Remunerating Conservation:
The Faustmann-Hartman Approach and its Limits

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Abstract

The method introduced by Faustmann and extended by Hartman is used for calculating present values of forestry assetts under various conditions and for determining the optimal rotation. The approach is not stochastic and very simple. The forest benefit contemplated additional to timber is the conservation of biodiversity. It is well established that the redevelopment of old forests including decay stages is by far the most efficient measure to enhance the survival chances of endangered species. For simplicity, it is assumed that the forest's value increases linearly with age. For this case, it is not only easy to calculate the payments necessary to incite the forest owner to delay the time of harvest, but also to give a simple condition for it becoming profitable to abstain from wood harvesting altogether. A numerical simulation is carried out using data from typical Central European beech forests (Fagus sylvatica). Payments and present values capable of persuading owners never to harvest are very high, as compared to conventional income from forestry. Society has to decide on the basis of its value judgements whether or not such payments are warranted. Important problems include liquidity and risk, the choice of an interest rate, forest management costs and the necessity of spatial planning. It is concluded that without financial incentives the perspectives for conservation in forestry are precarious, at least in Germany. On the other hand, a fair remuneration is only one measure and cannot alone solve the problems. It has to be integrated into a bundle of appropriate planning instruments.

1 Introduction

In 1849, MARTIN FAUSTMANN paved the way for the discovery of the optimal forest rotation from a capital-theoretical point of view. His classic approach assumed that lumber production was the only benefit to society derived from forestry. Although this was a reasonable approximation in FAUSTMANN'S epoch, it is definitely no longer the case because other forest functions have gained importance ever since. They are described in a rich literature, ranging from protective functions with regard to soils, climate, water resources to amenity values for recreation and the conservation of biodiversity (see e.g. SHARMA 1992, RAMAKRISHNA & WOODWELL 1993, ADAMOWICZ et al. 1996). Some of the benefits have been monetarised in the literature, notably concerning recreation (WILLIS 1991, KRAMER et al. 1992, ELSASSER 1996). If these benefit streams depend on the forest's age, their inclusion in the economic analysis must affect the optimal rotation. This is so regardless of whether or not the owner receives payments for the benefits - a decision reflecting society's judgement on a just distribution of property rights. If however the owner *does* receive such payments, these will incite him or her to find the rotation period which maximises the economic performance of the forest.

Not until the 1970's these perspectives had raised the interest of scolars, pioneering works include SAMUELSON (1976), HARTMAN (1976), STRANG (1983), BOWES & KRUTILLA (1985, 1989) and others. In the sequel, important contributions extended and refined the relevant concepts and added advanced analytical methods, for instance MITRA & WAN (1985), SNYDER & BHATTACHARYYA (1990), MONTGOMERY & ADAMS (1995) and SWALLOW et al. (1997). The deterministic nature of the Faustmann-Hartman approach with respect to wood prices and amenity values is now considered as its greatest drawback. Both parameters may of course change. For want of knowledge about future prices contemporary models therefore utilise stochastic approaches (THOMSON 1992, REED 1993, PROVENCHER 1995, CONRAD 1997).

Without denying the progress achieved here, the shortcomings of determinism may be less severe than suggested to-day, at least when focussing on Central Europe. Experience shows that although sudden price changes naturally affect short-time decisions of forest owners, long-run tendencies in this region never altered the rotations chosen in a systematic way. Econometric models tell us that substantial price changes in world wood markets are unlikely for decades (SEDJO & LYON 1990). Price changes in the distant future have little effect on current decisions because of heavy discounting. Stochastic models often calculate longer optimal rotations, as compared with deterministic models. Following this rule, the latter may at least provide a lower bound which may be a useful information. As to the valuation of non-wood benefits it seems at present more fruitful to ask what *will be* the consequences of certain valuations *if* they are expressed in the future rather than to attempt their prediction.

Therefore, it appears promising for once to return to the early simple models and rediscover some of their capital-theoretical aspects which received insufficient interest during the last 20 years. Using a simple method, this contribution addresses some straightforward implications of the original Faustmann-Hartman approach including its ambiguities and pitfalls (not remedied by stochastic treatment) which will prove particularly important once attempts are made to apply it in practice. If financial incentives are offered to private forest owners for the provision of benefits other than lumber, it is important to be able to anticipate their probable reaction to such incentives.

The benefit considered in this contribution is conservation. How can forest owners be stimulated to contribute more efficiently to the conservation and redevelopment of biotic diversity? As explained in some detail below, this is tantamount to the question of which financial incentives make it profitable for owners to lengthen the rotation period, possibly to a point of not harvesting lumber altogether in certain types of forests.

2 The Faustmann-Hartman Approach

Let VL(T) be the value of lumber at age T and i the discount rate. Preliminarily neglecting costs, the present value of all lumber cutting operations PVL is obtained by simple series expansion

$$PVL(T)=VL(T)(e^{-iT}+e^{-2iT}+...)=VL(T)(\frac{1}{1-e^{-iT}}-1)=\frac{VL(T)}{e^{iT}-1} \tag{1}$$

Maximization of (1) with respect to T yields what is known as „Faustmann's equation" in the modern literature although his main discovery was (1)(see JOHANSSON & LÖFGREN 1989)

$$\frac{\dot{VL}(T)}{VL(T)}=\frac{i}{1-e^{-iT}} \tag{2}$$

The growth rate of the lumber value $\dot{VL}(T)/VL(T)$ must equal the interest rate i divided by $1-e^{-iT}$. The graphical representation in figure 1 is equally familiar; the intersections of $\dot{VL}/VL$ with members of the curve family $i/(1-e^{-iT})$, each representing a particular interest rate, indicate the respective optimal cutting date T*(i). Naturally, high interest rates demand shorter rotations than lower rates. In practice, VL has to be modelled appropriately, costs have to be considered just as other factors of importance including variable prices and interest rates, risk, liquidity and so forth.

HARTMAN (1976) was the first to straightforwardly extend the original approach such that non-timber benefits are allowed for. Let α(t) be the instantaneous value of an amenity provided by the standing forest at age t. The present value PVA of the amenity stream then amounts to

$$PVA(T)=\int_0^T \alpha(t)e^{-it}dt\,(1+e^{-iT}+e^{-2iT}+\ldots)=\frac{\int_0^T \alpha(t)e^{-it}dt}{1-e^{-iT}} \tag{3}$$

so that the total present value including timber production plus amenity benefits is

$$PVLA(T)=\frac{VL(T)}{e^{iT}-1}+\frac{\int_0^T \alpha(t)e^{-it}dt}{1-e^{-iT}} \tag{4}$$

Maximisation of (4) with respect to T gives the generalized Faustmann-Hartman solution

$$\frac{\dot{V}LA(T)}{VLA(T)}=\frac{i}{1-e^{-iT}}+\frac{i\int_0^T \alpha(t)e^{-it}dt-\alpha(T)(1-e^{-iT})}{VL(T)(1-e^{-iT})} \tag{5}$$

As observed by PRICE (1987), for all monotonously decreasing $\dot{V}LA/VLA$ and all monotonously increasing α(t) the optimal rotation is longer than in (2). Write (5) as

$$\frac{\dot{V}LA(T)}{VLA(T)}=x+\frac{y}{z} \tag{6}$$

and consider y. If α(t) was specified as A > 0, constant, we would have

$$i\int_0^T Ae^{-it}dt=A(1-e^{-iT}) \tag{7}$$

in which case y would be zero and (2) would apply. Understandably, a time-independent A cannot affect the optimal rotation T. Now consider α(t) monotonously increasing with α(T) = A. For all $0<\alpha(t<T)<A$ it must be obviously true that

$$i\int_0^T \alpha(t)e^{-it}dt<i\int_0^T Ae^{-it}dt=A(1-e^{-iT}) \tag{8}$$

so that y must be negative. z being positive throughout, for (5) to hold, $\dot{V}LA/VLA$ must therefore be smaller than $\dot{V}L/VL$ which implies a longer optimal rotation period.

For the special case α(t) = At, A constant, (5) takes the form

$$\frac{\dot{V}LA(T)}{VLA(T)} = \frac{i}{1-e^{-iT}} + \frac{A\left(1-Ti-e^{-iT}\right)}{VL(T)i\left(1-e^{-iT}\right)} \qquad (9)$$

Its graphical representation is shown in figure 2 for a given discount rate. For small values of A the optimal rotation is extended slightly. Increasing A results in two intersections with $\dot{V}LA/VLA$ (only one of which can reflect the „correct" T*), and increasing A further leads to the fact that there is no intersection any longer so that (9) cannot hold for any T (except in the upper left which is economically irrelevant). Of course, this is the most interesting case which seems to imply that upon passing a certain threshold it becomes optimal to refrain from harvesting the wood altogether. The amenity value of the standing forest, increasing with age, becomes so important that it dominates the management and requires to forego the value of the wood harvest.

The expression (9) is flawed by several shortcomings. In figure 2, a minor shift of the curves involved can lead to qualitatively different results because their slopes differ only slightly. Furthermore, the meaning of several intersections in figure 2 is not clear and may require tedious analyses of second order conditions. Finally, some conclusions drawn from figure 2 may be wrong altogether as will become obvious below.

3 Assessing the conservation value of a forest

Biodiversity is an extremely complex notion which is little conducive to exact measurement (WILSON 1988). Paradoxically, at least under present conditions prevailing in Central Europe it is none the less easy to define a forest's value with respect to important conservation issues in qualitative terms. Almost all ecologists will agree that in order to protect biodiversity in Central European forest ecosystems the most effective measure is the redevelopment of *old* forests of indigenous tree species including decay stages (PETERKEN 1996). The biotopes should be large and contiguous such that heterogenous spatial patterns can develop in the long run. Despite their tiny area in most cases, remaining patches of very old forest stands which have escaped logging for several hundred years for some historical reason or another exhibit an amazing richness of plant, animal and fungus species many of which are very rare or absent in managed forests. Among the fungi, numerous species are poorly described taxonomically. The main reason for their absence in managed forests is the deliberate suppression of large-scale wood decomposition due to the harvest of trees in relatively early stages of maturity. In contrast to Europe, some old-growth forests remained in the Pacific region of North America whose grandeur and problems are described in NORSE (1990) and BOOTH (1993).

Without doubt, from a conservationist's point of view, the value of a forest increases monotonically with age for a very long period. The time scale involves several centuries. Although a linearly increasing conservation value function α = At (A constant) is, of course, an arbitrary assumption, there is at the outset no evidence that more complicated approaches are more adequate. Therefore, we are justified in choosing this function because of its mathematical simplicity which makes the results particularly transparent. We are free to resort to nonlinear functions if necessary.

Neither natural nor social scientists are at present able to state a „correct" value for A. Economic valuation of biodiversity is even more difficult than understanding its physical features (see

PERRINGS et al. 1995, 1995a, SWANSON 1995, MORAN & PEARCE 1997). One reason is that, due to the possibility of irreversible extinction, questions of intergenerational justice are involved - to conserve species is not only a matter of maximising one's own welfare but may also be a duty. Certain limits to the principle of „consumer's sovereignty" are approached as are in the management of the Earth's atmosphere and the global climate, the deposition of radioactive wastes and in other issues.

All the economist can do is to investigate the consequences of different choices of A. He can confront decision-makers with the probable outcomes of their choices which may help in finding not „the optimal" but perhaps the least controversial perspective.

4 A heuristic model

We return to (4) and assume, as already in (9), that $\alpha(t) = At$, $A>0$, constant. Because of

$$\int_0^T Ate^{-it}dt = A\left\{\frac{1-e^{-iT}}{i^2} - \frac{Te^{-iT}}{i}\right\} \tag{10}$$

(4) reduces to

$$PVLA(T) = \frac{VL(T)i - AT}{i\left(e^{iT}-1\right)} + \frac{A}{i^2} \tag{11}$$

Assuming $\lim\limits_{T\to\infty} VL(t) = VL^*$, $VL^* \geq 0, const.$, l'Hôpital's rule yiels (12)

$$\lim_{T\to\infty}\frac{VL(T)i - AT}{i\left(e^{iT}-1\right)} = \lim_{T\to\infty}\frac{VL'(T)i - A}{i^2e^{iT}} = \frac{0-A}{"\infty"} = 0, \text{ so that} \tag{13}$$

$$\lim_{T\to\infty} PVLA(T) = \frac{A}{i^2} \tag{14}$$

Depending on the relative magnitudes of VL(T), A and i, five cases can be distinguished as shown in figure 3 and table 1:

1 A = 0 yields the familiar Faustmann case as in (2) with optimal cutting date T_1^*.

2 For small A the optimal cutting is delayed to T_2^*.

3 Increasing A further shifts the optimal cutting to T_3^* and produces a minimum at T_4^*. The present value resumes growth beyond T_4^* but not to the level reached at T_3^*. This case was shown in figure 2 with Z crossing $\dot{V}LA(T)/VLA(T)$ twice.

4 The same applies for this case except that for large T the present value increases to the extent that it becomes worthwhile never to cut the forest. Cases 3 and 4 cannot be distinguished from one another in figure 2 because the curve intersections represent *local* maxima and minima of the present value. Therefore, figure 2 is a misleading guide.

5 Finally, A can be increased to the point that the local maxima and minima vanish so that the limit is approached monotonously. This is the case in figure 2 without intersection.

Case 1 being a clear matter (A=0), there is little point in distinguishing cases 2 and 3 from one another for practical reasons which requires awkward calculations. The same applies to cases 4 and 5. There is a very special case where the local maximum of PVLA(T) exactly equals lim PVLA(T) for $T \to \infty$, making the forest owner indifferent between choosing a finite or an infinite age. The important point is to distinguish cases (2,3) from cases (4,5) which is impossible in figure 2. In the given model, the distinction is possible by a very simple procedure. In case 4 and case 5 it is true that

$$PVLA(T)=\frac{VL(T)i-AT}{i\left(e^{iT}-1\right)}+\frac{A}{i^2}<\frac{A}{i^2} \qquad \forall\, T, \tag{15}$$

which reduces to

$$A>\frac{VL(T)}{T}i=(MAI)i \tag{16}$$

If A exceeds the product of the mean annual increment (MAI) in monetary terms, measured at the optimal cutting age T, times the interest rate, it is advisable never to cut the forest. For $0<A<(MAI)i$ the forest is cut at a delayed date, as compared with the classical Faustmann solution. For MAI = A/i the owner is indifferent between cutting at some optimal date or not cutting at all.

At some T considered optimal, the owner can choose between two options: *Either* he cuts and sells VL(T), does so again after 2T, 3T... and at each T starts receiving At from zero (figure 4a). Capitalized at T, he receives

$$PV_{Cutting}=\frac{VL(T)}{1-e^{-iT}}+\frac{A}{i^2}\left(\frac{1-e^{-iT}(1+Ti)}{1-e^{-iT}}\right) \tag{17}$$

where the first term is the present value of the actual and all future cuttings and the second term ist the present value of the saw-like stream of amenity payments, at each T starting from zero. *Or* he chooses never to cut and continues to receive A(t). Geometrically (figure 4b), his future receipts can then be split up into a constant annual payment AT plus a linearly increasing part A(t-T). The sum of both present values is

$$PV_{Conservation}=\frac{A}{i^2}+\frac{AT}{i} \tag{18}$$

The owner is indifferent between cutting and never cutting if $PV_{Cutting} = PV_{Conservation}$, or

$$\frac{A}{i^2}+\frac{AT}{i}-\frac{VL(T)}{1-e^{-iT}}-\frac{A}{i^2}\left(\frac{1-e^{-iT}(1+Ti)}{1-e^{-iT}}\right)=0 \tag{19}$$

Little calculation and rearrangement proves that this condition is met if

$$A = \frac{VL(T)}{T} i \tag{20}$$

Even allowing for the linearity of $\alpha(t)$ the condition derived is unexpectedly simple. No specific assumptions about VL(t) except (11) are required.

As an example, suppose VL(T*) = DM 70,000, T* = 150, i = 0,02 and A = 10. At T*, the respective PVs are (in DM):

Cutting:		*Never Cutting:*
Cash from actual cutting:	70,000	PV of future conservation payments after (18)
PV of future cuttings after (1)	3,668	
PV of future conservation payments after (17, right term)	21,070	
Sum:	DM 94,738	DM 100,000

In this case it is chosen not to cut.

5 Numerical simulation

Table 2 shows data of a typical beech forest (*Fagus sylvatica*) in Central or South Germany, assuming wood prices around 1996. This type of deciduous forest is chosen for the simulation experiment because due to its relative naturalness it is best suited for conservation purposes in the area, in contrast to artificial spruce or pine plantations. Columns 2-7 show harvest, average wood price, gross revenue, harvest costs, revenue net of harvest costs and finally, revenue minus harvest cost minus costs for establishing the subsequent tree generation, assumed at DM 5,000 per hectare if natural seeding is possible (artificial planting would amount to DM 12,000-15,000 per hectare). Revenues and costs of thinning are ignored because of their low importance in forestry of broad-leaved trees in the region. The values are derived from indemnification cases due to premature felling, using SYLVAL 3.0, a computer programme developed by the Federal Ministry of Finance. 10-year-intervals from age 50 to 150 are considered. The usual cutting age is between 130 and 150 years.

Column 8 shows values calculated by a growth function. It is difficult to accurately model forest growth using simple functions. However, for ages > 90 the fit to the empirical data is satisfacory (shaded area); earlier age classes are little relevant. A bell-shaped first time derivative of a logistic function is used, assuming a maximal monetary yield V* of DM 75,000 (net of replanting costs) at age t*=170 and a coefficient b=208. The derivative of the original logistic function $N = M / \left(1 - be^{-rt}\right)$ is transformed into

$$V(t) = \frac{4V^* b^{\left(1-\frac{t}{t^*}\right)}}{\left(1 + b^{\left(1-\frac{t}{t^*}\right)}\right)^2} \tag{21}$$

substituting r by b and t*. At ages >170 years the stumpage value diminuishes symmetrically to the increase prior to t*=170 which may be somewhat too fast but does hardly influence the results (figure 5).

Although costs of replanting are considered, the costs of the first plantation (which ex ante may affect the optimal rotation period considerably at high interest rates) are ignored. This is justified by the assumption that any decision whether to harvest a forest or to delay the harvest due to payments for conservation is taken *after* the first foundation of the forest so that costs involved there are *sunk costs* which cannot affect further decisions. Annual costs are ignored in the simulation but their significance is discussed later.

Although the conditions (16) and (20) above are evaluated at specific optimal ages T, a proxy for the size of A required to outcompete cutting is obtained in calculating the *maximal* MAI value of the growth function as shown in figure 6. For (21), MAI_{max} amounts to 458 at age T=157, less than 500. On the assumption of i=0,02 p.a., a value of A=10 should therefore just suffice to incite the owner never to harvest as is confirmed below. A=10 implies that the owner yearly receives DM 100 for a 10-years-old stand, DM 1,000 for a hundred-years old, and so forth.

Figures 7 and 8 contain the results of two simulations; in tables 3 and 4 significant values are shown. The section 0<t<z is of no economic significance. An interest rate i=0,02 p.a. is combined with values for A of 0, 5, 10 and 15, whereas i=0,01 p.a. is combined with A = 0, 5/2, 5, 15/2.

In both cases A=0 reduces to the classical Faustmann case. With i=0,02, A=5 results in a delay of the optimal harvest from 114 to 140 years (case 2 in figure 4), A=10 produces a local PV maximum at age 159, although the optimal decision is never to harvest (case 4), and A=15 obviously demands the same (case 5). With i=0,01, the cases are analogous except that even for A=7,5 case 4 pertains, there remains a local maximum at T=163.

6 Discussion

Despite the simplicity of the analysis the following findings appear to be robust, that is their reproduction by studies using more advanced methods is highly probable:

- Payments capable of persuading the owners never to harvest produce present values which are extremely high in relation to present values attainable by conventional forestry. This is of course not equivalent to stating that they are „too high", particularly in view of the modesty of the PV's attainable by the conventional method due to low wood prices (remember that even all annual costs are excluded from the calculation). There is no a priori reason that PV's of conservation activities as shown in the results should not be accepted by society.

- Intuition would suggest that in order to stop cutting once and for ever it should suffice to pay the owner a sum which just perceptibly exceeded the highest possible PV achievable in conventional forestry and to let him choose between both options. For instance, at i=0,02 (table 3) a payment of DM 5,000 should be preferred to the Faustmannian PV of DM 4,286. This conclusion is erroneous because it presumes that a forest cut at age 114 has no conservation value at all. In reality, conventional beech forests managed with cutting ages of 100 to 150 years are already valuable from a conservationist's point of view although less so than very old forests. In order to economically justify the option of never cutting, its value must exceed that of the sum of timber value and conservation value at any finite age T. This is the reason why only high conservation PV's can outcompete cutting.

- The latter effect is reduced by using functions $\alpha(t)$ which shift the conservation value further into the future. For instance, $\alpha(t) = At$ may be truncated for low values of t; the first payment may be due at, say, t=100. Or a function $\alpha(t) = At^k$ (k>1) may be used. Exponential variants of $\alpha(t)$ will soon lead into problems of divergent integrals. In any case, the choice of $\alpha(t)$ must be based on ecological facts rather than on aspects of mathematical convenience or the desire to achieve certain results considered favourable from a financial point of view.

- At least for the interest rates used here, the effect of postponing the harvest is feeble. Even high payments merely result in heavy income effects with little significant reallocation. From a pragmatic point of view and interpreting $\alpha(t)$ as a policy tool rather than as an exact yardstick for the value of biodiversity, one would suggest to apply payments, if at all, only for the explicit objective to abandon harvesting altogether rather than for achieving longer rotation periods. But here again: Should $\alpha(t)$ be found such that it reflected the „true" value of biodiversity and society's value judgment stated that this value ought to be the property of the forest owner just as the trees growing are, an outcome implying redistribution in favour of the forest owner combined with little postponement of the harvest had to be accepted as an efficient allocation (see also the distributive aspects discussed below).

- Several curves in figures 7 and 8 have very smooth curvatures and go almost horizontally over long periods. For instance, in case of i=0,02/A=10 the owner receives an almost identical present value whether he cuts at T=150 or at T=250 or not at all. As already known from conventional forestry and reinforced here, the choice of a rotation may have small consequences in the long run: Someone who misses the optimal date by many years may in fact lose very little. Under these circumstances, economic incentives may easily prove ineffectual because the addressees have many options to react to them. Unintended effects may produce heavier deviations as to the rotation chosen than purposeful policy measures. Only clearly distinguishable signals, such as high payments (e.g. A=15 in the case of i=0,02) are exempt from these concerns.

7 Problems and Policy

It is impossible in a short contribution to address all possible aspects of the topic discussed. Only four points as to the practicability of the instrument analysed can be briefly mentioned:

Liquidity, Risk and Confidence: Cutting and selling trees yields immediate cash free of risk. In contrast, the wealth of an owner who keeps his forest uncut rests on the promise of an authority to pay him regularly certain sums till the distant future. Only if he trusts that he and his heirs will receive those payments for hundreds of years can he accept such an alternative. Even if the promise appears trustworthy to him he may be forced not to accept it for reasons of liquidity. He may simply need cash.

Experience suggest that there will remain strong tendencies to continue conventional forestry including cutting even if calculated PV's of the conservation option are attractive on paper. This problem is solved by capitalising future rents. The owner who considers cutting is offered

(18) as a once-and-for-all payment for abstaining from doing so together with the information that he had to pay back the sum should he decide to cut at a later date (in the example given at the end of section 4, he would receive DM 100,000). This measure provides the conservation option with an equal chance as compared to conventional forestry.

Choice of the Interest Rate: The interest rate chosen in the problems discussed here reflects the forest owner's alternatives for investing his capital, allowing for transaction costs, taxes and other institutional constraints. Due to imperfect capital markets, these alternatives differ from those open to other economic agents including the state. In general, Germany's forest owners appear to be sceptical as to their profit chances outside the forestry sector (say, by investing in urban real estate). Long rotations by international standards (KUUSELA 1994) can only be explained by low assumtions regarding i, often considerably lower than 0.02 p.a. in real terms.

Low interest rates imply *low* annual payments A_t for conservation but *high* capitalised once-and-for-all payments (see tables 3 and 4). Therefore, forest owners will state relatively high interest rates when claiming annual payments and low rates once a decision has to be made on the magnitude of a PV. There is clearly an incentive to react strategically.

In calculating PV's, the conservation agency faces an odd situation if its own investment opportunities are superior to those of the forest owners. According to tables 3 and 4, an owner assumung i = 0.01 demands a PV around DM 50,000 for abstaining from cutting at age 157 while the agency, estimating i at 0.02, would be prepared to pay only DM 25,000. There is no solution to this problem except to mitigate the imperfection of capital markets such that interest rates converge.

Production Costs: Besides costs for cutting and replanting, continuous costs have to be considered. They would not affect the calculations if they did not differ between conventional forestry and conservation and if they were borne by the same party in both cases. These assumptions are questionable however. Although in some German national parks the number of employees per hectare is about equal to the personnel in commercial forests, resulting in similar expenditures, this need not invariably be the case. Part of the staff in national parks consists of scientists and educators who will certainly be paid by the conservation agency once schemes as suggested here are put into practice. It is probable that conservation arrangements leading to the result that a forest is never cut will reduce the current costs in private forestry at least in the long run.

On the average, current costs including administration amount to nearly exactly DM 300 per hectare in Germany's private forests (AGRARBERICHT 1998. MATERIALBAND, p. 209). This is transformed into present values of DM 15,000 respectively DM 30,000, assuming interest rates of 0.02 resp. 0.01. The first rows in tables 3 and 4 show that the conventional business in broad-leaved forests achieves present values net of harvest and replantation costs of roughly DM 4,300 (assuming i = 0.02) respectively DM 20,000 (i = 0.01). From a capital-theoretical point of view it is difficult to understand why private forestry is not abandoned completely on these sites given the disproportion between costs and benefits.

The best explanation for the persistence of private forestry in Germany is that most of the costs are *sunk costs* at any given point of time. The economic situation of the sector – whose excellent performance in physical terms is never disputed - is non the less increasingly precarious. Two consequences arise: The possibility of cost savings may result in substantially reduced expenditures on the part of the conservation agency, as compared to the values shown in tables 3 and 4. Presumably, each contract will have to be designed individually, reflecting the special situation of a particular firm. More important, however, is the perspective that payments for conservation – thereby redefining property rights in favour of forestry - will enhance the overall economic situation of the sector to the point that full costs are covered by revenues in the long run, making the business economically sustainable which is far from true to-day.

Spatial Planning: Ignoring for a moment the important problems just mentioned, one may imagine a solvent conservation agency offering payments attractive to all forest owners in a large region. If all of them accept, the wood shortage ensuing the stop of all cuttings will rise prices, thereby undermining the results of the simple analysis presented here. Even conservationists will not demand that *no* wood at all be produced in the region. Should the agency offer payments attractive to some but not to all forest owners, a selection would arise to the effect that the less productive stands would be singled out for conservation. Although from a conservationist's point of view this would be much preferable to not conserving at all, the out-come would not be satisfactory. The examples teach us a fact some economists are reluctant in accepting: The conservation of biodiversity is so complex a matter that any attempt relying on one *single* measure must miscarry. While it is imaginable to regulate some important environmental problems by a single measure - such as global climate protection by a carbon tax -, this is not possible in the case of biodiversity due to the overwhelming influence of the spatial structure (see also SWALLOW et al. 1997).

8 Conclusion

Whether or not private owners are remunerated for any non-market benefit their forests offer to society, can only be decided relying on value judgements. If the benefit is considered as their property they can sell it just as they do in the case of timber. If it is not, they cannot claim any payment. Again, the central role of the distribution of property rights in any problem of environmental and resource economics becomes obvious.

If owners are not paid (as is the case in most countries) it is erroneous to infer that the non-market benefit is not valuable. Rather, society expects to receive the service free of charge. Momentous arguments endorse the case for a distribution of property rights in favour of forest owners, one of the most important being that only then *incentives* are operative motivating the owners to improve the supply.

In order to foster biodiversity conservation in Central European forests, owners have to be incited financially to increase the ages of their forests, possibly to a point of refraining from cutting altogether. The exact functional relation between the forest's age and its value for biodiversity is not known, nor is it possible to fully monetise species richness. Using as a first approach a linear amenity function in a deterministic setting, a very simple condition is derived for the size of the payments necessary to induce owners not to cut. Using data for typical forests, stylized semi-empirical calculations are possible which have of course to be corroborated by more detailed analyses. Notwithstanding, they provide first insights into the dynamics of the problem and can particularly hint at obstacles for practical applications which include the following.

It is not possible to postpone cuttings for many decades; if a payment is high enough, it will obviate wood harvesting altogether relatively early after the usual cutting date (This may depend somewhat on the modelling of forest growth and decay). Payments of this kind sum up to high present values, as compared to conventional incomes in forestry. Unfortunately, the accuracy of aim of the measure is low in many cases; an owner receiving a certain payment for conservation may decide to cut at T=120 or T=180 or never and may yet enjoy about an identical economic success. This is a general waekness of the Faustmann-Hartman approach, as indicated by almost horizontal curves in figures 7 and 8.

Presumably, remunerations for abstaining from cutting are only accepted if offered as capitalised once-and-for-all payments at the time of planned cutting. It will be very difficult to agree on a proper interest rate which is crucial in calculating present values. The choice of an interest rate must be a binding act prior to the operation of the scheme in order to avoid high transaction costs through individual strategic bargaining. Finally, the scheme has to be embedded into an overall forestry and conservation policy allowing for spatial planning.

Financial restrictions in many countries will militate against practical applications in the near future. However, the economic situation of private forestry in Germany being more and more precarious, new perspectives for the future are due anyway. Unless wood prices increase strongly (which is unlikely), firms may lose interest in forestry given the present pattern of property rights. The remuneration of non-marketed benefits including conservation, carbon sequestering, recreation and others may become one way of securing forestry in some European countries in the long run.

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Case	Nos. of solutions in fig 3	A	PVLA(T) $\forall T$	Optimal Decision
1	1	0	-	Cutting at T_1*
2	1	>0	$>A/i^2$	Cutting at T_2*
3	2	>0	$>A/i^2$	Cutting at T_3*
4	2	>0	$<A/i^2$	Never Cutting
5	0	>0	$<A/i^2$	Never Cutting

Table 1: Properties of five cases in figure 3

1 Age (years)	2 Harvest (m^3)	3 Average Wood Price DM/m^3	4 Gross Revenue DM	5 H DM	6 Net Rev. VL(T) DM	7 VL(T) minus K DM	8 VL(T)-K simulated DM
50	126	58.02	7,310	3,685	3,625	-1,375	6,622
60	175	64.34	11,276	4,465	6,811	1,811	8,916
70	220	73.28	16,121	5,293	10,828	5,828	11,933
80	255	85.15	21,714	5,901	15,813	10,813	15,845
90	285	108.55	30,938	6,318	24,620	19,620	20,822
100	312	124.12	38,726	6,757	31,969	26,969	26,987
110	335	139.03	46,576	7,057	39,519	34,519	34,361
120	355	158.17	56,149	7,232	48,917	43,917	42,771
130	373	169.43	63,197	7,458	55,739	50,739	51,761
140	390	185.80	72,461	7,646	64,815	59,815	60,548
150	404	200.10	80,839	7,788	73,051	68,051	68,067

Table 2: Growth Simulation of a German Beech Forest (Fagus sylvatica) by Function (21)
All figures per hectare. 1 DM ≈ 0,58 US$ ≈ 0,5 Euro. Empirical data kindly provided by W.-D. Radike (Gräflich Arco-Zinnebergsches Forstamt, Moos, Bavaria) H: Harvest Costs, K: Costs of Replanting

A (DM)	T (years)	PVLA(T) (DM)	lim PVLA(T) $t \to \infty$
0	114	4,286	0
5	140	14,155	12,500
10	159	24,710	25,000
15	-	-	37,500

Table 3: Local maxima of PVLA(T), i = 0,02 (Figure 7)

A (DM)	T (years)	PVLA(T) (DM)	lim PVLA(T) $t \to \infty$
0	140	19,822	0
2,5	150	33,779	25,000
5	157	48,284	50,000
7,5	167	63,309	75,000

Table 4: Local maxima of PVLA(T), i = 0,01 (Figure 8)

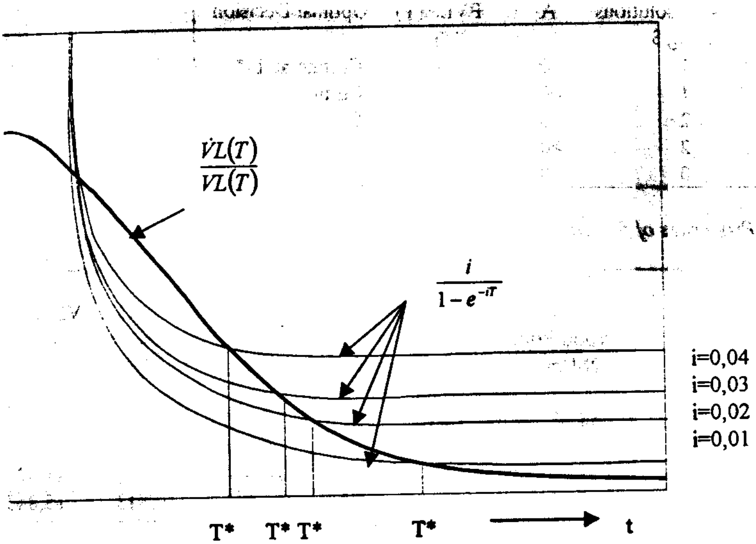


Figure 1: Faustmann's equation

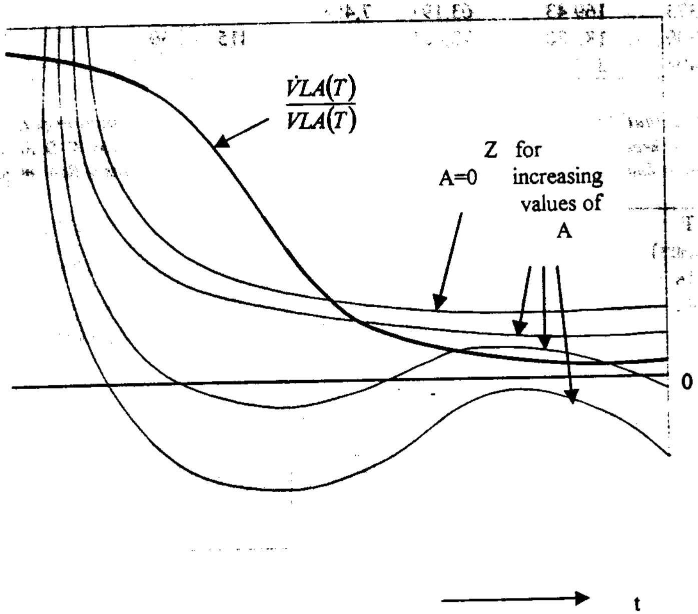


Figure 2: The generalised Faustmann-Hartman approach

$$Z = \frac{i}{1-e^{-iT}} + \frac{A\left(1 - Ti - e^{-iT}\right)}{VL(T)i\left(1-e^{-iT}\right)},$$ see (5),(9)

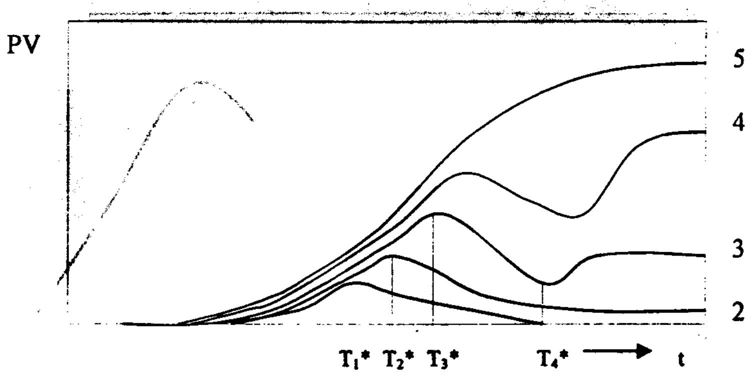
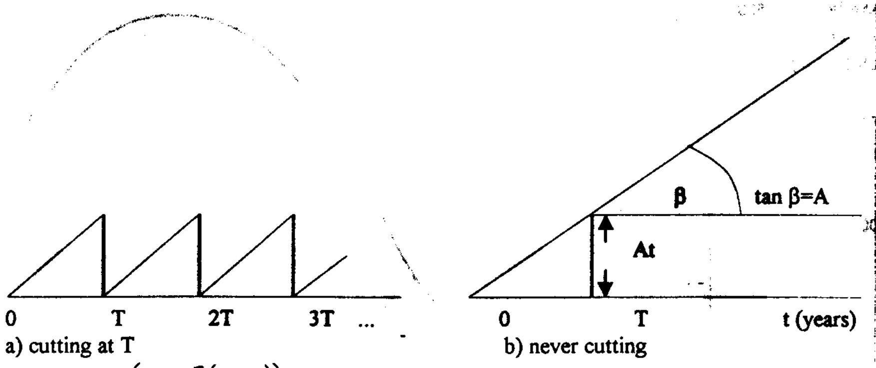


Figure 3: Five cases of equation (11)



$$PV = \frac{A}{i^2}\left(\frac{1-e^{-iT}(1+iT)}{1-e^{-iT}}\right)$$

$$PV = \frac{A}{i^2} + \frac{At}{i}$$

Figure 4: Present value PV of future conservation payments at age T

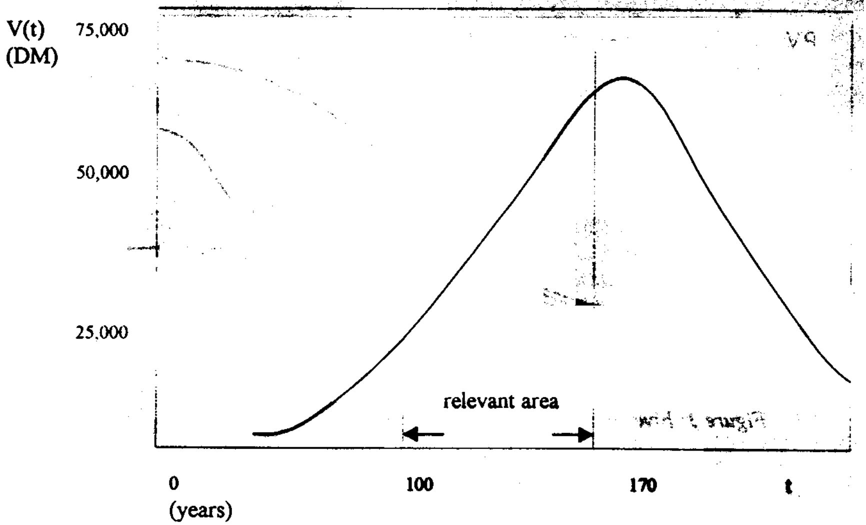


Figure 5: Growth simulation function (21)

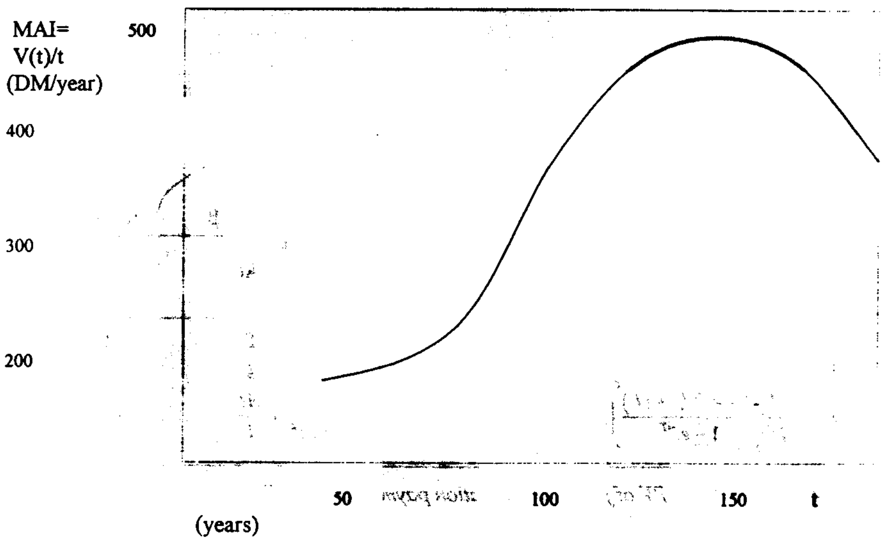


Figure 6: Mean annual increment MAI(t) of (21)

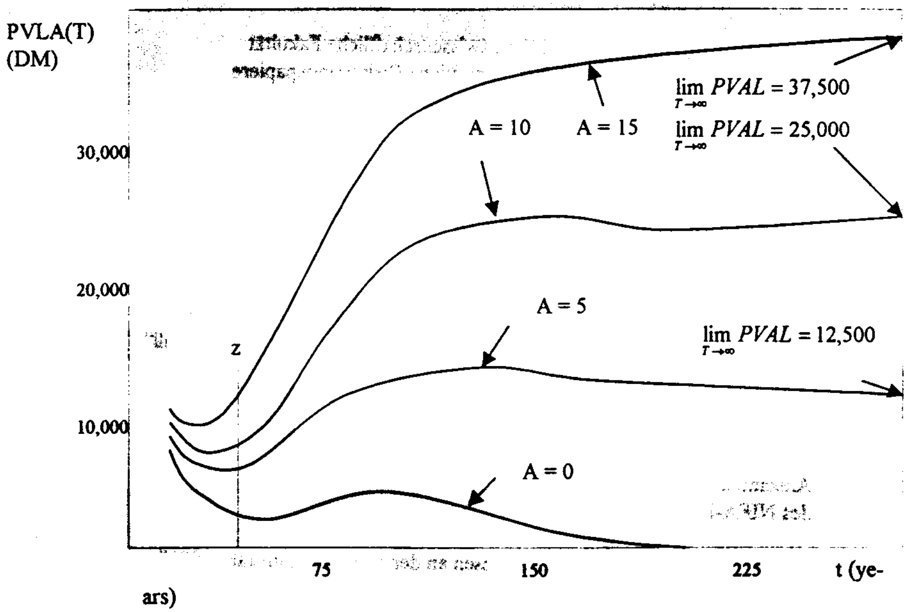


Figure 7: Present value, lumber production plus conservation, after (11), i=0,02

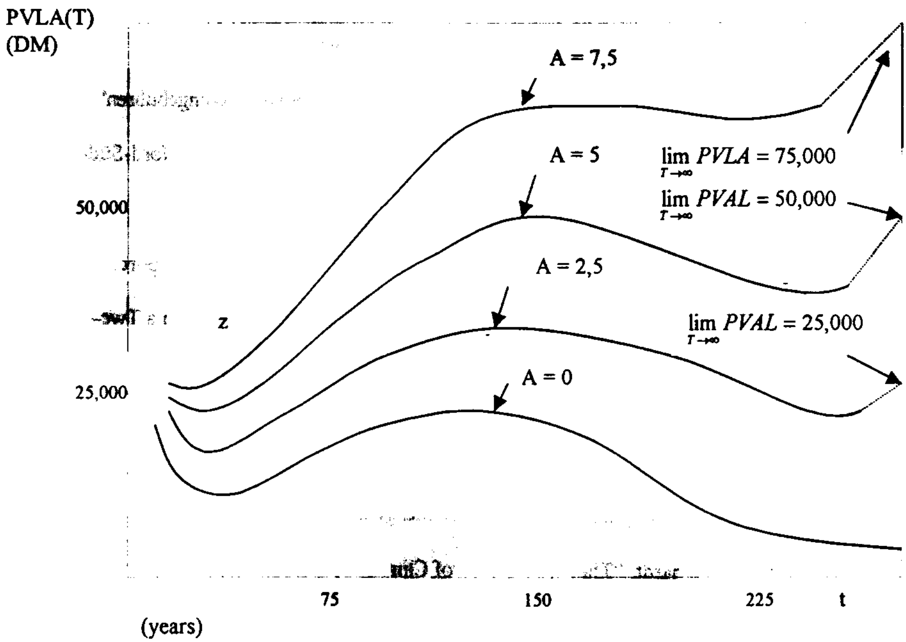


Figure 8: Present value, lumber production plus conservation, after (11), i=0,01

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