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Impact of storm risk on Faustmann rotation

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ABSTRACT

Global warming may induce in Western Europe an increase in storms. Hence the forest managers will have to take into account the risk increase. We study the impact of storm risk at the stand level. From the analytical expressions of the Faustmann criterion and the Expected Long-Run Average Yield, we deduce in presence of storm risk the influence of criteria and of discount rate in terms of optimal thinnings and cutting age. We discuss the validity of using a risk adjusted discount rate (a rate of storm risk added to the discount rate) without risk to mimic the storm risk case in terms of optimal thinnings.

1. Introduction

Global warming may induce in Western Europe an increase in storms (Haarsma et al., in press) and also a modification of the distributions governing their frequency and severity. Wind storms will induce high yield losses for forest managers in terms of timber losses and clearing costs (Hanewinkel et al., 2013). Moreover, after a storm, due to an influx of wood on the market, the timber price and hence the future value of forest will decrease. So the forest managers will have to take into account the risk increase and its consequences for stand forest. Therefore they will probably have to modify the rotation period and more generally the silviculture.

In the absence of risk, Faustmann (1849) proposed a formalism, based on the expected discounted income, which allows to determine the optimal rotation period. Many authors have been studying (Clark, 1976; Haight et al., 1992; Kao and Brodie, 1980; Näslund, 1969; Schreuder, 1971) the determination of optimal thinning and cutting age at the stand level. In parallel, empirical studies examined the economic impact on optimal silviculture: Brodie et al. (1978) analyzed the impact of discount rate on optimal thinnings by simulation for Douglas stand, Hyytiainen and Tahvonen (2003) studied the joint influence of the rate of interest and the initial state on the rotation period for Spruce and Scots Pine sites.

The risk of destruction has been introduced for forest stands by Martell (1980) and Routledge (1980) in discrete time. Thereafter, Reed (1984) has studied the optimal forest rotation in continuous time with the risk of fire. Thorsen and Helles (1998) analyzed endogenous risk. More recently concerning natural risk, Staupendahl and Möhring (2011) studied the impact of risk on the expected value of a Spruce stand for various hazard rate functions. Loisel (2011) examined the impact of density dependence growth on optimal cutting age. Price (2011) focused on the validity of using the rate of physical risk, added to the discount rate as a new adjusted discount rate.

More precisely, concerning the risk of storm, Schmidt et al. (2010) studied the impact of storm on the stand forest. Holecy and Hanewinkel (2006) analyzed model insurance. But few works in the literature were focused on the impact of storm risk on forest rotation: Haight et al. (1995) studied the impact of storm on the expected present value without taking thinnings into account. Meilby et al. (2001) focalized their analysis on shelter effect to prevent windthrow in multiple-stand model but they considered an exogeneous land value. Moreover, using empirical material Deegen and Matolepszy (2012) studied the combined effects if storm survival probabilities and site productivities change simultaneously. Susaeta et al. (2012) evaluated the impact of hurricane-related production risk in Pine plantations using a generalized Reed model. In all these numerical studies concerning the storm risk, thinnings are either fixed or not taken into account. There is a lack of studies permitting the analysis and the prediction of the modification induced by storm risk on optimal thinnings and cutting age. In contrast with the previous studies, our analysis is generic and based on the analytic expressions of the criteria. More precisely, it uses the relative contribution of thinnings income in case of storm risk. In this paper, the analytical nature of the proposed methology is a novelty in contrast with the previous works available in the literature, which were based on empirical/numerical techniques.

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In the present work, we model the impact of storm risk on optimal silviculture at the stand level. We consider two criteria which permit to evaluate scenario with various thinnings and cutting age: the Expected Discounted Value (the Faustmann criterion) and the Expected Long-Run Average Yield. We optimize these criteria in presence of storm risk. We consider an adaptation of the model of Reed (1984) toward a forest stand to take into account thinnings for the specific storm risk case. Moreover, the depreciation of timber price due to an influx of wood on the market after a storm is considered. The goal is to determine the joined influence of the presence of storm risk and of the chosen maximized criteria on optimal thinnings and rotation period.

In the first section, we consider the reference case without the storm risk, which will be used for comparison. In the second section, we present the different models in case of storm risk: the storm risk process, the impact of the storm on the stand forest, the timber price depreciation. Assuming we know the expected thinning incomes, final income at cutting age and the various costs link to storm risk, we develop the obtaining of analytical expressions of the Faustmann Value and the Expected Long-Run Averaged Yield in the presence of storm risk taking the depreciation of timber price reference into account. From these analytic expressions, we highlight in presence of storm risk the influence of criteria and of discount rate in terms of optimal thinnings and cutting age. Even if, the influence of the discount rate or the level of risk has been previously observed empirically in specific forest stands, the originality of our work is to provide an explanation of generic properties: the obtained results do not depend on the species or the forest growth. Moreover we discuss the validity of using a risk adjusted discount rate (a rate of storm risk added to the discount rate) without risk to mimic the storm risk case in terms of optimal thinnings. Due to the fact that, if a storm occurs at a date anterior to a fixed time limit, the storm has no impact, we infer that the time limit is an important threshold. The relative positions in time of the optimal thinning without risk and of the time limit allow to deduce the behavior of the optimal thinning with respect to the risk. Finally we illustrate and confirm the obtained conjectures by considering a beech stand.

2. In absence of storm risk

We first consider a forest stand in the absence of storm risk. The analysis of this case will allow us to give the notations and to define a benchmark management of the stand, useful for comparison with the more complex case in presence of storm risk.

2.1. The Faustmann Value

For a cutting age T, a discount rate δ, the Faustmann Value J_0 taking into account thinning incomes (up to the constant cost of regeneration c_1) of a stand is the discounted value of cutting incomes minus cost of regeneration c_1:

$$J_0 = \sum_{i=1}^{+\infty}(W(0,T)-c_1)e^{-i\delta T} = \frac{(W(0,T)-c_1)e^{-\delta T}}{1-e^{-\delta T}} = \frac{W(0,T)-c_1}{e^{\delta T}-1} \quad (1)$$

where $W(0,T)$ is the total income on $[0,T]$ composed of the sum of thinning incomes summed on $[0,T]$ actualized at time T and the final income.

We express the thinning income and the final income. Let N the number of thinning dates, let the thinning dates $(u_k)_{k=1..N}$ such that $0 < u_1 < u_2 < .. < u_N < T$ and h_k the vector of the corresponding rate of thinnings at these dates. Let a timber price reference p_0, which can depend on the economic conditions, $R(p_0,t)$ the vector of potential income at time t. We denote $R_k = R(p_0,u_k)$. Hence $\mathcal{H}_0(t_1,t_2)$ the thinning income on period $[t_1,t_2]$ actualized to time t_2 is given by: $\mathcal{H}_0(t_1,t_2) = \sum_{t_1 < u_k \le t_2}^{N} {}^{\mathbf{t}}\mathbf{R_k}.\mathbf{h_k}e^{\delta(t_2-u_k)}$ and the final income: $V(T) = {}^{\mathbf{t}}\mathbf{R}(\mathbf{p_0},\mathbf{T}).1$. Thus the total income is:

$$W(0,T) = \mathcal{H}_0(0,T) + V(T) = \sum_{k=1}^{N} {}^{\mathbf{t}}\mathbf{R_k}.\mathbf{h_k}e^{\delta(T-u_k)} + V(T). \quad (2)$$

The expression of income $R(p_0,t)$ depends on the type of the model chosen for forest growth: $R(p_0,t)$. For a stand model Clark (1976) or an average tree model, h_k is reduced to scalar. For a size-structured model or a tree-individualized model, the components of h_k are related to the tree-sizes, classically the tree-basal area. We assume that income R is linear in its first argument.

2.2. The Long Run Average Yield

The Long-Run Average Yield is defined by the ratio of the averaged net economic return (stumpage minus regeneration cost) and the cutting age:

$$\overline{Y}_0 = \frac{W_0(0,T)-c_1}{T} \quad \text{wher} \quad W_0(0,T) = \sum_{k=1}^{N} {}^{\mathbf{t}}\mathbf{R_k}.\mathbf{h_k} + V(T). \quad (3)$$

2.3. Maximization of the Faustmann Value

We consider the maximization of the Faustmann Value with respect to thinnings and cutting age: $\max_{(h_k)_k,(u_k)_k,T} J_0$. For fixed cutting age T, the maximization of the Faustmann Value J_0 is equivalent to the maximization of $W(0,T)$. Hence the maximization with respect to thinnings and cutting age can be decomposed into two levels: $\max_T [W^*(0,T)-c_1]/\left(e^{\delta T}-1\right)$ where $W^*(0,T)$ is the maximum of $W(0,T)$ with respect to thinnings: $\max_{(h_k)_k,(u_k)_k} W(0,T)$.

For a fixed cutting age T, the behavior of the coefficient relative to the thinning income $\beta^k_{\delta,0} = e^{\delta(T-u_k)}$ in the income $W(0,T)$ be studied in order to deduce the influence of the discount rate in terms of optimal thinnings.

2.3.1. Dependence of optimal thinning with respect to the discount rate

The derivative of $\beta^k_{\delta,0}$ with respect to the discount rate δ normalized by $\beta^k_{0,0}$ is:

$$\frac{1}{\beta^k_{0,0}}\frac{\partial \beta^k_{\delta,0}}{\partial \delta}|_{\delta=0} = T-u_k \quad (4)$$

We deduce that the relative additional contribution of $\beta^k_{\delta,0}$ decreases as k increases. Hence for a fixed cutting age T, the greater the discount rate δ, the earlier the optimal thinnings. Moreover, the optimal cutting age decreases with respect to the discount rate (Appendix A). Hence, also for the optimal cutting age, by considering a fixed final tree-density and a fixed number of thinning dates (only thinning dates can be changed), the greater the discount rate δ, the earlier the optimal thinnings.

This result is not surprising and well known: the greater the discount rate, the lower the actualized income for the last thinnings. In earlier works such as in Brodie et al. (1978), a similar result has been checked by simulation for specific Douglas stand. In contrast to this study, the obtained result is generic and does not depend on the forest growth.

3. In the presence of storm risk

In order to deduce the behavior of a forest in presence of storm risk, we present the risk model, then obtain analytical expressions of the