ANALYSIS

Sustainable management of uneven-aged private forests: a case study from Ontario, Canada

Shashi Kant *

Faculty of Forestry, University of Toronto, 33 Willcocks Street, Toronto, Ontario, M5S 3B3, Canada

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Abstract

A matrix growth model is estimated on the basis of growth data (growth period 5 years) of 14 measurement plots of uneven-aged white pine from southern Ontario. The impact of three economic factors specific to the private forests on the sustainable management of private woodlots is evaluated and discussed, and the trade-off between environmental and economic values is examined. These three economic factors are: (1) choice of the rate of time preference; (2) income and property taxes; and (3) subsidy for rehabilitation of degraded forests. Property tax, based on market price of land, is neutral, but income tax is not neutral with respect to harvesting decisions, growing stock, environmental and ecological values, and economic values. High rates of time preference and income tax will lead to the conversion of uneven-aged forest into even-aged young forest leading to the loss of ecological and environmental values. As a result of the discrete nature of tree distribution and prices of different size trees, increased income tax rates may not result in higher tax revenue. The fiscal policies need be sensitive to the nature of forests to encourage sustainable management practices on private woodlots. In the case of degraded private woodlots, a subsidy on rehabilitation cost will be desirable in place of property tax subsidy. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Ecological and environmental values; Fiscal policies; Growth model; Income tax; Property tax; Tax rebate program

1. Introduction

In Canada, approximately 400,000 private woodlots make up 9% of the total forestland. Moreover, these properties provide 24 million m³ (13%) of the raw material supplied to the manufacturing sector (Baker, 1990). In Ontario, 5555 thousand hectares of forestland are under non-industrial private ownership and yield at least one-third of Ontario’s roundwood production and an even higher proportion of its value (Aird, 1980). Most of Ontario’s private forests are in southern Ontario while most crown forests are located in
northern Ontario. These private forests have a greater potential for production than that of crown forests and are often relatively close to markets. However, there is a substantial imbalance in the attention received by these private forests. Crown forests, with a timber harvest just double that of private forests, receive eight times the regeneration and tending activity of privately owned forests (Aird, 1980). In view of environmental and conservation movements, it is expected that the management focus on public forestlands will shift towards natural system preservation and non-commodity outputs. In such situations, an optimal strategy to reduce the pressure for timber from existing old-growth and secondary growth public forests, that are important for biological conservation, may be to bring private forests under sustainable management practices. This strategy seems to offer a win–win situation, providing economic and social benefits to private woodlot owners and environmental benefits for conservationist as well as to the local public (Sedjo and Botkin, 1997).

In order to encourage better management of private woodlands and to help improve productivity, the Ontario Ministry of Natural Resources (OMNR) offers assistance to private landowners through the provision of information, advisory services, and woodland improvement act assistance programs (OMNR, 1991). While technical support for sustainable forest management is necessary, in itself it is insufficient to promote sustainable management practices on private forests. Another important dimension of sustainable forest management is an understanding of the economic behaviour of private woodlot owners. These woodlot owners can be motivated to implement sustainable management practices through appropriate economic incentives in the form of rational taxation policies and financial support for the rehabilitation of degraded forests. The OMNR has made a beginning in this direction by starting the ‘Managed Forest Tax Rebate Program’ for private woodlot owners.

In non-industrial private forests (NIPF), uneven-aged management has been a common practice, while even-aged management with clear-cutting has been the rule for crown and private industrial forests (Baker, 1990). Nevertheless, most literature on uneven-aged forest management has focused mainly on issues concerned with crown or public forests rather than with private forests. This paper addresses the issue of uneven-aged forest management on private forests in Ontario. The main purpose of this paper is to demonstrate the impact of human economic behaviour and government fiscal policies on sustainable forest management practices that include economic, ecological, and environmental values, and trade-offs between these values. The paper uses a matrix growth model (Buongiorno and Michie, 1980) and employs a linear programming technique for evaluating the impact of the tax rebate program of the OMNR. The optimal harvesting regime is determined, and the effects of three economic factors on the long-term sustainability of uneven-aged forests are examined. These factors are: (1) choice of the rate of time preference; (2) property and income taxes; and (3) subsidies for rehabilitating degraded forests. The data used are from the measurement plots of uneven-aged stands of white pine forests in southern Ontario, but is mainly for illustrative purposes.

First, the sustainable management of uneven-aged forests is defined and the socio-economic context of private woodlot owners in Ontario is discussed. Second, the theoretical formulation of the matrix growth model of uneven-aged forests is summarised. Third, the estimated parameters of the growth model and price data are presented. Fourth, economically and environmentally optimum harvesting regimes and the impact of the three economic factors mentioned above are discussed. Finally, some policy suggestions are drawn.

2. Sustainable forest management (SFM) of uneven-aged forests

Normally, uneven-aged forests are managed under the selection system. In this system, individual large trees (single-tree selection) are cut periodically, and natural regeneration is relied upon to reforest the gaps so created (Kimmins 1992, p. 63). This practice results in a forest comprising
trees of all ages or age-classes. This system is excellent where environmental conditions, protection considerations, or aesthetic considerations require that forest cover remain continuously on the landscape (Kimmins 1992, p. 63). The main feature of SFM is to provide environmental, ecological, economic, and social values for the benefit of present and future generations (CCFM, 1993). In the case of selection system, this specific feature of SFM can be achieved by maintaining a steady state stand structure in perpetuity that is determined by biological (growth) and socio-economic factors. For example, ecological and environmental values are incorporated in the selection system, biological growth and socio-economic factors in the stand structure, and inter-temporal equity in a steady state structure in perpetuity.

3. Socio-economic context of private woodlot owners

In the case of private ownership, relevant socio-economic factors are governed by the preferences of the woodlot owner. These preferences can be categorized into two main groups: (1) maximization of financial returns; and; (2) maximization of the utility derived from nonfinancial returns, such as environmental and ecological returns from the existence of forest that is a part of a farm or residence, and the recreational value of forests. In Ontario, approximately 13% of private woodlot owners keep woodlots for financial returns and 44% keep woodlots because the woodlots are part of other properties (Smyth and Nausedas, 1982). But, as these timber producing woodlot owners provide at least one-third of Ontario’s roundwood production (Aird, 1980), these small numbers of woodlot owners who prefer financial returns play an important role in the roundwood production of Ontario. In this paper, therefore, the focus will be on the first category of woodlot owners. In the case of second category of owners, who prefer maximization of utility, financial returns are of secondary importance. The measurement of utility derived from nonfinancial environmental and ecological returns is problematic. However, the owners of this category have very low or zero preference for immediate economic returns from harvestable timber that indicates a low rate of time preference for the financial returns from forests. Hence, for an overview of the response of the second category of owners, the impact of the rate of time preference on management decisions relating to uneven-aged forests is evaluated. Next, a summary of the theoretical formulation of the matrix growth model is presented for quick reference.

4. Theoretical formulation of matrix growth model

Buongiorno and Michie (1980) included ingrowth in the matrix growth model suggested by Seth and Shukla (1972) to deal with the problem of exponential growth of the number of trees in each size class that was suggested by previous models, such as Adams and Ek (1974) and Adams (1976). The matrix growth model has been used by many researchers, such as Buongiorno and Lu (1990) and Buongiorno et al., (1995), to address a number of issues relevant to uneven-aged forest management. The model is based on the probabilities of transition of trees between diameter classes and ingrowth of new trees in the lowest diameter class. Suppose there are \( n \) diameter classes in an uneven-aged forest and \( T \), the growth period under consideration, is so small and the range of diameter classes so large that a tree cannot move more than one diameter class during this period. Suppose the total stand of living trees at time \( t \) is represented by a column vector \( X_t = [X_{it}] \), and the number of trees harvested during the period \( T \) is represented by a column vector \( h_t = [h_{it}] \), where \( i = 1, 2, \ldots, n \) diameter classes. Let \( x_i \) denote the probability of a tree in diameter class \( i \) at time \( t \), which is not harvested during the interval \( T \), to continue to be in the same diameter class at time \( t + T \); and \( \beta_i \) denote the probability of a tree in diameter class \( i - 1 \) at time \( t \), which is not harvested during the interval \( T \), to move to the diameter class \( i \) at time \( t + T \). Let, \( I_i \) denote the expected ingrowth (during the interval \( T \)) that is inversely related to the basal area of the stand; and that for a given basal area, ingrowth is di-
directly related to the number of trees. Hence, the ingrowth function is specified as:

\[ I_t = \delta_0 + \delta_1 \sum_{i=1}^{n} B_i (X_{it} - h_i) + \delta_2 \sum_{i=1}^{n} (X_{it} - h_i), \]  

(1)

where \( I_t \geq 0 \), \( B_i \) is the basal area of a tree of average diameter in class \( i \), while \( \delta_0, \delta_1, \) and \( \delta_2 \) are coefficients which are expected to be positive, negative, and positive, respectively. The growth model can be expressed as:

\[ X_{t+T} = G(X_t - h_t) + C, \]  

(2)

where \( G \), a growth matrix and \( C \), a column vector are as given next.

\[
G = \begin{pmatrix}
  a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \\
  \beta_2 & \beta_3 & \beta_4 & \beta_5 & \beta_6 & \beta_7 \\
  \alpha_2 & \alpha_3 & \alpha_4 & \alpha_5 & \alpha_6 & \alpha_7 \\
  \gamma_2 & \gamma_3 & \gamma_4 & \gamma_5 & \gamma_6 & \gamma_7 \\
  \delta_2 & \delta_3 & \delta_4 & \delta_5 & \delta_6 & \delta_7 \\
  \kappa_2 & \kappa_3 & \kappa_4 & \kappa_5 & \kappa_6 & \kappa_7 \\
\end{pmatrix}
\]

and \( C = \begin{pmatrix}
  \delta_0 \\
  0 \\
  0 \\
  0 \\
  0 \\
\end{pmatrix} \).

In this matrix, the first row gives \( a_i \); and in the second to the sixth row, the two non-zero elements are \( \beta_i \) and \( \alpha_i \) (where \( i = 2, 3, \ldots, 6 \)), respectively.

The ingrowth equation estimated by the ordinary least square (OLS) method is:

\[
I_t = 24.1716 + 0.69235 \% n_1 B_i \left(X_{it} - h_i\right) \\
+ 0.01094 \sum_{i=1}^{n} \left(X_{it} - h_i\right) \\
+ 0.01094 \sum_{i=1}^{n} (X_{it} - h_i),
\]

with \( t \)-value in bottom parenthesis, adjusted \( R^2 = 0.04 \), \( F \) value = 1.77, and significance of \( F = 0.19 \).

The values of adjusted \( R^2 \) and significance level of \( F \) indicate that the regression as a whole does not explain ingrowth. The coefficients of the number of trees, as well as of the basal area, are also not different from zero at the 5% significance level. These results, though disappointing, are not much different from those obtained by previous researchers. Buongiorno and Michie (1980) and Dupont (1990), for example, obtained adjusted \( R^2 \) of 0.15 and 0.24, respectively. In both cases, however, the coefficients of two variables were different from zero at the 5% significance level. Our results indicate that ingrowth is independent of the number of trees and their basal area, and, hence, is constant. Constant ingrowth is calculated by the average ingrowth over 1 ha during an interval of 5 years and it is 20 trees/ha. In the case of constant ingrowth, there is no feedback from data, the number of trees entering the lowest diameter class can be calculated. In the data set, I did not find a single case in which trees moved more than one diameter class during the period of 5 years. The calculated probabilities of \( x \) and \( \beta \) are given in the following matrix.

\[
\begin{pmatrix}
  0.78 \\
  0.08 & 0.75 \\
  0.00 & 0.20 & 0.74 \\
  0.00 & 0.00 & 0.22 & 0.72 \\
  0.00 & 0.00 & 0.00 & 0.25 & 0.69 \\
  0.00 & 0.00 & 0.00 & 0.00 & 0.28 & 0.95 \\
\end{pmatrix}
\]

5. Data

5.1. Estimated growth model

Growth data from 14 measurement plots located in the Algonquin Park area and maintained by the Ontario Forest Research Institute have been used. Each plot is 0.101 ha, and is dominated by white pine with a small fraction (0–10%) of other tree species, such as red pine, jack pine, balsam fir, and white birch. Therefore, these plots are treated as pure stands of white pine. All plots were established in 1873 and numerous measurements have been taken since then. To maintain uniformity, only those measurement points that are at an interval of 5 years have been included. The total data provide 35 growth data points for growth period of 5 years each. Trees are grouped into six diameter classes, the lowest class ranging from 8 to 15 cm dbh, the next four classes of 5 cm each (15–20, 20–25, 25–30, and 30–35), and the last class of above 35 cm dbh. The lowest diameter class is selected such that, from the available
the number of trees in different diameter classes to the ingrowth into the lowest diameter class. It results in \( \delta_0 = 20, \delta_1 = \delta_2 = 0; a_i = x_i, \) and \( a_i = 0 \) for \( i > 1 \). Hence, growth matrix \( G \) will be the same as the matrix of \( x \)'s and \( b \)'s as given before, and the constant matrix \( C \) will be:

\[
C = \begin{pmatrix}
20 \\
0 \\
0 \\
0 \\
0 \\
0
\end{pmatrix}.
\]

5.2. Price data

Most of the timber harvested from private woodlots in southern Ontario is sold on the open market. Nautiyal et al. (1995) developed econometric models to estimate the stumpage value of a stand as well as of different species. Using their model for private lands, the prices of standing white pine trees of different diameter classes receivable by woodlot owners are calculated as: $0.50, $2.66, $6.37, $11.75, $21.98, and $34.25 per tree for the six diameter classes (8–15, 15–20, 20–25, 25–30, 30–35, and >35 cm dbh), respectively. These prices are average prices for southern Ontario, and, in the use of these prices, the implicit assumption is that the price per tree is independent of the total volume or total number of trees sold from a lot. In light of the total analysis in this paper being independent of the scale of forest area because analysis is done for 1 ha, this implicit assumption is reasonable. These prices, as given above, indicate the step-like nature of price function of a tree of different diameter classes. The similar nature of the price function has been observed by many authors (Buongiorno and Michie, 1980; Nautiyal, 1982; Buongiorno et al., 1995).

In the management of uneven-aged forests under the Selection System, specifically for the woodlot owners whose objective is timber production, major decision variables are the cutting cycle, the diameter class distribution of the timber to be harvested, and the growing stock to be left after harvest so as to sustain future supply. These decision variables are common to the decision variables relevant to crown forests. In the case of private forests, these variables will also be influenced by such socio-economic factors as property and income tax rates, in addition to prices and the rate of time preference. I, therefore, first determine the economically optimal cutting cycle and harvest level without incorporating specific features of private ownership, and, thereafter, evaluate the impact of the specific features of private ownership on sustainable management decisions.

6. Analysis and discussion

6.1. Economically and environmentally optimum harvesting regimes

The objective of an economic harvesting regime is to maximize the net present value of production subject to a periodic sustained yield. The growth of a stand for a cutting cycle of \( mT \) years can be expressed as:

\[
X_{t+mT} = G^m(X_t - h_t) + \sum_{i=0}^{m-1} G^j C.
\]

A periodic sustained yield requirement will result in periodic sustained harvesting and the growing stock being the same at the beginning and end of each cutting cycle. It means

\[
H_t = H_{t+mT} = h^*
\]

and

\[
X_t = X_{t+mT} = X^*
\]

for all \( t \).

Substitution of these values of \( h \) and \( X \) into Eq. (3) will give the following sustained-yield constraints:

\[
G^m h^* + (I - G^m) X^* = \sum_{i=0}^{m-1} G^i C \quad (4a)
\]

\[
X^* - h^* \geq 0 \quad (4b)
\]

and

\[
h^* \geq 0. \quad (4c)
\]
Table 1
Tree distribution (number of trees per hectare) for different cutting cycles (rate of time preference = 3%)

<table>
<thead>
<tr>
<th>PRIVATE Diameter class</th>
<th>Cutting cycle (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>8–15 cm</td>
<td>91</td>
</tr>
<tr>
<td>15–20 cm</td>
<td>29</td>
</tr>
<tr>
<td>20–25 cm</td>
<td>22</td>
</tr>
<tr>
<td>25–30 cm</td>
<td>18</td>
</tr>
<tr>
<td>30–35 cm</td>
<td>4*</td>
</tr>
<tr>
<td>&gt;35 cm</td>
<td>0</td>
</tr>
<tr>
<td>Pre-harvest (trees/ha)</td>
<td>164</td>
</tr>
<tr>
<td>Post-harvest (trees/ha)</td>
<td>160</td>
</tr>
<tr>
<td>Soil-rent ($/ha)</td>
<td>134.62</td>
</tr>
</tbody>
</table>

* Indicates the number of trees to be harvested.

The first constraint (4a) regulates the growth of a forest over a period of time; the second (4b) and third (4c) constraints ensure that the harvest does not exceed the growing stock and is non-negative. In addition to these constraints, the harvest and growing stock must also maximize an objective function given by the net present value or soil rent. In the nonregulated forest, maximization over an infinite horizon of the present value of returns (net of investment in the growing stock), known as soil rent, leads to the following objective function:

\[
\max Z(h^*, X^*) = \left[ \frac{(p(h^* - F)}{(1 + R)^{mT} - 1} \right] - p(X^* - h^*), \tag{5}
\]

where \( p = (p_1, p_2, \ldots, p_n) \) is a vector of the dollar value of an average tree from \( n \) different diameter classes net of variable costs of harvesting, \( F \) is the fixed cost of harvesting per hectare, and \( R \) is the rate of time preference (rate of discount).\(^1\) Hence, \( ph^* - F \) is the net value of harvest obtained every \( mT \) years, and \( p(X^* - h^*) \) is the opportunity (investment) cost of the growing-stock left after harvest. The objective function (5) and the three constraints (4a, 4b, and 4c) are linear in the growing stock \( X \) and harvest \( h \) variables and can be solved by linear programming techniques. The solution of this linear programming problem allows a simultaneous determination of optimal growing stock and harvest for a given cutting cycle. By solving the LP problem for different cutting cycles, an economically optimal cutting cycle can be determined.

The non-availability of growth data for a growth period shorter than 5 years restricted the choice of cutting cycle to 5 years and 5-year multiples. Hence, I determined the economic sustainable harvest and the corresponding growing stock for cutting cycles of 5, 10, 15, 20, and 25 years for a woodlot growing in accordance with the growth matrix \( (G) \), and the constant matrix \( (C) \) given in the estimation section, the prices of trees as given in the price data, and a fixed cost \( F = 0 \). In this calculation, the rate of time preference is equal to 3%, a value close to the average value of real rate of interest of 2.57% for the period of 1960–1985 (Nautiyal, 1988). The results are given in Table 1. The soil rent is the maximum

\(^1\)In this paper, I am using the rate of time preference instead of rate of interest. I feel that due to different socio-economic conditions, every private owner may not have the rate of time preference equal to the interest rate, and hence use of the rate of time preference is more appropriate than that of the rate of interest. For details on this topic, interested readers may refer to Kant (1996).
for a cutting cycle of 5 years. Hence, 5 years is an optimal economic cutting cycle. Under these conditions, the woodlot owner should harvest four trees from the 30–35 diameter class at an interval of 5 years, and he or she can harvest four trees on a sustainable basis forever. The number of trees per hectare before and after harvest will be 164 and 160, respectively.

The soil rent for the 10-year cutting cycle is only $1.86 less than the soil rent for the 5-year cutting cycle, but the stand will have more trees in the 30–35 cm and above 35 cm diameter classes. For a cutting cycle of 15 years, the soil rent decreases by $21.67 from the soil rent for the 10-year cutting cycle, but the number of trees in the 30–35 cm and above 35 cm diameter increases. However, for 20- and 25-year cutting cycles, soil rent as well as the number of trees in the two highest diameter classes are less than those found in the 5-year cutting cycle. A stand structure that has trees from all diameter classes will have greater structural diversity and balanced age distribution that may result in greater diversity of flora and fauna, and increased owners’ utility from ecological and environmental values. Hence, this analysis provides a basis for private woodlot owners to make a rational choice of cutting cycle depending upon their economic and environmental preferences. A cutting cycle of 15 years will be environmentally optimal, of 5 years economically optimal, and of 10 years the best for woodlot owners who have some preference for environmental values but who are not willing to give up many economic returns.

The present discussion is based on the objective function given by Eq. (5) which does not include specific features of private forests. Next, three specific factors of private forests and the tax rebate program are included in the model and discussion. These factors are related to: (1) the nature of the private woodlot owner—his or her choice of the rate of time preference; (2) the ownership of the forest—income and property taxes; and, (3) the rehabilitation of degraded forests and the managed forest tax rebate program—the minimum number of trees a woodlot must have in order for its owner to qualify for the program.

6.2. Choice of the rate of time preference

In the literature, the choice of the rate of time preference has been confused with the real rate of interest; without any distinction, the real rate of interest has been used as a measure of the rate of time preference. Fisher (1930, p. 104–106) postulates that under the conditions of the perfect capital market, the rate of time preference will be, at the margin, equal to the real rate of interest. Fisher’s argument is based on there being no distinction between natural and human-made capital, thereby implying that human-made capital and natural capital are perfect substitutes. Costanza and Daly (1992) point out that human-made capital is derived from natural capital, and that if both capitals are perfect substitutes, there was no need for human-made capital to develop. In fact, human-made capital and natural capital are complementary but are not substitutes for each other. The realisation of complementarity between human-made capital and natural capital indicates that the rate of interest earned on human-made capital cannot be an appropriate measure for discounting natural capital. In the case of the two categories of private woodlot owners, mentioned above, it can be argued that, for the first category of woodlot owners, the rate of time preference will be equal to the real rate of interest, but for the second category of owners, the actual rate of time preference of the owner for financial returns from forests will be an appropriate discounting rate for determining the present value of returns from forests. Without further elaboration of this issue, our main argument is that for crown or public forests a single rate of time preference dictated by the government may be used. But, in the case of private forests, different forest owners may have different rates of time preference. The choice of a rate of time preference by an individual will be governed by the nature of and role the forest plays in his or her economic and social needs; personal factors such as habit and self-control, expectation of life and concern for the lives

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2 In fact, the soil rent decreases as the cutting cycle increases from 5 to 20 years, but it increases for a cutting cycle of 25 years. Hence, to make sure that 5 years is an optimal cutting cycle, the LP problem is also solved for a cutting cycle of 30 and 35 years. It is found that the soil rent decreases for a cutting cycle of 35 years, and that soil rent for a cutting cycle of 5 years is the highest.
of other persons, fashion, and foresight, and time span of consideration (Kant, 1996). Hence, economically optimum cutting cycles are estimated for 0.5, 2, 3, 4, and 5% rates of time preference; for every rate of time preference, the optimum cutting cycle is 5 years.\(^3\) The rate of time preference may also have an impact on the optimal growing stock and harvesting for any given cutting cycle. Hence, the LP problem of maximizing the soil rent (objective function Eq. (5)) subject to the growth constraints given by Eqs. 4a, b, c is solved for a cutting cycle of 5 years and the rate of time preference varying from 0.5 to 10%. The results are given in Table 2.

These results indicate that, in the case of low rates of time preference, those ranging from 0% to 2%, woodlots will have trees in all diameter classes in a steady state, and the owner can harvest four trees in the highest diameter class every 5 years. In the case of the rate of time preference being 3%, the woodlot owner can harvest four trees in the diameter class of 30–35 cm at an interval of 5 years, and the woodlot will not have any tree bigger than 35 cm in a steady state. In the case of a 4% rate of time preference, the owner can harvest six trees in the 20–25 cm diameter class, and there will be no tree bigger than 25 cm in a steady state. In the case of the time preference being 5% or higher, the owner will be so impatient that he or she will not allow the trees to grow, and will harvest all ingrowth trees while are still in the lowest diameter class. Hence, higher rates of time preference will convert uneven-aged forests into young and uniform stands which will probably have few snags and little coarse woody debris and underground vegetation that may not be desirable from an ecological and environmental perspective.

In this analysis, I have not included explicitly the objective of utility maximization of the second category of woodlot owners, but a lower rate of time preference leads to a steady state in which the representation of all diameter classes should lead to higher environmental and ecological values. Hence, the objective of utility maximization is dealt implicitly.

A discontinuous, step-like nature of stumpage price function of trees from different diameter classes, as mentioned before, has been confirmed by Nautiyal et al. (1995) study of stumpage of private woodlots in southern Ontario. This discontinuous price function can be used strategically by government and forest industries to increase financial returns from big trees to private woodlot owners so as to encourage SFM. Wood markets being subject to a number of imperfections, forest firms and government can influence the prices of wood in the long term by managerial and technical innovations such as the develop-

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\(^3\)The optimum cutting cycles for the five rates of time preference are the same due to the discrete nature of diameter class distribution of trees and the limit, imposed by the growth data, on the value of cutting cycle (5 years or multiple of 5 years). If growth data were available for 1-year intervals, the optimum cutting cycle for these five rates of time preference might have been different.
Table 3
Tree distribution (number of trees per hectare) for different changes in prices of trees of 30–35 cm and above 35 cm diameter (cutting cycle = 5 years and rate of time preference = 3%)

<table>
<thead>
<tr>
<th>PRIVATE Diameter class</th>
<th>Increase in pricesb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/1.75</td>
</tr>
<tr>
<td>8–15 cm</td>
<td>91</td>
</tr>
<tr>
<td>15–20 cm</td>
<td>29</td>
</tr>
<tr>
<td>20–25 cm</td>
<td>23</td>
</tr>
<tr>
<td>25–30 cm</td>
<td>18</td>
</tr>
<tr>
<td>30–35 cm</td>
<td>14</td>
</tr>
<tr>
<td>&gt;35 cm</td>
<td>4a</td>
</tr>
</tbody>
</table>

a Note: indicates the number of trees to be harvested.
b The first and second figures indicate an increase in the price of 30–35 cm and above 35 cm diameter class trees, respectively. For example, 1/1.75 means that the price of 30–35 cm dbh tree remains at the present level, but the price of a tree above 35 cm dbh is increased by 75%.

ment of new luxury products, customer-specific diversification of products, and market segmentation. The demand for wood is a derived demand, and, therefore, is subject to such innovations. A recent example of such an innovation is the development of oriented strand board (OSB) and medium density fibreboard (MDF). The introduction of these products increased the prices of small size trees and wood wastes such as chips. Hence, the impact of the change in the prices of trees of 30–35 cm and above 35 cm diameter is simulated in this research.

Simulation results are given in Table 3. The results indicate that if the price of trees above 35 cm diameter (only) is increased by 75%, private woodlot owners would prefer to wait until a tree reaches the highest diameter class and will cut four trees, on a sustained basis, in this class at an interval of 5 years. Similarly, if the prices of 30–35 cm and above 35 cm diameter trees are increased by 50%, owners will harvest four trees in the 30–35 cm diameter class. If the prices of 30–35 cm and above 35 cm diameter trees are increased by 50 and 125%, respectively, the owner will harvest four trees in the above 35 cm diameter class. These increases in prices compensate for the high impatience level of private landowners and will help maintain trees in all diameter classes. Hence, in order to encourage sustainable forest management practices by private landowners, emphasis should be given to the importance of increasing per unit returns from big trees. However, it should be noted that this impact of change in prices is only due to a change in the price differential between the prices of small trees and big trees. Hence, an increase in the prices of all trees by the same proportion will not change tree distribution in the steady state.4

6.3. Property and income taxes

Private woodlot owners pay property tax5 for woodlots and income tax6 on the income gener-

4 For example, increasing the prices of all trees (trees from all the six diameter classes) by 75% will not change the relative price of a tree from highest diameter class (above 35 cm) with respect to a tree from any other diameter class. But, if the price of a tree of above 35 cm dbh only is increased by 75%, it becomes more valuable with respect to the trees from all other diameter classes. This changed price ratio (differential) is responsible for the impact of change in prices.

5 The property tax is an ad valorem tax on the value of land. Generally, broad guidelines are decided by the province, but tax rates vary across municipalities. There is a considerable difference across provinces in the methodology of valuation of land and the treatment of forestland for tax purposes. In Ontario, land is assessed at fair market value, and forestland is treated similarly to other lands. In Newfoundland, forestland is assessed by land value and timber value (Baker, 1990).

6 In Canada, farming income is treated differently than a private income as well as corporate income. A farmer does not have to incorporate in order to receive many of the corporate income tax instruments. Private woodlots also fall under farming income. But, attaining farm status for woodlot owners has been and continues to be an arduous task (Baker, 1990).
ated by woodlots. Property tax is proportional to the total value of property while income tax depends upon total income from the woodlot. In Ontario, the rate of property tax varies from county to county. Since this study deals with an average stand of white pine, it incorporates an average yearly property tax per hectare of woodlot in the analysis. Suppose the property tax is \( ST_p/ha\text{/year} \). The present value of this tax stream over an infinite period at \( R\% \) rate of time preference will be \( T_p/R \). Let a woodlot owner pay an income tax of \( Tin\% \). In addition, private woodlot owners sell standing trees, and prices paid by buyers are net prices. Hence, there is neither a fixed nor a variable cost of harvesting to the woodlot owner. Hence, the objective function\(^7\) of the woodlot owner will be:

\[
\max Z(h^*, X^*)
\]

\[
= [(1 - T_m/100)(ph^*)/((1 + R)^{mT} - 1)]
\]

\[
- p(X^* - h^*) - T_p/R.
\] \( (6) \)

In this formulation, there are two assumptions: (1) the absence of interactions between property taxes and income taxes; and (2) the fact that property tax and income tax are independent of two decision variables, i.e. growing stock \((X)\) and harvest \((h)\).\(^8\) Normally, there is an interaction between property taxes and income taxes; for example, property taxes paid every year are deductible from income taxes. As our analysis is only for 1 ha, the impact of these interactions on the total income tax paid is expected to be negligible; hence, income tax is treated as being independent of property taxes paid. An analysis of the impact of these two taxes on the two decision variables \((X\) and \(h)\) needs careful scrutiny. A property tax not directly dependent on the productivity of the property or on its present or projected output, which is the case in Ontario, will have no effect on the decision variables \((X\) or \(h)\) unless the tax rate is so high that net returns from the property are negative.\(^9\) This result is the same as the common argument of the neutrality of property taxes (Gregory, 1987). But, if the property tax is based on the value of forests assessed on the basis of growing stock, as is the case in Newfoundland, this would affect the decision variables \((X\) and \(h)\).

In the case of income tax, the argument is that as long as income tax is a percentage reduction of net revenue it will have no effect on timber production decisions. Hence, a tax on ordinary income is neutral (Dennis, 1985). Johansson and Lofgren (1985) demonstrate that a proportional income tax will not affect the optimal rotation period. Nevertheless, this argument is applicable only to even-aged forests. In the case of uneven-aged forests, in which trees of different sizes have different values and there is an opportunity cost of not harvesting the remaining timber, income tax will not be neutral. The impact of income tax on the present value of net revenue is similar to the impact of the rate of time preference\(^10\), hence the impact on two decision variables \((X\) and \(h)\).

\(^7\) The measure of opportunity cost by the value of unharvested growing stock at market price is debatable. It is a simplistic version to capture a complicated process of forest growth. For example, harvesting of all growing stock of an uneven-aged forest will convert it into an even-aged forest, or in an uneven-aged forest that is totally dependent on natural regeneration for restocking, there will be no forest after harvest of the total growing stock. On the other hand, private woodlot owners, who are maintaining the woodlots because these are part of their home or farm, will lose all future utility due to harvesting of the total growing stock. In these cases, it is very difficult to assign a realistic value to the opportunity cost of not harvesting the remaining timber. However, in the absence of any other better measure, we continue to use the conventional measure of opportunity cost.

\(^8\) Since, in Ontario, the valuation of woodlots for property tax purposes is based on land value and is independent of the growing stock, treating property tax independent of growing stock and harvest is realistic. The rate of income tax is also independent of these two decision variables.

\(^9\) In the case of soil rent being negative due to high property tax, a private woodlot owner may lose interest in the management of his woodlot which will affect decision variables \(X\) and \(h)\).

\(^10\) The rate of time preference is in the denominator of the present value of net revenue, and income tax is a negative term in the numerator. Hence, an increase in both will lead to a decrease in the present value. However, the rate of time preference has an exponential of time (cutting cycle under consideration); hence, it will have an exponential effect.
will also be similar. Therefore, the inclusion of property tax will affect only the value of objective function; while income tax may affect the optimum cutting cycle as well as the optimal values of $X$ and $h$ in addition to the optimal value of the objective function.

Next, I evaluate the impact of different tax rates in Ontario. The evaluation is done for the fixed rate of time preference of 3%. The nature of the impact of tax rates will be the same for any other rate of time preference. But to see the actual impact of tax rates on the second category of woodlot owners, the same exercise will need to be done for lower rates of time preference.

In Ontario, during 1995, property tax rates on woodlots varied from approximately $2.00–100.00/ha, and the weighted average was approximately $20/ha (Denys, 1996). The soil rent values indicate that an average stand of white pine subject to a property tax of $20/ha will yield a negative soil rent (−$532) even for zero income tax. The soil rent becomes positive ($1.29) at $4/ha property tax. According to the present tax rebate program of the OMNR, the maximum tax rebate is 75% of the total property tax. Hence, at the rate of $20/ha, the rebate available will be $15.00. Hence, an average stand, represented by the growth matrix as given in the estimated model section, will yield a negative soil rent even after a tax rebate from the OMNR. Therefore, an average woodlot owner may agree to participate in the managed forest tax rebate program for short-term monetary benefits, but the program will not encourage the owner to manage the forest on a sustainable basis. However, the program may encourage the participation of those woodlot owners who pay a property tax ranging from $5 to $16/ha because these owners will pay only $1.25–4.00/ha after a tax rebate from the OMNR.

As indicated above, income taxes may affect the optimal cutting cycle as well as growing stock and harvesting variables. The economically optimal cutting cycle is 5 years for 5% income tax, and 10 years for 10%, 15%, and 20% income tax. The impact of income tax on growing stock and harvesting variables was evaluated for a fixed cycle of 5 years and 3% rate of time preference. The results are given in Table 4. At a 3% rate of time preference, there will be no tree bigger than 35 cm dbh in steady state, even at zero income tax, and four trees in the 30–35 cm diameter class will be harvested every 5 years. This steady state stand structure will remain intact up to the 6% income tax level. At the 7% income tax level, the woodlot owner will harvest six trees in the diameter class of 20–25 cm dbh, and will not allow any tree to grow older. This stand structure will be maintained up to the 27% income tax level. At 28% income tax, the woodlot owner will cut all the ingrowth trees in the lowest diameter class.

<table>
<thead>
<tr>
<th>Diameter class</th>
<th>PRIVATE Income tax rates (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>8–15 cm</td>
<td>91</td>
</tr>
<tr>
<td>15–20 cm</td>
<td>29</td>
</tr>
<tr>
<td>20–25 cm</td>
<td>22</td>
</tr>
<tr>
<td>25–30 cm</td>
<td>18</td>
</tr>
<tr>
<td>30–35 cm</td>
<td>4$^b$</td>
</tr>
<tr>
<td>&gt;35 cm</td>
<td>0</td>
</tr>
<tr>
<td>Soil rent ($/ha)$^c</td>
<td>134.62</td>
</tr>
</tbody>
</table>

$^a$ Property tax = 0, rate of time preference = 3%, and cutting cycle = 5 years.

$^b$ Indicates the number of trees to be harvested.

$^c$ Soil rent is net of income tax.
Hence, a 28% income tax level gives the same results as those in the 5% rate of time preference. Thus, the same rate of income tax on all income is neutral, either with respect to harvesting decisions and the resulting stand structure or with respect to the cutting cycle. In the case of uneven-aged forests, income tax works against the principle of keeping trees in all diameter classes and the concept of having old growth forests.

With respect to diameter distribution, an increase in income tax has the same impact as an increase in the rate of time preference; this can be compensated for, to some extent, by the same measure—an increase in the relative price of high diameter trees. The range of income tax in which tree distribution remains the same is 0–6% and 7–22%, and this range can be used by income tax authorities so that the structural diversity of the stand is not reduced by a change in income tax rates. An interesting feature of this tax range is that total tax revenue may not always increase as a result of an increase in the tax rate. For example, if a woodlot is being managed on a sustainable basis, and it is in the steady state, an increase in income tax from a level of 20–30% will decrease the total income tax received from $7.64 (trees harvested*price*income tax rate = 6*6.37*0.2) to $3.00 (20*0.50*0.3). Hence, under these conditions, an increase in income tax will have a double-edged sword effect: (1) it will reduce total tax revenue; and; (2) it will lead to an uneven-aged forest with no trees in the upper diameter classes in the steady state. Hence, from the perspective of ecological and environmental values, the impact of high income tax rates will be the same as the impact of a high rate of time preference. Fiscal policies designed without knowledge of specific features of forests may not only prove to be disastrous for ecological and environmental values, but may also prove to be blunder from an economic perspective.

Let us now analyze the impact of income and property taxes together. This analysis is performed for two extremes of the critical ranges of income taxes, 6 and 27%. The results of this analysis are given in Table 5. At a 6% income tax level, soil rent is positive only up to a property tax of $2/ha, and at a 27% income tax level, soil rent is positive only for $1/ha property tax. Therefore, on average at the present income tax rates, which are between 20 and 30%, the tax rebate program will encourage only those private woodlot owners who are paying a property tax up to $4/ha (and $1/ha after tax rebate from the OMNR). Other private woodlot owners may agree to participate in the program for monetary benefits, but the impact of the program may not be long lasting. If the OMNR decides to stop the subsidy on property tax, woodlot owners may cancel all management activities initiated under the requirements of the program. An alternative to a tax subsidy would be a subsidy on the cost of the rehabilitation of degraded forests. In fact, an interesting feature of the tax rebate program is the minimum number of trees of different sizes per hectare required in order to qualify for the program. This feature will require rehabilitation of degraded forests in order to qualify for the program. Next, I incorporate this feature of rehabilitation in the discussion.

### Table 5

Soil rent ($/ha) for different rates of income and property taxes\(^a,b\)

<table>
<thead>
<tr>
<th>PRIVATE Income tax (%)</th>
<th>Property tax ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>134.62</td>
</tr>
<tr>
<td>6</td>
<td>98.23</td>
</tr>
<tr>
<td>27</td>
<td>47.02</td>
</tr>
</tbody>
</table>

\(^a\) Rate of time preference = 3% and cutting cycle = 5 years.

\(^b\) Note: Soil rent is net of income and property tax.
Table 6
Net soil rent ($/ha) in the steady state for different additional ingrowth

<table>
<thead>
<tr>
<th>PRIVATE Income tax (%)</th>
<th>Additional ingrowth (trees/ha)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-397.42</td>
<td>-262.78</td>
<td>-128.17</td>
<td>6.44</td>
<td>141.07</td>
<td>275.69</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-460.21</td>
<td>-371.98</td>
<td>-273.75</td>
<td>-175.53</td>
<td>-77.30</td>
<td>20.92</td>
<td></td>
</tr>
</tbody>
</table>

* Property tax = $20/ha, rate of time preference = 3%, and cutting cycle = 5 years.

6.4. Subsidy for rehabilitating degraded forests

In our sample stand, an ingrowth level of 20 trees in 5 years indicates a degraded stage of forest. One option for the rehabilitation of these forests may be to subsidize activities in order to increase ingrowth. One of the requirements of the tax rebate program is the minimum number of trees of different sizes. The requirement is one of the following: (1) 1000 trees per ha of any size; (2) 750 trees per ha measuring over 5 cm diameter, and; (3) 500 trees per ha measuring over 12 cm in diameter, or (4) 250 trees per ha measuring over 20 cm in dbh. In the sample stand, the number of trees in the six different diameter classes are 281, 205, 179, 114, 41 and 15; and these trees give 835 trees bigger than 8 cm dbh and 349 trees above 20 cm dbh. Hence, the sample stand meets the requirements of the program. But, in a steady state achieved through the economic harvesting regime, the number of trees (trees above 8 cm dbh = 164 and trees above 20 cm dbh = 44) falls below the requirements of the tax rebate program.

Hence, in the long-run, these stands will not be eligible for a tax rebate under the present program. Also, if someone has been managing the sample stand under an economic harvesting regime for a long time, the number of trees may have fallen below the number of trees required to qualify for the tax rebate program. The required minimum number of trees can be maintained by increasing ingrowth that may be obtained by supplementing natural regeneration with planting. Rehabilitation of degraded forests is also important from an ecological and an environmental perspective. Increased ingrowth will, finally, result in an increased number of trees in all diameter classes, balanced age distribution, reduced canopy gaps, increased biomass, higher carbon storage, and a possible increase in the level of diversity of flora and fauna. At the same time, woodlot owners who are paying property taxes at higher rates will also be encouraged to take up the management of these areas due to increased soil rents. Approximately 30% woodlot owners in Ontario have indicated their willingness to take up plantation activities (Smyth and Nausedas, 1982). Hence, plantation for rehabilitation seems to be environmentally, ecologically, and economically desirable as well as acceptable to woodlot owners.

In the sample plots, as ingrowth is constant irrespective of the total number of trees and the basal area, increased ingrowth will increase the number of trees in each diameter class by the same multiple as an increase in ingrowth. Hence, a private woodlot owner or forest department will have to decide the rate of increase in ingrowth. Target ingrowth will depend upon: (1) the shortage of the number of trees from the required minimum number in different diameter classes, and; (2) the extent to which the government is willing to subsidize the woodlot owner.\[11\] Our sample stand will require 60 additional ingrowth trees\[12\] in order to maintain the minimum number

\[11\] The target ingrowth will also depend upon the capacity of the stand to absorb the increased ingrowth without disturbing the growth pattern. We have assumed that the rate of ingrowth discussed here is within this capacity.

\[12\] Additional ingrowth of 60 additional trees (or total ingrowth of 80 trees) will result in (164*80/20) 656 trees above 8 cm diameter. The requirement of 750 trees above 5 cm diameter and 500 trees above 12 cm diameter will give approximately 609 trees above 8 cm diameter (assuming linear distribution from 5 cm to 12 cm).
of trees in accordance with present requirements of the tax rebate program, but the actual number of additional ingrowth trees can be decided based on income and property tax structure. I simulate the outcomes for no income tax and 6% income tax. Results are given in Table 6.

The simulation results will help the government to select the mode of subsidy—either on property tax or on the cost of woodlot rehabilitation. In the case of a tax subsidy, even a subsidy of $15/year (75% of average property tax of $20/year) is insufficient to have positive soil rent on a sustainable basis. In a period of 5 years, a subsidy of $15/ha per year will amount to a total subsidy of $75. On the other hand, a subsidy on increasing ingrowth by 80 trees/ha in a period of 5 years will amount to not more than $40 (given a liberal estimate of planting cost at $0.50/tree), and the forest owner will have the positive soil rent forever. The other issue is of the period of subsidy. In the case of property tax, the subsidy has to be continued forever. But, through rehabilitation, the forests may be fully stocked after a few cutting cycles in which case the subsidy for ingrowth may be discontinued.

On the other hand, in the present situation of no subsidy for rehabilitation and no effort by the private woodlot owner to increase ingrowth, at a income tax rate of 20% (zero property tax)\textsuperscript{13}, the land owner will harvest six trees of 20–25 cm dbh (refer to Table 4) and will pay $7.64 in income tax during a period of 5 years. In this particular case, an income tax higher than 6% will not be desirable from the point of stand structure. But, if the government decides to subsidize ingrowth up to 120 trees/ha in the period of 5 years and charges 6% income tax and $20/ha property tax, a private woodlot owner will be able to harvest 28 trees\textsuperscript{14} of 30–35 cm dbh at an interval of 5 years, and will pay an income tax of $36.93 (28*$21.98*$0.06). In this case, the total cost to the government will be the subsidy for ingrowth which should not be more than $60 in 5 years. The total saving to the government will be $75 (saving from stopping the subsidy on property tax) with an additional revenue of $29.29 ($36.93 – $7.64) from increased income tax. Hence, the total subsidy on rehabilitation cost in place of the property tax subsidy and a reduction in the income tax rate from 20% to 6% leads to a saving of $15 on the subsidy and an additional revenue of $29.29 from income tax to the government, a positive soil rent of $20.92 (Table 6) to the land owner, and practices of sustainable forest management. Therefore, on this type of degraded forest stand, it seems that a subsidy for rehabilitation will be desirable from an environmental and an economic perspective to both land owner as well as to the government.

### 7. Conclusions

I have used a specific data set to demonstrate the impact of economic behaviour of woodlot owners and government policies, mainly fiscal policies, on sustainable management practices for uneven-aged private forests. Hence, the results of the present analysis are only indicative and are subject to the limitations of the model, such as the linear relationship between the variables, and assumptions, such as range of ingrowth discussed is within the biological capacity of the stand. Even though most of the results are general in nature, the results should be used only to understand the expected trends of outcomes of the impact of economic factors and to analyze the existing policies in that context. Conclusions are as follows:

An increase in the rate of time preference would lead to the harvesting of smaller diameter (young) trees. At a reasonably high rate of time preference, an uneven-aged forest will be converted into an even-aged young forest leading to a loss of ecological and environmental values.

Due to the discontinuous step-like nature of price function, government and forest firms can use technological and marketing innovations to increase the prices of big trees so to promote sustainable management practices, leading to higher environmental and economic values, by compensating impatient private woodlot owners.

\textsuperscript{13} Even positive property tax will not change the harvesting decisions till the soil rent is positive.

\textsuperscript{14} The ratio of total ingrowth (120 + 20) to original ingrowth (20) is 7, and hence the number of trees which can be harvested is equal to 4*7 = 28.
In the case of positive soil rent, the impact of property tax is neutral on harvesting decisions and, hence, on economic and environmental values. But, property tax will discourage sustainable management practices if the soil rent becomes negative; in addition the reduction of property tax to the extent that it makes the soil rent positive, will encourage sustainable management practices.

In contrast to even-aged forests, the impact of income tax on uneven-aged forests is not neutral with respect to harvesting decisions, ecological and environmental values, and economic values. The impact of income tax is similar to the impact of the rate of time preference. As income tax increases, smaller size (young) trees are harvested and higher diameter classes disappear from the forest. At a reasonably high rate of income tax, an uneven-aged forest will be converted into an even-aged forest. Hence, higher income tax rates also work against the ecological and environmental values and principles of sustainable management.

The discrete structure of tree distribution and the step-like nature of prices result in a range of income tax in which the stand structure will remain the same. The two factors, discrete structure and the step-like nature of price function, also result in some income tax ranges in which an increase in income tax rate may lead to a decrease in total income tax. Tax structure should be sensitive to these ranges; otherwise, an increase in income tax rates will work against ecological and environmental values, as well as defeating the objective of higher revenue.

In view of these outcomes, a critical evaluation of fiscal policies for private forests seems necessary. Normally, fiscal policies are based on common economic principles, such as economic growth, economic stability, and income distribution. However, for encouraging sustainable forest management, the fiscal policies for forestlands have to be sensitive to specific features of forests (even-aged as well as uneven-aged). For example, income tax rates for private woodlots should not be decided solely on the basis of income from sale of forest produce, but these rates should be sensitive to the forest structure of private woodlots. In addition to changes in fiscal policies, government programs (such as a tax rebate program) to encourage sustainable forest management on private forests should also be sensitive to specific features of different types of forests, and it may require different programs across the province. For example, for degraded forests in Ontario, a subsidy for the rehabilitation of degraded forests may be desirable. These outcomes also demonstrate that only new silvicultural options, such as ecological pathways, ecosystem management, and extended rotation periods, are insufficient in themselves for sustainable forest management, and, hence, these options are to be backed by the appropriate fiscal and other governmental policies.

Finally, this paper demonstrates that a matrix growth model of an uneven-aged forest is a useful tool, not only for planning silvicultural operations, but also for evaluating the impact of economic parameters on sustainable forest management practices and for examining the trade-off between environmental and economic values. Hence, growth models should be estimated and published for uneven-aged forests of different species composition similar to general yield tables of even-aged forests.

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