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Economics of rotation and thinning revisited: the optimality of clearcuts versus continuous cover forestry

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ABSTRACT

A continuous time-economic model for optimal thinning and rotation is modified to include natural regeneration. The respecified model is capable of describing both optimal forest rotation and continuous cover forestry (uneven-aged management). Continuous cover forestry is shown to be optimal if the preset value of continuous sustainable harvesting income over an infinite horizon is higher than the clearcut revenue and the highest possible value of bare land. Negative bare land value implies optimality of continuous cover forestry but only if clearcut stumpage prices are not higher than thinning stumpage prices. Given low interest rate optimized thinning is shown to increase rotation length.

1. Introduction

Resource economics for forestry is strongly based on the Faustmann (1849) approach, whose rotation structure suits well for plantation forestry. However, the rotation framework assumes the optimality of the given forest management type a priori, instead of allowing it to be determined endogenously via optimization. Thus, no guarantee exists that the given forest management type yields the highest economic surplus, even if evaluated solely from the wood production perspective. Furthermore, several problems, for example biodiversity considerations, deforestation, and climate change, call for expanding the set of forest management alternatives. By specializing on the optimal rotation model and even-aged forestry, resource economics may unintentionally promote plantation forestry at the expense of alternatives with interesting potential in developing wood production, fighting against deforestation, and preserving various forest values.

The alternative to rotation forestry is uneven-aged management or continuous cover forestry, where harvests are only partial and tree density is maintained at a level that enables natural regeneration. Size-structured models are usually used to describe the growth of uneven-aged forests, and optimal harvesting is solved using numerical methods (an exception being Tahvonen, 2015). This line of research originates from Adams and Ek (1974), but the literature is heterogeneous and often without strong economic basis, as already shown in Getz and Haight (1989). This is a consequence of problem complexity, heterogeneous numerical approaches, and nearly complete lack of analytical results.

In one branch of studies Chang (1981) and Chang and Gadow (2010) develop a rotation model that includes partial harvests instead of clearcuts. Khazri and Lasserre (2011) and Halbritter (2014) extend the generic rotation model to include double cohorts and rotations. Halbritter and Deegen (2015) and Coordes (2014) study optimal thinning with and without optimized initial stand density. While these studies present many results beyond the generic rotation approach, their focus is not the optimal choice between clearcuts and continuous cover regimes.

In his classic volume, Clark (1976, p. 263) respecifies a forestry model originally developed by Kilkki and Väisänen (1969). Stand growth depends on stand age and volume (or density), and the model becomes a “Schaefer–Faustmann mixture.” The fact that growth depends separately on density and stand age implies that, besides a clearcut, it may become optimal to apply intermediate cuttings or thinnings. In this model, thinning and stand volume decrease until the clearcut or thinning operation is stopped somewhat prior to the clearcut. Thus, the clearcuts and the classic rotation structure remain. It should be noted that thinning is included in the original land value formula by Faustmann (1849) but is typically neglected in economic studies after Samuelson (1976). However, for some tree species their inclusion has a strong effect on optimal rotation and they may contribute more than 40% of the bare land value (Tahvonen et al., 2013).

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Kilkki and Väisänen (1969) and Clark (1976) (KVC) assume that stand growth in the long run decreases toward zero independently of stand density. This may be suitable in plantation forestry without any natural regeneration. However, given native trees and a more natural forest, trees regeneration depends on stand volume or density. I add this feature into the KVC model to allow the description of both continuous cover and rotation-based forestry and the optimal choice between these alternatives. Without explicit tree size classes this model is necessarily heuristic. However, its merit is the intuitive Schaefer–Faustmann-structure (Schaefer, 1954) and analytical tractability. While the main message of the classic Faustmann model is that it is optimal to clearcut when the stand value growth rate falls short of interest earnings on the value of bare land and revenues from the next clearcut, the main message here is that it is not optimal to clearcut if the revenues from thinning remain higher than interest earnings for the value of bare land and revenues from clearcutting. This situation may remain forever, implying that continuous cover forestry is optimal instead of clearcuts. Interest rate shortens rotation in the Faustmann framework, but a higher interest rate in the model with natural regeneration may imply longer rotation and abandoning clearcuts. Optimized thinning is proved to lengthen rotation period given the interest rate is low. Numerical example demonstrates that the inclusion of thinning widens the gap between economic optimality and solutions maximizing volume yield.

The setup of this study and the results are new. Additionally, the analysis of the original KVC model will be based on simpler methods than previously used, and an unnoticed, unwarranted result in Clark's (1976) classic volume will be corrected. The KVC model is elaborated earlier by Cawrse (1984); Betters et al. (1991) (who focused on mathematical solution methods), and Halbritter and Deegen (2015) (who focused on optimized artificial regeneration). In these models, the original rotation structure with clearcuts is maintained.

Section 2 introduces the model, the underlying assumptions, necessary optimality conditions, and the optimal path for thinning. Section 3 presents optimal rotation period results and the choice of clearcut versus continuous cover solutions in two parts. First, optimal solutions are analyzed assuming that the stumpage price is equal for thinnings and clearcut and next that the thinning stumpage price is lower. In the next section, a numerical example is presented (roughly in line with empirical data) within the original continuous time framework (instead of switching to discrete time, as in Clark and De Pree, 1979). Finally, the results are discussed with respect to some earlier studies and forest policy aiming to maximum sustainable yield.

2. An analytical model for thinning and rotation: the “Schaefer–Faustmann” mixture

Let $x(t)$ denote the stand volume (m^3) and $h(t)$ the rate of harvested volume ($m^3\ a^{-1}$) in thinning. The stand volume evolves according to.

$$\dot{x}(t) = g(t)f[x(t)] - h(t), x(t_0) = x_0, \tag{1}$$

where x_0 (>0) is the initial stand volume and $t_0 = 0$ is the moment just after a clearcut. In the KVC model, the function g is assumed to satisfy $g(0) > 0$, $g(t) \to 0$ as $t \to \infty$. The f function has a maximum with some $0 < \hat{x}$, and f is increasing and strictly concave for $0 \le x \le \hat{x}$. More specifically KVC applies $g(t) = at^{-bt}$ and $f(x) = xe^{-cx}$, where a, b, and c are positive constants. These assumptions are somewhat problematic, even for even-aged plantation forestry, but they are surely not suitable for tree species with density-dependent natural regeneration since growth decreases toward zero independently of stand density.

Let the function g be twice and continuously differentiable. For tree species that regenerate naturally (and artificially), g should remain positive when $t \to \infty$. Thus, suppose

$$\text{a) } g(0) > 0,\ \text{ b) } g'(t)|_{t>0} < 0 \text{ and c) } \lim_{t\to\infty} g(t) \to \hat{g} > 0. \tag{A1}$$

The f function is assumed to satisfy

$$\text{a)} f(0) \ge 0,\ \text{ b)} f(\overline{x}) = 0,\ \text{ c)} f''(x) < 0 \text{ and d)} f'(\hat{x}) = 0, 0 < \hat{x} < \overline{x}. \tag{A2}$$

An example of such a growth model is shown in Fig. 1. The solid, monotonically increasing line shows the undisturbed stand growth. Applying thinning, any state on the RHS of this curve is admissible. Let $\delta(\ge 0)$ denote the interest rate, and to rule out less interesting boundary solutions, suppose.

$$\lim_{x\to 0} \hat{g}\ f'(x) > \delta. \tag{A3}$$

Thus, it is assumed that the growth rate, with low volume levels, always exceeds the interest rate. Given (A1) and (A2), the differential Eq. (1) implies that in the absence of harvesting, $x(t) \to \overline{x}$ as $t \to \infty$. More generally, long-run growth and sustainable harvesting approach $\hat{g}f(x)$. The essential difference, with the KVC specification, is that as the originally planted trees disappear due to mortality or cuttings, the stand regenerates naturally, and the growth of naturally regenerated stands is characterized by normal density-dependence properties.

Let p_1 and p_2 denote the stumpage prices (per m^3) for thinned and clearcut wood, respectively, and assume $p_1 \le p_2$ (cf. Clark (1976, p.268). Given $w_i \ge 0, i = a,b$ is the regeneration cost, T the rotation period, and V the bare land value, the objective function over infinite rotations can be given as

$$\max_{\{h(t),T\}} J(T) = -w_a + \int_0^T p_1 h(t) e^{-\delta t} dt + e^{-\delta T}[p_2 x(T) + V]. \tag{2}$$

In addition to Eq. (1), any solution must satisfy,

$$0 \le h \le h_{\max}, \text{ and } x(T) \ge 0, \tag{3}$$

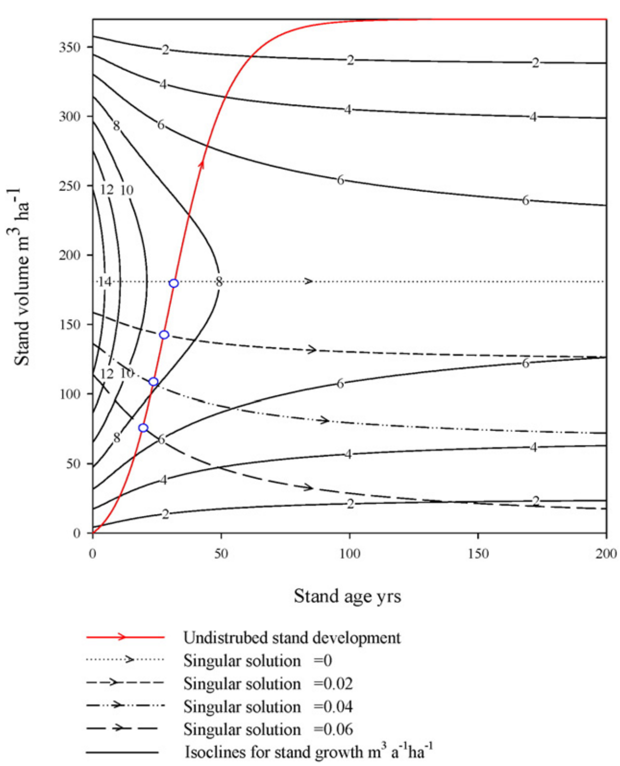

Fig. 1. The growth function and singular solutions.