AN ECONOMIC FRAMEWORK TO EVALUATE TREE IMPROVEMENT

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The economic evaluation of a phenotypically or genotypically improved forest is conceptually quite easy: the cost and revenue streams of the improved stand are compared with a similar non-improved one and the one that gives the highest net discounted revenue is selected. Or a cost - benefit analysis can be carried out to see whether tree and stand improvement pays. However, upon closer inspection a number of problems arise when one tries to carry out such an economic analysis. These problems are quite apart from the ones associated with the insufficiency of data to estimate the additional revenues and costs. Rather, these problems are part of the economic analysis itself. Finally, the above procedure does not give the geneticist any a priori information about what is likely to be economically desirable so he has to rely on his own economic instinct. This paper will try to provide a framework within which economic decisions can be made and which can provide some guidelines as to what to strive for in tree improvement. Specifically it will adapt the traditional framework of optimising the rate of return when investing in a forest stand to incorporate tree improvement decisions.

Suppose capital has been invested in land and it has been decided to grow trees. The following costs and revenues are defined:

C_o = stand establishment costs, including possibly land preparation, seed and/or seedling costs, planting charges and others. It is assumed that the most economical way of establishing a stand is known.

$c_1(t)$ = sum of all compounded costs incurred up to time t which are a function of the amount of the cut Y; e.g., certain severance and income taxes and costs associated with intermediate cuts.

$c_2(t)$ = sum of all compounded costs incurred up to time t which are a function of the volume V present on the ground; e.g., certain ad valorem taxes, insurance and protection costs.

$c_3(t)$ = sum of all compounded costs incurred up to time t which are neither a function of the volume present nor of the amount cut. They include certain cleaning costs of the young stands and certain fixed management and overhead costs.

$c(t)$ = $c_1(t)+c_2(t)+c_3(t)$

i = cost of capital used to compound or discount all costs and revenues.

$r_1(t)$ = value of the stand on the ground at time t net of all harvesting costs. In formula form $r_1(t)=V_tP_t-Ct$, where V_t is volume present at time t, Pt is price per unit of timber at time t and C_t are the harvesting costs.

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$r_2(t)$ = sum of all compounded revenues received up to time t. In formula form $r_2(t)=\sum_{j=1}^{t} (Y_jP_j)(1+i)^{t-j}$ where P_j is the price per unit of timber cut at time j and Y_j is amount of timber cut in period j. Note that felling costs are included in $c_1(t)$.

S = the value of the land or the land expectation value.

δ = the kronecker delta, a variable which can assume only the values o (case of no tree improvement) or 1 (case of tree improvement).

Δ in front of any of the above symbols indicates a small change in the associated symbol as a result of tree improvement. For example:

ΔC_o = increase or decrease in stand establishment costs as a result of using improved stock. It can consist of increased seed costs because of using superior seed; of the difference between regular regeneration costs and the regeneration costs necessitated by the use of superior seedlings; and others.

$\Delta r_2(t)$ = increase or decrease in the sum of all revenues compounded up to time t, i.e. $\Delta r_2(t)=\sum_{j=1}^{t} [(Y_j+\Delta Y_j)\Delta P_j(1+i)^{t-j}+(\Delta Y_jP_j)(1+i)^{t-j}]$ Here ΔP_j is the possible increase or decrease in price per unit of timber cut in period j as a result of a change in the quality of the wood produced under a tree improvement program. And ΔY_j is the increase or decrease in timber cut in period j. The first part of the formula represents an allowance for the possible change in price, the second part for a possible change in the amount cut.

$\Delta r_1(t)$ = $(V_t+\Delta V_t)\Delta P_t+\Delta V_tP_t-\Delta C_t$

$\Delta c_1(t)$, $\Delta c_2(t)$ and $\Delta c_3(t)$ are changes in costs as a result of ΔY_t, ΔV_t and ΔP_t. For example, if an improved tree is more resistant against a disease, the cost of protection may drop to zero. Again $\Delta c(t)=\Delta c_1(t)+\Delta c_2(t)+\Delta c_3(t)$.

Note that $V_j=V_{j-1}+G_{j-1}-Y_{j-1}$ where G_{j-1} is the growth in period j-1. Note also that while $Y_j \geq o, \Delta Y_j \geq -Y_j$. It is assumed that it is known when and by how much to thin both the unimproved and improved stands, though the thinning schedules may be different in the two cases. This is why ΔY_j is allowed to be negative: if it is decided to thin in improved stands in the 10th year instead of in the 15th year in the case of unimproved stands, then $Y_{10}=o, Y_{15}>o, \Delta Y_{15}=-Y_{15}$, while $\Delta Y_{10}>o$. Hence ΔY_{15} serves to negate Y_{15}. It is well to emphasize that the assumption of known thinning schedules is a very strong one, especially since a large part of the success of a tree improvement program may be found in larger and earlier intermediate harvests. Finally it is assumed that tree improvement is an either/or decision, either we do it or we do not; no gradations of tree improvement are considered.

With the above symbols defined, we can now write:

$$S=\{r_1(t)+r_2(t)-C_o(1+i)^t-c(t)+\delta[\Delta r_1(t)+\Delta r_2(t)-\Delta C_o(1+i)^t-\Delta c(t)]\}\{(1+i)^t-1\}^{-1} \quad (1)$$

This is nothing else than a slightly modified version of Faustmann's formula. If we assume a known i, we can determine t so that S is maximized; in that case S is the soil or land expectation value. Or a known value for S can be assumed and t determined so as to maximize i. The first approach is employed in this paper since it is the most familiar one to foresters and the second one did not offer any special advantages.

Taking the first derivative of S with respect to t, equating the result to zero and solving for t, the following expression is obtained (primed symbols denote that the first derivative with respect to t is involved, while Ln stands for logarithm).

$$t=\mathrm{Ln}\left[r_1'(t)+r_2'(t)-c'(t)+\delta[\Delta r_1'(t)+\Delta r_2'(t)-\Delta c'(t)]\right]\{\mathrm{Ln}(1+i)\}^{-1}- \mathrm{Ln}\left[r_1'(t)+r_2'(t)-c'(t)+\{C_o+c(t)-r_1(t)-r_2(t)\}\mathrm{Ln}(1+i)+\delta[\Delta r_1'(t) +\Delta r_2'(t)-\Delta c'(t)+\{\Delta C_o+\Delta c(t)-\Delta r_1(t)-\Delta r_2(t)\}\mathrm{Ln}(1+i)]\right]\{\mathrm{Ln}(1+i)\}^{-1} \qquad (2)$$

Note that this is still an implicit solution for t, since the revenue and cost functions are functions of it. Thus it must be interpreted with care. If we abstract from the possibilities of local optima, the above expression when solved for t, gives the optimal S.[2]

For analytical purposes it is illuminating to recast the solution for t in its marginal form. The optimising value of t is obtained when:

$$\mathrm{Ln}\,(1+i)=\frac{r_1'(t)+r_2'(t)-c'(t)+\delta[\Delta r_1'(t)+\Delta r_2'(t)-\Delta c'(t)]}{r_1(t)+\delta r_1(t)+S} \qquad (3)$$

i.e. the cost of capital should equal the present net rate of return earned by the land divided by the value of the growing stock plus the land value. Substituting the original expression for S into the formula and reworking it slightly, the following expression is obtained:

$$\frac{(1+i)^t\mathrm{Ln}(1+i)}{(1+i)^t-1}=\frac{r_1'(t)+r_2'(t)-c'(t)+\delta[\Delta r_1'(t)+\Delta r_2'(t)-\Delta c'(t)]}{r_1(t)-C_o+\delta[\Delta r_1(t)-\Delta Co]+\{r_2(t)-c(t)+\delta[\Delta r_2(t)-\Delta c(t)]\}(1+i)^{-t}} \qquad (4)$$

This is perhaps the most operational way to calculatethe optimal rotation,t*.

Tf S with σ=1 is larger than S with σ=o, genetic improvement is economically advantageous by the amount of the difference. However, whether or not this is the case, cannot be read from the formula for S by stating that the term with which σ is multiplied should be larger than zero if tree improvement is to be advantageous. This is because the optimal rotation t* may change if σ=1, thus changing the whole first part of the formula for S as well. Hence the first question that arises is: In what direction will the rotation change as a result of tree improvement?

2/ Needless to say, this way of determinging t serves only one purpose: to trace through the separate influence of genetic improvement and to compare it with an unimproved stand. If only the optimising solution is desired for an improved stand, it will be determined in the regular way familiar to foresters.

Under the program of tree improvement, ΔC_o is likely to be positive. Hence, under ceteris paribus conditions, the denominator of expression (4) will go down, thus increasing the age and thus the rotation that will equalize the two parts of the expression. However, a tree improvement program will have two additional effects: it affects both the revenue and cost streams. It is not difficult to see that at any one point in time Δr_1, Δr_2, Δc and their first derivatives with respect to t may be positive or negative. Thus a priori, it is impossible to predict whether a program of tree improvement will increase or decrease rotations. It can do either.

To show this more vividly assume the case that perhaps many people have in mind when they discuss a tree improvement program: the cumulative value growth curve of the improved stand lies uniformly above the one of the unimproved stand. This means that $\Delta r_1+\Delta r_2$ will be positive for all t even though at some ages Δr_1 or Δr_2 may be negative because of a different thinning or intermediate cutting régime. A positive Δr_2 increases the land expectation value S (expression 1) and thus tends to decrease the rotation (expression 3). If Δr_1 is negative throughout (meaning less value per acre is maintained at each t), this would also increase the rotation. It is, however, more likely that Δr_1 will be positive throughout, leading to a reduced rotation. At the same time nothing can really be said about the first derivatives $\Delta r_1'$ and $\Delta r_2'$. Depending on the shape of the total value growth curve they may be positive at some points in time and negative at others. One can visualize improved stands showing a much more rapid increase in value growth at a young age than an unimproved stand, only to fall back and approach unimproved stands again, as well as those that show the most rapid growth long after the age at which the growth of the unimproved stand culminates. Finally Δc is likely to be positive (though not by as much as $\Delta r_1+\Delta r_2$), but it could be negative if, for example, tree improvement substantially increases resistance against disease and thus reduces the costs of protection. But $\Delta c'$ can again be either positive or negative. In short, the rotation can either be increased or decreased, even in this case where one would expect a priori a shorter rotation.

Both the rotation and the land expectation value and thus the financial success of a tree improvement program, depend critically on the cost of capital i that is used. An increase in i, increases the left hand side of expression (4) and thus reduces the rotation. The influence of a rise in i on the land expectation value and thus on the financial success of the tree improvement program is much more uncertain. It is fairly trivial to say that high capital costs favor those programs that concentrate the bulk of the value growth early in the life of a stand, ceteris paribus. Much more important is whether or not at some i, stand improvement is uneconomical while at other rates stand improvement becomes desirable. What are the critical rates and what type of tree improvement (that is, cumulative growth curve) should one strive for under the different rates?

To be able to answer this, it becomes necessary to trace through the influence of i on S in expression (1). However, because changes in i as we have seen, change the rotation, whether or not stand improvement is involved, this is a very difficult task. To show this, assume the easiest case where δ=o; that is, the absence of stand improvement. Most authors state that increasing i, decreases S (see for example Davis 1966 page 240 and Gaffney 1957 pages 33 and 35). However, no proof is given and this author believes that the contrary is possible in some instances. If i, for example, increases, this increases $C_o(1+i)^t$, $c(t)$, $r_2(t)$ and $(1+i)^t-1$ at any one time, while $r_1(t)$ at any one time remains unchanged. Since the increase in costs is likely to swamp the increase in $r_2(t)$ this seemingly leads to a reduction in S. However, it was shown that an increase in i, reduces t*. It is possible to think of realistic growth functions where an increase in i reduces t* so much that (1+1) is reduced, rather than increased. Thus it is possible that an increase in i, increases S. It is not difficult to show that at extreme values of i this will not happen. As i approaches zero, the rotation will never be increased beyond the age of maximum mean annual net value growth; hence S will then approach infinity because the significance of an increase in t* disappears. Similarly as i approaches very big values, the rotation will never be decreased beyond the point of maximum net marginal value growth; hence S will then approach zero. But this does not preclude reversals to occur inbetween two extreme values.

Hence it must be concluded that beyond the economic framework provided above, for the time being, conclusions about the dependence of S on i can only be obtained if specific functions and shifts in these functions are used.

The next question of interest that arises is the following: assuming stand improvement is an economic success, how fast should an existing unimproved stand be replaced? Should it be cut at the originally calculated rotation or at a different age. This is a problem- similar to an eauipment replacement problem as described, for example, by Masse (1962) with one exception: the forest stand is an appreciating rather than a depreciating asset. The revised rotation for the existing stand is easy to calculate using expression (3). All we have to do is calculate t for the improved stand according to expression (2) or (4) with σ=1 and to substitute this value into equation (1) to obtain S. Using this value of S in equation (3) with 6=o, gives us the revised rotation for the unimproved stand. Future stands are accounted for through the use of the best future land value S obtainable. Since this new value of S is higher than the old one (because by assumption stand improvement is economically desirable), the revised rotation of the old stand will be shorter as can be seen from equation (3). That is, the existing unimproved stand should be liquidated faster than originally planned.

In equipment replacement problems one factor influencing the optimal time to replace a machine is the prospect of a continuous rise in technology. The question is: should the current old machine be replaced by the new, more advanced one currently on the market or should one wait a year or so for an even more advanced type? Masse (1962) shows that under stringent assumptions as to the path of technology, an analytic solution can be obtained. In tree improvement a similar situation can be visualized: genetic research may produce better and better trees over time. Of course only those improvements that pay will be taken into account. It now becomes very difficult to calculate S, since the rotation of each stand started keeps changing as yet another improved strain or variety becomes available. Moreover, the S thus calculated will be a function of the time at which the series of rotations is assumed to start: each year later that the series is assumed to start, will increase S. This is what Masse refers to as the "Boiteux effect." Only under certain rigid assumptions concerning the future path of tree improvements can an analytic solution be obtained.

As a result of such a series of tree improvements over time, the land expectation value S will increase over time (always assuming that these tree improvements are economical). This by itself will reduce rotations over time (see expression (3)). However, as was pointed out before, tree improvements have other effects as well which may increase or decrease rotations.

Until now the discussion has centered on an even-aged stand grown on a unit area. Wood producers will however wonder how they will be affected by a change in rotation. A shorter rotation will not affect them adversely: the returns to their land through their land value S will be increased while they get these higher receipts earlier. However, as was shown, tree improvement may be economical while increasing rotations. That is, landowners may have to wait a bit longer until they get the higher (discounted) receipts. A landowner producing wood for the open market and with accessibility to credit (at a cost i) should not be affected. But a woodlands manager having to satisfy the wood requirements of a plant may very well see in the short run a reduced output of wood. And, if tree improvement consists mainly of increasing the quality of the wood produced, even in the long run, wood production in purely volumetric terms may be decreased. Whether and how this affects him, depends on the individual case. It is necessary, however, to take the repercussions on the whole enterprise into account when evaluating a tree improvement program.

In summary, an economic framework is provided within which to evaluate and judge some of the implications of a tree improvement program. It can of course be used most easily when the necessary data are available or can be predicted. However, perhaps its greatest usefulness is when the manager or geneticist has only some preliminary notions about the cumulative growth and cost functions of the improved stand. For example, if he knows the general shape of these functions and the direction these functions have changed in comparison with the unimproved stands, but not the absolute magnitudes involved.

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