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The Faustmann model under storm risk and price uncertainty: A case study of European beech in Northwestern France

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ABSTRACT

International, economic and environmental contexts in this century are strongly affected by risks and uncertainties. Due to the long-term nature of forest investment, forest managers must integrate risks and uncertainties into their decisions. Our objective is to build a decision support tool to optimize forest management under multiple risks: extreme events and price variations. Our method integrates, into an economic model, different types of models on forest growth, price functions, predicted storm intensity and intervals, and damage functions. A numerical simulation applied to European beech (*Fagus sylvatica*) in Northwestern France shows that price variation as between 1974 and 2016 produces higher economic loss than does storm damage. We conclude on the need to concentrate forest policy on the development of new technologies and wood industry practices to increase the value of this natural resource. However, future climate change may well influence storm frequency and intensity, and this places limits on our conclusions.

1. Introduction

French forest managers are deeply concerned by storm risks and price variations. For example, a recent national survey mentioned that storms are one the risks most feared by French private forest managers (RESOFOP, 2011). Their fears are justified by the number of significant storms experienced during this century. Gardiner et al. (2013) counted 130 storms over the last sixty years in Europe, that is an average of two per year. In particular, the storm Klaus in January 2009 induced an average cost of 1.5 billion euros on maritime pine in the South-West of France and damage from Lothar and Martin in December 1999 was estimated at about 6 billion euros for the whole of France (Peyron et al., 2009).

European beech (*Fagus sylvatica*) represents 9% of the total forest surface in France (IGN, 2016) and is the second hardwood species after oak. A decrease in timber prices for this species has heavily affected the entire French forest sector over the last 20 years, but the *Office National des Forêts* (ONF), which manages public forests in France, has especially suffered. Beech sales represented approximately 25.5% of the ONF annual turnover in 1999 when beech prices were high against 12% in 2015; this equates to a total accumulated loss of approximately one billion euros during the last sixteen years and an annual average loss of 62 million euros (Rakotoarison, 2016).

Faustmann (1849) proposed a simple deterministic economic model for evaluating the Land Expectation Value (LEV) over an infinite sequence of rotation. One of the fundamental assumptions of this model is that timber prices are constant over time and known with certainty. Costs and volume production are also considered to be fixed and without risk. This model makes it possible to calculate the optimal rotation age but does not treat the two above-mentioned concerns: fluctuating prices and natural risk. Reed (1984) introduced fire risk (into the equation) for optimal forest rotation and showed that taking risk into account is equivalent to increasing the discount rate. In Reed (1984), the tree damage is not modelled and thinnings are not considered. In the case of a storm, its occurrence depends on a probability density function but the intensity of damage is closely linked with the stand characteristics such as height and diameter (Loisel, 2014). Susaeta et al. (2016) explored the impact of an increasing wildfire risk probability but this generalized Reed model would require information about both current and all future timber crops.

Concerning timber price, previous economic research has shown that it is an extremely variable parameter. The sources of this considerable variation in timber price have already been identified: time and space (Mitlin, 1987; Valsta, 1994), variations in supply and demand (Caurla et al., 2010), climatic policies (Buongiorno et al., 2011; Lecocq et al., 2011) and wood quality and characteristics (Cavaignac et al., 2006; Heshmatol Vaezin et al., 2008). However, several researchers have

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examined the effects of price uncertainty within the framework of a forest economic model like Faustmann's. From our point of view, timber price variation merits deeper research because it determines the profitability of forest management and is the main incentive to convince forest managers to reinvest in silviculture. Studying multiple risks inside economic models can also provide realistic assumptions concerning the value of adaptive policies in a context of climate change. As shown by Guo and Costello (2013), timber price variation is one of the most sensitive parameters when comparing climatic adaptation strategies such as reducing rotation age or changing species.

In the present work, our objective is to integrate multiple risks into the Faustmann model. In the first section, we review the literature focused on price uncertainty inside forest economic models similar to Faustmann's. In the second section, we present different models and the data we used to calculate the optimal Faustmann rotation with risks: economic criteria, storm risks, a storm damage function, price models and a growth model. In the third section, an empirical simulation on beech stands in northwestern France is presented in order to compare the situation with and without risks in two different conjunctures: high price values and low price values for beech. Finally, we discuss our results in terms of current forest management policies.

2. Review of the literature on price uncertainty

Due to some economic and political shocks experienced by the forest sector, some authors have begun to extend Faustmann's deterministic model in order to include the impact of price uncertainty. In this section, we review the models in each of three methodological families. We will see that conclusions diverge.

2.1. Discrete-time price processes

These models are based on the assumption that, due to price uncertainty, the best forest management strategy is to adapt harvesting decisions depending on the current price market. Results of optimization concern not only the LEV and the final rotation age but also a threshold price below which the forest manager decides to postpone the final harvest. This is known as the *Reservation Price Strategy* (RPS) or the "*flexible harvest policy*". Bhattacharyya and Snyder (1987) and Lohmander (1987) were among the first economists to integrate price uncertainty into the Faustmann model. They calculated two probabilities: the probability of a fixed price occurring year after year and the probability that a standing forest will survive from one year to the next. The first probability was calculated from price data. Survival probability depended on the price probability of the previous period and the reservation price was calculated by using a recursive simulation. Brazee and Mendelsohn (1988) conducted numerical simulations by using historical prices for Lobolly pine between 1970 and 1979 and Douglas fir between 1975 and 1984 in the US. They established that the reservation price decreases with standing age as forest growth slows down over time. They also found that the use of RPS increases forest value and optimal rotation age compared to the deterministic Faustmann model. Forboseh et al. (1996) pointed out that separately considering the reservation price of sawtimber and pulpwood can give the forest manager more flexibility. They noticed that variations in pulpwood prices had a more significant effect on the LEV than variations in sawtimber prices. Reeves and Haight (2000) found that a second-order autoregressive model was significant for monthly sawtimber prices and a first-order autoregressive model for monthly pulpwood prices. They showed that price uncertainty induces important effects on income and rotation age. Lu and Gong (2005) used the RPS with a discrete growth forest model which included thinning. In simulations for Scots pine in Northern Sweden, their results agreed with the majority of the previous RPS results: i.e. that incorporating flexibility due to price uncertainty increases the economic benefits. They pointed out the importance of taking thinning into account in the economic model. Lohmander (2007) argued that the RPS is particularly helpful to obey the constraints faced in the actively changing world such as the modification of harvesting capacity or the climate changes.

The RPS models create a net gain in LEV of between 8% and 80% depending on tree species, site quality, discount rate and degree of uncertainty (Gong and Löfgren, 2007). However, these models were criticized by Gong and Löfgren (2007) who showed that the RPS has a tendency to reduce the timber supply and is only correct for short-run price variations. In the long term, this strategy generally has a low impact on forest NPV (Net Present Value: present value of an investment's expected cash inflow minus the cost of acquiring the investment) and no influence on consumer surplus. Another drawback of the RPS is that analytical causes and the process of timber price variation are not clearly analyzed and then, solutions for forest managers are difficult to characterize.

2.2. Continuous-time price processes

With these models, temporal variations in price are broken down into a continuous trend, a structural change and a random variation. The main difference compared with the RPS models is that timber price is assumed to be exogenous to the decision to harvest. Different functional forms are used in the literature.

The Wiener process or the geometric Brownian motion (GBM) is a common continuous-time price process to describe the dynamics of timber price. In this model, variations in price are broken down into two components: i) the trend, or drift rate, which describes the long-term change in price; and ii) an instantaneous deviation which follows a geometric Brownian motion. There are different extensions of this functional form. Thomson (1992) used a binomial probability for price and showed that the optimal rotation age increases compared with deterministic models. However, with low prices, he condoned converting land to another activity, and in that case, the optimal harvesting age is reduced. In Japan, Yoshimoto and Shoji (1998) and Yoshimoto (2002) used a Bernouilli probability for *Pinus densiflora*, *Cryptomeria japonica* and *Chamaecyparis obtuse* whose prices decreased between 1975 and 1998. They found that the optimal rotation age was delayed when the price level was crucially low. Navarrete (2012) analyzed the simultaneous impact of a diffusion process on stock and price functions for *Pinus radiata* in Chile between 1985 and 2007. He showed that price drift rate can be assimilated to a decrease in the discount rate if the price drifts upwards. His results also revealed that price and wood stock volatility significantly increases physical stock but seems to have little influence on NPV and LEV compared with deterministic models.

The main advantage of using continuous-time price process model is linked to the possibility to completely characterize the optimal harvesting policy as a function of the discount rate and the drift of the price process. Lohmander (2007) remarked however that these models are not relevant for forest sector as they are based on an assumption that price dynamics will definitely follow the same process over the rotation, ignoring the presence of economic, biological or climate shocks.

Other authors used price process models with fixed growth rates and structural changes whichare intermediate between discrete and continuous-time models. Newman et al. (1985) found that an exponentially increasing price model induced a 1% to 3% increase in the optimal rotation age compared with the Faustmann model. Sandhu and Phillips (1991) showed that there are three types of changes in price: i) an exponentially increasing price such as Newman et al. (1985); ii) a progressive change with tree age but without any structural change under elastic demand; and iii) a progressive change with tree age mixed with a structural change under inelastic demand. They concluded that in both the first and second types, optimal rotation age decreases while it increases in the third type, when compared to the Faustmann model.