THE EFFECT OF THE NON-MARKET COMPONENT OF STANDING VALUE ON THE OPTIMAL FOREST ROTATION

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ABSTRACT

The non-market component of forest standing value is considered by many to exceed the value of market goods from the forest, but this part of forest standing value is usually omitted from economic models that are used to determine the optimal forest rotation. These models therefore produce erroneous results. It is argued that for the Mountain Ash forests of South-Eastern Australia, a standardised version of the above ground biomass function (AGBF) of the dominant tree can provide a useful representation of the non-market part of forest standing value. An economic model of optimal forest rotation, which includes a standardised version of the AGBF, is used to find the minimum valuation of non-market standing value which produces the result that the forest should be preserved.

Key words: forest rotation, non-market valuation

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1. Introduction

In a recent survey of the reasons for valuing forests in South East Gippsland, Australia (Lockwood *et al.*, 1993), respondents to the state-wide survey indicated that the non-market components of forest standing value were more important than the market components (Lockwood *et al.*, 1993, p.237). Specifically, the preservation of the forest for its plants and animals received the highest ranking, followed (in order), by preservation for future generations, for visitation, and to know the forest exists. The value of the forests for timber production and employment received the lowest rankings.[1]

This supports Dasgupta's opinion (Dasgupta, 1982, p.178) that "the value of a forest typically exceeds the value of timber it nurtures, and on occasion exceeds it greatly". Dasgupta (1982, p.178) does, however, note that the measurement of forest externalities "poses vast problems at both the conceptual and practical level". Samuelson (1976, p.486) argued that once sufficiently informed, the preferences of the electorate for forest conservation will lead to forest preservation.

Samuelson's analysis of the problem of finding the optimal forest rotation time does not include forest standing value. The principal technical focus of his paper is an exposition of the Faustmann solution to the forest rotation problem. This involves finding the forest rotation time which maximises the net present value of the land occupied by the forest ($V_0(t)$) under a logging regime of an infinite number of harvesting cycles (or rotations) starting with bare ground.

Hartman (1976) modified the Faustmann problem by introducing a function ($F(t)$) which represents forest standing value into the objective function of the Faustmann problem. Let $V(t)$ represent the net present value of the land occupied by the forest (under a regime of infinite rotations) inclusive of standing value. Hartman provided a detailed analysis of the case when standing value is large enough so that no *t* can be found which satisfies the first order condition $dV(t)/dt = 0$. In this event, Hartman concluded that the forest should be preserved.[2]

Strang (1983) extended Hartman's (1976) results by comparing the asymptotic value of $V(t)$ as $t \to \infty$ ($lim V(t)$) to the maximised value of $V(t)$ when an interior solution exists ($V(t_1)$). When $lim V(t) \geq V(t_1)$, Strang concluded that the forest should be preserved. Strang also analysed the case of whether or not to log a forest of age $t_0>0$.

The author has only found applications of the work of Hartman and Strang which incorporated forest standing value which produces market goods into $V(t)$. Examples are Clarke (1994) which included water supply and Swallow *et al.* (1990) which included cattle production.

The conservation value of indigenous forests, which includes biodiversity preservation, existence value, bequest and option values and in the case of tall forests, water precipitation enhancement (Ashton and Attiwill, 1984, p.168), is very high.[3] In addition, growing forests, which are recovering from fire or clear felling can make a useful contribution to reducing atmospheric CO_2 levels through carbon sequestration (Schelling, 1992, p.9).

The Mountain Ash (*Eucalyptus regnans*) forests of the Thomson Dam catchment in Central Gippsland, Victoria, Australia are used in the application of this paper. For these forests, the work of Norton (1996), Lindenmayer and Franklin (1997) and Lindenmayer (1999) indicate that current logging practices based on clear felling and the burning of residues have a deleterious effect on biodiversity conservation.[4]

Thus, for these forests, the omission of the non-market component of standing value from $V(t)$ is likely to lead to an incorrect optimal rotation period and bias any estimate of the opportunity cost of conserving these forests which are based on $V(t)$. These points may be clarified as follows.

Let the net present value of forest standing value per hectare of forest be

$$F(t) = F_1(t) + pF_2(t) \ . \tag{1}$$

In (1), $F_1(t)$ is due to market goods, $F_2(t)$ is due to non-market goods and p is the price of the non-market component of forest standing value. When this formulation of $F(t)$ is included in $V(t)$, the objective function may be written as $V(t,p)$. If $p = 0$, then the objective function contains only the market good component of forest standing value and this may be written as $V(t,0)$.

Now suppose that t_1 produces an internal maximum of $V(t,0)$ and let $limV(t,0)$ be the asymptotic value of $V(t,0)$ as $t \to \infty$. When $V(t_1,0) > limV(t,0)$, timber production is worth more than conservation. An estimate of the annual opportunity cost of conservation may be obtained from $r[V(t_1,0) - lim V(t,0)]$, where r is the continuous discount rate used in calculating $V(t,0)$.

This analysis will produce incorrect results because the omission of $pF_2(t)$ in $V(t,0)$ will lead to an incorrect optimal rotation period, t_1. If $pF_2(t)$ is included in the analysis, the t which maximises $V(t,p)$, say t_2, will in general not equal t_1, and in the event that $V(t_2,p) > lim V(t,p)$, the annual opportunity cost of conservation may be estimated by $r[V(t_2,p) - lim V(t,p)]$.

Finding the correct optimal rotation period and annual opportunity cost of conservation is difficult because p and $F_2(t)$ are not known. An alternative approach is developed in this paper. Suppose that a good estimate of $F_2(t)$ is available, then under certain conditions, an estimate of the minimum annual valuation of the non-market component of forest standing value that would warrant conservation, as opposed to logging, may be obtained.

Let $t_2(p)$ be the rotation time that maximises $V(t,p)$, and suppose a value of p say $p = p_a$ can be found which satisfies $V(t_2(p_a), p_a) = lim V(t, p_a)$, then p_a is the price of the non-market component of forest standing value which equates the net present value of logging, to the asymptotic net present value of forest standing value.

The present value of the non-market component of forest standing value which produces this result is the limit as $t \to \infty$ of $p_a F_2(t)$, denoted as $lim\, p_a F_2(t)$, and the corresponding annual value of the non-market component of forest standing value is $r\, lim\, p_a F_2(t)$. This is the minimum annual valuation of the non-market component of forest standing value that would produce the formal result of no logging, since if society values conservation at or above $r\, lim\, p_a F_2(t)$, the forest should be preserved.

A standardised version of the above ground biomass function for the Mountain Ash forests of South Eastern Victoria (Grierson *et al.*1991, p.16 and Grierson *et al.* 1992, p.634), is used to approximate of $F_2(t)$ in the application of this paper.

The rest of the paper is organised as follows. The next section contains technical details including a set of sufficient conditions for the existence of p_a and similar results for a forest aged $t_0 > 0$, which is being considered for logging. The case of a standing forest is generally important. Also, 80.12% (2,979ha) of the Mountain

Ash forests of the catchment of the Thomson Dam which were available for logging in 1992, are re-growth forests which regenerated after the bushfires of 1939 (Appendix B of Read, Sturgess and Associates, 1992). For these re-growth forests t_0 was around 60 years at the beginning of 2000.

Section 3 contains a description of the functions and parameters used in the application of the paper. Section 4 contains a discussion of the results obtained for the Mountain Ash forests of the Thomson Dam catchment.

Using the base case values of water prices, timber prices and discount rate at the beginning of 2000, the minimum annual valuation of the non-market component of forest standing value required for forest conservation, starting from cleared land, was estimated at between \$500.81 and \$530.56 per hectare per annum. For a forest aged 60 years, the minimum annual valuation of the non-market component of forest standing value required for forest conservation ranged from \$714.20 to \$730.06 per hectare per annum. Results varied with the water price, timber prices and the discount rate. The final section of the paper contains a summary of the principal results.

2. Technical results

In this section we present sufficient conditions for the existence of the minimum annual valuation of the non-market component of forest standing value which would warrant conservation of the forest as opposed to logging. This is done for two cases (i) starting with cleared land and (ii) starting with a forest of age $t_0>0$.

(i) Cleared land

Let e be regeneration cost per hectare of cleared land, r be the continuous discount rate, $G(t)$ be the net timber value per hectare of forest, $f_1(t)$ be the market component of forest standing value per hectare and $pf_2(t)$ be the non-market component of standing value (at price p) per hectare. Then $G(t)e^{-rt}$ is the net present value of timber per hectare; $F_1(t)=\int_0^t f_1(x)e^{-rx}dx$ and $pF_2(t)= p\int_0^t f_2(x)e^{-rx}dx$ are the net present value of the market component and the present value of the non-market component of forest standing value per hectare respectively.

Let the net present value of a hectare of forest aged t, starting with cleared land, be

$$V_1(t, p)=G(t)e^{-rt}+\left[F_1(t)+ pF_2(t)-e\right]. \quad (2)$$

The present value of a hectare of forest following a regime of harvesting at age *t* and then regenerating the forest *n* times, assuming all prices and the discount rate are constant, is

$$V_n(t, p) = G(t)\left(\sum_{i=1}^{n} e^{-irt}\right) + \left[F_1(t) + pF_2(t) - e\right]\left(1 + \sum_{i=1}^{n-1} e^{-irt}\right).$$

Let $V(t,p)$ be the limit of $V_n(t,p)$ as $n \to \infty$, then

$$V(t, p) = \left(G(t)e^{-rt} + F_1(t) + pF_2(t) - e\right) / \left(1 - e^{-rt}\right), \qquad (3)$$

which is similar to equation (8) of Hartman (1976, p.56).

The objective is to find the rotation time, t, which maximizes $V(t,p)$. Assume that $V(t,p)$ is at least twice differentiable in *t*, and that $t = t_2$ yields an internal ($t_2 < \infty$) global maximum of $V(t,p)$, then $\partial V(t_2,p)/\partial t = 0$ and $\partial^2 V(t_2,p)/\partial t^2 \leq 0$.

Assuming that $\partial^2 V(t_2,p)/\partial t^2 < 0$, the assumptions of the implicit function theorem are satisfied (Fulks, 1978, pp.350-356) and a differentiable implicit function, $t_2(p)$ exists in a neighbourhood of *p*. Let the limit of $V(t,p)$ as $t \to \infty$ be $\lim V(t, p) = \lim F_1(t) + p \lim F_2(t) - e$, where *lim* $F_1(t)$ is the limit of $F_1(t)$ as $t \to \infty$, and assume these limits exist, then we seek a set of sufficient conditions for the existence of $p = p_a$ which satisfies $V(t_2, p_a) = \lim F_1(t) + \lim p_a F_2(t) - e$. Differentiating $V(t_2,p)$ and $V(p) = \lim F_1(t) + p \lim F_2(t) - e$ with respect to *p*, we obtain:

$$\begin{aligned} \partial V(t_2,p)/\partial p &= \partial V(t_2,p)/\partial t \cdot \partial t/\partial p + \partial V(t_2,p)/\partial p\big|_{t=t_2} \\ &= F_2(t_2)/\left(1 - e^{-rt_2}\right) > 0 \end{aligned} \qquad (4)$$

and

$$dV(p)/dp = lim\, F_2(t) > 0 . \qquad (5)$$

Equation (4) is a version of the envelope theorem (Varian, 1992, pp.490-491). Now define the difference function $D(p)$:

$$D(p) = V(t_2(p), p) - V(p) \; . \qquad (6)$$

Assuming that in some closed interval $I = [p_1, p_2]$, with $p_1 < p_2$, $D(p_1) > 0$, $D(p_2) < 0$ and $dD(p)/dp < 0$ for all *p* in (p_1, p_2), then there is a unique $p = p_a$ in *I* for which $D(p_a) = 0$. The existence of $p = p_a$ in *I* follows because $D(p)$ is a continuous (and by assumption) strictly decreasing function of *p* in *I*. Since $D(p)$ is continuous, it takes all values in its range $R = [D(p_1), D(p_2)]$ and since 0 is in R, there is a $p = p_a$ satisfying $D(p_a) = 0$ (Burkill, 1962, pp.56-57). Since $D(p)$ is a single valued function on I, there is only one p in I which satisfies $D(p) = 0$, thus $p = p_a$ is unique in I.

The intuition behind this result is as follows. The function $D(p) = V(t_2(p), p) - V(p)$ has an intercept $V(t_2(0), 0)$ on the horizontal axis and slope $F_2(t_2)/\left(1 - e^{-rt_2}\right)$, $V(p)$ is a function with intercept on the horizontal axis equal to $\lim F_1(t) - e$ and constant slope $lim\, F_2(t)$. Suppose that $p_1 = 0$, then the condition $D(p_1) > 0$ requires $V(t_2(0), 0) > \lim F_1(t) - e$. The condition $dD(p)/dp < 0$ for all p in (p_1, p_2) requires that $F_2(t_2(p))/\left(1 - e^{-rt_2(p)}\right) < lim\, F_2(t)$ for all p in (p_1, p_2), which is plausible since we would expect $t_2(p)$ to be increasing in p and $lim\, F_2(t)$ is the limit as $t \to \infty$ of $F_2(t)/\left(1 - e^{-rt}\right)$. Thus, if $p_1 = 0$, $D(p_1) > 0$ and $dD(p)/dp < 0$ for all p in (p_1, p_2), $V(t_2(p), p)$ is an increasing function of p with slope less than the slope of $V(p)$ which is also an increasing (linear) function of p. If a $p = p_2$ exists, then $V(t_2(p_2), p_2) < V(p_2)$ and the functions $V(t(p), p)$ and $V(p)$ have crossed at some $p = p_a$ in I.

Whether or not these sufficient conditions are satisfied in practice will depend on the functions and parameters of the problem being studied. As it turns out, these sufficient conditions are satisfied for the functions and parameters used in the applications of the paper.

Once p_a has been estimated, the minimum annual valuation of the non-market component of forest standing value (starting with cleared land) which would warrant conservation as opposed to logging may be estimated by $rp_a\, lim\, F_2(t)$.

(ii) Standing forest

Sufficient conditions for the existence of the minimum annual valuation of the non-market component of forest standing value, of a forest aged $t_0 > 0$, which would warrant preservation as opposed to logging are similar to those of a forest regenerated from cleared land. The logging strategy involves clear felling the standing forest, regenerating the forest from cleared land and then following a regime of continuous forestry based on harvesting at age $t = t_2$ and then regenerating the forest for the next cycle. The conservation strategy involves no logging.

Assuming the forest is aged t_0 years, the maximised net present value of a hectare of land under logging is:

$$W(t_2(p),p) = G(t_0) + V(t_2(p),p) \ . \tag{7}$$

In (7), $G(t)$ and $V(t_2(p),p)$ are as defined above.

The present value of the forest under conservation at time $t > t_0$ is

$$PV(t,p) = G(t)e^{-r(t-t_0)} + \int_{t_0}^{t} f_1(x)e^{-r(x-t_0)}dx + p\int_{t_0}^{t} f_2(x)e^{-r(x-t_0)}dt \, ,$$

or equivalently

$$PV(t,p) = G(t)e^{rt_0}e^{-rt} + e^{rt_0}(F_1(t) - F_1(t_0)) + e^{rt_0}\,p(F_2(t) - F_2(t_0)) \ . \tag{8}$$

The limit of $PV(t,p)$ as $t \to \infty$, is:

$$W(p) = e^{rt_0}(lim\,F_1(t) - F_1(t_0)) + e^{rt_0}\,p(lim\,F_2(t) - F_2(t_0)). \tag{9}$$

In (9), $lim\,F_1(t)$, $lim\,F_2(t)$, $F_1(t)$ and $F_2(t)$ are as defined above. We seek a set of sufficient conditions for the existence of $p = p_b$ which satisfies:

$$W(t_2(p_b),p_b) = W(p_b) \ .$$

Differentiating $W(t_2,p)$ and $W(p)$ with respect to *p*, we obtain:

$$\partial W(t_2,p)/\partial p = F_2(t_2)/\left(1 - e^{-rt_2}\right) , \tag{10}$$

and

$$dW(p)/dp = e^{rt_0}(lim\,F_2(t) - F_2(t_0)) \ . \tag{11}$$

Now define the difference function, $D_1(p) = W(t_2(p),p) - W(p)$ and assume that in some closed interval $I' = [p_1', p_2']$ with $p_2' > p_1'$, $D_1(p_1') > 0$, $D_1(p_2') < 0$ and $dD_1(p)/dp < 0$ for all p in (p_1', p_2'), then there is a unique $p = p_b$ in I' for which $D(p_b) = 0$.

The proof of this result is similar to that above for the existence of p_a and is omitted. The sufficient conditions for the existence of p_b are satisfied in the application of this paper.

Once p_b has been estimated, the minimum annual valuation of the non-market component of forest standing value, of a hectare of forest aged $t_0 > 0$, which would warrant conservation as opposed to logging may be estimated by $rp_b e^{rt_0}\left[\lim F_2(t) - F_2(t_0)\right]$.

3. Functions and parameters used in the study

Background

The catchment of the Thomson Dam has an area of 48,700 ha of mainly State Forest and is managed by Melbourne Water and the Department of Natural Resources and Environment (DNRE). Melbourne Water is a state government statutory corporation which supplies bulk water to three water distributors (City West Water, Yarra Valley Water and South East Water) which sell water to households and firms in the city of Melbourne, its metropolitan area (combined population of 3.41 million persons) and some regional centres. The three water distributors are also state government statutory corporations.

The Thomson Dam has an active capacity of 1,068 GL and was completed in 1983 as a carryover storage to “drought proof” Melbourne. Average annual inflow into the Thomson Dam is 243 GL and average annual storage is around 190 GL. The Dam supplies the Thomson River below the storage with an annual water allocation of 52 GL made up of 40 GL for environmental flow and 12 GL for irrigation.

Irrigation water is supplied free of charge to compensate farmers for the loss of riparian water rights due to the construction of the reservoir. In this study, the water allocated to the Thomson River downstream from the storage is priced at opportunity cost.

Mountain Ash forests in the state of Victoria generally grow at altitudes of between 200 and 1000 m where mean annual rainfall exceeds 1200 mm (Vertessy *et al*., pp.5-6). Average annual rainfall in the catchment of the Thomson Dam ranges from 980 mm to 1710 mm (Read et al., 1992, p. 14) and the altitude ranges from 300 m to 1500 m (Melbourne and Metropolitan Board of Works (MMBW), 1975, p. 56).

The principal forest types in the catchment of the Thomson Dam are ash-type forests comprising of Mountain Ash (*E. regnans*), Alpine Ash (*E. delegatensis*) and Shining Gum (*E. nitens*) and mixed species forest. Mountain Ash forms around 80% of the ash-type forests (Kuczera, 1985, p.9). In mixed species forests, Messmate (*E. obliqua*) is the most important timber species. *Eucalyptus regnans* and *E. obliqua* occasionally form hybrids (Ashton, 1958).

Ash-type forests occupy the higher rainfall parts of the catchment and more sheltered slopes and gullies at lower elevations. Mixed species forests occupy the exposed, lower elevation areas and some sheltered slopes at higher elevations (Kuczera, 1985, MMBW, 1975).

Logging operations in the Thomson catchment are licensed by the DNRE. In the case of Mountain Ash forest, an area upwards of 10 hectares is clear felled each time and the residues burnt to form a nutrient rich ash seedbed for regeneration. In practice, mature living trees, old dead trees and trees in gullies are not harvested. Although the official rotation time is 80 years, 1939 re-growth has been harvested.

Annual harvesting of ash-type forest in the Thomson catchment has averaged around 143 ha over the past 14 years. The total area of ash-type forest is 16,000 ha, of which 11,000 ha is available for logging as of January 2001.[5]

We now present the various functions and parameters used in the applied part of the study.

Water

The water yield per hectare from a Mountain Ash forest of age *t* years in the Thomson catchment was obtained from Kuczera (1985). This function may be written:

$$\begin{aligned} f_1(t) &= Y && t < 2 \\ &= Y - LK(t-2)e^{(1-K(t-2))} \,. && t \geq 2 \end{aligned} \tag{12}$$

In (12), $f_1(t)$ is the water yield (ML/ha/annum) of regrowth forest aged *t* years,

Y is the average annual yield (ML/ha) from the mature forest (Y = 11.95),

L is the maximum annual yield reduction (ML/ha) below that of mature forest (L = 6.15),

t is the age of the re-growth forest (in years) and

K is the reciprocal of the time taken to maximum water yield reduction minus two years (K = 0.039).

Kuczera’s water yield function was used in the studies of Read *et al.* (1992, p.17) and Clarke (1994), and is currently used by Melbourne Water to estimate water yield from stands of Mountain Ash forest of various ages (Vertessy *et al.*, 1998).[6]

The present value of water is

$$F_1(t) = p_w \int_0^t f_1(x) e^{-rx} dx\,. \tag{13}$$

In (13), p_w is the water price. After substituting parameter values into (13) and simplifying,

$$F_1(t) = p_w \int_0^2 11.95 e^{-rx} dx + p_w \left\{ \int_2^t \left(11.95 - 0.70487 x e^{-0.039x} + 1.40974 e^{-0.039x}\right) e^{-rx} dx \right\}. \tag{14}$$

Clarke (1994) used only the second term of equation (14) in his paper.

To simplify the presentation of $F_1(t)$, let a = 11.95, b = 0.70487, c = 1.40974 and d = (0.039+r), then for $t \geq 2$, $F_1(t)$ may be written

$$F_1(t) = p_w \left(\frac{a}{r} - \left(\frac{b}{d^2} + \frac{2b}{d} - \frac{c}{d} \right) e^{-2d} \right) - p_w \left(\frac{a}{r} \right) e^{-rt} - p_w \left(\frac{c}{d} - \frac{b}{d^2} - \frac{bt}{d} \right) e^{-dt}\,. \tag{15}$$

Equation (15) was obtained from (14) using tabulated values of the integrals of functions involving the exponential function (Peirce 1929, p.53). The limit of $F_1(t)$ as $t \to \infty$, $lim\,F_1(t)$ is

$$lim\,F_1(t) = p_w \left(\frac{a}{r} - \left(\frac{b}{d^2} + \frac{2b}{d} - \frac{c}{d} \right) e^{-2d} \right)\,. \tag{16}$$

In estimating the water price (p_w), we shall assume marginal cost pricing.[7] Melbourne’s water supply system is mainly a gravity system and the principal variable costs of water supply are due to chemical treatment and pumping. All water is chemically treated but only some water is pumped.

Read *et al.* (1992, p.36) report that chemical treatment costs were \$7.25/ML and pumping costs were \$18/ML. To obtain a beginning of year 2000 value, the chemical treatment costs were inflated using the Australian Bureau of Statistics (ABS) price index for chemicals and chemical products to yield a beginning of year 2000 estimate of the cost of chemical treatment of \$7.627/ML.

The ABS does not publish an index of energy costs, so pumping costs were inflated using the ABS price index for petroleum and coal products to yield a beginning of year 2000 estimate of pumping costs of \$19.836/ML. The two price indexes used for inflating chemical and pumping costs are in the ABS publication “Price indexes of articles produced by manufacturing industry”, catalogue No.6412.0.

This gives two estimates for the water price: $P_w = \$7.63/\mathrm{ML}$ for water that is not pumped and $P_w = \$27.46/\mathrm{ML}$ for water that is pumped. It is estimated that 14% of water leaving the Thomson Dam is lost through leakage in the supply system (Read *et al.*, 1992, p.33). Adjusting these prices to yield prices for water in the Dam yields $P_w = \$7.63/1.14 = \$6.69/\mathrm{ML}$ and $P_w = \$27.46/1.14 = \$24.09/\mathrm{ML}$ for water that is not pumped and for water that is pumped respectively.

It is not known how much of the water released from the Thomson dam is pumped, so both prices were used in the applied work, $P_w = \$6.69/\mathrm{ML}$ being the "low" water price and $P_w = \$24.09/\mathrm{ML}$ being the "high" water price.

The non-market component of forest standing value

The non-market component of the standing value of the Mountain Ash forests of the Thomson catchment includes a contribution to biodiversity preservation, use value, option value, existence value, bequest value, carbon fixation and possible rainfall enhancement for stands around 100 metres in height. There is a vast literature on the ecology of the Mountain Ash and similar forest types in South Eastern Australia, which is reviewed in the following articles: Lindenmayer (1999), Lindenmayer and Franklin (1997), Norton (1996), Attiwill (1994) and Ashton and Attiwill (1984). The extensive study of these forests reflects their important scientific and ecological value. MMBW (1975) contains a detailed review of the flora and fauna of the catchment of the Thomson Dam.

We shall use a standardised version of the above-ground biomass function for Mountain Ash forests which has been estimated using data from mainland South Eastern Australia by Grierson *et al.* (1991, p.16) to represent the non-market component of forest standing value. This function is quadratic with a maximum at 98.09 years and is used here because around 50% of biomass is carbon and the function is increasing over the time range when many of the other factors contributing to the non-market standing value of the forest have their most important increase. The function used in this study is a standardised version of that of Grierson *et al.* (1991) because a function representing many components of non-market standing value should not have the units of any particular component of standing value.

We shall now briefly review the most important factors affecting non-market standing value as the Mountain Ash forest ages, starting with an ash seedbed formed by the burning of residues after clear felling or bushfire. In its natural state, the forest is regenerated by seed falling from capsules held in the canopy (seed which falls on the ground is harvested by insects).

The regenerating forest is self-thinning. Starting with around 205,000 seedlings per hectare, this falls to around 17,440/ha at age 8 years, 1,205/ha at age 26 years (the “pole” stage), 227/ha at age 50 years (the beginning of the spar stage), 126/ha at age 80 years, 82/ha at age 150 years and 47/ha at 220 (+ 100) years (Ashton, 1976, p.400).

Understory is fully developed at between 20-30 years (Attiwill, 1994) or 80 years (Vertessey *et al.*, 1998, p.7). Bird life resembles that of the mature forest at between 25-40 years (Attwill, 1994).

Forest height is between 15-35 m at age 15-30 years, 45-60 m at age 40-80 years, 60-100 m at age 100-300 years falling to 30-60 m for “overmature” forest at age 300-400+ years. Average height at maturity (100-300 years) is 75 m with a normal limit of 105 m (Ashton, 1975a, p.868).

Flowers and fruit (which are important food sources for arboreal marsupial mammals, birds and insects) increase with forest age (Ashton, 1975b), as does forest litter (Ashton, 1975c) which provides habitat and food sources for ground dwelling fauna which include the superb lyrebird and the rare smoky mouse (MMBW, 1975, pp.155-157). In the case of forest ground litter, only a marginal increase was found between forest at the spar stage and mature forest (Ashton, 1975c, p.416).

Arboreal marsupials (possums and gliders, including the rare Leadbeater’s possum) and some birds (including the yellow tailed black cockatoo and sooty owl) require hollows for nesting sites (Lindenmayer and Franklin, 1997, Nelson and Morris, 1994). Hollows begin to develop in Mountain Ash forest at around 90 years (Ball *et al.*, 1999, p.189).

The resilience of the Mountain Ash forest to bushfire improves with age. This occurs because trees older than 20 years have thicker bark and are likely to be more fire resistant (Lindenmayer and Franklin, 1997, p.1060). Although Mountain Ash forests flower prolifically at 6-8 years, young trees produce flowers that fail to set fruit in poor (dry) years (Ashton, 1975b, pp.408-409), implying that they may not successfully regenerate after fire.

Kuczera (1985, pp.21-22) deduced from this phenomenon that the 1926 fires could not have been as extensive as the 1939 fires in some of Melbourne’s water catchments: “Thus if large areas of 1926 ash were burnt in 1939 one would expect extensive areas of scrub. However Figure 2-4 indicates otherwise”. The survival of some Mountain Ash trees after fire is important because it produces a regrowth forest of mainly even age with some trees of different vintages contributing to diversity.

We shall now turn to the specification of the function used to represent the non-market component of forest standing value. As noted above, the above ground biomass function for Mountain Ash forest estimated by Grierson *et al.* (1991) has a maximum at 98.09 years.

While much of the non-market standing value of a Mountain Ash forest is likely to have been achieved by 98 years, non-market standing value is likely to continue to increase slowly if old trees with hollows are present in the regrowth forest. This is because Mountain Ash forests increase in height up to maturity at 100-300 years, the number of hollows increases with age after 90 years and, over time, the forest approaches the tree density attained at maturity.

With annual discount rates of 5% and 6% used in this study, a low annual increase in the value of the non-market component of standing value after 98 years will have a negligible effect on present value calculations. Thus, we shall assume that the non-market component of standing value is constant for $t > 98.09$.

The above-ground biomass mass function estimated by Grierson *et al.* (1991, p.16) for Mountain Ash may be written:

$$h(t) = a_1 + b_1 t + c_1 t^2, \qquad \left(R^2 = 0.952\right). \tag{17}$$

In equation (17), $a_1 = 4.9916$, $b_1 = 12.826$, c_1 = -0.065378, $h(t)$ is in tonnes/ha and t is in years. This function has a maximum at $t^* = -b_1/2c_1$ = 98.0911098 years. The above ground biomass per hectare at t^* years is $d_1 = h(t^*) = 634.098306$ tonnes. We shall use this maximum biomass to produce a standardised function to represent the non-market component of forest standing value:

$$\begin{aligned} f_2(t) &= h(t)/d_1 = \frac{1}{d_1}\left(a_1 + b_1 t + c_1 t^2\right), && t \le t^* \\ &= 1 && t > t^*. \end{aligned} \tag{18}$$

The present value of the non-market component of standing value is $pF_2(t)$, where

$$F_2(t) = \frac{1}{d_1}\int_0^t \left(a_1 + b_1 x + c_1 x^2\right) e^{-rx} dx, \qquad t \le t^*$$
$$= \frac{1}{d_1}\int_0^{t^*} \left(a_1 + b_1 x + c_1 x^2\right) e^{-rx} dx + \frac{1}{d_1}\int_{t^*}^{t} d_1 e^{-rx} dx \qquad t > t^* . \tag{19}$$

Evaluating (19) using tabulated integrals (Peirce, 1929, p.53)

$$F_2(t) = A\left(1 - e^{-rt}\right) - Bte^{-rt} - Ct^2 e^{-rt} \qquad t \le t^*$$
$$= A\left(1 - e^{-rt^*}\right) - Bt^* e^{-rt^*} - Ct^{*2} e^{-rt^*} + \frac{1}{r}\left(e^{-rt^*} - e^{-rt}\right) \qquad t > t^* . \tag{20}$$

In equation (20), $A = \left(a_1/d_1 r + b_1/d_1 r^2 + 2c_1/d_1 r^3\right)$, $B = \left(b_1/d_1 r + 2c_1/d_1 r^2\right)$ and $C = c_1/d_1 r$. The limit of $F_2(t)$ as $t \to \infty$ is

$$lim\, F_2(t) = A\left(1 - e^{-rt^*}\right) - Bt^* e^{-rt^*} - Ct^{*2} e^{-rt^*} + \frac{1}{r} e^{-rt^*} . \tag{21}$$

Timber Value

Timber is harvested in the Thomson catchment by private companies, which are licensed by the DNRE. The main timber products are sawlogs and pulpwood. Harvesting and transportation costs are borne by the timber companies and a royalty paid to the DNRE for timber harvested. The timber value function may be written

$$G(t) = p_s f_s(t) + p_p f_p(t) . \tag{22}$$

In (22), $f_s(t)$ is the sawlog yield (m^3/ha), $f_p(t)$ is the pulpwood yield (m^3/ha), p_s (\$/m^3) is the price received by the DNRE for sawlogs (as royalty) and p_p (\$/m^3) is the price received by the DNRE (as royalty) for pulpwood.

The sawlog and pulpwood yield functions for Mountain Ash were estimated from the yield tables published in Read *et al.* (1992, p.8). These tables give the yield (m^3/ha) for sawlogs of grades A and B combined and for sawlogs of grade C in 10 year intervals from age 40 years. For pulpwood, the tables give the yield (m^3/ha) in 10 year intervals from age 30. The yield data beyond age 100 years are considered to be unreliable. The range given in the yield tables reflects the stand ages currently harvested; however, sawlogs are available from Mountain Ash forests from age 20 years (West, 1991, p.33).

The yield functions were estimated by fitting quadratic functions using OLS to the combined sawlog yield data (the yield of sawlogs of grade A and grade B added to the yield of sawlogs of grade C) and to the pulpwood yield data from age 40 to 100 years. The results are as follows (standard errors are in brackets):

$$f_s(t) = \underset{(81.05)}{-148.93} + \underset{(2.447)}{7.7607t} - \underset{(0.01734)}{0.028929t^2} \tag{23}$$

$$R^2 = 0.9749,\ n = 7$$

$$f_p(t) = \underset{(85.33)}{12.143} + \underset{(2.576)}{5.6750t} - \underset{(0.01826)}{0.025357t^2} \tag{24}$$

$$R^2 = 0.9217,\ n = 7\,.$$

The fitted equations have satisfactory coefficients of determination. In the case of sawlogs, the fitted function explains 97.5% of the variation in the yield data and in the case of pulpwood, the fitted function explains 92.2% of the variation in the yield data. However, in both cases only the coefficient on t is statistically significant at the 5% level (one tailed test). The lack of statistical significance of the other coefficients in the estimated equations may be due to the small sample size (n = 7).

Average royalties for Mountain Ash sawlogs at the beginning of 2000 were: $\$85/m^3$ for grade A sawlogs, $\$60/m^3$ for grade B sawlogs, $\$45/m^3$ for grade C sawlogs and $\$10/m^3$ for pulpwood. The average royalties for Mountain Ash wood were calculated by the DNRE from license data for 1999/2000. The expected grade recoveries for sawlogs in the Central Gippsland Forest Management Area (Read *et al.*, 1992) are 1% for grade A sawlogs, 42% for grade B sawlogs and 57% for grade C sawlogs.

The average royalty and sawlog recovery data were used to calculate an average price for sawlogs: $p_s = 85 \times 0.01 + 60 \times 0.42 + 45 \times 0.57 = \$51.70 / m^3$. The price of pulpwood was taken as $p_p =$ $\$10/m^3$. The average sawlog price and the pulpwood price were used in the study as the "base" prices for wood. Base wood prices were inflated by 20% to give the "high" wood prices used for sensitivity analysis.

Discount Rates

The discount rate chosen for the base case in this study is $r = 0.05$. This reflects the real risk-free borrowing rates applicable for Australia over the past four years to 2000. The annual yield on 10 year Australian Treasury Bonds (in December of each year) minus the annual change in the CPI, for each of the past four years to

2000 are as follows: 1996 (5.07%), 1997 (4.75%), 1998 (3.51%) and 1999 (5.76%) for an average annual rate of 4.77%. The base discount rate was inflated by 20% to give the "high" discount rate ($r = 0.06$) used for sensitivity analysis.

Regeneration Costs

Forest regeneration costs are borne by the DNRE and include the burning of residues after logging operations and the aerial sowing of seed. These costs have been estimated by the DNRE to be \$500/ha in 2000. Thus, in this study e = \$500.

4. Results

The results presented in this section were obtained using the software package Shazam version 7.0. As mentioned in section 2, the sufficient conditions for the existence of p_a and p_b were found to hold in practice. The values of p_a and p_b for the functions and parameter values given in section 3 were found by evaluating $V(t_2, p)$ and $V(p)$ (for p_a) and evaluating $W(t_2, p)$ and $W(p)$ (for p_b) on successively refined grids for $p \geq 0$.

Before discussing the major results, we note the following:

(i) By directly computing $V(t, p)$, for selected values of $p \geq 0$, it was found that there was a single $t = t_2$, which satisfied the first and second order conditions $\left(\partial V(p,t)/\partial t = 0, \partial^2 V(t,p)/\partial t^2 < 0\right)$ for a maximum of $V(t, p)$, that is, there was a single internal maximum of $V(t, p)$.

(ii) In doing the grid searches to find p_a and p_b, it was generally found that $\Delta V(t_2, p)/\Delta p > 0$ for $p \geq 0$.

(iii) While it was found that the sufficient conditions for the existence of p_a and p_b were satisfied, it should be noted (setting $t_2 = t$) that: $dD(p)/dp = F_2(t)/\left(1 - e^{-rt}\right) - \lim F_2(t)$ and $dD_1(p)/dp = F_2(t)/\left(1 - e^{-rt}\right) - e^{rt_0}\left(\lim F_2(t) - F_2(t_0)\right)$ are functions of t. By direct evaluation of $dD(p)/dp$ and $dD_1(p)/dp$, it was found that $dD(p)/dp < 0$ and $dD_1(p)/dp < 0$ for $t > 0$, so that p_a and p_b are uniquely determined.

The value of p which (approximately) equated $V(t_2,p)$ and $V(p)$, $p = p_a$, was found (for each set of parameter values) by evaluating these functions on successively refined grids for $p \geq 0$. Beginning with a grid for which $\Delta p =$ \$40, an approximate value for p_a was found, the grid refined until the approximation for p_a reported in Table 1 (for each set of parameter values) was found on a grid of $\Delta p =$ \$5. The difference between $V(t_2,p_a)$ and $V(p_a)$ was small (usually only a few cents) for the values of p_a reported in Table 1. Defining the following percentage error: $E_1 = ((V_2(t_2, p_a) - V(p_a))/0.5(V(t_2, p_a) + V(p_a))) \times 100$, the absolute values of E_1 for the values of p_a reported in Table 1 ranged from a minimum of 0.0% to a maximum of 3.57×10^{-4}%.

The value of p which approximately equated $W(t_2,p)$ and $W(p)$, $p = p_b$, was found (for each set of parameter values) by evaluating these functions on successively refined grids for $p \geq 0$. Beginning with a grid for which $\Delta p =$ \$40.00, an approximate value for p_b was found, the grid refined until the approximation for p_b reported in Table 3 (for each set of parameter values) was found on a grid of $\Delta p =$ \$0.01. The difference between $W(t_2,p_b)$ and $W(p_b)$ was only a few cents for the values of p_b reported in Table 3. Defining the following percentage error: $E_2 = ((W(t_2, p_b) - W(p_b))/0.5(W(t_2, p_b) + W(p_b))) \times 100$, the absolute value of E_2 for the values of p_b reported in Table 3 ranged from a minimum of 1.46×10^{-4}% to a maximum of 5.93×10^{-3}%.

The minimum annual valuation of the non-market component of standing value required to conserve the forest starting with cleared land is given in Table 1 as ANV_1 $(ANV_1 = rp_a \lim F_2(t))$. For the base case (wood prices: $p_s =$ \$51.7/m^3 and $p_p =$ \$10/m^3 and $r = 0.05$), $ANV_1 =$ \$530.56/ha for water price $p_w =$ \$6.69/ML and $ANV_1 =$ \$500.81/ha for water price $p_w =$ \$24.09/ML. For the cases of high wood prices ($p_s =$ \$62.04/m^3, $p_p =$ \$12.00/m^3) and $r = 0.05$, $ANV_1 =$ \$641.30/ha when $p_w =$ \$6.69/ML and $ANV_1 =$ \$611.55/ha when $p_w =$ \$24.09/ML. Thus, ANV_1 is not particularly sensitive to water price but increases substantially (by 20.87% when $p_w = 6.69$ and by 22.11% when $p_w = 24.09$) when wood prices are increased by 20%.

The values of ANV_1 when $r = 0.06$ are also shown in Table 1 and these are close to the corresponding values of ANV_1, calculated when $r = 0.05$.

The annual opportunity cost of not cutting down the forest, starting with bare ground and omitting the non-market component of standing value in the objective function of the optimal rotation problem $V(t,0)$ is shown in Table 2 as ANV_2 $\left(ANV_2 = r\left(V(t_2,0) - \left(\lim F_1(t) - e\right)\right)\right)$. For each set of parameter values, ANV_2 is substantially less than the corresponding value of ANV_1 shown in Table 1. For example, for the base values of the parameters r, p_s, p_p and for $p_w =$ \$6.69/ML, $ANV_1 =$ \$530.56/ha and ANV_2 = \$62.03/ha. Thus, ANV_1 is more than eight times ANV_2.

The minimum annual valuation of the non-market component of standing value required to conserve the forest, starting with a forest aged t_0 = 60 years is given in Table 3 as ANV$_3$ $\left(ANV_3 = rp_b e^{rt_0}\left(lim\,F_2(t) - F_2(t_0)\right)\right)$. For the base case ($p_s =$ \$51.7/m^3, $p_b =$ \$10.00/m^3 and $r = 0.05$), $ANV_3 =$ \$730.06/ha when $p_w =$ \$6.69/ML and $ANV_3 =$ \$714.20/ha when $p_w =$ \$24.09/ML. For the cases of high wood prices ($p_s =$ \$62.04/m^3, $p_p =$ \$12.00/m^3) and $r = 0.05$, $ANV_3 =$ \$883.62/ha when $p_w =$ \$6.69/ML and $ANV_3 =$ \$867.67/ha when $p_w =$ \$24.09/ML.Thus, ANV_3 is not particularly sensitive to water price but does increase substantially (by 21% when $p_w = 6.69$ and by 21.5% when $p_w = 24.09$) when wood prices are increased by 20%.

The values of ANV_3 when $r = 0.06$ are also shown in Table 3 and these are substantially higher than the corresponding values of ANV_3 calculated when $r = 0.05$.

The annual opportunity cost of not cutting down the forest, starting with a forest aged $t_0 =$ 60 years and omitting the non-market component of standing value in the objective function of the optimal rotation problem $\left(W(t,0)\right)$ is shown in Table 4 as ANV_4 $\left(ANV_4 = r\left(W(t_2,0) - e^{rt_0}\left(lim\,F_1(t) - F_1(t_0)\right)\right)\right)$. For each set of parameter values, ANV_4 is smaller than the corresponding value of ANV_3 shown in Table 3, but not by much. For example, for the base values of the parameters, r, p_s, p_p, and $p_w = \$6.69$/ML, $ANV_3 = \$730.06$/ha and $ANV_4 = \$710.54$/ha.

5. Summary and Conclusions

Indigenous forests have high conservation value and omitting this non-market component of forest standing value from the objective function of a problem aimed at finding the optimal forest rotation can be expected to bias results. The difficulty is that the price or value of the non-market component of standing value is unknown.

An important application of the results of optimal forest rotation problems is that of estimating the opportunity cost of not harvesting the forest (or forest preservation). This may be done by subtracting the asymptotic present value of the objective function from the net present value of following an optimal forest rotation policy as estimated by the maximised value of the objective function. However, the omission of the non-market component of forest standing value from the objective function of the optimal rotation problem will produce an erroneous result.

An alternative approach to that of estimating the opportunity cost of conservation is developed in the paper. Assuming that a suitable functional form for the non-market component of forest standing value is known, an estimate of the minimum valuation of the non-market component of forest standing value which would warrant forest conservation may be obtained by finding the price of the non-market component of forest standing value which equates the net present value of the optimal forest rotation policy to the asymptotic present value of the standing value of the forest.

Sufficient conditions for the existence of this value of the price of the non-market component of forest standing value were presented in this paper for the cases of forestry commencing with cleared ground and forestry after harvesting a standing forest aged $t_0 > 0$ years.

The applied results of the paper involved estimating the minimum annual valuation of the non-market component of forest standing value which would warrant conservation of the Mountain Ash forests of the Thomson Dam Catchment in Central Gippsland, Victoria, Australia. These forests have very high conservation value and are also of great scientific interest. For the Mountain Ash forests it was argued that a standardised version of the above ground biomass function for the dominant forest tree (estimated by Grierson *et al.*, 1991) would be a satisfactory functional form for the non-market component of forest standing value.

Starting with cleared ground and using the base set of parameters, r = 0.05, p_s = \$51.7, p_p = \$10.00/m^3 and with the low water price $p_w =$ \$6.69/ML, the minimum annual valuation of the non-market component of forest standing value that would warrant conservation was estimated at \$530.56/ha. Using the same parameter values, the opportunity cost of conserving the forest (obtained by omitting the non-market component of forest standing value from the objective function of the optimal rotation problem) was estimated at \$62.03/ha.

Starting with cleared ground and using the base set of parameters and increasing the water price to $p_w =$ \$24.09/ML, the minimum annual valuation of the non-market component of forest standing value that would warrant conservation decreased to \$500.81/ha. Using the same parameter values, the opportunity cost of conserving the forest (obtained by omitting the non-market component of forest standing value from the objective function of the optimal rotation problem) is \$66.51/ha.

For the base set of parameters and the low water price and starting with a forest aged 60 years, the minimum annual valuation of the non-market component of forest standing value that would warrant conservation was estimated at \$730.06/ha. Using the same parameter values, the opportunity cost of conserving the forest (obtained by omitting the non-market component of forest standing value from the objective function of the optimal rotation problem) was estimated at \$710.54/ha.

For the base set of parameters and the high water price and starting with a forest aged 60 years, the minimum annual valuation of the non-market component of forest standing value that would warrant conservation decreased to \$714.20/ha. Using the same parameter values, the opportunity cost of conserving the forest (obtained by omitting the non-market component of forest standing value from the objective function of the optimal rotation problem) was estimated at \$695.78/ha.

It may therefore be concluded that the estimated opportunity cost of conserving the Mountain Ash forests of the catchment of the Thomson Dam underestimates the minimum valuation of the non-market component of forest standing value that would warrant the conservation of these forests. In the case where forestry commences with cleared ground, the estimated opportunity cost of conservation underestimates the minimum valuation of the non-market component of forest standing value that would warrant conservation by a factor between 7.5 and 8.6.

Results were also presented for wood prices and the discount rate set at 20% higher than the base case.

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Endnotes

[1] Lockwood *et al.* (1993) note that "preserving the forest for its plants and animals" expresses existence value, "keeping the forest for future generations" expresses bequest value, "to know the forest exists" expresses existence value and "to visit the forest" expresses present use and option value.

[2] Let $G(t)$ be the value of timber in a forest of age *t*, $F(t)$ the present value of forest standing value at age *t* and *r* the continuous discount rate. Assume that harvesting and regeneration are costless and that timber prices are constant, then Hartman (1976) shows that forestry involving infinite rotations of age *t* has a present value $V(t) = \left(G(t)e^{-rt} + F(t)\right) / \left(1 - e^{-rt}\right)$. Deleting $F(t)$ from $V(t)$ yields the objective function of the Faustmann problem, $V_0(t) = G(t)e^{-rt} / \left(1 - e^{-rt}\right)$.

[3] Norton (1996, p.22) defines biodiversity as "the variety of life – the different plants animals and microorganisms, the genes they contain and the ecosystems of which they form a part.

[4] Attiwill (1994) notes that all of the species found in mature forests can be found in regrowth Mountain Ash forests which have been logged or burned in the past 50 years but which include large dead or living trees which provide adequate hollows for nest sites (p.315). However, he also states that it takes 20-30 years after logging for the regrowth understory to resemble that of mature forest (p.313) and 25-40 years after logging for the abundance and diversity of birds to be similar to that of mature forest (p.314). Generally, however he notes that vertebrates are more abundant in older forests than in younger forests and that large trees older than 120 years are required to provide nesting sites for many species of possums, gliders, owls and cockatoos (p.314). Thus, it seems that biodiversity is reduced in regrowth forest for up to 40 years after logging and for up to 120 years if adequate nesting sites for some birds and mammals are not provided. Despite this, Attiwill argues that regional biodiversity can be maintained if part of the forest estate is logged, provided that timber harvesting is planned to create a mosaic of age classes so that diversity is maintained for the future (p.334). For an alternative viewpoint, see Lindenmayer (1999, p.281).

[5]Information in this section for which no source is given was obtained from Officers of Melbourne Water or Officers of the DNRE, Victoria or from the websites of Melbourne Water (www.melbwater.com.au), City West Water (www.citywestwater.com.au), South East Water (www.sewl.com.au) and Yarra Valley Water (www.yvw.com.au).

[6] Jayasuriya *et al.* (1993) have experimental evidence supporting the hypothesis that the main difference in stream flow from 50 year old and 230 year old Mountain Ash forest is due to differences in transpiration. Transpiration was higher from a forest stand aged 50 years, than from a forest stand aged 230 years.

[7] A two-part tariff applies for Melbourne's water consumers, and each retailer has a different water tariff for domestic and commercial customers. For domestic consumers, the year 2000 service fee ranged from \$13.15 to \$31.28 per quarter and the year 2000 usage charge ranged from \$0.69/kl to \$0.77/kl. For commercial consumers the year 2000 quarterly service fee ranged from \$36.00 to \$9.38 and the year 2000 usage charge ranged from \$0.67/kl to \$0.70/kl. (See footnote 5).

Table 1: Results for cleared land, standardised biomass in standing value

Discount rate *r* = 0.05

Water Price	Wood Prices (Base) $p_s = \$51.70/m^3$ & $p_p = \$10/m^3$					Wood Prices (High) $p_s = \$62.04/m^3$ & $p_p = \$12.00/m^3$				
	Years	$	$/ha	$/ha	$/ha	Years	$	$/ha	$/ha	$/ha
	t_2	p_a	*AVB*	*AVW-e*	ANV_1	t_2	p_a	*AVB*	*AVW-e*	ANV_1
$6.69/ML	130.94	1605	10611.25	600.66	530.56	130.97	1940	12826.06	600.66	641.30
$24.09/ML	129.37	1515	10016.23	3463.35	500.81	129.68	1850	12231.03	3463.35	611.55

Discount rate *r* = 0.06

	t_2	p_a	*AVB*	*AVW-e*	ANV_1	t_2	p_a	*AVB*	*AVW-e*	ANV_1
$6.69/ML	131.29	1820	8732.74	437.72	523.96	130.76	2195	10532.06	437.72	631.92
$24.09/ML	129.77	1740	8348.88	2876.63	500.93	130.39	2120	10172.20	2876.63	610.33

Note: t_2 is the optimal rotation period, p_a is the price of a standardised biomass unit which equates the net present value of forestry (not in table) to the sum of *AVB* and *AVW-e*. *AVB* is the asymptotic present value of standardised biomass and *AVW-e* is the asymptotic present value of water minus the regeneration cost. ANV_1 is the annual value of standardised biomass obtained using the formula $ANV_1 = r \times AVB$.

Table 2: Results for cleared land, no standardised biomass in standing value

Discount rate r = 0.05

Water Price	Wood Prices (Base) P_s = \$51.70/m^3 & p_p = \$10/m^3					Wood Prices (High) p_s = \$62.04/m^3 & p_p = \$12.00/m^3				
	Years	\$	\$/ha	\$/ha	\$/ha	Years	\$	\$/ha	\$/ha	\$/ha
	t_2	p	*PVF*	*AVW-e*	ANV_2	t_2	P	*PVF*	*AVW-e*	ANV_2
\$6.69/ML	33.40	0.0	1849.19	600.66	62.03	33.29	0.0	2116.75	600.66	75.80
\$24.09/ML	31.19	0.0	4793.49	3463.35	66.51	31.45	0.0	5060.21	3463.35	79.84

Discount rate r = 0.06

	t_2	p	*PVF*	*AVW-e*	ANV_2	T_2	p	*PVF*	*AVW-e*	ANV_2
\$6.69/ML	31.63	0.0	1286.77	437.72	50.94	31.51	0.0	1468.73	437.72	61.86
\$24.09/ML	29.58	0.0	3806.78	2876.63	55.81	29.81	0.0	3988.15	2876.63	66.69

Note: t_2 is the optimal rotation period, p is the price of a standardised biomass unit, *PVF* is the net present value of forestry, *AVW-e* is the asymptotic present value of water minus the regeneration cost and ANV_2 is the annual opportunity cost of not cutting down the forest, starting with cleared land. ANV_2 is obtained using the formula $ANV_2 = r\left[PVF - \left(AVW - e\right)\right]$.

Table 3: Results for forest aged 60 years, standardised biomass in standing value

Discount rate *r* = 0.05

Water Price	Wood Prices (Base) p_s = \$51.70/m^3 & p_p = \$10/m^3					Wood Prices (High) p_s = \$62.04/m^3 & p_p = \$12.00/m^3				
	Years	\$	\$/ha	\$/ha	\$/ha	Years	\$	\$/ha	\$/ha	\$/ha
	t_2	p_b	*AVB*	*AVW*	ANV_3	t_2	p_b	*AVB*	*AVW*	ANV_3
\$6.69/ML	34.86	83.30	14601.31	1245.54	730.06	34.75	100.82	17672.32	1245.54	883.62
\$24.09/ML	32.54	81.49	14284.04	4485.07	714.20	32.83	99.00	17353.30	4485.07	867.67

Discount rate *r* = 0.06

	t_2	p_b	*AVB*	*AVW*	ANV_3	t_2	p_b	*AVB*	*AVW*	ANV_3
\$6.69/ML	32.43	56.73	14075.10	1019.96	844.51	32.32	68.60	17020.13	1019.96	1021.21
\$24.09/ML	30.32	56.16	13933.68	3672.76	836.02	30.56	68.03	16878.71	3672.76	1012.72

Note: t_2 is the optimal rotation period, p_b is the price of a standardised biomass unit which equates the net present value of forestry (not in table) to the sum of *AVB* and *AVW*, where *AVB* is the asymptotic present value of standardised biomass and *AVW* is the asymptotic present value of water. ANV_3 is the annual value of standardised biomass obtained using the formula $ANV_3 = r \times AVB$.

Table 4: Results for forest aged 60 years, no standardised biomass in standing value

Discount rate *r* = 0.05

Water Price	Wood Prices (Base) $p_s = \$51.70/m^3$ & $p_p = \$10/m^3$					Wood Prices (High) $p_s = \$62.04/m^3$ & $p_p = \$12.00/m^3$				
	Years	$	$/ha	$/ha	$/ha	Years	$	$/ha	$/ha	$/ha
	t_2	*p*	*PVF*	*AVW*	ANV_4	t_2	*p*	*PVF*	*AVW*	ANV_4
$6.69/ML	33.40	0.0	15456.36	1245.54	710.54	33.29	0.0	18445.36	1245.54	859.99
$24.09/ML	31.19	0.0	18400.66	4485.07	695.78	31.45	0.0	21388.82	4485.07	845.19

Discount rate *r* = 0.06

	t_2	*p*	*PVF*	*AVW*	ANV_4	t_2	*p*	*AVB*	*AVW*	ANV_4
$6.69/ML	31.63	0.0	14893.14	1019.96	832.39	31.51	0.0	17797.34	1019.96	1006.64
$24.09/ML	29.58	0.0	17413.95	3672.76	824.47	29.80	0.0	20316.76	3672.76	998.64

Note: t_2 is the optimal rotation period, *p* is the price of a standardised biomass unit, *PVF* is the net present value of forestry, *AVW* is the asymptotic present value of water, *ANV4* is the annual opportunity cost of not cutting down the forest. ANV_4 is estimated using the formula $ANV_4 = r[PVF - AVW]$.