Temporary carbon storage and discount rates

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Abstract

Several approaches have been proposed for accounting for temporary carbon sequestration in land-use change and forestry projects that are implemented to offset permanent emissions of carbon dioxide from the energy sector. In a previous paper, we evaluated the incentives provided by some of these approaches. In this paper, we investigate further what we call the "ideal" accounting system, where the forest owner would be paid for carbon sequestration as the service is provided and redeem payments when the forest is harvested and carbon is released back into the atmosphere. We demonstrate how discounting affects the net present value of the forest when carbon sequestration is taken into account under this ideal system. Not all carbon is released back into the atmosphere at harvest, however, since a large proportion may remain fixed in forest products for many years. Here, we compare the profitability of the forest under full redemption of credits at harvest, with partial redemption of credits at harvest followed by annual redemption post-harvest as the carbon decays in a durable forest product. The analysis is based on simulation of farm-forestry systems in south-eastern Australia.

Keywords: carbon accounting, reforestation, discounting, bioeconomics

Introduction

Large-scale transformation of agricultural land to forests will reduce atmospheric carbon. Trees remove carbon dioxide (CO_2) from the atmosphere during photosynthesis, store the carbon (C) in wood, leaves and roots and release the oxygen back into the atmosphere. However, carbon sequestered by trees is not removed from the atmosphere indefinitely, since trees may die, be destroyed (eg. by fire) or be harvested for forest products, and re-emit CO_2. A major concern with the use of forestry and other land-use sinks for greenhouse-gas mitigation is the temporary nature of carbon storage in vegetation and forest products, in contrast to emission reductions in the energy sector which are permanent in the sense that an avoided emission will never reach the atmosphere.

Several approaches have been proposed for accounting for temporary carbon sequestration in land-use change and forestry projects (LUCF) that are implemented to offset permanent emissions of carbon dioxide from the energy sector. In a previous paper, we describe some of these approaches and evaluate the incentives they provide for farm forestry (see Cacho *et al.*, 2003). In this paper, we investigate further what we call the "ideal" system, where carbon-sequestration credits and debits accrue in the

year in which they are incurred. This accounting system is equivalent to the "stock-change" method that the Intergovernmental Panel on Climiate Change (IPCC) has agreed to use in the implementation of LUCF projects under the Kyoto Protocol.

The model is briefly described below, and implemented for a *Eucalypt* forest in Australia. We use the model to investigate how discounting affects the profitability of the forest for timber as well as for carbon. This study was motivated by the analysis of Tomich *et al.* (1997) of an *Acacia mangium* system in South Kalimantan, Indonesia. In their study, Tomich *et al.* (1997) found that at discount rates above 15-20 percent (approximately the real cost of capital in that country), *Acacia mangium* was unprofitable in the absence of carbon-sequestration payments. Including carbon credits with full redemption at harvest increased the profitability of the system significantly. At discount rates above 10-15 percent, the value of carbon outweighed the value of timber.

Acacia mangium is primarily a pulpwood species however, and a substantial proportion of the sequestered carbon will be released back into the atmosphere with the disposal of pulp and paper products. Consequently, the value of the sequestered carbon will be offset by the value of post-harvest carbon emissions. Tomich *et al.* (1997) report that if the half-life of pulp and paper products is 2.5 years, 80 percent of the value of the sequestered carbon will be offset by post-harvest emissions at a zero discount rate, and that this effect diminishes as the discount rate increases. This prompted us to also use our model to investigate the effect on the profitability of the *Eucalypt* forest of different debit regimes based on the rate at which carbon decays in forest products, for a range of discount rates. Some carbon is lost when trees are harvested and when raw timber is processed and converted into forest products, however the fate of the remaining carbon depends on its end use. This is illustrated in Figure 1. For example, carbon in durable forest products such as construction timber may be stored for decades, while carbon in less resilient products such as pulp and paper will be stored for far less time. In this paper, we compare the profitability of the forest with full payment of debits at harvest, and with partial payment of debits at harvest followed by annual payments post-harvest as the carbon decays in a durable forest product.
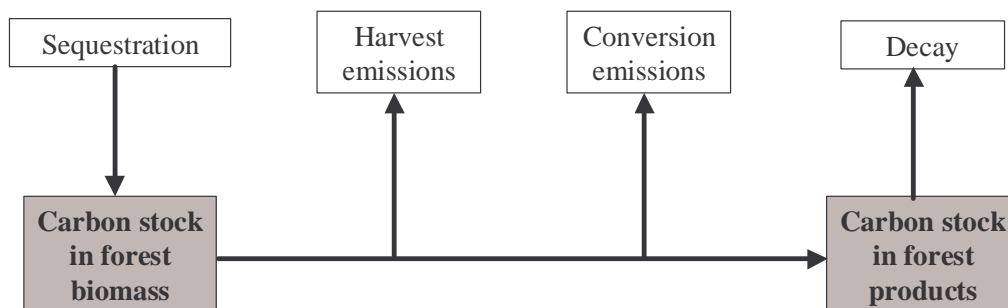

Figure 1. Carbon stocks and flows in forestry systems.

Carbon-accounting model

Consider the case of a landholder evaluating the prospect of planting trees and an investor who is willing to pay price p_b per tonne of carbon sequestered by those trees. The value of a forest stand at harvest in the presence of annual carbon-sequestration payments is:

$$\pi(T) = v(T) \cdot p_v\big(d(T)\big) \cdot [1+r]^{-T} + \sum_{t=0}^{T}\left[\Delta b(t) \cdot p_b \cdot [1+r]^{-t} \right] - c_E - D(T) \tag{1}$$

where $\pi(T)$ is the net present value of the forest harvested in year T after planting. The first term on the right-hand side represents the value of the timber harvest, the second term represents the sum of the annual payments for carbon sequestered in the interval $(0, ...,T)$, c_E is the forest establishment cost, p_v is the price of timber which depends on the average stem diameter (d, cm) of the trees at harvest, and r is the discount rate. The state variables $v(t)$ and $b(t)$ are, respectively, the timber (stemwood) volume in cubic meters per hectare (m³/ha), and the carbon stock in forest biomass in tonnes of carbon per hectare (tC/ha). The last term in equation (1), $D(T)$, is the debit applied upon harvest to account for the release of CO_2 into the atmosphere. With full debit this function is:

$$D(T) = b(T) \cdot p_b \cdot [1+r]^{-T} \tag{2}$$

Equation (2) means that the total amount of carbon credits received during the life of the forest must be paid back (ie. redeemed) to the investor by the landholder at harvest. This implicitly assumes that the contract ends as the sequestered carbon is no longer under the control of the landholder. This scheme is equivalent to the rental carbon market proposed by Marland *et al.* (2001).

Forest growth model

The Chapman-Richards function has been shown to provide a good representation of growth in timber (stemwood) volume, $v(t)$, and basal area, $a(t)$ (Venn *et al.*, 2000, p. 75). So the growth of the forest stand can be represented as:

$$v(t) = \theta_v \big[1 - \exp(-\alpha_v \cdot t)\big]^{\beta_v} \tag{3a}$$

$$a(t) = \theta_a \big[1 - \exp(-\alpha_a \cdot t)\big]^{\beta_a} \tag{3b}$$

where the parameters θ, α and β are determined by the species of tree, environmental conditions and forest management. Once parameterised, equation (3a) is used to estimate timber volume at harvest, while equation (3b) is used to estimate the average diameter of the trees:

$$d(t) = 200 \cdot \sqrt{\frac{a(t)}{\pi \cdot tph}} \tag{4}$$

where tph is the number of trees per hectare. The value of d is used to calculate the price received for the timber harvest:

$$p_v = \gamma_0 + \gamma_1 \cdot d(T) \tag{5}$$

If wood density and the proportion of carbon in stemwood biomass are known, the stock of carbon in stemwood biomass ($w(t)$, tC/ha), can be estimated as:

$$w(t) = \delta \cdot v(t) \tag{6}$$

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where δ is the carbon content per cubic meter of stemwood (tC/m^3). The ratio of forest biomass to stemwood biomass depends on the type of tree and its age. Young trees generally have more branches and foliage relative to stem than old trees. This is represented in the following function, derived from the model of Kirschbaum (2000):

$$b(t) = \phi \cdot \left[(\delta \cdot \theta)^\mu \cdot w(t) \right]^{1/_{1+\mu}} \tag{7}$$

where $b(t)$ is the total carbon stock in the standing forest biomass (tC/ha), ϕ and μ are parameters determined by tree shape, and the remaining variables have been previously defined. Annual changes in the standing carbon stock can now be estimated by differencing:

$$\Delta b(t) = b(t) - b(t-1) \tag{8}$$

This is the stock-change method defined by the IPCC.

Equations (2) (3a), (5), (7) and (8) are substituted into (1) for $t=T$ to solve the carbon-accounting model. Only above-ground biomass carbon has been considered here; $b(t)$ includes stem, branches, and foliage, but not carbon contained in the soil or roots. Including soil and root carbon will increase the stock of carbon that receives payment but will also increase the cost of measuring that carbon; this is discussed by Cacho *et al*. (2002) and is not considered further in this paper.

Land-use scenarios and model calibration

Tree-growth parameters for equations (3a) and (3b) are presented in Table 1 for two sites in south-eastern Australia. These parameters were estimated statistically based on values reported by Wong *et al*. (2000) for *Eucalyptus nitens* (commonly known as Shining Gum). Site 1 has high rainfall and Site 2 has moderate rainfall. Further details about the sites are presented in Cacho *et al.* (2003).

Table 1. Tree parameter values used in the model, estimated from data reported by Wong *et al.* (2000).

Parameter	Site 1	Site 2
θ_v	842.87	262.96
α_v	0.190	0.252
β_v	3.759	4.651
θ_a	69.54	30.12
α_a	0.139	0.383
β_a	1.724	5.000

Observed and predicted timber volumes for *E. nitens* for the two sites are presented in Figure 2. It is obvious that the growth function (3a) provides a good fit to the data, however data were only available for trees up to 10 years of age; this means that predictions regarding the steady state which is reached after year 30 are uncertain. However, the predicted maximum volumes (given by θ in Table 1) at steady state are plausible (863 m^3/ha and 263 m^3/ha for sites 1 and 2 respectively).

Base values for other parameters used in the numerical model are presented in Table 2.

The model was implemented for both Site 1 and Site 2 for the base parameter values presented in Tables 1 and 2, for a hypothetical project of 30 years duration (ie. T=30) and discount rates between zero and 25 percent.
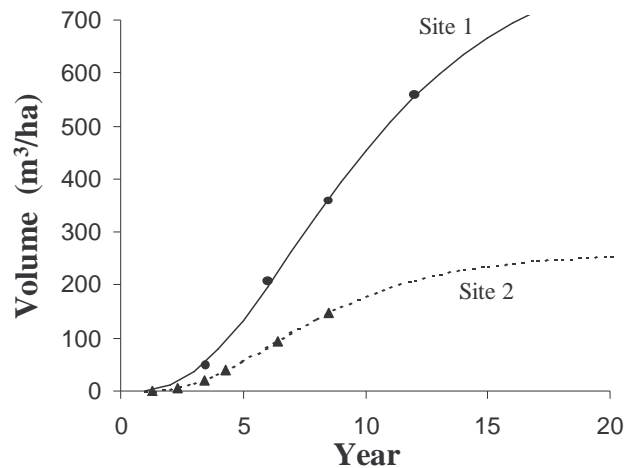

Figure 2. *Eucalyptus nitens* growth at the two sites. Predicted and observed values for Site 1 (solid line and dots respectively) and Site 2 (dashed line and triangles respectively). Data from Wong *et al*. (2000).

Table 2. Base parameter values.

Parameter	Value	Units	Description	Source
γ_0	-4.342	$	timber price intercept	d
γ_1	0.936	$/cm	timber price slope	d
p_b	20	$/tC	price of carbon	f
Tph	250	trees/ha	tree density	e
c_E	2,300	$/ha	establishment cost	a
δ	0.378	t C /m^3	carbon content of wood	b
ϕ	1.429	*	biomass in mature forest relative to stemwood biomass	c
μ	0.2	*	forest biomass parameter	c

* unitless coefficient.

Sources: a: Hassall and Associates (1999); b: estimated as wood density $\times$ C content of biomass = 0.7 (t/m^3) $\times$ 0.54; c: calculated from parameters presented by Kirschbaum (2000); d: linear approximation to assumed data following discussions with Signor (2001, pers. comm.); e: assumed value following discussions with Signor (2001, pers. comm.); f: arbitrary value subject to sensitivity analysis.

Results

Figure 3 illustrates the effect of discounting on the net present value of the project for both sites, with full debit at harvest. As expected, the net present value of the timber harvest decreases as the discount rate increases. Timber returns eventually become negative, this occurs at a discount rate of 10 percent for Site 1 and four percent for Site 2. In contrast, the net present value of carbon sequestration (the stream of annual

credit payments less redemption at harvest) increases until it reaches a maximum (of $2166 for Site 1 and $784 for Site 2, at a discount rate of six percent) and then decreases as the discount rate increases further. This occurs because discounting has less effect on the stream of credit payments than it does on the one-off redemption payment at the end of the project, for discount rates up to six percent. This is demonstrated in Figure 4, where the value of credit payments initially decreases more slowly than the value of the debit payment. This effect is greatest for the higher-quality site (Site 1) at which more carbon is sequestered.
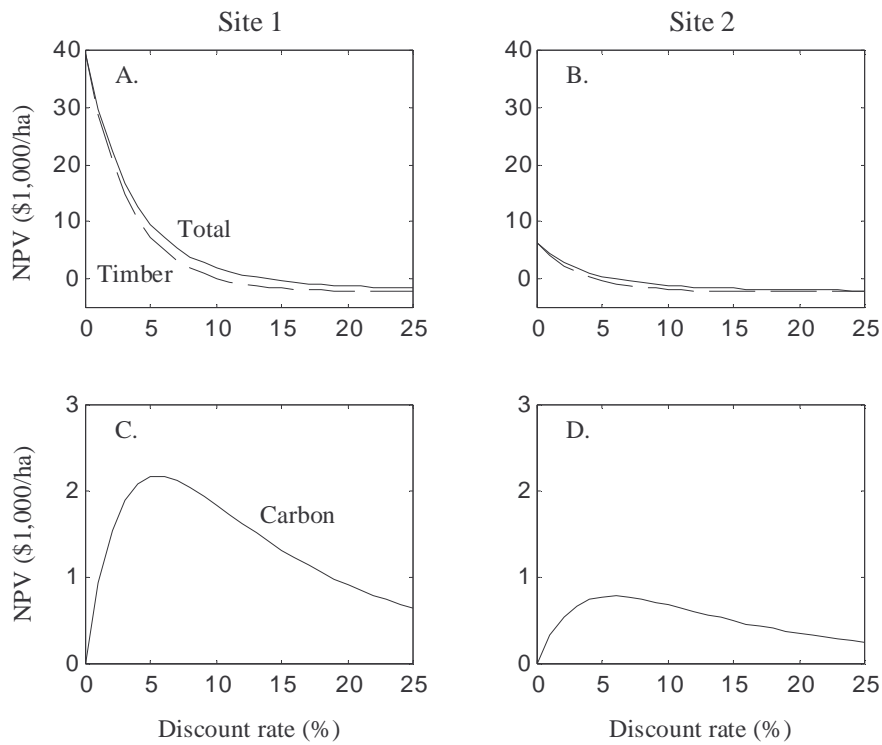

Figure 3. Present value of profits for Site 1 (charts A and C) and Site 2 (charts B and D). The top charts are total profits (solid line) and profits from timber harvest (dashed line), and the bottom charts are profits from carbon sequestration (solid line).
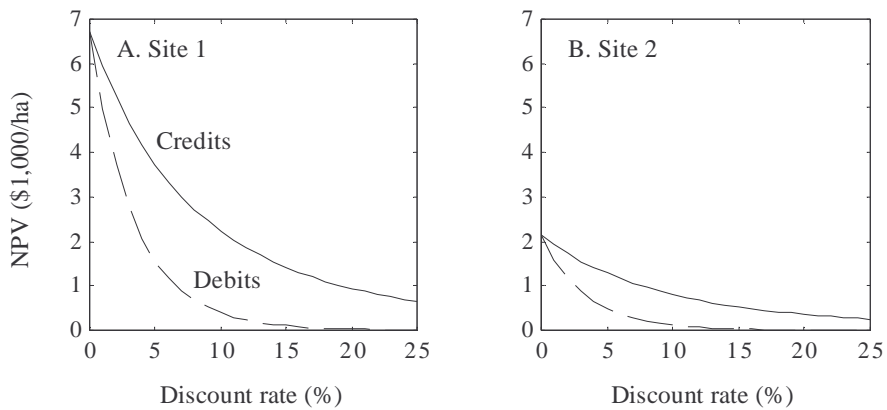

Figure 4. Present value of annual credit payments (solid line) and the one-off debit payment (dashed line) for Site 1 (chart A) and Site 2 (chart B).

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These results clearly demonstrate that temporary carbon sequestration has a positive net value when discount rates are greater than zero, and that this value increases as the discount rate increases up to a maximum, even when carbon payments are paid back in full at harvest. It is also obvious that the project is unprofitable in the absence of carbon-sequestration payments for both sites at even conservative discount rates (10 percent for Site 1 and four percent for Site 2). However, even with carbon credits, the project remains unprofitable at discount rates above 14 percent for Site 1 and six percent for Site 2 (Figure 3).

The discount rates at which NPVs become zero in Figure 3 represent internal rates of return for the project. These values are 10 percent and four percent for timber alone (IRR_W), and 14 percent and six percent for timber plus carbon sequestration (IRR_P), for Site 1 and Site 2 respectively. IRR_W and IRR_P form the bounds of a "critical interval" of discount rates. Within this interval carbon payments "swing the deal" and make the project profitable (NPV>0).

The critical interval is illustrated in Figure 5, by the shaded area, which represents the returns from carbon sequestration. At discount rates below IRR_W, the landholder will establish the forest for timber alone. Between IRR_W and IRR_P, the landholder will establish the forest if carbon payments are also received. Above IRR_P the landholder will not establish the forest because it is unprofitable.
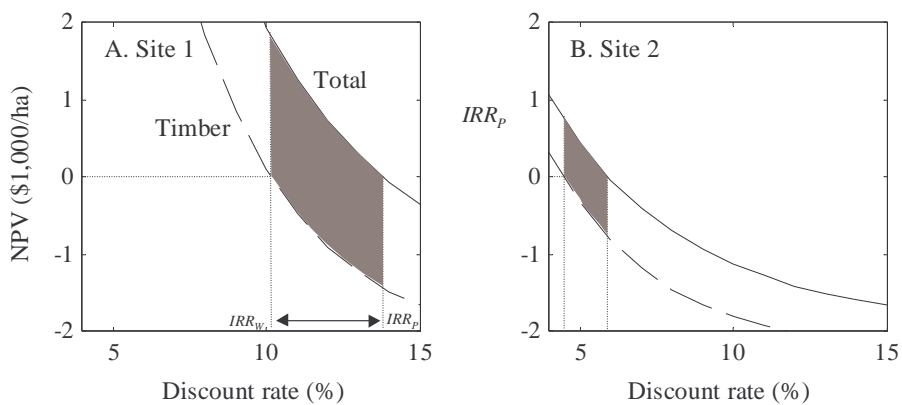

Figure 5. Present value of total profits (solid line) and profits from timber harvest (dashed line) for Site 1 (chart A) and Site 2 (chart B). The shaded area represents the critical interval where carbon payments "swing the deal".

Including carbon payments clearly increases the profitability of the project, and the value of carbon outweighs the value of timber at discount rates above eight percent for Site 1 and above four percent for Site 2. This is illustrated in Figure 5, where the two curves intersect. To the left of the intersection point timber is more valuable than carbon and this relationship is reversed to the right of the point.
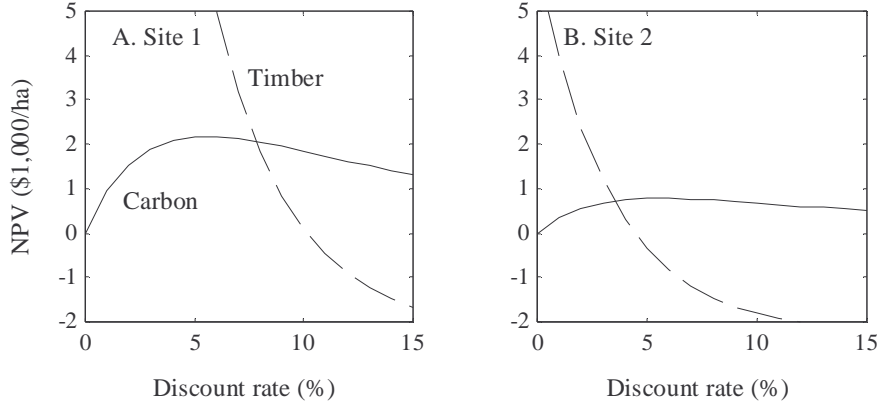
Figure 5. Present value of profits from carbon sequestration (solid line) and timber harvest (dashed line) for Site 1 (chart A) and Site 2 (chart B).

Analysis of post-harvest emissions

Carbon decay in forest products can be described by its half-life, which is the time required for one-half of the carbon to decay before being released back into the atmosphere as CO_2.

Below, carbon in forest products is assumed to be released back into the atmosphere after harvest, based on a half-life of H years. Some carbon is lost in the process of harvesting and converting trees into forest products (recovery). The carbon stock remaining in forest products at a given point in time ($f(t)$, tC/ha) is given by:

$$f(t) = R \cdot b(T) \cdot \exp\left(\frac{\ln\left(1/2\right)}{H} \cdot (t - T) \right) ; \; for \; t > T \tag{9}$$

And the debit function (2) becomes:

$$D(T) = \sum_{t=T}^{N} \left[f(t+1) - f(t) \right] \cdot p_b \cdot \left[1 + r \right]^{-t} \tag{10}$$

where N is a suitably long planning horizon to account for the life of forest products (in this analysis assumed to be 30 years). This equation is substituted into (1) to obtain the results presented in Table 3. The recovery (R) is assumed to be 0.5, and a half-life (H) of 50 years is used for illustration. Some debits are therefore paid up-front at harvest, while the remainder are paid annually post-harvest as the carbon decays in the forest product (ie. the redemption period is extended). In Table 3 this scenario is compared with the results under full debit at harvest from the previous section, which equates to a half-life of zero.

The value of carbon redemption is significantly lower when the half-life is longer (Table 3). This occurs because post-harvest debit payments are delayed and therefore more heavily discounted. This effect is greater for the higher-quality site (Site 1) at which more carbon is sequestered. The value of carbon redemption offsets the value of sequestered carbon (ie. the gross carbon payment) by a smaller proportion when the half-life is longer. For Site 1, 42 percent and 25 percent of the value of the sequestered carbon is offset by debit payments within the post-harvest time horizon considered here, for the half-lives of zero and 50 years respectively, when r is five

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percent. This effect diminishes as the discount rate increases, and is negligible (ie. one percent or less) for both half-lives when r is 25 percent. For Site 2, these trends are similar. Although much of the carbon is returned to the atmosphere within 30 years of harvest, there is still a substantial benefit from carbon sequestration. Were the planning horizon extended for the analysis, a greater proportion of the sequestered carbon value would be offset by post-harvest emissions, and the benefit from carbon sequestration would be reduced.

Table 3 also shows that varying the timing of debit payments has a relatively insignificant effect on the total profitability of the forest, particularly at high discount rates. Although the forest is clearly more profitable at a discount rate of 5 percent when H is 50 years, it remains unprofitable at discount rates of 15 and 25 percent. This result holds for both sites.

Table 3. Present values of various forest components for both sites.

Present value of various Forest components ($1,000)	Site 1 Discount rate (%)			Site 2 Discount rate (%)		
	5	15	25	5	15	25
Forest product (a)	7,335	-1,671	-2,248	-340	-2,172	-2,290
Gross carbon payment (b)	3,720	1,417	660	1,275	532	261
Carbon redemption (c):						
$H = 0$ years	1,557	102	8	496	32	3
$H = 50$ years	921	55	4	294	18	1
Net Carbon benefit ($b - c$):						
$H=0$ years	2,163	1,315	652	779	500	258
$H=50$ years	2,799	1,362	656	981	514	260
Total Benefit ($a + b - c$):						
$H=0$ years	9,498	-356	-1,596	439	-1,672	-2,032
$H=50$ years	10,134	-309	-1,592	641	-1,658	-2,030

Sensitivity Analysis

We evaluated the effect of changes in the price of carbon and the duration of the project on the internal rate of return of the project (timber plus carbon sequestration, IRR_P). The model was solved for a range of carbon prices (ranging from $5/tC to $50/tC) and for two project lengths (20 years and 30 years).

Results are presented in Table 4, for both full debit at harvest, and delayed debit payments. As expected, increasing the price of carbon, increases IRR_P, since returns from carbon sequestration, and hence total profits, are higher at all discount rates. Increasing the project length reduces IRR_P. Timber returns are lower at all discount rates, because the growth of the trees is relatively unchanged but the harvest is delayed and hence more heavily discounted. In contrast, carbon returns are higher because discounting has more effect on the value of the one-off redemption payment

at the end of the project than on the stream of credit payments. Nevertheless, total project profits are lower at all discount rates. Interestingly, the results are unchanged for delayed debit payments, for any value of N. This result is not investigated further here.

Table 4. Internal rates of return for timber plus carbon sequestration (IRR_P), with full debit at harvest, for both sites.

Project length (T, years)	IRR_P (%)					
	Site 1			Site 2		
	Price of carbon ($/tC)			Price of carbon ($/tC)		
	5	20	50	5	20	50
20	15	18	23	7	8	11
30	11	14	21	5	6	10

We also evaluated the effect of changing the duration of the project on the internal rate of return of timber alone (IRR_W), in order to assess the sensitivity of the critical interval of discount rates over which carbon payments "swing the deal". (Changing the price of carbon will obviously have no effect on IRR_W and was therefore not considered). Results are presented in Table 5.

Table 5. Internal rates of return for timber (IRR_W), with full debit at harvest, for both sites.

Project length (T, years)	IRR_W (%)	
	Site 1	Site 2
20	15	7
30	10	4

By comparing Tables 4 and 5, it is clear that increasing the project length expands the critical interval of discount rates over which carbon payments provide the incentive for the landholder to establish the forest. This effect is greater at higher carbon prices. For example, when carbon is $50/tC, carbon payments "swing the deal" when discount rates are between 15-23 percent for a 20-year project, and between 10-21 percent for a 30-year project, for Site 1.

Summary and conclusions

This paper was motivated by the observations of Tomich *et al*. (1997) regarding the effect of discount rates on the profitability of an *Acacia mangium* system grown for pulp and paper products and carbon sequestration. Here we present an analysis of the "ideal" carbon-accounting method proposed by Cacho *et al*. (2003) for a *Eucalypt* forest in Australia. Our results corroborate those from Tomich *et al*. (1997). As expected, the net present value of harvested timber decreases with increasing discount rates (and vice versa for decreasing discount rates). However, in contrast, the net present value of temporary carbon sequestration increases to a maximum and then decreases. We also found that the value of carbon sequestration is offset by the value of carbon redemption, and that this effect is greatest when debits are paid in full at harvest, and diminishes as the discount rate increases. The results of sensitivity analysis indicate that the internal rate of return of the project increases with increases in the carbon price and decreases in the project length, and that the critical interval of

discount rates over which carbon payments "swing the deal" expands with increases in the project length.

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