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Asset retirement with infinitely repeated alternative replacements: Harvest age and species choice in forestry

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ABSTRACT

At what age should productive assets be retired? How should replacements be chosen when they differ in their uncertain ability to generate future incomes? As a particular version of that problem, we study the tree harvesting decision with two possible replacement species whose values as timber are stochastic and whose growth functions are deterministic. In the single-rotation (Wicksell) problem starting with a bare piece of land (an empty shop), it is optimal to choose and plant one species immediately if its current value is sufficiently high relative to that of the other species (the alternative equipment). However, if the species are insufficiently price-differentiated, it is preferable to leave the land vacant (the shop empty) despite the opportunity cost of doing so. In the repeated version of the problem, it is never optimal to leave the land bare provided the cost of replacement is null. Furthermore, the optimal harvest (tree retirement) age not only depends on the price and current productivity of the trees in place but also on the price and productivity of the other species, because it may replace the current one. The harvest age reaches a peak at some critical threshold of the relative price that signals the necessity to switch to the alternative species; indeed this is when the opportunity cost of choosing one alternative replacement over the other is the highest. The land value (and also the value of the firm) is similar to an American option with free boundary, infinite expiry period, and endogenous payoff. The paper highlights the opportunity cost of alternative replacement options, and the central role of their volatility in both asset-retirement and replacement-choice decisions. All results are derived analytically; a numerical treatment by the penalty method completes the resolution.

1. Introduction

At what age should current productive assets be retired when alternative replacements exist that differ in their uncertain ability to generate future incomes? To focus on the opportunity cost of choosing between alternatives, this paper assumes the direct cost of replacement to be zero so that either choice of replacement is economically desirable in the absence of alternative. However choosing one option over the other may prove to be a mistake *ex post* if the latter turns out to be more

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profitable. Retirement and adoption decisions must keep the risk of making such mistakes reasonably low. Applying the proper decision rule for current and future decisions will maximize firm value or rent.

Our paper addresses these questions by focusing on extensions of the conventional forestry economics model. This archetypal investment problem has played a central role in the development of economic investment theory and is associated with famous figures such as Jevons, Wicksell or Von Thunen. As Samuelson (1976) pointed out not without cruelty, early and more recent work on that model provided the economic profession with ample opportunities to learn from the mistakes of such brilliant economists as Irving Fisher, Harold Hotelling, or Kenneth Boulding while pondering on the contribution of the accounting profession to economics (see Amacher, 2015). Economists had erred by failing to recognize that occupying land imparts an opportunity cost to delaying harvest.

In the infinite horizon version of our extended model, trees are the equipment of the forest firm, whose capital also includes the forest land, of endogenous value. Existing trees are 'retired' by harvesting at an optimally chosen age and two alternative species may be planted to replace them. These replacements may differ in their ability to generate future income and their current price conveys information on the value of future harvests. Leaving the land bare for any amount of time and mixing species for diversification are possible. This entails more sophisticated harvesting (or retirement) and replacement decisions than had been considered before. In particular the importance as opportunity cost of an alternative replacement option is clarified and the central role of its volatility in both asset-retirement and replacement-adoption decisions is brought to light.

Forest management involves time, uncertainty, and irreversible decisions with consequences in the future. It also exemplifies investments that open up new options: harvesting a tree opens the option of planting a new one or using the land differently. Faustmann (1849) gave forestry economics its foundations by addressing the question: at what age should a stand of even-aged trees be harvested? He did so under the assumption of a known constant timber price by comparing the net marginal benefits from letting timber grow further, to the opportunity cost of existing trees plus the opportunity cost of occupying the land, itself a function of timber management decisions.

Faustmann's original problem has been refined and generalized in many ways. In this paper we focus on the availability of alternative species or land uses to replace the trees being harvested. We show how this choice should be made and timed, how it affects the harvesting decision, and how it ultimately determines the value of the firm.

While species choice or land use is clearly important for the forester, that question has much wider relevance and may be viewed as illustrating the resolution of a general investment problem. The question of choosing a harvest age is akin to that of deciding at what age an equipment should be retired; the declining rate of growth of trees is akin to the declining productivity of equipment with usage or obsolescence. The species choice is similar to the choice of alternative technologies or alternative activities for replacing the retired equipment, where the timber price may also represent the ability of alternatives to generate income. Thus we introduce alternative assets in situations where decisions open up new options in a process that repeats itself indefinitely, and must be reevaluated at each instant. The options to be considered remain available forever and include reinstalling a new version of the asset currently in place or adopt the alternative one. This most common practical situation has not been fully investigated theoretically before, although the real option literature, the forestry, and the asset replacement literature have gone some way toward solving related problems.[1] As will become apparent from a brief review of the relevant literature and from the description of our results, we combine and complement these strands of work in a simplified model that brings out clear and intuitive results and decision rules.

The real option approach has been widely applied in natural resource exploitation and management. In the real option framework, a typical investment involves an optimum stopping rule that defines the date at which conditions have become favorable enough to justify committing resources toward a project irreversibly. A typical result is that more uncertainty postpones investment although it increases asset value.

Applying this approach, a number of studies (e.g. Brazee and Mendelsohn, 1988; Clarke and Reed, 1989; Reed and Clarke, 1990; Thomson, 1992) examine the optimal harvesting age in forestry under stochastic timber price.[2] These studies show that when timber price or stand value follow a Brownian motion and regeneration costs are absent, the optimal harvest age is insensitive to price despite the fact that the price is not assumed constant as in the deterministic case. However, when regeneration costs are present, the choice of the harvest age can be improved by exploiting the stochasticity of the price, which provides an opportunity to delay regeneration costs until future prices are observed. Platinga (1998) shows that the option value to delay harvest when timber prices are stationary stems both from the level of the current stumpage price relative to its long-term mean and from the stand value relative to the fixed regeneration cost. Over time, applications have been extended to include more and more features, such as differentiated timber prices (Forboseh et al., 1996), a variety of price processes (Alvarez and Koskela, 2007), uneven-aged management (Haight, 1990), multi-species stands under changing growth conditions (Jacobsen and Thorsen, 2003), stochastic discount rate (Alvarez and Koskela, 2005), endogenous forest area (Sahashi, 2002), the value of carbon storage (Ekholm, 2015), and many others referred to in Amacher et al. (2009).

The real option literature has treated situations where a one-shot action simultaneously involves the timing of an investment and choosing between alternative opportunities. These alternative opportunities may differ with respect to

[1] Although the possibility of abandoning timber production for some alternative forest use or activity such as agriculture or housing is frequently envisaged, we are aware only of cases where the switch is considered irreversible.

[2] Willassen (1998) dismisses the optimal stopping methodology and uses impulse control.