NORMAL FOREST STRUCTURES AND THE COSTS OF AGE-CLASS TRANSFORMATION

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Abstract

It is sometimes suggested that, because transformation of uneven-aged stands into an even-aged structure reduces profit, even-aged stands should be transformed to uneven-aged structure. The argument is false, because transformation in *either* direction incurs opportunity costs of felling trees before and/or after their optimal rotations. This effect can be demonstrated, without the complicating factors of interaction between trees in a stand, by modelling transformations and reverse transformations between an even-aged *forest* and a forest containing a normal age-class series of *even-aged stands*. The current age-class structure affects what age-class structure it is best to create by transformation. Optimising the transformation strategy shows that, *at best*, transformation of the existing structure is expensive. Transformation of even-aged to uneven-aged *stands* must rely on some other justifications.

We need to check how much of this is done previously, e.g. in Tahvonen (2004) mentioned in Viitala (2006), and in Faustmann's classic, p.32 ff in JFE: "This hypothetical form of husbandry, though it accords with sound forestry principles, is clearly less advantageous than intermittent management because a large part of the area must remain unused in the first rotation. Actually the calculation also gives a smaller land value." (p.33).

Introduction

The benefits and disadvantages of even- and uneven-aged forest stands, and of the best means of transforming between those conditions, have recently been much in debate in European and even world forestry. All too often, however, the discussion has been based on anecdote, impression or even prejudice, and economists have been less commonly consulted than might have been helpful to objective appraisal.

Two years ago Pukkala et al. (2010) provided a welcome, dispassionate comparison of regimes, centred effectively on the question: "which structure of uneven-sized forest stand would I least wish to clear fell and transform to even-aged"? This is a practical matter, given that forest owners sometimes need to raise cash quickly, and it is difficult to decide intuitively which stand can most readily be sacrificed to meet such a requirement.

Their paper is based on a complex model of tree interaction within a mixed-age or -size stand. But apart from these biological matters there is also a crucial economic issue: clearing a mixed-age or -size stand inevitably means felling some trees either before, or after individual trees' optimal rotation, or sometimes both.

This paper abstracts from the issue of tree interaction, and focuses on this matter of deviating from the optimal felling age. It does so by referring to a forest consisting all of one age-class, compared with a normal forest in which all age classes up to the final felling age are represented in even-aged stands, each of equal area. It addresses further questions, about the optimal transformation between age-class structures within the forest, which may help to identify which are the important factors in economic transformation, whether the stands composing a forest are even- or uneven-aged.

Optimising a normal series of even-aged stands

The model presents a forest consisting of a normal series of age-classes in which one stand is to be felled and regenerated each year. Normality might be sought at various scales: at small scale for recreation or landscape reasons; at medium scale for biodiversity reasons; at ownership scale for employment, timber supply or cash flow reasons. For the purposes of this model, what matters is that there is a regular series of age-classes. Initially, however, it is assumed that the forest is of sufficient size, that there is no loss of scale economy by division into age-classes. (Very little difference in economic outcome of the model would arise if stands were aggregated into, say, five-year age classes that were felled in one coupe so as to achieve scale economies.) To maintain comparability between treatments, NPV figures are given per hectare, averaged over the entire forest area.

For simplicity, only regeneration cost (€1500/ha) and final felling revenue (time-dependent, but with an asymptotic maximum of €30 000/ha) are considered. There are no day-to-day management costs (which should not much affect choice of regime anyway), and no thinning revenues (an initial wide spacing might be assumed, and some natural mortality). Nor are other benefits and costs which vary with stand age considered. These are all subjects of great current interest and discussion among forest economists, and there is no implication that they would not affect rotation or social value of forestry: in particular, values of carbon fluxes are of crucial importance, though having surprisingly small effect on optimal rotation (Price, 2011). However, they would not be expected greatly to change the *relative* results given below. A base discount rate of 3% is used, in line with that commonly used among European forest economists, and advocated (with modifications that need not concern us) by the UK Treasury (undated). This is sometimes varied for exploratory purposes.

Some questions and answers

(a) "What, starting from scratch, is the optimal forest rotation?"

This question, which has preoccupied forest economists throughout the existence of the profession, was answered in its basic form by the work of Martin Faustmann (1849). Since then there have been endless variants on the circumstances treated: there is a periodic Faustmann symposium at which upwards of 50 papers are presented, and before and in between there has flowed a steady stream of papers (see Newman, 2002 for a review).

Credit for the evolution of Faustmann's solution has been differently attributed (Samuelson, 1976; Viitala, 2012), but the correctness of the solution, which maximises the NPV of a perpetual series of rotations, has not been seriously disputed. For compactness, the NPV of a perpetual series of rotations will hereinafter be referred to as the land expectation value (LEV).

$$\text{LEV} = \frac{-C + V_T \times e^{-\rho T}}{1 - e^{-\rho T}}$$

where C = regeneration cost, V_T is final felling revenue at age T, and ρ is the discount rate in continuous format. (The results arising are not different from those derived from the discontinuous discounting format using $1/(1+r)^T$ as a discount factor, with which UK and other foresters may be more familiar.)

Choosing the rotation which maximises LEV also at first sight would appear to answer the question:

(b) "What <u>normal age-class</u> structure (all else being equal) would I most like to possess?"

In Tait's (1987) construction, the question is: "if a good fairy were to offer you such a structure, what rotation length would you most like, with the constraint that the embedded cutting cycle must be maintained in perpetuity?" (Without this constraint, the optimum tends towards the entire physical growth cycle of the trees, which yields a very large instant liquidation value.) It might well be asked, what is the relevance of this question, in a world more characterised by trolls threatening stochastic misfortune than by good fairies offering unearned bonuses? There are at least three answers. Firstly, the ideal stand structure to own would be one argument in directing forest acquisition, acknowledging that ideal structures would be expected to command a higher price, but also recognising that in the complex field of forest valuation some stands may be underpriced. Secondly, the ideal structure might serve as a target to which the stand might be directed, when opportunities and money are available, if maximum sustainable yield (of profit, or of other measure of good) is the objective. But always we should be aware that later generations could undo our work, by liquidating the ideal structure at times of cash flow crisis. Thirdly, the ideal structure is the limiting case of the most profitable forest, as the discount rate tends to zero, so that the one-off costs of changing the structure become less significant than the perpetual benefits of having the structure. Tait reports that, responding to a questionnaire, forest economists on the whole chose the Faustmann rotation as the most desirable, while silviculturists chose the rotation of maximum forest rent (mean annual net revenue). And, from an economic point of view, the silviculturists were right! *Irrespective of discount rate*, the highest LEV is given by the age class structure that delivers the greatest annual net revenue, as capitalised in the formula:

LEV = [annual net revenue] ÷ [discount rate].

Just how different the answers to (a) and (b) are, is shown in figure 1, which also records the model's revenue profile as the rotation lengthens.

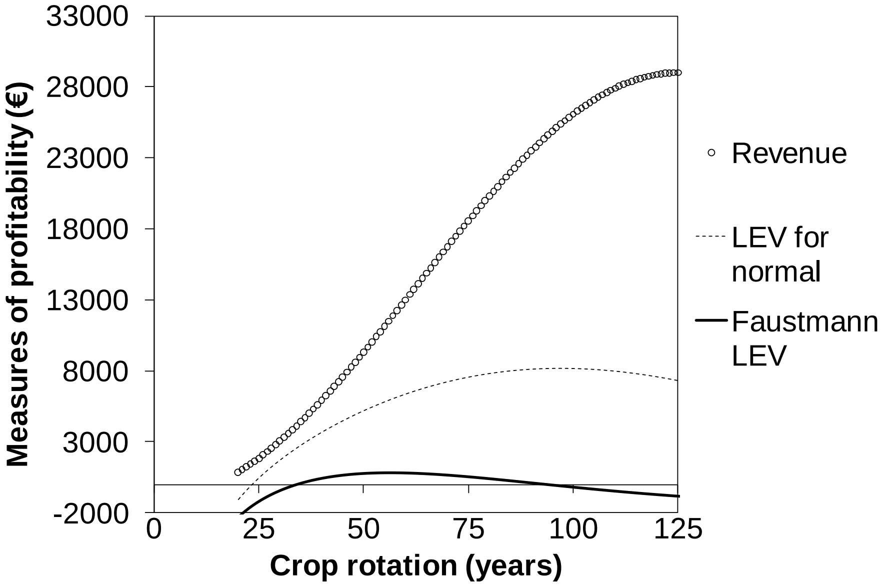

Figure 1: Optimal rotation with even-aged stands

The good fairy answer (= "LEV for normal") is a rotation of 97 years, compared with the Faustmann answer of 56 years. These answers consider only the future net cash flows from the crop, *not* the resource endowment embodied in each age-class structure. This endowment might, according to circumstances, be quantified as immediate liquidation value forgone, or as cost of creating the stand structure. To include this factor, questions (a) and (b) can be re-posed:

(c) *"What normal series of stands would I* <u>*least*</u> *like to sacrifice by liquidating the growing stock value?"* and

(d) *"What normal series of stands would I be* <u>*most*</u> *prepared to sacrifice?"*

(e) *"What normal series of stands would I most like to* <u>*create*</u> *from* <u>*bare land*</u>*?* and …

(f) *"What normal series of stands would I most like to create from an* <u>*established single-aged forest*</u>*?"*

To answer these questions we need to consider the sequences of premature and postmature felling that are entailed for (c), (d) and (f); and, for (e), the sequences of delayed planting.

For (c) and (d), the objective function is specified as follows: minimise (for (c)) or maximise (for (d)) the difference of NPV between:

- continuing to harvest 1/*T* of the forest annually on the given rotation in perpetuity on one hand; and on the other hand
- the liquidation value of felling all the age-classes immediately plus
- the LEV of a replacement even-aged forest.

The optimal replacement rotation, <u>starting from the created bare land</u>, is the Faustmann rotation. Since its LEV is the same irrespective of what it replaces in the existing forest, its value does not affect the least and most desirable crops to sacrifice (but does determine whether it is worth sacrificing them at all). Figure 2 shows the results.

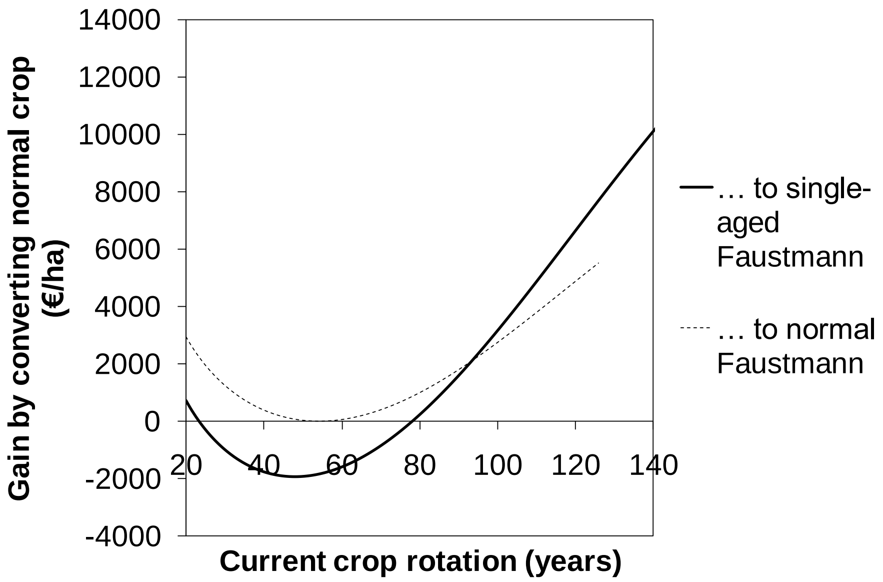

Figure 2: Net advantage in transforming to single-aged and normal Faustmann rotation

The least desirable to convert to a single-aged Faustmann rotation is a normal sequence on a rotation of 49 years. This is shorter than the Faustmann rotation of 56 years: any older and it has better liquidation value, any younger and wasn't very valuable anyway. It is *much* shorter than the "good fairy" rotation of 97 years. It is notable that the "good fairy" rotation lies well within the zone – anything more than 77 years or less than 27 years – in which transformation to a single-aged Faustmann rotation would be preferable to maintaining the current rotation, irrespective of the need to raise money quickly. The optimal "good fairy" strategy is to be given a normal forest with a 97-year rotation (or more), then cheat by felling all crops older than the Faustmann rotation immediately. Rotations shorter than 27 years offer extremely low revenues in perpetuity, even compared with the modest value of the Faustmann rotation, while those of more than 77 years have a high aggregate immediate liquidation value, so all those are worth liquidating immediately. The matter of which is the *most* desirable rotation to transform to a single-aged forest is open-ended: the value of transformation rises indefinitely at both extremes of rotation.

On (c) and (d) there are the following variants: suppose I have a normal forest on something other-than an optimal Faustmann rotation: which will I most wish, and which will I least wish to convert to a normal series on an optimal Faustmann rotation? To answer these requires age-classes to be:

- aggregated into timely coupes (for existing rotations longer than the Faustmann one) or
- split up (for existing shorter rotations).

Alternatively (and this greatly eases the calculations) the inter-felling period can be shortened or lengthened as required. Thus, if the target Faustmann rotation were 50 years, and the current rotation is 100 years, the 99-year and 100-year age classes would be felled in the first year, and so on until the present 1- and 2-year age classes would be felled in the fiftieth year. (Or, the felling cycle would be reduced to six months, and 100 separate coupes would be made.)

If a present forest of normal but not optimal age-class structure is replaced by a normal series on a Faustmann rotation of 56 years, the replacement times are different between different existing rotations, and this affects the rate at which the current crop can be liquidated. In all cases, first harvest is at the end of the first year (it is assumed that the current year's harvest on the mature component has just taken place). To repeat, in order to maintain comparability the figures are calculated as a mean per hectare over the whole forest.

The results, again shown in figure 2, are rather different now that the target of transformation is a normal structure. (Naturally, if the forest already has this structure there is no cost of transformation.) Between a current crop rotation of 49 years and 88 years there is greater gain in converting to a normal series, rather than to a single-aged Faustmann rotation. This is because this transformation can be made gradually, with more crops being felled close to their optimal rotation. Beyond 88 years, it is better to convert to a single-aged Faustmann forest than to a normal series. This is because of the high immediate liquidation value, contrasted with the long delay to the later stages of the transformation to a normal series.

Next, consider question (e): what normal sequence of ages would it be most desirable to create, starting from “bare land” (either land to be afforested, or land which has just been cleared)? The value is that arising from establishing $1/T$ of the forest area each year up to T. The comparator here is leaving the land in an unproductive state. However, planting the entire area as a single-aged forest would give an LEV of €791 LEV on the Faustmann rotation, and this may be compared with values in figure 3.

The best rotation to create is one of 53 years. This is slightly shorter than the Faustmann rotation, because of the desirability of launching a (modestly) profitable crop sooner rather than later: a longer rotation would mean that most stands are significantly delayed in planting. On the other hand a rotation much shorter than that, 35 years, would give no profit at all, so delay is not an issue. The LEV of this strategy is €390, less than the Faustmann LEV, largely because of the delay in bringing the whole area to profit, to a much lesser extent because of the shortening of rotation. The bottom curve shows the *net* gain from creating a normal forest, compared with that of immediately planting a single-aged forest on the same rotation.

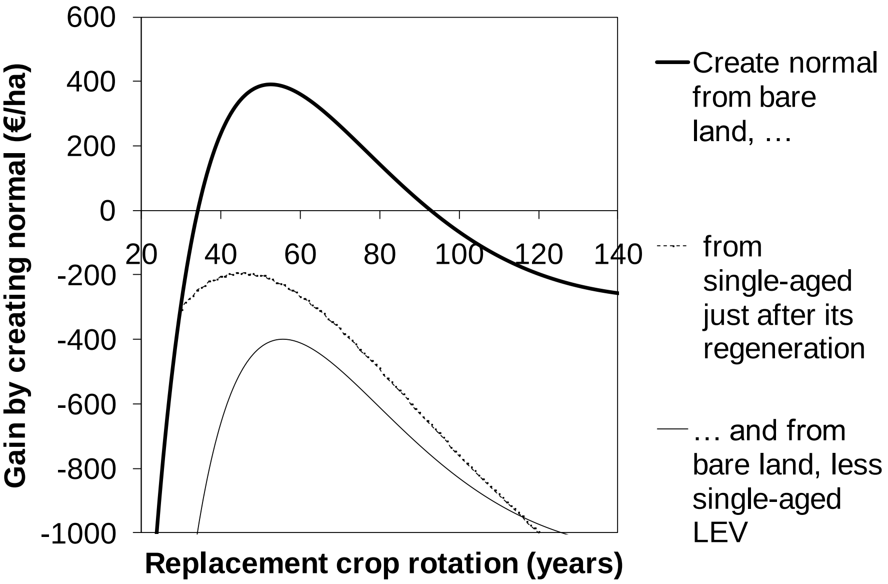

Figure 3: Net advantage in transforming to normal

With a higher discount rate, for example 4%, the advantage of postponing a large proportion of investment in a loss-making crop favours a longer replacement rotation than the Faustmann one. At 4.4% in this case, an indefinitely long replacement rotation is indicated, putting off costs as long as possible. With very low discount rates (0.1%) the optimum rotation to create is more or less the same as the Faustmann rotation, because achieving the highest long-term net income becomes more important than reaching this state quickly. If a negligibly small discount rate is used, all the rotations so far discussed, and to be discussed, converge on the good fairy rotation of 97 years.

(f) *“What normal series of stands would I most like to create from an established single-aged forest?”*

To create a normal sequence of age classes, felling of an existing single-aged forest must be spaced out over whatever period is adopted as the target rotation. Because this requires felling before or after the optimal rotation (usually, both), this must entail loss of medium-term profitability. The least loss is incurred by transforming to a rotation of 44 years (the middle curve in figure 3); the transformation begins at age 33 (earlier or later start times incur greater losses) and ending at age 76. Thus transformation is slightly asymmetrical about the Faustmann rotation of 56 years, because of the shape of the revenue curve. The slightly irregular nature of the curve is due to discontinuous change in the age at which transformation begins. This shorter target rotation occurs because of the advantage of narrowing the window of suboptimality during which untimely felling takes place.

The cost shown is discounted to a time immediately after regeneration of the single-aged crop has taken place. The optimal replacement rotation does not change, but the absolute discounted cost of transforming rises, as the time of initiating transformation comes closer.

Differential cash flows

Up to this point, it has been considered that cash flows per hectare are not different between age-class structures: transformation to or from a normal age-class sequence would take place only because of the need to raise cash quickly by transformation *from* a normal structure, or the perceived non-cash advantages of transforming *to* a normal structure. It is apparent, as expected, that transformation in *either* direction has a cost in terms of reduced NPV. Thus to demonstrate that it is not worth transforming uneven-aged crops to even-aged ones is not a sufficient argument for making the transformation in the opposite direction, from even- to uneven-aged. Such claims are not infrequently found or implied in discussion.

The question therefore arises, what cash flow differential would be needed to justify transformation, in one direction or the other? For example, suppose a relatively intimate mixture of normal stands allowed savings, by utilisation of natural regeneration. This would not be achieved in the initial stage of creating a normal series from bare land or a cleared site, but only when this created structure subsequently regenerated. This long delay to the time of advantage means that, even if subsequent regeneration is costless, creation of a single-aged forest is more lucrative. Only at extremely low discount rates, around 0.1%, does it appear to be worth creating a normal structure in order to have the benefit of free regeneration.

On the other hand, creating a normal structure from a single-aged regenerated forest would bring savings from the time of initiation of transformation. A reduction in regeneration cost from €1500 to €800 per hectare would suffice to make it worthwhile to transform to a normal structure on a rotation of 44 years, beginning transformation at 33 years (supposing a seed source to exist by then) and concluding it at 76 years. The slight shortening of rotation compared with the rotation under full regeneration cost is a standard consequence of reduced costs (Johannson and Löfgren, 1985; Price, 1989), and the earlier initiation of transformation springs from the same cause.

Suppose on the other hand that a normal structure already exist, and that this entails extra costs, for example because of small scale of harvesting coupes. A saving of harvesting costs of €2500 per hectare would just suffice to justify clearance in a single coupe and replacement with a single-aged forest. This is near to the difference in cost between small group felling and clear felling found by Price and Price (2006, 2008), but is unreasonably large for the difference between large- and small-scale clear felling. The result is surprisingly insensitive to discount rate: with a 1% discount rate, a saving of €1800 per hectare is needed to justify converting a normal series on an 80-year optimal rotation to a single-aged stand.

Note that in all the cases treated above, the transformation occurs over one rotation. Less sacrifice is incurred by spreading transformation over more rotations, but then the benefits of normality, whatever they may be, are further delayed.

Conclusions and implications for uneven-aged stand transformation

Optimising the transformation strategy shows that, *at best*, transformation of the existing structure, whatever it is, is usually expensive. The exception is when the rotation of the current crop is seriously suboptimal, a situation from which Knoke and Plusczyk (2001) seem to have claimed an advantage of continuous cover forestry, without considering the alternative of converting to an optimal rotation on a clear felling regime.

Transformation of even-aged to uneven-aged *stands* must rely on some other justifications. Among these are:

- the assortment argument, that by single tree selection a higher proportion of increment can be in the high value classes (Price and Price, 2006);
- the “economic thinning” argument, that transformation can be conducted by removing large trees that are near their *individual* optimal rotation, during late thinning (Price and Price, 2009);
- the “cheap regeneration” argument, as evaluated above;
- the environmental benefits argument – which should however bear in mind that there may also be environmental costs in continuous cover forestry (Price and Price, in prep.).

Whatever the case, the balance of benefits and disadvantages is such, that no reliance can be placed on intuition to balance them. Forest economists have a crucial role to play.

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