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THE ECONOMICS OF PRIVATE FOREST MANAGEMENT

UNIFYING THE FAUSTMANN MODEL AND NON-INDUSTRIAL PRIVATE FOREST MANAGEMENT MODELS

D.D. Dole

Agricultural & Resource Economics
Discussion Paper: 4/94

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Abstract

The majority of forest land in the U.S. is owned by individuals and institutions that are not directly involved in the forest products industry. Much of this land is thought to be managed inefficiently, but the reasons for this are unclear. This article focusses on three possible factors: information and transactions costs; nonfinancial forest values; and liquidity constraints. Models for the reforestation and harvesting decisions are presented that incorporate these factors. These models use the Faustmann model to define the financial value of forest land, and borrow from previously developed models of nonindustrial private forest management to incorporate the other factors into the forest management decision. A wealth of data exists on nonindustrial private forest management, and discussion focusses in particular on models that are suitable for the study of existing data.

The vast majority of commercial forest land in the United States is privately owned.[1] This land is commonly considered as falling into two separate classes, defined by a particular characteristic of the landowner: whether the owner is involved in the forest products industry (industrial, private forest land), or not (nonindustrial private forest land).[2] Landowners in the former class can be taken as principally profit-oriented, and so management can be analyzed via the Faustmann model. Landowners in the latter class, though, have diverse management objectives, and so are more difficult to characterize. In essence, the nonindustrial private forests are a residual class (as the name suggests), despite the fact that they hold up to 80% of all private forest land.

The management of these nonindustrial private forests (NIPF's) has "long been considered a problem by many resource managers and policy makers." (Kurtz, 1989, p. 342). In periodic inventories of the nation's forest resources, the Forest Service has repeatedly identified opportunities for increased timber production on NIPF land. Presumably accompanying this productive potential must be profits for the landowners who exploit it, but for reasons that are largely unknown, landowners have ignored these potential profits. Numerous studies have been conducted, but "what motivates landowner behavior remains incompletely understood." (Martin and Bliss, 1990, p. 248).

A variety of approaches have been taken to modelling NIPF management. (See Binkley, 1981; Boyd, 1984; Hyberg and Holthausen, 1989; Kuuluvainen, 1989) The following presents a synthesis of these models and the standard, Faustmann model. As will be shown below, the forest management rules generated by the Faustmann model can be easily modified to account for the different objectives and characteristics of NIPF landowners. The modified decision rules are consistent with the Faustmann model in the sense that, if the additional factors are unimportant, the rules reduce to the Faustmann forms. So under this synthesis, profit-maximizing forest management appears as a special type of NIPF management. This will make it possible to empirically identify and interpret the factors (if any) that distinguish industrial and nonindustrial forest management.

The discussion focusses in particular on models that are suitable for application with existing data. By calling upon recently developed methods of nonparametric regression, these models need not sacrifice their essential economic content for the sake of empirical applicability. It's worth noting here that these models are not excessively difficult to apply or interpret for anyone with reasonable knowledge and experience in econometrics. Most of the variables required by the models are typically available in data collected by the Forest Service or by state forestry departments. The models also point to other variables that may improve the information set maintained by these agencies.

The discussion begins, in section I, with the standard economic model of private forest management, the Faustmann (or profit-maximization) model. This model establishes the pure financial value of a forest asset, and is the foundation on which the rest of the models are built. It is maintained here that NIPF management may be distinguished from industrial forest management by information and transactions costs; by the nonfinancial values that some landowners derive from their forests; and by the long term to maturity

[1]"Commercial forest land", or "timberland", is defined by the Forest Service as "forest land that is producing or is capable of producing crops of industrial wood and is not withdrawn from timber utilization by statute or administrative regulation." (U.S.D.A., Forest Service, 1990, p. 254) For the sake of readability, commercial forest land will hereafter be referred to simply as "forest land."

[2]Nonindustrial, private forest land is sometimes classified into 'farmer' and 'other' classes.

and low liquidity of forest investments. Following section I, the discussion considers each of these factors in turn, analyzing how they may affect the forest management decisions of private landowners. These factors give rise to a variety of socioeconomic effects, and can explain virtually all of the socioeconomic variables that have appeared in empirical studies of NIPF management. The discussion focusses on reforestation and timber harvesting, but other forest management practices can also be accommodated within this framework. The last section discusses directions for further research, including strategies for both applying and improving the models.

I. The Faustmann model

The standard economic model of forest management is the Faustmann (or profit-maximization) model. This model, in its standard formulation, focusses on the pure and simple financial values of forest management. Of course, a variety of other aspects of forest management may also be important to real landowners. However, by clearly establishing the financial values of forest management, the Faustmann model provides a solid foundation upon which other aspects of forest management can be built. This section will define the Faustmann decision rules for reforestation and timber harvesting. Subsequent sections will show how these decision rules can be modified to account for various factors not incorporated in the standard Faustmann model formulation.

The Faustmann model and its implications for forest management are well-known, so the discussion here need not be thorough.[3] As is well known, in the Faustmann model the forest is managed to maximize the present value of all future timber profits. This may be expressed mathematically as

$$\pi = \max_{\alpha} \frac{p_s G(\alpha) - c_r}{(1+i)^{\alpha} - 1} \tag{1}$$

where

α = rotation length in (an integer number) of years;
p_s = stumpage value (net of harvest costs) per unit volume;
$G(\alpha)$ = predicted marketable volume per unit area at stand age α;
c_r = cost per unit area of reforestation after harvest;
i = annual real interest rate.[4]

The reforestation decision

Consider first what this model implies for the decision to clear and reforest a site taken over by bush or by some noncommercial species.[5] Assume that somehow the landowner calculates π. The landowner ignores risk and assumes that land markets will properly value his property -- that is, that land markets are "efficient." π is the value of a newly planted stand, so $(\pi - c_r)$ is the value of bare land. If c_c is the cost of land clearing and site preparation, then $(\pi - c_r - c_c)$ is the value of reforesting the site. It is also the current market value of the unforested site, assuming that land markets are efficient. Of course

[3]For further discussion see Clark (1976).

[4]The Faustmann model is perhaps more commonly expressed in continuous time, but annual growth models are more appropriate for empirical work -- $G(\alpha)$, for example, may be taken from yield tables. (See Dole, 1993)

[5]This will hereafter be referred to simply as "reforestation."

the landowner does not receive this value unless the reforestation project is undertaken, or unless the land is sold immediately. If the landowner plans to sell the property some length of time T into the future, the present value to the landowner of the unforested site is $(\pi - c_r - c_c)\delta^T$, where

$\delta = 1/(1+i)$.

The length of tenure for the typical NIPF landowner is much less than the rotation length of most commercial species, so most of these landowners would never see the profits from even the first timber harvest. Of course, the economically rational landowner does not invest in reforestation specifically for the potential timber profits, but for the value that the investment adds to the property. If the reforestation project is undertaken, the change in the present value of the property is

$$(\pi - c_r - c_c) - (\pi - c_r - c_c)\delta^T = (\pi - c_r - c_c)(1 - \delta^T) \qquad (2)$$

The profit-maximization rule for reforestation is to invest whenever the project adds positive value to the property -- whenever the financial benefit of reforestation is positive. So the landowner undertakes the reforestation project whenever $(\pi - c_r - c_c)(1-\delta^T)>0$, or equivalently whenever the profit per unit area is positive: $(\pi - c_r - c_c)>0$.

The harvesting decision

Now consider what the Faustmann model implies for the decision to harvest an established stand. The landowner observes the stand's age, α, measures the current merchantable volume, $G(\alpha)$, and makes a prediction for this year's growth, $g(\alpha)$.[6] With this information, the landowner can calculate the site value, Π, at the rotation lengths α and $\alpha+1$; namely

$$\Pi(\alpha) = \frac{p_s G(\alpha) - c_r}{(1+i)^{\alpha} - 1}, \quad \Pi(\alpha+1) = \frac{p_s (G(\alpha) + g(\alpha)) - c_r}{(1+i)^{\alpha+1} - 1} \qquad (3)$$

The difference $\Pi(\alpha+1)-\Pi(\alpha)$ is the benefit of increasing the rotation length by one year, or the benefit of letting the forest grow for one more year. The difference $\Pi(\alpha)-\Pi(\alpha+1)$ can also be thought of as the financial benefit of harvesting this year instead of next year. The profit-maximizing harvesting rule is to let the forest grow while the financial benefit of additional growth is positive ($\Pi(\alpha+1)-\Pi(\alpha)>0$), or equivalently while the financial benefit of harvesting is negative ($\Pi(\alpha)-\Pi(\alpha+1)<0$). Harvest occurs as soon as the benefit of harvesting is positive. Following this rule, the first year that $\Pi(\alpha)-\Pi(\alpha+1)>0$ is the optimal rotation length, α^* -- that is, the solution to the maximization problem in expression (1). Of course, once the landowner knows α^*, π is also known.

It can be shown that

$$\Pi(\alpha+1) - \Pi(\alpha) = \frac{p_s g(\alpha) - i\Pi(\alpha)\delta^{-\alpha}}{\delta^{-(\alpha+1)} - 1} \qquad (4)$$

So the profit-maximizing harvesting rule is, equivalently, to delay harvest while

[6]Equivalently, and more practically, these calculations can also be made using last year's observed growth, $g(\alpha)$.

$$p_s g(\alpha) - i\Pi(\alpha)\delta^{-\alpha} > 0 \qquad (5)$$

It is easy to see that this is consistent with the usual (continuous time) form of the Faustmann harvesting rule (the Faustmann formula). In continuous time, the site value at rotation length α is

$$\mathrm{PI}(\alpha) = \frac{p_s G(\alpha) - c_r}{e^{i\alpha} - 1} \qquad (6)$$

In this formulation it is possible to take the derivative with respect to α:

$$\mathrm{PI}'(\alpha) = \frac{p_s g(\alpha)}{e^{i\alpha} - 1} - \frac{p_s G(\alpha) - c_r}{(e^{i\alpha} - 1)^2} ie^{i\alpha} = \frac{p_s g(\alpha) - i\mathrm{PI}(\alpha)e^{i\alpha}}{e^{i\alpha} - 1} \qquad (7)$$

Of course, the maximum site value occurs when $\mathrm{PI}'(\alpha)=0$; the landowner will delay harvest while $\mathrm{PI}'(\alpha)>0$, or equivalently whenever

$$p_s g(\alpha) - i\mathrm{PI}(\alpha)e^{i\alpha} > 0 \qquad (8)$$

So except for the discount factor, the harvesting rules are essentially the same.

Summary

The crucial point to observe in the Faustmann model is that a given forest management practice takes place whenever the *marginal* financial benefit of the activity is positive, where the margin is a unit area of land. The financial benefit of reforestation and of harvesting, as given above, is taken as uniform over the existing area to which the activity is to be applied -- either by averaging across the existing area, or by partitioning the property into reasonably uniform plots. When the marginal financial benefit is positive, the activity takes place to the full extent possible, constrained only by the boundary of the area to which it can be applied: the whole site is reforested, or the whole stand is harvested.

The Faustmann model has had great appeal to economists, but it has not been entirely successful at describing the actual forest management practices of real private landowners. As mentioned above, over the past few decades the Forest Service has repeatedly identified forestry investment opportunities on NIPF land. Attempts to estimate timber supply relationships for NIPF landowners have had limited success. (Adams and Haynes, 1980) Somehow the Faustmann model must be overestimating the benefits of forest management to private landowners.

II. Information and transaction costs

Forest management can be a very difficult process for a landowner untrained and inexperienced in forestry -- the vast majority of NIPF landowners. Undertaking any forest management practice requires some basic knowledge of forestry, market information and information about one's own resources. This information can be very costly to collect and difficult to process. Collecting and processing the requisite knowledge and information may not impose direct monetary costs on the landowner, but may instead impose a cost in terms of the landowner's time and effort. Even if the landowner does not undertake the management in person, there is still a cost in collecting and processing information about potential agents, in contracting with an agent and in overseeing the agent's activities. Regardless of how the landowner decides to proceed, the amount of time and effort required will be more or less independent of the scale of the forest management operation. Hence these (nonfinancial) information and transaction costs are part of the fixed costs of engaging in forest management.

The importance of these information and transaction costs has been clearly established in previous empirical studies of forest management (although they have not always been recognized as such). Landowners with greater knowledge and information have been found to be more likely to engage in both timber harvesting and reforestation: their information costs are lower. (Boyd, 1984; Hyberg and Holthausen, 1989; Jamnick and Beckett, 1988) Some empirical research has also found that residence status or the distance the landowner lives from the property has a negative effect on the likelihood of reforestation: undertaking or overseeing a forest management project is clearly less difficult the closer the landowner lives to the property. (Romm, et al., 1987; Boyd, 1984; Jamnick and Beckitt, 1988; Dole, 1993)

However, information and transaction costs have not been specifically incorporated in previous economic models of forest management. This section shows that the profit-maximization conditions for reforestation and for harvesting can be easily modified to account for these costs in at least two different ways. The simplest approach is to treat these rather arbitrary costs as if they were actual financial costs imposed on the landowner, or at least as if some actual financial costs were dependent upon them. In this case, the landowner will undertake forest management only when the marginal *net* financial benefit is positive -- that is, when the marginal financial benefit exceeds the fixed costs *per unit area.*

The reforestation decision

Let $k \geq 0$ denote the (fixed) information and transaction costs of engaging in forest management, and let A denote the area to which the management practice is to be applied. Consider first the decision to reforest. The landowner will undertake a reforestation project only when

$$(\pi - c_r - c_c)(1 - \delta^T) - k/A > 0 \qquad (9)$$

Clearly if $k=0$, the decision rule reduces to profit-maximization.

As in the previous section, π is the optimal (Faustmann) site value, which is assumed to be independent of the information and transaction costs k. This holds provided the land market is driven by landowners with the most information and expertise, and hence, the lowest information and transaction costs. This of course implies that there are some landowners with such costs above that which the market will reward.[7] π can also be viewed as incorporating the lowest information and transaction costs, with k denoting the costs above this minimum level. Indeed, the level of knowledge and information of NIPF

[7] Of course if profits are the only motivation of landowners, then those landowners with higher information and transaction costs would be driven out of the market -- they would not go into forest ownership, or they would be bought out by others. But most NIPF landowners declare nonfinancial values as their primary management objectives, and presumably seek out and maintain landownership in spite of lower returns. Nonfinancial values are considered in section III.

landowners is known to vary substantially;[8] clearly the market cannot simultaneously reward every different level of cost.

So in the presence of these fixed costs, as the land available increases, the net benefit of reforestation increases, other things being equal. That is, fixed costs induce economies of scale in reforestation. The net benefit also increases as the planned period of tenure increases, so fixed costs may be said to induce "economies of tenure length" in reforestation. The landowner's planned period of tenure has not been considered in previous empirical studies of reforestation. However, the age of the landowner has been found to be negatively related to the propensity to undertake reforestation. (Romm, et al.; Dole) As the age of the landowner increases, on average planned tenure T should decrease, so there is at least indirect evidence of economies of tenure length in reforestation.

The harvesting decision

In the presence of these fixed information and transaction costs, it is no longer sufficient that the financial benefit of harvesting is merely positive; it must be greater than the fixed costs per unit area. Again these fixed costs are taken as above those rewarded by the market, so they do not affect the optimal (Faustmann) rotation, α^*, nor the optimal site value, π. Clearly the landowner will not harvest before the forest reaches α^*. In order to accumulate sufficient financial benefits to cover the fixed costs incurred in a single harvest, the landowner must let the forest grow beyond α^*.

As above, the financial benefit of harvesting is the difference between the optimal site values at consecutive ages. Consider a site that has an existing stand with age $\alpha > \alpha^*$. The optimal financial value of this site is

$$p_s G(\alpha) + \pi - c_r \tag{10}$$

That is, from the market's perspective, the best that can be done at this site is to harvest immediately and reforest. If the stand is allowed to grow another year, the present value of the site is

$$(p_s(G(\alpha) + g(\alpha)) + \pi - c_r)\delta \tag{11}$$

The benefit of harvesting a stand with age $\alpha > \alpha^*$ is the difference between these two values:

$$(i(p_s G(\alpha) + \pi - c_r) - p_s g(\alpha))\delta \tag{12}$$

In the presence of the information and transaction costs, k, the decision rule is that the landowner will harvest in the first year that

$$(i(p_s G(\alpha) + \pi - c_r) - p_s g(\alpha))\delta - k/A > 0 \tag{13}$$

Note that the closer k/A is to 0, the closer the decision rule is to profit-maximization, and so the closer the harvesting age is to α^*. So harvesting age can be expected to increase as information and transaction costs increase, and as land area (or property size) decreases.

[8] See Dole for the case of Oregon landowners.

Of course, k is not fixed, and may vary over time with a given landowner. In particular, k will be substantially and suddenly reduced if the landowner receives an unsolicited offer for the timber. So landowners with high information and transaction costs can be expected to deny any plans to harvest, and then be observed to harvest at a later time if they receive a reasonable offer for their timber.

Utility-based decision rules

The information and transaction costs represent essentially the time and effort required from a landowner who undertakes forest management: the less information the landowner possesses, the more difficult is the management practice and the more effort is required from the landowner. Since k is not measured in monetary units, in principle it cannot be directly compared to the pure financial benefits of forest management. Instead of considering forest management strictly in terms of its marginal *financial* benefits, these arbitrary costs can be incorporated into the decision process by considering the marginal *utility* of forest management. This perspective is perhaps most relevant for properties held in sole proprietorships, as the standard economic theory of utility maximization subject to the household budget constraint can be invoked directly. Since most NIPF land and most landowners are in sole proprietorships, there is in general no problem applying this view to most NIPF land. However, it may also be applied to other types of ownerships, provided the objectives and constraints of the ownership unit as a whole are clearly defined.

Once again, the margin is a unit area of land, and the rule is that forest management will occur whenever the marginal utility of the management practice is positive. This does not require a major modification of the decision rules discussed above. The marginal utility of forest management is given simply by the marginal financial benefit times the marginal utility of wealth (U'_W), minus the marginal time and effort required times the marginal utility of this time and effort (U'_E).[9] The marginal utility of reforestation (MU(r)) and of harvesting (MU(h)) are thus given by

$$\text{MU}(r) = (\pi - c_r - c_c)(1 - \delta^T)U'_W - (k/A)U'_E \quad (14)$$

and

$$\text{MU}(h) = (i(p_s\text{G}(\alpha) + \pi - c_r) - p_s\text{g}(\alpha))\delta U'_W - (k/A)U'_E \quad (15)$$

Wealth is defined here as the market value of the landowner's total portfolio of assets. According to standard economic theory, the marginal utility of wealth decreases as wealth increases. In general income will be positively correlated with wealth, so other things being equal, both marginal utilities above will decrease as wealth or income increases.[10] This means that wealthier landowners will be more apt to ignore relatively insignificant financial opportunities on their properties, especially when a lot of time and effort is required. For timber harvesting, in particular, this implies that wealthier landowners will allow their forests to grow longer, even if they place little or no nonfinancial values on the forest. In a number of empirical studies of NIPF harvesting,

[9]This is only an approximation to the formally correct decision rule. It is derived and discussed further in Dole, 1993.

[10]If the marginal utility of wealth is constant (as it would be for industrial landowners), the decision rules are independent of wealth and income. With k=0, the decision rules again reduce to profit-maximization.

income has been observed to have a negative effect on the likelihood of harvesting.[11] This effect has mostly been attributed to nonfinancial forest values, but information and transaction costs alone are sufficient to induce a negative income effect in timber harvesting. A negative income effect for reforestation is contrary to both prior economic and empirical research.

Application in empirical research

NIPF landowners have been surveyed across the U.S., and a wealth of data exists that can be used to investigate the importance of (among other things) information and transaction costs in forest management. Responses in these surveys are typically qualitative -- whether or not a given management practice has occurred or is planned. Such a response is best analyzed in terms of a likelihood, a frequency, or a propensity of engaging in forest management. Previous studies have used economic models derived for the *scale* of operation, but the scale and frequency of management do not have a clear relationship. Note that as the scale increases, the frequency of management may decrease -- 100 acres can be harvested every year one acre at a time, or once every 100 years 100 acres at a time -- so a factor with a positive effect on the scale of a given management practice can conceivably have the opposite effect on its frequency or likelihood.

The expressions presented here indicate specifically whether or not a landowner will engage in forest management, and they can be employed (almost) directly in empirical research on NIPF management. Consider the marginal utility of reforestation (expression (14)). The model for the decision process is that the landowner will undertake reforestation only when $MU(r)>0$. Clearly the landowner would never undertake a reforestation if $(\pi-c_r-c_c)\leq 0$, so this is relevant only when $(\pi-c_r-c_c)>0$. In this case, after solving for $(k/A)U_E'$, a logarithm can be applied to both sides of the inequality. After some simplification this yields

$$\log(\pi-c_r-c_c)+\log(1-\delta^T)+\log U_W'-\log(k)+\log(A)>\log U_E' \tag{16}$$

The variable $(\pi-c_r-c_c)$ can be measured either directly or indirectly. (See Dole) Planned tenure length T is usually not collected in NIPF surveys, but the effect can be approximated using the landowner's age. That is, let

$$\log(1-\delta^T)=\phi_A(Age)+error \tag{17}$$

where $\phi_A(Age)$ is an arbitrary smooth function of the landowner's age. The total wealth of landowners is not collected in these surveys, either. Income is usually collected, though, so the marginal utility of wealth can be approximated as

$$U_W'=\phi_Y(Y)+error,\ \phi_Y'(Y)\leq 0 \tag{18}$$

where Y is income and $\phi_Y(Y)$ is an arbitrary smooth and decreasing function. The forest property may also be a significant component of the landowner's wealth, in which case the property size will also have a negative effect on the marginal utility of reforestation.

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[11]The income effect has not always been judged to be statistically significant. See Binkley; Boyd; Dennis (1989); Hyberg and Holthausen; Kuuluvainen; and Romm, et al.

The same reasoning can be applied to any or all of the terms in expression (16) that may be subject to data limitations, yielding a general approximation for the marginal utility of reforestation. In terms of the data that is usually available, a *generalized additive model* for the reforestation decision can be specified as[12]

$$\Pr[Reforest] = \Pr[\ \log(\pi - c_c - c_r) + \phi_A(Age) + \phi_Y(Y) + \phi_I(Info) + \phi_D(Distance) + \phi_L(Land) > \varepsilon\ ] \qquad (19)$$

where *Info* is a measurement of the landowner's knowledge and information; *Distance* is the travel distance between the landowner's property and residence; *Land* is the area of the property; and ε is an error term with mean 0. The marginal utility of time and effort, U_E', may be taken as constant across all landowners, or as random variable and so subsumed into the error term. Note that the effect of *Land* may be associated with both the potential scale of the reforestation, *A*, and the landowner's wealth. These have opposing effects on the marginal utility, so the effect of *Land* cannot be predicted *a priori.* Estimation of generalized additive models is discussed in Hastie and Tibshirani (1986) and (1990).[13] Constraints on the shape of the transformations, such as $\phi_Y'(Y) \leq 0$, may or may not be imposed.

The same can be done with the expression for the marginal financial benefits of reforestation (expression (9)), the only difference being the term involving income. So expression (19) encompasses both the marginal financial benefits and the marginal utility perspectives of the decision process, and the term $\phi_Y(Y)$ will measure the average income effect in the sample under consideration. Arguably the marginal utility perspective should apply strictly to sole proprietors. However expression (19) can nonetheless be applied to all types of ownerships, as the "income" for such observations can be defined such that it has no impact on the estimates of the other variables.[14] Thus, expression (19) provides not only a means for measuring the importance of information and transaction costs, but also a means for comparing the marginal financial benefits and marginal utility models.

Similarly, a general approximation to the marginal utility of harvesting can be derived from expression (15):

$$\log(i(p_s G(\alpha) + \pi - c_r) - p_s g(\alpha)) + \phi_Y(Y) + \phi_I(Info) + \phi_D(Distance) + \phi_L(Land) > \varepsilon \qquad (20)$$

This expression requires information on the age, growth and volume of the landowner's current forest inventory, information which is not collected in the mail surveys of NIPF landowners. However, this information is collected in the periodic private forest inventories conducted by the Forest Service. So expression (20) may be used with this data, augmented by a personal survey of the particular landowners involved in the inventory. Alternatively, the missing variable $\log(i(p_s G(\alpha)+\pi-c_r)-p_s g(\alpha))$ may be taken as

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[12]Implicit assumptions here are that the utility function is additively separable, and that

$$k = \exp(\phi_I(Info) + \phi_D(Distance))$$

[13]See Dole for an application to NIPF timber harvesting.

[14]That is, by assigning missing values to the income of the non-sole proprietors. See Hastie and Tibshirani, 1990, p. 166.

a random variable and may then be moved to the right side of the inequality, where it also becomes part of the error term. However, the larger the property, the more likely the landowner is to have a marketable stand, so the distribution of the error term would depend on the property size. Modelling this effect would be difficult, and ignoring it would confuse the interpretation of the property size effect. Absent information on the present financial benefits of harvesting (i.e., the term $i(p_s G(\alpha)+\pi-c_r)-p_s g(\alpha))$, expression (20) has limited potential for practical application.

Summary

Foresters have long been aware of the practical importance of information and transaction costs, but these costs have not previously been studied from an economic perspective. Clearly these costs are difficult to measure, and have largely been ignored in estimating the benefits of forest management. So information and transaction costs alone may explain the reluctance of some landowners to engage in forest management. These costs can also explain the importance of various socioeconomic effects that have been uncovered in various empirical studies, either directly (*Info* and *Distance*) or indirectly (*Income* and *Age*). This implies that private forest management may change with the demography of ownership, and so increased monitoring of demographic factors may be warranted.

The models of the reforestation and harvesting decisions are not difficult to implement with suitable data. And even when data is severely limited, the models retain the essence of their economic content, so interpretation of empirical results should be reasonably clear. An obvious limitation of the models is the absence of nonfinancial forest values. This aspect is discussed in the following section, where it is shown how the basic framework presented here can be modified to incorporate nonfinancial values. However, this does not render the models in this section redundant. Section V. discusses how they fit into a hierarchical strategy for the empirical analysis of private forest management.

III. Nonfinancial forest values

The Faustmann model as it was presented in section I is concerned purely with the financial value of forest land. The previous section considered how forest management for financial values might be affected by basically *non*financial management costs. However, in addition to the financial values, many private landowners derive apparently nonfinancial values from their land. In the periodic surveys of NIPF landowners, respondents typically cite outdoor recreation, aesthetics, conservation of nature, etc., as among their most important management objectives.

By focussing attention on the rotation length, the Faustmann model can appear to be concerned only with the value of timber. However, the rotation length is important *not* because the forest has value only at the time of timber harvest. The rotation length is important because this marks the end of the forest cycle, with the cycle starting anew after each harvest. The value accruing to a site is the sum of the values over all cycles, with the rotation length -- the length of the cycle -- as the natural, determining characteristic of the cycle. The timber harvest is the *last* value that is received over the cycle, but it need not be the *only* value. Any other financial values (or costs) that occur over the cycle can easily be incorporated into the total value of the cycle.

So any timber or non-timber values expressed in monetary units can be incorporated into the Faustmann model. Hartman (1976) incorporated a continuous stream of values, interpreted as recreation values, into the basic Faustmann model. This approach is appropriate for the management of public forest land, and non-timber values such as recreation may also be reflected in the market (or financial) value of private forest land.[15] This section considers how forest management is affected by forest values that are *not* reflected in the financial value of forest land -- nonfinancial forest values. However it is determined, the financial value of forest land, as characterized by the rotation length, is taken as fixed. This is appropriate if forest land market values do not reflect non-timber values, or if there are landowners with non-timber values above that which the market rewards. In deciding how to manage the forest, the landowner trades off the financial and nonfinancial values. This is approach is consistent with Binkley, who considered choice of the scale of timber harvesting. The focus here will be on the timing of forest management.

Nonfinancial values are in principle easy to incorporate into the basic framework presented in section II. Again, the general decision rule is that the management practice occurs whenever the marginal utility of the given activity is positive. The marginal utilities of reforestation and harvesting are as given above (expressions (14) and (15)), but with one extra term added on: the marginal utility of the nonfinancial forest values (U_{NF}') times the marginal *effect* of the given activity on the attributes of the forest that are valued.

Beyond this very general principle, though, nonfinancial values are in practice much more difficult to specify. The attributes of forests that are valued by private landowners have not been identified -- nor even studied -- and they may vary greatly across the population of landowners. Indeed, landowners themselves may not be able to state specifically what forest attributes they value. Nor is it true, in general, that a given management practice always affects nonfinancial values in the same direction: aesthetics may be enhanced by reforestation and hindered by timber harvesting, but the opposite may hold for some types of wildlife habitat.

The decision rules

The previous discussion has already set out the attributes of the forest that are important from a financial perspective: the volume per acre at age α, $G(\alpha)$, and the area of the given site, A. For the purposes of the present discussion, it is assumed that these attributes also determine the nonfinancial forest values. Let G(0) denote the volume per acre of a newly reforested site -- so G(0) is the marginal effect of a reforestation project on the forest attributes valued for nonfinancial reasons.[16] Clearly $-G(\alpha)$ is the marginal effect of timber harvesting on the forest attributes, but if the site is replanted, then the net effect is $-G(\alpha)+G(0)$. The marginal utilities of reforestation and of harvesting can thus be expressed

$$MU(r) = (\pi - c_r - c_c)(1 - \delta^T)U_W' - (k/A)U_B' + G(0)U_{NF}' \qquad (21)$$

and

$$MU(h) = (i(p_s G(\alpha) + \pi - c_r) - p_s g(\alpha))\delta U_W' - (k/A)U_B' - (G(\alpha) - G(0))U_{NF}' \qquad (22)$$

So (by assumption) nonfinancial values increase the marginal utility of reforestation, and decrease the marginal utility of harvesting. The presence of (positive)

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[15] Hyberg and Holthausen also considered how non-timber values affect the optimal rotation length.

[16] If, say, 2 year old seedlings are planted, then G(0) is very small but still positive. The "age" α then refers to the time the stand has occupied the site, not the biological age of the trees.

nonfinancial values in reforestation can counteract the adverse effects of the fixed management costs, and may motivate some landowners to engage in reforestation even if their information and transaction costs are high. However, nonfinancial values have the same effect on timber harvesting as the information and transaction costs: landowners will allow the forest to grow even further beyond the profit-maximizing harvesting age. Note that the marginal utility of harvesting does not necessarily increase as the forest grows, though. The marginal financial benefit increases, but so does the marginal effect on the nonfinancial values. The overall impact on the marginal utility depends on the net effect of forest growth on the marginal utility of wealth, and the marginal utility of the nonfinancial forest benefits. For some landowners the latter may predominate, and there may be no time when the landowner would consider harvesting.

Analogous to the marginal utility of wealth, the marginal utility of the nonfinancial forest values (U_{NF}') can be assumed to decrease as the "size" of the forest increases. So other things being equal,[17] the marginal utility of reforestation decreases as the forest size increases, but the marginal utility of harvesting increases. In other words, nonfinancial motivations are apt to play a smaller role in the decision process on larger properties, even if landowners on larger properties express as much (total) interest in nonfinancial values as other landowners. Of course, the information and transaction costs k also diminish in importance as property size increases. So even if the marginal utility view of the decision making process is appropriate, the decision rules for both harvesting and reforestation approach pure profit-maximization as property size increases. From this perspective, management objectives change with property size. So it may make more sense to classify landowners by this variable, rather than whether the landowner is also a mill owner.

Decreasing marginal utility is the only aspect of the marginal utility of wealth that was discussed previously, but there is at least one other aspect that is important for the present discussion. The utility of wealth derives (presumably) from the utility of the future consumption that the stock of wealth can finance. Wealth is more important the longer is the potential period of future consumption -- for example, if one retires at the age of 45 instead of 65. This is sometimes expressed by defining utility in terms of the present value of all future consumption. The consumer is then viewed as planning consumption in the present and in every future time period. However it is much simpler to specify utility as a function of current consumption and wealth, with the length of the horizon as a parameter in the utility of wealth.[18] The total and marginal utility of wealth (U_W, U'_W, respectively) are then assumed to increase as the length of the horizon increases.

Similarly, the planned remaining length of tenure, T, can be taken as a parameter in the utility of the nonfinancial forest values. A forest can generate "consumption value" throughout the landowner's entire period of tenure, so both the total and the marginal utility of the nonfinancial forest values (U_{NF}, U'_{NF}, respectively) can be assumed to increase as the planned length of tenure increases. Since planned tenure length is usually not collected in the periodic surveys of NIPF landowners, this effect may manifest itself via the landowner's age. This was noted in the previous section for the marginal utility of reforestation, but when nonfinancial values are present, there is also potentially a landowner's age effect in the marginal utility of harvesting. Since this effect may also

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[17]Namely, total wealth and k/A.

[18]These approaches are effectively the same under Bellman's optimality principal.

appear in the marginal utility of wealth (in the opposite direction), its overall impact on the marginal utility of harvesting cannot be predicted *a priori*.

Application in empirical research

The marginal utility models are more difficult to use in empirical research when nonfinancial values are present. Of course with a sum of three terms, the logarithm can't be used to separate the components, as was done in section II. Dole used expression (21) directly in an econometric analysis of the reforestation plans of NIPF landowners in Oregon. This required (among other things) an assumption that the marginal utility of wealth was a linear function of income. Conditional on this assumption, the marginal utility model of the reforestation decision process was rejected. The reforestation decision appeared much closer to the profit maximization model, though there was evidence that nonfinancial motivations, and information and transaction costs played some role.

With some compromise, though, a simplification of expressions (21) and (22) is possible. Suppose

$$A = \exp(\phi_L(Land)) * error, \quad U'_{NF} = NF/(\exp(\phi_L(Land)) * error) \tag{23}$$

where NF is some measure of the landowner's nonfinancial motivations; $\phi_L(Land)$ is an arbitrary, smooth increasing function of *Land*; and *error* is a positive, random error term. Substituting these expressions into the marginal utility of reforestation yields

$$MU(r) = (\pi - c_r - c_c)(1 - \delta^T)U'_W - (kU'_B - G(0)NF)\exp(-\phi(Land)) * error \tag{24}$$

Provided $(\pi\text{-}c_r\text{-}c_c)$ and $(kU_B'\text{-}G(0)NF)$ are both positive, $MU(r)>0$ is now equivalent to

$$\log(\pi - c_r - c_c) + \log(1 - \delta^T) + \log U'_W - \log(kU'_B - G(0)NF) + \phi_L(Land) > \varepsilon \tag{25}$$

This expression is very close to that derived in section II, the main difference being that the information and transaction costs k and the nonfinancial motivations NF are not additively separable. Following the reasoning of section II, a generalized additive model for the reforestation decision may be specified, one that is identical to that in expression (19), except for the addition of bivariate interactions between the information and transaction costs, and the nonfinancial motivations. As discussed in section II, a similar generalized additive model may be employed for the timber harvesting decision, subject to the availability of suitable data.

Summary

The models presented here show how financial and nonfinancial values and costs can be traded off in the timber harvesting and reforestation decisions. Financial values are determined by the standard Faustmann model of forest management. This applies provided that the market for forest land is driven by (potential) landowners with predominantly financial motivations. In any case, the Faustmann model provides a convenient and easily assessable lower bound for the financial value of forest land. The approach taken here is consistent with previously developed models for the decision regarding the *scale* of the management to be undertaken,[19] but the discussion is restricted

[19] See Binkley, Boyd, Hyberg and Holthausen, for example, and Dole.

to models that would be more applicable to commonly available data on forest management.

The simplified version of the decision rule (expression (25)) imposes strong restrictions, but offers considerable benefits in terms of ease of application. This is especially important given the limitations of currently available data. The general forms (expressions (21) and (22)) are more difficult though not infeasible to use. Section V discusses a strategy of empirical analysis that involves the use of both models. It has been assumed throughout that the landowner can freely distribute financial assets across time. The next section loosens this restriction, and considers the harvesting and reforestation decisions when the landowner is unable to bring forward the property value from the end of tenure.

IV. Liquidity constraints

Forest land is a very illiquid asset. It is generally unacceptable as collateral, so a forest landowner is typically unable to borrow against any wealth stored in the land. For the most part, a forest asset can be converted into a more liquid form only by harvesting timber, or by selling both the land and the forest. Of course the former applies only to marketable stands, so during a large part of its growing period a forest investment may be liquidated only through the sale of the property. Selling any kind of real estate is a lengthy and difficult process, but it is even more so for "undeveloped" land, which is how forest land is usually treated in real estate markets.

From a pure financial perspective, though, the illiquidity of forest assets need not hinder forest management. Landowners can invest their own liquid assets in the land and sell the property when their liquidity runs low. If investing is worthwhile at all, landowners should receive an attractive return over the period during which they were able to hold the asset.[20] For most NIPF landowners, though, the difficulty of selling land is probably less of a problem than the fact that they don't *want* to sell their land. As discussed in the previous section, most NIPF landowners claim nonfinancial values as among their most important management objectives. These nonfinancial values clearly add to the benefit of landownership, and may drive a landowner to want to hold the land longer than is beneficial on purely *financial* considerations. In order to do so, such a landowner would conserve liquid assets and avoid investing in the land. So to a large extent, nonfinancial motivations may be held responsible if illiquidity is a problem in forest management. In this sense, nonfinancial motivations can deter reforestation as well as timber harvesting.

Foresters and economists have long recognized the constraint that the illiquidity of forest assets may impose on private forest management. The various government-sponsored, cost-sharing programs are motivated partly by perceived liquidity constraints. There is some empirical evidence that liquidity constraints may be important in NIPF management: as discussed above, income should have a negative effect on the propensity to reforest, but most empirical studies have found a positive income effect. (Alig, et al., 1990) The proper interpretation of this income effect is unclear though, for these studies have not specifically considered the implications of liquidity constraints on observable landowner behavior.

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[20]Assuming land markets are "efficient", and neglecting fixed management costs, of course.

This section considers the effect on the reforestation and harvesting decisions of a liquidity constraint imposed at the end of tenure. This type of constraint can be easily incorporated into the same basic model used in the previous sections. As argued above, liquidity constraints ought to be associated mainly with nonfinancial values, so they are best considered from the utility perspective. The same decision rule applies as previously: forest management occurs when the marginal utility of the given practice is positive. However, in the presence of liquidity constraints the utility of the financial benefits of forest management must be redefined.

The utility of wealth under liquidity constraints

In the previous sections, financial benefits were evaluated in terms of the marginal utility of wealth. "Wealth" was defined as the market value of the landowner's total portfolio of assets, which has utility (presumably) for its ability to finance future spending. Of course, a forest asset can be used directly in this sense only after the land has been sold or the timber harvested. However, forest land contributes to the value of wealth in the same way as any liquid asset, *provided* there is otherwise an adequate supply of liquid assets in the landowner's portfolio. A liquidity constraint occurs when the landowner forecasts that the supply of liquid assets will run out before the planned end of tenure; or equivalently, when there is an excess supply of wealth at the planned end of tenure, wealth that cannot otherwise be brought forward in time.

So when a liquidity constraint occurs, the landowner's portfolio separates into two distinct components: liquid assets, and illiquid assets realized at the end of tenure (i.e., the equity of the property). These two components of wealth have different uses, so they are valued separately -- that is, the value of liquid and illiquid assets enter the utility function as separate arguments. Any changes in the portfolio are valued in terms of the change in the financial value of each component of wealth, multiplied by the marginal utility of each component.

The reforestation decision

Consider first the effect that a reforestation project has on the landowner's portfolio. The landowner spends (c_c+c_r) to undertake the project, so liquid assets are reduced by this amount. The value of the reforested land at the end of tenure is $\pi\delta^{T}$, so the value of illiquid assets increases by $\pi\delta^{T}-(\pi-c_c-c_r)$. The marginal utility of reforestation under liquidity constraints is then

$$MU(r) = -(c_r+c_c)U_L' + (\pi\delta^{T} - (\pi-c_c-c_r))U_{IL}' - (k/A)U_B' + G(0)U_{NF}' \tag{26}$$

where U_L' and U_{IL}' denote the marginal utilities of liquid and illiquid wealth, respectively.

Note that the only effect of cost-sharing is to reduce the direct financial cost to the landowner, (c_c+c_r). The marginal utility of illiquid assets is apt to be quite low for a liquidity constrained landowner, so the net financial benefit of reforestation may be quite low despite the availability of cost-sharing. If information and transaction costs are high (as they naturally would be for a liquidity constrained landowner), the marginal utility of reforestation may be negative even if 100% of financial costs are covered. A better response to liquidity constraints would be to also reduce information and transaction costs, or better yet to eliminate the constraint altogether.[21]

[21]This is discussed further in Dole, pp. 175-189.

If the illiquid assets are independent of income, only U_L' will decrease as income increases. Since the coefficient of U_L' is necessarily negative, under liquidity constraints the marginal utility of reforestation increases as income increases. However, a positive income effect observed empirically is at best a crude indicator of the presence of liquidity constraints. Liquidity constrained landowners will arguably never reforest, so as income increases these landowners are not any more likely to reforest, given that they are liquidity constrained. They are, however, less likely to be liquidity constrained as income increases, but once the constraint is released income has a negative effect on the propensity to reforest.

A better indicator of the presence of liquidity constraints is the landowner's response to the gross financial benefit of reforestation -- that is, the change in the present value of the property: $\Delta P=\pi-(\pi-c_c-c_r)\delta^T$. Landowners not subject to liquidity constraints will respond positively to ΔP, but, assuming the marginal utility of illiquid assets is negligible, liquidity constrained landowners will respond weakly if at all. The marginal utility of reforestation can be expressed in general as

$$MU(r) = (\beta_L \Delta P - (c_r + c_c))(U_L' + \beta_L U_{IL}') - (k/A)U_B' + G(0)U_{NF}' \tag{27}$$

where $\beta_L=0$ if the liquidity constraint holds, and $\beta_L=1$ otherwise. The term $(U_L'+\beta_L U_{IL}')$ denotes the marginal utility of wealth, in general. If the liquidity constraint does not hold ($\beta_L=1$), both marginal utilities in this expression have the same argument, namely *total* wealth. The decision rule then reduces to the unconstrained version (expression (21)). If the liquidity constraint is binding ($\beta_L=0$), liquid wealth is the only argument in the marginal utility of wealth.

Application in empirical research

This expression can be employed in empirical research, after allowing for some simplification of the marginal utility of wealth. Taking the marginal utility of wealth as linear, for example, yields

$$(\beta_L \Delta P - (c_r + c_c))(\beta_0 - \beta_1 Y - \beta_L P) \tag{28}$$

where P denotes the present value of illiquid assets, and β_0, β_1 and β_L are unknown parameters to be estimated. Clearly this expands to an expression that is purely linear in the unknown parameters, and again amounts to a simple modification of the profit-maximizing decision rule. After specifying the remainder of the marginal utility function, the presence of liquidity constraints can be investigated quite simply via the coefficients on ΔP and its multiplicative interactions with liquid and illiquid assets. This was done in Dole, where it was found (among other things) that NIPF landowners in Oregon were indeed responsive to the financial benefit of reforestation.

Of course it is unlikely that the entire population of landowners is either liquidity constrained, or not. The estimated coefficient β_L can really only be interpreted as an average effect of liquidity constraints across the population. If, for example, β_L was found to be significantly above 0, the proper interpretation would be that, on the whole, landowners were not behaving as if they were liquidity constrained. It may still be of some importance, though, to identify which landowners, if any, were managing under liquidity constraints.

A simple and reasonable predictor of liquidity constraints could be developed via a discriminant analysis of reforestation, using property size (illiquid wealth) and income (liquid wealth) as discriminating variables. For every given level of income, the larger the property size, the more likely is the landowner to be liquidity constrained. If any landowners are liquidity constrained, some combination of income and property size ought to be able to discriminate between landowners that are reforesting, and those that are not. Of course, both of these variables are also related to the reforestation decision if liquidity constraints are not present. But this predictor will indicate liquidity constraints if landowners in the (predicted) constrained and non-constrained groups behave in qualitatively different ways -- namely, landowners in the non-constrained group should respond positively to ΔP, while those in the constrained group should not respond at all. This could be tested by taking the derived predictor as an estimate of β_L, and using this variable directly in expression (27).

The harvesting decision

Liquidity constraints can similarly be incorporated into the marginal utility of harvesting. If the landowner harvests this year, cash assets increase by $(p_s G(\alpha)-c_r)$[22], and liquid forest assets decrease by $p_s(G(\alpha)+g(\alpha))\delta$. The change in the landowners liquid assets is then $(i(p_s G(\alpha)-c_r)-p_s g(\alpha))\delta$. Assuming the marginal utility of illiquid assets is negligible, the marginal utility of harvesting is

$$MU(h) = (i(p_s G(\alpha)-c_r)-p_s g(\alpha))\delta U_L' - (k/A)U_E' - (G(\alpha)-G(0))U_{NF}' \qquad (29)$$

In this formulation the effect of liquidity constraints on harvesting is that the landowner ignores the site value; or in other words, the landowner effectively considers only the value of the first rotation. As is well known, this means the landowner will allow the forest to grow longer than α^*. This is contrary to the real experience with liquidity constraints among private landowners: liquidity problems can force a landowner to harvest before the forest reaches economic maturity. The problem with this formulation is that it is assumed that the liquidity constraint holds only at the end of tenure, and the landowner is able to bring forward the value of next year's growth, $p_s g(\alpha))\delta$. If the landowner faces extreme liquidity constraints and is unable to do this (or to sell the property), the financial benefit of harvesting is the harvest revenue $(p_s G(\alpha)-c_r)$ times the marginal utility of current consumption. In this case, the marginal utility of harvesting can be positive as soon as the stand reaches a marketable age.

The presence of severe liquidity constraints in timber harvesting should thus be simple to observe: any landowner harvesting before $\alpha=\alpha^*$ must be liquidity-constrained. This assumes, though, that the landowner is unable or unwilling to sell the property -- selling the property would be the optimal financial decision. A potentially perverse effect is introduced if the landowner's unwillingness to sell the property is assumed to be due to nonfinancial values: nonfinancial values drive the landowner to harvest even before the profit-maximizing harvest age. This could reasonably result only if the landowner has predominant nonfinancial motivations (say, to preserve family ownership) that are unrelated to the state of the forest.

[22]Assuming that reforestation is required by law.

V. Directions for further research

The hypothesis maintained throughout this paper has been that NIPF management may differ from industrial forest management due to information and transaction costs, nonfinancial values and liquidity constraints. The preceding has analyzed how these factors may affect the harvesting and reforestation decisions of private forest landowners. The real importance of these factors is an empirical question though, and the discussion has emphasized models that may be useful in the empirical analysis of existing data on NIPF management. Of course, other factors may also be important in NIPF management. The following presents a general strategy for empirical analysis using the models presented above, and discusses how the models can be improved and extended.

A strategy for empirical research

The discussion was ordered according to increasing complexity in landowner behavior, with information and transaction costs generating the simplest behavior, and liquidity constraints the most complex. Empirical analysis, on the other hand, should proceed in the opposite direction -- the simple model incorporating information and transaction costs assumes landowners are not liquidity constrained, and interpretation of the model would be confusing if they were.

Consider, first, analysis of the reforestation decision. As discussed in section IV, the behavior of landowners subject to liquidity constraints is qualitatively different from unconstrained landowners. It may be possible to identify liquidity constrained landowners via a discriminant analysis of the reforestation decision, using income and property size as discriminating variables. Any discrimination that results can be verified as a liquidity constraint by examining the response to the gross financial benefit of reforestation, using a parametric version of expression (27). The functional form and significance of the other factors is less important, as these are useful only to increase the potential of identifying the constraint. The non-constrained group should respond positively to the financial benefit of reforestation, and the constrained group should not respond at all -- nor to any other factor. Any liquidity constrained landowners need not be analyzed any further, and can excluded from any further analysis.

For landowners not identified as liquidity constrained, expression (25) can then be used to investigate the importance of nonfinancial values, and information and transaction costs. This model is fairly restrictive, but should be easy to use and strong enough to determine whether these factors are indeed important in the decisions of real landowners. More particular questions about these variables can be addressed using a parametric version of expression (21).

The central variable in an analysis of either reforestation or harvesting is the financial benefit of the given activity. This information is typically not collected directly in the periodic surveys of NIPF owners. A reasonable prediction of the financial benefit of reforestation can be constructed through easily observable local market and environmental conditions. However, the same does not apply to timber harvesting, and analysis of harvesting requires more information from landowners -- in particular, an estimate of the age, growth and volume of the landowners' most mature stand. Note that this does not require any direct measurement of these variables, which would be an expensive operation. The focus of the analysis is the *landowner's* decision process, and so the analysis should use only the information that the landowner possesses. Thus, a survey need only ask landowners to report their information on age, growth and volume. With this information, analysis of the timber harvesting decision can proceed using the equivalent of expressions (25) and (21), as described for the reforestation decision.

Landowners who lack this information are clearly incapable of making an informed and reasoned decision, and so should be excluded from the analysis. It would then be an important (though ancillary) issue to investigate why these landowners lack such information.

Further development of the decision models

Forest assets have inherent risks, like any other financial asset. An obviously important factor that has been ignored throughout is the landowner's behavior towards risk. Empirical investigation of this is generally not possible with existing data, but risk factors should be incorporated in the decision models if any new data on private forest management is collected.

Another neglected factor that may distinguish industrial and nonindustrial landowners is the cost of shutting down a mill. With an inadequate supply of logs, an industrial landowner may have to shut down milling operations, with consequent shut down costs. If supply diminishes to the point of shut down, these costs will decrease the benefit of delaying timber harvest, and can lead the industrial landowner to harvest before the (nominally) profit-maximizing harvest age. This factor can easily be incorporated into the basic framework employed here.

Finally, while the focus of this paper has been on private forest management, the decision rules can be applied to the management of any type of ownership that faces nonfinancial costs or benefits -- in particular, to the management of public forest lands. Public land management arguably does not involve nonfinancial costs, nor liquidity constraints, so the decision rules are considerably simplified. Note that the decision of *whether* to undertake management does not require the specification of a utility function for the public. The decision rules require only the specification of the tradeoff between financial and nonfinancial values (U_W'/U_{NF}').

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