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# Applying portfolio optimisation to the harvesting decisions of non-industrial private forest owners

Kari Hyytiäinen *, Markku Penttinen

*Finnish Forest Research Institute, Unioninkatu 40 A, 00170 Helsinki, Finland*

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**Abstract**

The non-industrial private forest owner's optimal harvesting and investment strategies are studied at forest holding level by including individual forest stands in an asset class portfolio. The forest owner can either clearcut mature stands and invest the capital in financial or real asset classes (bank deposits, government bonds, stocks, apartments) or postpone clearcutting and retain capital in standing trees. Forest inventory data from actual forest holdings in Southwest Finland, the simulation–optimisation software MELA, and statistics on timber prices are utilised to compute the return series for forest stands. The numerical results show that the optimal level of clearcutting decreases markedly with initial non-forest wealth, especially at low risk-free rates of interest. It may therefore be rational for non-industrial private forest owners to consider shorter rotation periods than those of investors with diversified portfolios. The correlations between returns from forest stands are high, implying that increasing the variety of stand structures achieved by planting different species is not likely to bring substantial diversification benefits. The favoured investment outlet for harvesting revenues (apartments, government bonds or stocks) is sensitive to the period of historical data used to compute the return series and risk-free rate of interest. The value growth of forest stand can be used to estimate annual returns only for those stands that are readily mature. An alternative method of computing returns on stands in any development phase is proposed, based on net present value of stand adjusted for fluctuations in forest land prices. This method applies if selling forest land is considered an option. If selling is not an option, the ratio of maximised net present value to value at immediate harvest can be used as a 'maturity index' for ranking the stands for portfolio optimisation.


*Keywords:* Clearcutting; Efficient frontier; Forest management planning; Portfolio optimisation

## 1. Introduction

### *1.1. Aggregate level planning and control*

Modern portfolio theory (MPT), originating from Markowitz (1952), has inspired numerous studies and has established a basis for financial planning and control in various disciplines. In forestry, MPT has been employed mainly to compare investments in forest land *ex post* with alternative investments or markets as a whole. Mills and Hoover (1982) were the first to solve the *ex ante* investment problem including financial assets and farmland as alternative investments in addition to timberland. Since then, the question whether to buy or sell forest land has been investigated in several *ex-post* capital asset pricing model (CAPM) studies (e.g. Zinkhan et al., 1992; Binkley et al., 1996; Lundgren, 2005) and a few arbitrage pricing theory (APT) studies (Sun and Zhang, 2001). The standard Markowitz approach has been extended, for example, to multi-period portfolio optimisation (Thomson, 1991; Heikkinen, 2003).

The majority of CAPM studies report low or even negative systematic risk (i.e. beta values) for forestry investment (e.g. Redmond and Cubbage, 1988; Wagner et al., 1995). This indicates that forest land tends to reduce the risk of portfolios. Therefore, it may be rational for institutional investors to keep some, albeit small, proportion of forest land in well-diversified portfolios even if the expected returns on forest ownership are

* Corresponding author. Tel.: +358 10 211 2189; fax: +358 10 211 2104.
*E-mail address:* kari.hyytiainen@metla.fi (K. Hyytiäinen).

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lower than returns on alternative investment with similar risks. In Finland, non-industrial forest ownership has been demonstrated to have a rather low risk-related return (alpha = − 2.5%) and, compared to the US studies, a relatively high systematic risk (beta = 60%) (Lausti and Penttinen, 2006). Investments in forest land have also been found to serve as a hedge against inflation (Washburn and Binkley, 1993; Lausti, 2004).

In aggregate level studies, forestry returns are calculated for a hypothetical forest land investment, assuming certain management regimes, age class distributions, site qualities, and timber species. It is typically assumed that any amounts of fully regulated forest with given timber species and productivity can be purchased or sold in the forest land market (e.g. Thomson and Baumgartner, 1988; Thomson, 1992). Statistics on stumpage prices (e.g. Redmond and Cubbage, 1988) or timberland indices (e.g. Zinkhan, 1990; Sun and Zhang, 2001) have typically been employed to estimate series of forestry return. Forestry returns can be calculated for individual timberland funds (Caulfield, 1994) or real or hypothetical forest holdings (Lönnstedt and Svensson, 2000) or by combining information from regional forest inventories and statistics on prices and costs (Penttinen and Lausti, 2004).

### 1.2. Applying MPT for forest management

A less studied theme, proposed e.g. by Thomson and Baumgartner (1988), is to apply the techniques of MPT to optimise stand management activities such as regeneration harvests. In this line of research, the investor is typically assumed to have a forest holding. The management problem can be formulated to investigate whether it is rational to harvest forest stands and allocate harvesting revenues to alternative investments. Heikkinen (1999) included four subjectively selected stands as independent asset classes, and studied optimal level of clearcutting, assuming that the net harvesting revenues are invested on Finnish stock markets. Later, Heikkinen (2003) extended the approach to a multiperiod formulation and included several financial asset classes as alternative investments to net harvesting revenues. The harvest-investment decision problem has been examined also with two-period consumption–saving models (Ollikainen, 1993; Gong and Löfgren, 2003).

Determining returns for individual stands is a challenging task (Caulfield, 1998; Caulfield and Newman, 1999). Forest stands are unique and do not trade on organized exchanges. The value developments of individual stands cannot be derived directly from land sales price statistics because exchanged forest properties typically consist of several different stands. In addition, the value of a stand depends much on location, accessibility, climate and fertility of the site, as well as tree species, tree size, and tree age distributions. Therefore, the movements in market values of individual stands must be derived from secondary data. Alternatives include e.g. estimating stand value at immediate clearcutting (liquidation value) or net present value (NPV) of future revenues and costs (see e.g. Hyder et al., 1999). Developments in stand values are affected by several attributes and economic parameters: changes in roundwood category prices, growth of commercial timber volume, changes in timber quality (due to transition of timber volume between roundwood categories), tree mortality, changes in unit harvesting cost, and bare land value. Therefore, empirically validated models for stand growth and harvesting cost are needed for predicting stand return series.

### 1.3. Aim of the study

This study continues the research tradition of employing the techniques of MPT to investigate rational clearcutting decisions at forest holding level. Earlier research on the topic (Heikkinen, 1999, 2003) is extended by including in the analysis an actual forest holding consisting of a number of stands with varying characteristics. Special emphasis is placed on elaborating ways to compute return series for stands at any development phase, and developing criteria to rank stands with regard to economic maturity. Sensitivity analyses include various periods of historical data, selections of investment alternatives and levels of initial non-forest wealth. The applicability of portfolio optimisation as a practical decision making tool for harvesting is discussed.

## 2. Methods

### 2.1. Estimating return series

Statistical data from the recent past is used to estimate return series for each financial and real asset class. This information is needed for computing expected returns, risks (standard deviations of returns), and covariances between alternative asset classes, and finally for solving the forest owner's investment problem. Let $R_{tj}$ denote the annual return on the $j^{\text{th}}$ asset class in the $t^{\text{th}}$ year. The past years included in the data are denoted by $t = 1,\ldots,h$, where $h$ represents the time of investigation. The annual returns on financial assets, such as stocks or government bonds, can be easily computed using asset values in the successive years $V_{tj}$ and $V_{t+1,j}$. These values account for the asset's market value, annual dividends, coupon payments and other cash transactions. The series of logarithmic returns are computed for $m$ alternative investments to harvesting revenues, and $h-1$ pairs of successive years as

$$R_{tj} = \ln\left(\frac{V_{t+1,j}}{V_{t,j}}\right),\ t = 1,\ldots,h-1; j = 1,\ldots,m. \quad (1)$$

It is not possible to obtain equivalent market signals for forest stands. Therefore, we employ past development of timber prices at roadside $p_{tk}$, $t = 1,\ldots,h$, $k = 1,\ldots,u$, for $u$ roundwood categories to estimate their impact on return series for forest stands. The effect of tree growth on development of roundwood volumes $X_{tkj}$ between successive years, ($t = h+1$) and ($t = h$), is predicted with a deterministic model for stand growth. The harvesting cost (€/ha) $C_{tj}$ is subtracted from total revenues at roadside to attain harvesting revenue at stumpage. The annual