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Forest land value and rotation with an alternative land use

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ABSTRACT

We solve Faustmann's problem when the land manager plans to switch from the current tree species to some alternative species or land use. Such situations occur when the value of the alternative increases relative to the value of the species currently in place. The paper characterizes the land value function and the optimum rotations, highlighting the differences between this non-autonomous problem and the traditional Faustmann problem. We show that, from one harvest to the next until the switch, rotations can be constant and equal to the Faustmann rotation, or increasingly higher than the Faustmann rotation, or decreasingly lower. In the last two situations, the higher the number of previous harvests of the currently planted species before the switch to the alternative use, the closer the last rotation is to the Faustmann rotation.

1 Introduction

Optimal timber harvesting received great attention in forest management. Under the assumption of constant timber prices (Faustmann, 1849), the optimal harvesting age of an even-aged trees is obtained by comparing the net marginal benefits from letting timber grow further, to the opportunity cost of currently planted trees plus the opportunity cost of the land, itself determined by the optimization of all future harvest decisions. Faustmann's original problem has been refined and generalized in many ways to include for instance a rising timber price (Newman et al., 1985), a constrained harvest rate (Heaps and Neher, 1979), non-timber benefits (Hartman, 1976; Strang, 1983) and stochastic timber prices (e.g. Brazee and Mendelsohn, 1988; Clarke and Reed, 1989; Thomson, 1992; Reed, 1993; Willassen, 1998; Insley, 2002). Over time, applications have been extended to include more and more problems, such as differentiated timber prices (Forboseh et al., 1996), uneven-aged management (Haight, 1990; Chang and Gadow, 2010), multi-species stands under changing growth conditions caused by climate change (Jacobsen and Thorsen, 2003), the value of carbon storage (Ekholm, 2016), and many others referred to in Amacher et al. (2009).

When alternative species were considered in the literature, the future land value was treated as exogenous, independent of the current choice. For instance, Thorsen (1999) analyses the choice of tree species for afforestation as a real option problem, and Thorsen and Malchow-Møller (2003) extend it to a two-option problem with two mutually exclusive options (two tree species), where exercising one option implies losing the other irreversibly. With uncertain timber prices, Jacobsen (2007) goes one step further: upon harvest, the current stand (of spruce) may be allowed to regenerate naturally and costlessly, or may be replaced indefinitely with oaks at some cost. Jacobsen studies the optimum harvest age: it is not certain whether it is higher or lower than Faustmann's rotation.

In this paper, we reconsider the original Faustmann problem while assuming the availability of an alternative land use which is forestry with a different species or non forestry one such as agriculture, residential use, conservation, etc. We assume that the alternative use will become certainly more attractive than the current forestry use in such a way that a switch to the alternative use will become desirable at some time in the future. Thus, the land optimum management is not a time autonomous problem and has a solution notably different from that of the original Faustmann problem.

Prices are assumed known with certainty and increase at constant rates that may be non negative or negative, but are lower than the discount rate. Timber prices rising at a strictly positive rate were analyzed by Lyon (1981) who justified them on the ground that there is a mining dimension to forest exploitation, but that

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rising scarcity is moderated by the renewability of the resource. More to the point, at a disaggregated level, the prices of various timber species relative to other species or relative to alternative land uses may evolve differently because of differences in demand or, e.g., of their different abilities to sequester carbon (Sohngen and Mendelsohn, 1998). This implies that a switch from one species to the alternative species or land use may be desirable at some point in time while other features of Faustmann's model remain valid.

In these circumstances, that is to say when the current species is to be replaced by an alternative in the future, it turns out that the rotations of the current species, and therefore the land value, are considerably modified. Under the assumptions used, the nature of the alternative – alternative species or non forestry alternative use – does not change the implications on the choice of the rotation for the tree species in place. Hence for simplicity we will mostly refer to alternative tree species in the sequel.

Newman et al. (1985) find that, when regeneration costs are absent and the price evolves at constant rate, the rotation is also independent of the price level and constant from one harvest to the next; this constant rotation is higher, the higher the rate of price change. As a result, this model is the perfect laboratory to study the effect on rotation of a future switch to an alternative species as the optimum rotations with two alternative species then only needs to be compared with the single value that arises if only one species is available to populate the forest lot.[1]

We find that the optimal harvest age is not generally constant from one harvest to the next if a switch is to occur in the future. It is modified from harvest to harvest to take advantage of the change in the relative price of the two alternative species over time. A similar phenomenon was identified by numerical methods in a single species context by Newman et al. (1985), to whom we also owe some of the analytical apparatus used and adapted to the case of two species in this paper. The solution can be described in the two-dimensional space of tree age and relative species price. In that space there exists a "non maturity" or waiting region delimited by an upper age boundary: given some relative price, one should harvest if the age of the trees equals or exceeds the upper boundary.

Furthermore, over some range of relative prices, there also exists a lower boundary to the waiting region: if the age of the trees is higher than the boundary, it is optimal to allow them to grow until they reach maturity (the upper boundary); but if the age of the trees is lower than the lower boundary, they should be cut and the alternative species should be adopted immediately. However, this lower boundary cannot be reached as the continuation of an optimal exploitation program. While this paper characterizes the solution of the repeated harvesting problem for any initial prices and tree ages, we will emphasize economically meaningful solutions by later assuming that the land is initially bare, so that the initial planting decision needs to be rational.

When the land is bare, there is a critical relative price at which the investor would be indifferent between planting either species. Surprisingly, we show that, in an optimal sequence of harvests, that price never coincides with a harvest, let alone with the switch from one species to the next. If the optimal sequence is such that one species is to be replaced by the other at some date, the former will be last established at a price strictly below the critical indifference price, and the alternative species will first be established at a price strictly higher than the indifference price. In other words, if an optimal program has been followed before the relative price reaches the critical level, the land is not bare when this price is reached and the existing trees are to be allowed to grow further to reach financial maturity. Similarly, if timber producing land is to be reallocated to some alternative use, the switch should occur later, that is at a higher value of the alternative use, than if the land were bare.

The upper boundary is different when it leads to reestablishing the same species than when it leads to a switch. We call "replanting boundary" and "switching boundary" these alternative forms of the upper boundary. The replanting boundary applies when the relative price is below the critical level.[2] It is composed of a succession of segments giving the optimal harvest age as function of the price of the species to be adopted last relative to the price of the species in place. Each of these functions first decreases and then increases, forming a sequence of downward followed by upward sloping segments. Each downward segment indicates the optimal harvest age corresponding to a particular number of remaining harvests until the switch to the last species. Upward segments are not reached by any optimal sequence of relative-price tree-age pair; they indicates the age below which it is worth allowing a tree to reach maturity rather than cut it, given the relative price. The downward sloping segments start at an optimal harvest age above the Faustmann rotation and end below it. The upward sloping segments ensure the continuity of the forest value as a function of the relative price despite the decreasing number of further harvests of the initial species. The lower the number of remaining harvests of the initial species before the switch is, the higher the age difference spanned by the upward sloping segments is.

Another finding is that, before the switch, harvest ages from one harvest to the next are constant, or increasing, or decreasing; if constant, they remain equal to the Fautsmann rotation; if increasing, they are always higher than the Faustmann rotation; if decreasing, they are always lower than the Faustmann age.

The general setting and assumptions are introduced in Section 2. In Section 3, we extend Faustmann's framework to consider the availability of an alternative tree species or land use. After harvesting, the land may be planted with anyone of the two available tree species or converted to some other use. The forest manager must decide at what age the trees of the current stand must be cut, and whether they should be replaced with trees of the same species or whether the alternative species or use should be adopted. Some properties of the decision rules and the land and stand value functions are derived analytically and presented in a number of propositions. A numerical example complete the analysis and helps with its interpretation. Section 5 concludes.

2 General setting and assumptions

We study the decision of a forest manager to establish one or the other of two alternative tree species P and P' on a plot of bare land. We assume that the timber price of species P (respectively P') changes over time t at the instantaneous rate μ (respectively μ') as in the one-species model of Newman et al. (1985):

$$p_t = p_0 e^{\mu t}, \tag{1a}$$

$$p'_t = p'_0 e^{\mu' t}. \tag{1b}$$

Newman at al. justify their assumption on empirical grounds, rightly arguing that 'Timber is unique among natural resources in that its price shows a long-term increasing trend relative to the price of other goods.' While explanations for this empirical regularity may have been refined, the same regularity is still observed

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[1] Chang (1998) has proposed a generalized version of Faustmann's formula that applies when stumpage prices and costs are arbitrary known functions of time. The effect of a single future switch on Chang's generalized rotation would obey the same rationale. However it would be more difficult, and not very economically enriching, to determine conditions on the time path of the alternative species relative to that of the current species justifying one and only one switch. Clearly the real world entails a myriad of possibilities for repeated switches but the intuition provided by our simplified framework would be lost if we attempted a general treatment.

[2] Without loss of generality one can define the relative price such that it is rising.