AND CONCLUSIONS

Three previous studies evaluated how much the ranking of independent timber investments differed among the three major investment criteria and all three reached the same conclusion. Ranking differences did occur, but with very low frequencies.

Webster (1968) analyzed 23 independent timber investments in Pennsylvania. The investment cases were structured as marginal investments. That is, the treatment which represented the investment was an increment of management intensity added to some base level management. The 23 cases were about equally split between conifer plantings and intermediate treatments in cove hardwoods, oak-hickory, and northern hardwoods. The study included the IROR, PNW, and B/C criteria, the last two at 3 and 6 percent discount rates. Webster found some difference in ranking, but the relative displacement on the rank was usually only a few positions.

Haley (1969) analyzed 12 Douglas-fir investments in British Columbia using a marginal analysis format. Eight of the investments were reforestation and four were precommercial thinning. The two investment sets were ranked separately by IROR, PNW, and B/C; the last two at 3, 4, 5 and 6 percent discount rates. The rankings differed, but only slightly, and Haley concluded that the differences were not large enough to be of practical importance.

Goforth and Mills (1975) ranked 21 independent timber investments by IROR, PNW per acre, and B/C, the last two discounted at 5 percent. The marginal investments included reforestation, understory release, and precommercial thinning. Species included Douglas-fir, fir-spruce, lodgepole pine, ponderosa pine, and the major southern pines. There were only minor differences in the investment rankings.

These studies reached similar conclusions but each evaluated a small set of investments, many of the investments were similar, and a range of discount rates was not always studied. Their empirical results may not hold for a larger set of more diverse timber investments, such as might be encountered by a large private landowner or in the development of a national-scope public timber investment program. This study was undertaken to overcome those limitations.

Important theoretical distinctions underlie the several investment criteria. And the analyst must understand these

distinctions before choosing a criterion for a particular analysis. If the theoretically possible difficulties which plague the criteria occur infrequently, however, practical considerations should have a major effect on the criterion choice.

In this study, the theoretically possible ambiguity of multiple IROR's was not a problem. They were only found in two of the 1443 investments analyzed. When the subset of 231 independent investments were ranked by IROR, PNW per acre, and B/C, ranking differences did occur, but the displacement of an investment was usually only a few rank positions.

Given a fixed investment budget, the B/C criterion consistently produced the selection of investments which had the highest cumulative PNW. The advantage of the B/C criterion quickly disappeared, however, when the magnitude of the fixed budget was increased. The performance of the several investment criteria was similar at higher budget levels. Given large investment budgets, the consequences of ranking differences between the criteria were minimal, particularly if the investments were similar silviculturally.

In contrast to the general similarities in investment rankings displayed by the criteria, a differential sensitivity to input data errors or uncertainties was evident. The results from the PNW per acre criterion were much more affected by the removal of the second and perpetual rotations than was the IROR results. Changes in the discount rate, which are comparable to errors in the discount rate specification, also materially affected the PNW per acre investment ranking. The appropriate discount rate for public investments has been, and probably will be, a continuing point of debate. An error in the selection of the proper discount rate for the PNW per acre criterion may have more of an impact on investment ranking than the use of another investment criterion altogether.

Only independent timber investments were evaluated in this study. The differences that result from application of the different investment criteria would be more significant for mutually exclusive investments. A difference in rank position of a few places is quite unimportant if the investments are independent but a lower ranking would lead to the discarding of an investment from a group of mutually exclusive investments.

It is apparent from the literature that the several criteria produce investment ranking differences, that multiple IROR's do occur, and that the removal of perpetual rotations does affect financial return estimates. In this study, empirical results suggest that the practical importance of these theoretical problems for a sample of 231 independent timber investments was small.

REFERENCES

Bentley, William R.; Teeguarden, Dennis E. **Financial maturity: a theoretical review.** Forest Sci. 11(1):76-87; 1965 January.

Beuter, John H.; Handy, Jeffrey K. **Economic guidelines to reforestation for different ownerships; a case study for the coast range of western Oregon.** Res. Paper 23. Corvallis, OR: School of For., Oregon State Univ.; 1974. 69 p.

Bierman, H., Jr.; Smidt, S. **The capital budgeting decision: economic analysis of investment projects.** New York: MacMillan Co.; 1980. 544 p.

Boulding, Kenneth E. **Economic analysis.** 3d ed. New York: Harper and Brothers; 1955. 905 p.

Fisher, Irving. **The theory of interest.** New York: MacMillan Co.; 1930. 566 p.

Gaffney, M. Mason **Concepts of financial maturity of timber and other assets.** A. E. Inf. Series 62. Raleigh, NC: North Carolina State Univ.; 1960. 105 p.

Gansner, David A.; Larsen, David N. **Pitfalls of using internal rate of return to rank investments in forestry.** Res. Note NE-106. Broomhall, PA: Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 1969. 5 p.

Goforth, Marcus H.; Mills, Thomas J. **A financial return program for forestry investments; including sensitivity results to data errors.** Agric. Handb. 488. Washington, DC: U.S. Department of Agriculture; 1975. 18 p.

Gregory, G. Robinson. **Forest resource economics.** New York: Ronald Press Co.; 1972. 548 p.

Haley, David. **A comparison of alternative criteria for the evaluation of investment projects in forestry.** Vancouver, BC: Univ. British Columbia; 1969. 93 p.

Hirshleifer, J. **On the theory of optimal investment decisions.** J. Polit. Econ. 66(4):329-352; 1958 April.

Hirshleifer, J. **Investment, interest, and capital.** Englewood Cliffs: Prentice-Hall, Inc.; 1970. 320 p.

Lorie, James H.; Savage, Leonard J. **Three problems in rationing capital.** In: Solomon, Ezra, ed. The management of corporate capital. Glencoe: Free Press; 1959: 56-66.

Lutz, Frederick; Lutz, Vera. **The theory of investment of the firm.** Princeton: Princeton Univ. Press; 1951. 253 p.

Manthy, Robert S. **An investment guide for cooperative forest management in Pennsylvania.** Res. Paper NE-159. Broomhall, PA: Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 1970. 59 p.

Marty, Robert. **The composite internal rate of return.** Forest Sci. 16(3): 276-279; 1970 September.

McKean, Roland N. **Efficiency in government through systems analysis.** New York: John Wiley; 1958. 336 p.

Mills, Thomas J.; Cain, Daria. **Timber yield and financial return performance of the 1974 Forestry Incentives Program.** Res. Paper RM-204. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1978. 56 p.

Mills, Thomas J.; Goforth, Marcus H.; Hart, Thomas P. **Sensitivity of estimated financial returns on timber investments to data errors.** Res. Paper WO-31. Washington, DC: Forest Service, U.S. Department of Agriculture; 1976. 31 p.

Mishan, Edward J. **Cost-benefit analysis.** New York: Praeger Publishers; 1976. 454 p.

Row, Clark; Kaiser, H. Fred; Sessions, John. **Discount rate for long-term Forest Service investments.** J. For. 79(6):367-369, 376; 1981 June.

Schallau, C. H.; Wirth, M. E. **Reinvestment rate and the analysis of forestry enterprises.** J. For. 78(12):740-742; 1980 December.

Solomon, Ezra, ed. **The management of corporate capital.** Glencoe: Free Press; 1959. 327 p.

U.S. Department of Agriculture, Forest Service. **Forest Service Manual 1970** (draft). Washington, DC; 1980.

U.S. Department of Agriculture, Soil Conservation Service. **Watersheds Memorandum—92** (rev. 6). Washington, DC; 1973. 3 p.

U.S. Office of Management and Budget. **Circular A-94.** Washington, DC; 1972. 4 p.

Webster, Henry H. **Profit criteria and timber management.** J. For. 63(4): 260-266; 1968 April.