Economics of Forests as Carbon Sinks: An Australian Perspective

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Abstract

The Australian government is currently assessing the viability of using forestry carbon sinks as a means of meeting its CO_2 emission target under the Kyoto Protocol. As a direct consequence, the economic value of forests is undergoing significant change. Timber is no longer the only product to be taken into consideration when managers determine the profit maximising time to harvest. The effectiveness of policy in this area depends crucially on how the commercial forestry sector responds to such changes in value. Theoretical results conclude that a plantation for which carbon sequestration is taken into account will have a longer rotation than a forest which is grown for timber only. The particular institutional arrangements for recognising carbon sequestration will determine the extent to which the theoretical results will be played out. The Kyoto Protocol imposes some unique international institutional constraints.

This paper draws on the well known Faustmann theory to simulate the optimal forest rotation using Australian data. The results have implications for the commercial forestry sector and therefore for the effectiveness of Australian and international greenhouse policy.

Keywords: Carbon sinks, economics, greenhouse policy, plantation forestry.

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Introduction

Concern about the possible effect of global warming has led to international discussion on how carbon dioxide emissions should be reduced. Both a carbon tax and an emissions trading system aim to give value to carbon, encouraging net emitters to include the value of carbon in their production costs. One way to offset emissions, (and therefore costs), is to plant trees which sequester carbon dioxide. Placing a special value on carbon is likely to have an impact on the way in which plantation forests are managed. The Kyoto Protocol sets down some specific boundaries within which forests can be used to offset emissions.

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This paper aims to predict how explicitly recognising the value of carbon dioxide will change the management of commercial plantations in Australia. Implications of this prediction will be analysed in light of the unique institutional arrangements of the Kyoto protocol.

We begin by providing important background on international and Australian greenhouse policy resulting from the Kyoto protocol, including the definition and role of forests as carbon sinks. The conceptual framework of forest management is described and then simulated using Australian data. We continue by examining the implications of the results for the forestry sector and greenhouse policy. The paper is concluded with key findings and areas for further research.

GREENHOUSE POLICY

Kyoto

At the Kyoto Climate Change Conference held in December 1997, an agreement was reached between industrialised nations to reduce their collective greenhouse gas emissions by a total of 5.2% by the first commitment period, 2008–2012. Kyoto was the third conference of the parties of the United Nations Framework Convention on Climate Change (UNFCCC). Australia's commitment to the agreement involves an allowance to increase its emissions by 8% on the 1990 base year level (Department of Foreign Affairs and Trade, 1998). Australia's original projection of emissions growth was 43% above 1990 levels by 2008–2012 (Department of Foreign Affairs and Trade,1998, p. 3). According to Australia's second national communication to the UNFCCC Australia's business-as-usual greenhouse emissions in 1990 were 380Mt (Sturgiss, 1998). At this point, only one commitment period has been ratified. The timing of future commitment periods has not been announced and therefore it is unknown whether they will be run sequentially or separated by a period of years. It is believed that the commitment period approach was adopted because of the perceived difficulties of continuous measurement and reporting.

Other industrialised nations such as Japan and the United States face more stringent reductions, agreeing to reduce their emissions by 6% and 7% respectively. Australia, who is the 16th largest emitter by volume of carbon dioxide (CO_2) and the 2nd largest emitter when ranked on a per capita basis, argued at Kyoto that uniform reductions should not be enforced (U.S. Department of Energy, 1994). The Australian government put forth the argument that Australia would be disadvantaged by a uniform target relative to other developed nations such as those in the European Union. The Australian government's strong opposition to the uniform targets at Kyoto was based on the premise that as the world's largest coal exporter, the third largest aluminium exporter, and one of the largest energy exporters amongst OECD countries, it would incur a higher cost as these areas of export strength are CO_2 emission intensive (Australian Aluminium Council, 2000).

Australian Government's Greenhouse Policy

Whilst the Australian government is in the process of developing its greenhouse policy, there are two main schools of thought on the type of policy which could be used to meet the Kyoto target. Both are market-based instruments, which are generally regarded as more efficient than 'command and control' measures such as direct regulation (Cornwell *et al*., 1997).

One such instrument is a carbon dioxide (CO_2) tax, which could be implemented on a per tonne basis of CO_2 emitted. It has been proposed that such a tax would need to be levied at the rate of $26 per tonne of carbon dioxide ($100 per tonne of carbon) to meet Australia's Kyoto target (Cornwell *et al*., 1997, p. 8). The energy sector of the Australian economy is responsible for the majority of greenhouse emissions and is therefore the principal target of a carbon tax. Whilst the transportation and agricultural sectors of the Australian economy are also responsible for a significant proportion of total emissions, they are not the main focus of a carbon tax. Motor vehicles account for approximately 23 per cent of CO_2 emissions in Australia. As each vehicle emits about one tonne of CO_2 a year the monitoring costs of imposing a carbon tax would be high (Hinchy *et al*., 1998, p.26). This is in contrast to fossil fuel electricity generators who each emit around 17 million tonnes of CO_2 per annum (Hinchy *et al*., 1998, p.26).

A second policy option is to establish a market for tradeable CO_2 permits. Each permit entitles the holder to emit one tonne of CO_2. Under this policy companies can openly trade their certificates with one another. The permit price is set by the market, subject to the total number of permits initially allocated.

The most important consideration for any government party to the Kyoto Protocol is to ensure that the policy measures achieve the nation's target during the set commitment period. Countries party to the agreement must measure and report the level of greenhouse emissions during the period of time 2008–2012, but are not obliged to report accumulated emissions prior to 2008 or any emissions occurring after 2012. The Protocol therefore gives incentive for these countries to develop policies that lower emissions only during the commitment period, rather than policies that lower total emissions in the long term. In practice such a policy approach may not be feasible for all sectors of the economy, given the difficulty of suddenly reducing emissions when the year 2008 arrives. Each country's greenhouse policy is therefore likely to comprise a mix of longer-term emission reduction strategies and commitment period specific policies. For example, a carbon tax implemented some years prior to 2008, combined with a subsidy to encourage stockpiling of emission intensive commodities before 2008 and the subsequent ceasing of production until 2013.

Carbon Sinks

The use of 'carbon sinks' to offset CO_2 emissions was accepted by the Parties to the agreement at Kyoto. A carbon sink is a naturally occurring mechanism that removes carbon dioxide from the atmosphere (Kahn, 1997).

The creation of carbon sinks through new forest plantations reduces the amount of CO_2 stored in the air. While a forest is growing, CO_2 is absorbed into the trees (Gunasekera & Cornwell, 1998, p. 20). The rate of tree growth is the main determinant of the extent of carbon sequestration. A mature forest has a zero net effect on the level of CO_2 in the atmosphere because of the combined effect of a slow growth rate and degeneration which results in the gradual re-release of CO_2. In addition, different types of trees have different storage values of carbon and sequester CO_2 at different rates over time (Kahn, 1997, p.171). When trees are harvested, all of the carbon is eventually released as carbon dioxide into the atmosphere (Kahn, 1997, p.171). The rate of re-emission depends upon how the timber is used. Carbon preserved in wood products such as construction materials, furniture and books have different rates of decay. Forests therefore act both as a source and a sink of CO_2 depending on the forest life-cycle and timber uses.[1]

Carbon Sinks and Kyoto

The recognition and acceptance of carbon sinks is encompassed by a number of regulatory rules outlined by the UNFCCC. "The Kyoto Protocol as it now stands says that emissions and removals of greenhouse gases by certain land clearing and forest activities commenced since 1990 can be counted in meeting a country's commitments. For Kyoto Protocol accounting purposes, trees planted today will only have their carbon absorption counted during the period 2008–2012" (Greenhouse Response Branch., 1998). This has important ramifications for the forest plantations as CO_2 absorbed by the trees between now and 2008 will not be counted. The accurate scheduling of plantations so that maximum CO_2 absorption occurs between 2008–2012 is essential to the Australian government in its bid to reduce overall emissions during the commitment period.

According to the Protocol, 'greenhouse gas emissions from sources and removal by sinks resulting from direct human-induced land-use change and forestry activities limited to afforestation, reforestation and deforestation since 1990' can be included as part of the measurement toward Australia's target (Greenhouse Response Branch., 1998). Managed native forests and plantations established before 1990 are not included (Greenhouse Response Branch., 1998). Provided that they are established after 1990, activities such as commercial plantations, environmental plantings, windbreaks and shelter belts will be recognised as carbon sinks if they are of sufficient scale to qualify as a forest (Austral-

[1] "In a typical plantation or naturally regenerating forest, biomass accumulation usually occurs relatively slowly in the early stages following planting or regeneration. The process accelerates as the trees increase in size and maturity, potentially reaching a steady or declining state as mature trees begin to decay. Harvesting, disturbance by fire, storm or pests, or clearing will result in re-emission of sequestered carbon" (Australian Greenhouse Office, 1998, p. 6).

ian Greenhouse Office, 2000, p. 32).

Countries that plant trees post-1990 will only be entitled to credits for sequestration that occurs during the five-year commitment period. If those trees are harvested during the commitment period, the Party would be liable for emission debits equal to the entire growth of the tree (Australian Greenhouse Office, 2000, p. 85). Hence, trees harvested during the commitment period will be deemed to have released carbon emissions greater than the carbon they have sequestered from the atmosphere (Greenhouse Response Branch, 1998.) The carbon penalty will act as an incentive to refrain from harvesting during the commitment period. The UNFCCC's decision to treat forests harvested during the commitment period as net emitters will result in countries preventing forests from being harvest during 2008–2012. In terms of Australian government policy it is likely to obstruct harvest by introducing legislation or imposing a large financial penalty on forestry owners who harvest during the commitment period. This is an example of a specific commitment period policy aimed at achieving the nation's Kyoto target.

In the Australian context, carbon sinks would most easily be incorporated into a domestic emission trading regime. For every tonne of CO_2 sequestered by the forest sink, an emission permit would be allocated. The permit could be used to offset the carbon sink owner's emissions or sold to another party at the market price. Each year the forest owner would receive an emission permit equivalent to the sequestration of the forest. At the time of harvest the forest owner would be liable for the re-emission of the carbon into the atmosphere. The forest manager would then have to hold permits equal to the annual permits he had received. Over the long term, forest managers would see little value in investing in forests as carbon sinks, limiting the effectiveness of greenhouse policy.[2]

Achieving the Desired Result

[2] If the permit price is known, the forest owner would be better off receiving permits annually, due to the present value of the dollar. If however the market allows the price to fluctuate, these benefits may not be realised.

There are many risks associated with including carbon sinks in a Party's proposal to meet its target as they "cannot be measured with an acceptable level of certainty and are at risk of being destroyed through events such as fire" (Australian Greenhouse Office, 2000, p. 83). It is for these reasons that many of the Parties to the Kyoto Protocol seek to limit the acceptance of carbon sinks in meeting target commitments. Australia, on the other hand, is in favour of the inclusion of carbon sinks as it acknowledges the contribution they could make toward the attainment of its target. As mentioned above, Australia is an emission intensive exporter with few viable methods of low-cost abatement in the fossil fuel sector. Australia is however abundantly rich in the scarce resource of land relative to other countries such as many in the European Union. There is potential for Australia to exploit this position and make significant land use changes.

If carbon sinks are to make a contribution to solving the problem of global greenhouse emissions, much work needs to be done on the establishment of universal guidelines for accurate measurement. Factors such as the type of trees, the density of the stand, the age of the trees, and the natural environment all impact upon how much carbon is sequestered by any one forest. In Australia alone the difficulty of carbon sink measurement is evident as sequestration levels vary between regions. According to research into the nature of carbon sinks, "biospheric emissions and sequestrations from sources and sinks vary significantly on an inter-annual an decadal time-scale due to climatic changes (precipitation and temperature) as well as location and seasonal factors" (Australian Greenhouse Office, 2000, p. 83).

In an attempt to address the uncertainty of measurement, the Protocol states that each Party must have a national system to measure anthropogenic emissions by sources and removals by sinks, by the year 2007 (Australian Greenhouse Office, 2000, p. 79). Australia is adopting a coordinated approach whereby all available commercial and natural resource data is being used to supplement current information to produce a robust inventory (Australian Greenhouse Office, 2000, p. 81). International suggestions to combat measurement difficulties include the adaptation of what is known as the 'Kyoto lands accounting approach'. Kyoto lands are those forests which have been established since 1990. Once a piece of land is known as Kyoto land, the Party would be obliged to report changes in carbon stock on that land over the first and subsequent commitment periods, irrespective of whether the change in carbon stock was the result of a natural process or due to human intervention (Australian Greenhouse Office, 2000, p. 26). The argument in favour of the Kyoto lands approach is that it simplifies the measurement process as regular monitoring makes it easier to verify the changes in the carbon stock.

CONCEPTUAL FRAMEWORK

Recognising forests for their carbon sequestering properties is likely to change the way in which the world thinks about forests. In particular, private property owners will explicitly incorporate carbon into decisions about land use, along with the more traditional uses such as forestry for timber production and the various forms of agriculture. The well-established fields of natural resource and agricultural economics provide a conceptual framework that describes and analyses the traditional land use decision making processes. The concept of forests as carbon sinks adds another dimension to the forest management process. The economic theory surrounding forest economics can therefore be adapted to predict how forest owners, investors and managers will respond when carbon is included as a specific decision variable.

This paper is limited to consideration of decisions made by owners and managers of commercial forest plantations. This simplifies the conceptual framework and is in keeping with the Kyoto protocol, which only counts anthropogenic land use changes. After a decision is made to select forestry as the most profitable land use, an additional choice must be made about how often to harvest and replant a stand of trees so that profit is maximised. Economic theory provides an answer in the form of an optimal forest rotation.

The Literature

There is a well established body of literature which discusses the optimal time to harvest a stand of trees. The Faustmann calculation is generally regarded as the financially correct solution to the problem of when to cut down a stand of even aged trees (Faustmann, 1995). It maximises net financial benefit to the owner when timber is the only benefit to be derived. Hartman adjusted this calculation to take account of non-timber benefits such as those relating to the environment and water catchment, which is useful when analysing the multiple uses of public forests (Hartman, 1976). Works by Plantinga and Birdsey along with van Kooten, Binkly and Delcourt have adapted the Faustmann solution to include the benefits of carbon sequestration (Plantinga & Birdsey, 1994; van Kooten *et al*, 1995). Stavins draws on previous works and develops a model to address their shortcomings in analysing land use decisions with regard to forests as carbon sinks (Stavins, 1999)

The original Faustmann solution is presented below, followed by van Kooten's adaptation of the model to include carbon as a specific decision variable. The van Kooten approach has been used for this analysis because it incorporates variables useful for policy discussion whilst maintaining the simplicity of the Faustmann presentation. The presentation and notation used for both of these cases is taken from Bowes & Krutilla (1989).

The Models

The Faustmann approach to the optimal forest rotation is summarised as follows:

$$\frac{Pv'(t)}{\left[Pv(t)-C\right]}=\frac{r}{1-e^{-rt}}, \tag{1}$$

where

P = Price per cubic metre of timber,

$v(t)$ = Volume of timber which is a function of time (t),

C = planting costs,

r = discount rate, equal to the market rate of interest, and

$1-e^{-rt}$ adjusts the rate of interest for an infinite number of rotations.

Equation 1 is solved for t to obtain the optimal rotation period, T_F, where timber is the only product considered.

Carbon is sequestered by trees on a continuous basis according to the growth rate of the trees. A forest owner could therefore claim annual receipts for the value of the carbon sequestered over the growing period. Upon harvest, the forest owner incurs a financial penalty for the total amount of carbon that is re-emitted. If the trees were grown solely for the purpose of sequestering carbon, economic theory suggests that they should be left standing forever so that the owner would avoid paying for the re-emission of CO_2 upon harvest. This approach however ignores the opportunity cost of using the land on a continuous basis. The land could be used for some other form of agriculture or to replant a faster growing plantation.

The 'timber only' Faustmann model is therefore adjusted by van Kooten to include benefits and costs from carbon as follows:

$$\frac{\left[(P_F + P_C\alpha\beta)\dfrac{v'(t)}{v(t)} + rP_C\alpha\right]}{\left[(P_F + P_C\alpha\beta) + \dfrac{rP_C\alpha}{v(t)}\displaystyle\int_0^t v(t)e^{-rt}dt\right]} = \frac{r}{1-e^{-rt}} \tag{2}$$

where

P_F = net price of timber per cubic metre,

P_C = price per ton of carbon that is removed from the atmosphere (probably equivalent to the price of an emission credit),

α = conversion factor from tons of carbon to cubic metres of timber (metric tons of carbon per m^3 of timber biomass),

β = proportion of timber that is harvested but goes into long-term storage (pickling factor), and

r = rate of interest.

Equation 2 is solved for t to obtain the optimal rotation period, T_{FC}, where both timber and carbon sequestration products are considered.

The pickling factor β is significant in this model as it recognises that harvesting will not automatically cause re-emission of the total amount of carbon sequestered over the life of a tree. A proportion of the total carbon may be captured and stored in timber products. The value of growth for an additional year only therefore includes the 'pickled' carbon benefits plus the timber benefits.

Stavins (1999) recently asserted that the van Kooten model assumed land (opportunity) costs to be zero. As illustrated by Samuelson (1976), adjusting r for an infinite number of rotations has the same effect as explicitly including land costs.

SIMULATION OF THE MODEL

Data

Data is based on assumptions about growing conditions, species, timber uses and timber prices in the Central Gippsland area of the State of Victoria in south-eastern Australia. Plantations in this area mostly comprises the *Eucalyptus globulus* species planted on medium to poor site quality. The volume function of the trees with respect to time, $v(t)$ is provided by Australian Paper Plantations in the form of a yield table (Australian Paper Plantations, pers. comm., 1999). The trees from these plantations are likely to be used either for white paper production or sawn timber upon harvest, giving two variations on both the price of timber, P_F and the pickling factor, β (Australian Paper Plantations, pers. comm., 1999). The price per tonne (Australian dollars) of carbon, P_C is unknown at this point in time. Three iterations of the model are carried out, testing P_C at \$30, \$100 and \$180 per tonne of carbon. These prices are equivalent to approximately \$8, \$27 and \$50 per tonne of CO_2 respectively, which is in accordance with the Australian Greenhouse Office's estimates of the value of a carbon emission trading permit (Australian Greenhouse Office, 1999). As the model uses cubic metres of timber as the standard measurement, a conversion rate (α) between tonnes of carbon to m^3 of timber is required (Australian Greenhouse Office, 1999). The assumed conversion rate is $\alpha = 0.89$.[3] The assumed rate of return required, r, is 10%.

[3] The conversion rate for *E. globulus* species of trees is calculated in a two step process. The tree stem volume measured in m^3 is converted to a biomass measure in tonnes of carbon, and assumed to be 0.52 for *E. globulus* (Australian Greenhouse Office, 1998A). The harvest index (0.7) and root-to-shoot ratio (0.2) are used to extrapolate from the wood biomass to obtain total biomass including above ground mass (branches and leaves) and roots (Australian Greenhouse Office, 1998B).

From these assumptions and calculations:

$v(t)$ = growth function, see table included in Appendix 1,

P_{F1} = \$12 per cubic metre of pulpwood,

P_{F2} = \$30 per cubic metre of sawn timber,

P_{C1} = \$30 per tonne of Carbon,

P_{C2} = \$100 per tonne of Carbon,

P_{C3}= \$180 per tonne of Carbon,

$\beta_1 = 0.35$ (pulpwood),

$\beta_2 = 0.8$ (sawn timber),

$\alpha = 0.89$,

$r = 0.1$.

Model Predictions

Table 1 provides predictions for each combination of timber use and carbon price, calculated by applying the above data to Equations 1 and 2.

Figure 1 illustrates two different outcomes when the timber is used for pulpwood. The Timber Only curve represents the Faustmann solution calculated using the left-hand side of Equation 1. It is downward sloping, indicating a slowing in the net benefit growth rate as the stand of trees ages. The r^* curve = $\dfrac{r}{1-e^{-rT}}$ and slopes downward, always

TABLE 1. PREDICTIONS FOR TIMBER ONLY AND TIMBER PLUS CARBON.

Price per tonne of carbon	Rotation Lengths (T) $P_{F1} = 12$, $\beta_1 = 0.35$ Pulpwood	Rotation Lengths (T) $P_{F2} = 30$, $\beta_2 = 0.8$ Sawn timber
P_{C0} = 0 (timber only)	T_{F1} = 22 years	T_{F2} = 20 years
P_{C1} = 30	T_{F1C1} = 60 years	T_{F2C2} = 28 years
P_{C2} = 100	T_{F1C2} = 100+ years	T_{F2C2} = 42 years
P_{C3} = 180	T_{F1C3} = 100+ years	T_{F2C3} = 52 years

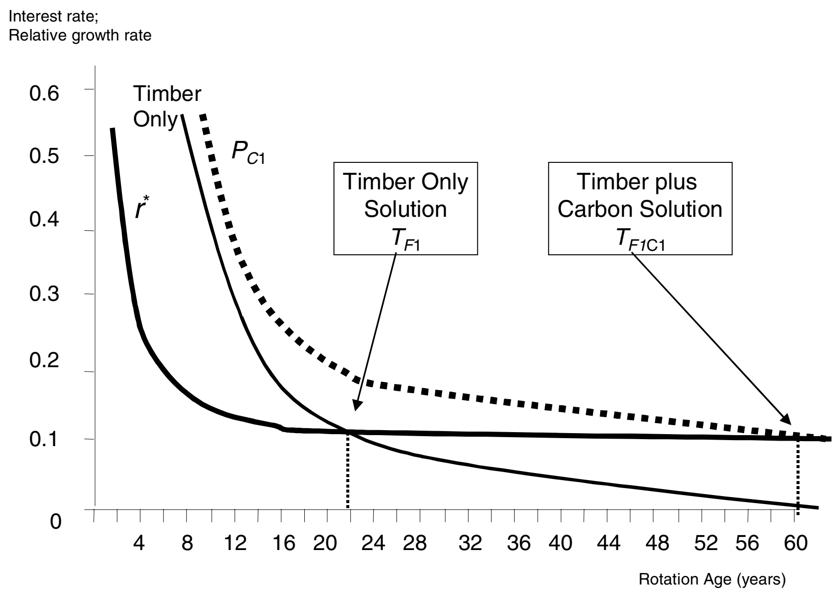

FIGURE 1. ROTATION LENGTHS WHEN TIMBER IS USED FOR PULPWOOD AND CARBON PRICE IS $30/TONNE OF CARBON.

The 'Timber Only' curve illustrates the annual relative growth rate in the value of one hectare of plantation when the timber is used for pulpwood. The r^* *curve represents the adjustment of the interest rate for an infinite number of rotations and approaching r from above, which is set at 0.1. The Timber plus Carbon curve* (P_{C1}) *illustrates the annual relative growth rate of one hectare of plantation when the products are pulpwood plus carbon sequestration.*

lying above *r,* which in this case is set at 0.1. The timber only solution to the optimal rotation problem is found at approximately 22 years in Figure 1 where the Timber Only and r^* curves intersect, illustrating the P_{C0}, P_{F1} result shown in Table 1 above.

The Timber plus Carbon curve (P_{C1}) is calculated using the left-hand side of Equation 2, and lies above the Timber Only curve due to the increased value from leaving trees standing for an additional year. The growth rate in net benefit is higher with carbon than timber only due to earnings from the carbon credits during the growing process. Including carbon means that the trees are worth more in the ground than harvested. The Timber Plus Carbon solution is found at approximately 60 years for P_{C1} and much longer for P_{C2} and P_{C3}, as indicated in Table 1.

Observations

Timber and carbon place opposing forces on the optimal rotation decision. The timber use is biased towards shorter rotations as significant costs present themselves in the form of forgone timber revenue and the opportunity to replant. Carbon use is biased towards longer rotations because the plantation owner receives annual income and avoids a carbon penalty upon harvest if the trees are left to grow. As it is impossible to separate the timber values from the carbon values that a plantation contains, there is no reason to assume a dominant use of the plantation for either timber or carbon. Conceptually, both uses must be considered simultaneously.

Including carbon values in the optimal rotation calculation clearly lengthens the rotation regardless of timber use or price. However, the disparity between timber only and timber-plus-carbon rotations is reduced when the price of carbon is lower, as evidenced by P_{C1} being closer to the timber only rotation than P_{C2} or P_{C3} (see Table 1). The disparity depends on the relative significance of the timber and carbon prices rather than their absolute values. As the timber price is increased, keeping the carbon price constant, the Timber Only and PC curves converge, reducing the gap between rotation lengths. This is due to an increased significance of the timber price relative to the carbon price, therefore indicating that timber dominates the investment decision. For example, if the plantation was to be utilised for sawn timber, the timber price would be closer to $30 per m^3 and the pickling factor, b, would be 0.8. As demonstrated in Table 1, this would result in a timber only rotation length of approximately 20 years and a timber plus carbon length of 28 years, 42 years and 52 years for P_{C1}, P_{C2} and P_{C3} respectively. Figure 2 illustrates the case of P_{C1}. As the ratio of timber price to carbon price falls, carbon becomes more important in the investment decision.

Timber use is only one influence on timber prices. When considering such long periods of time, it is unrealistic to expect that prices will remain constant. For instance, the very act of including carbon in a plantation's value may encourage reforestation, increasing the world supply of timber and driving timber prices down in the long run. In the short term, there may be a feedback effect in this model,

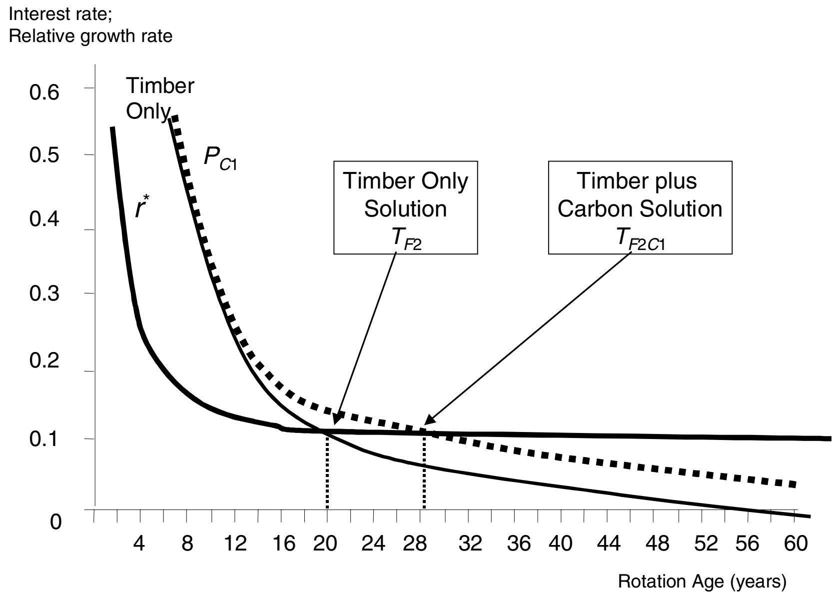

FIGURE 2. ROTATION LENGTHS WHEN TIMBER IS USED FOR SAWLOGS AND CARBON PRICE IS $30/TONNE OF CARBON.

The 'Timber Only' curve illustrates the annual relative growth rate in the value of one hectare of plantation when the timber is used for sawlogs. The r^* *curve represents the adjustment of the interest rate for an infinite number of rotations and approaching r from above, which is set at 0.1. The Timber plus Carbon curve* (P_{C1}) *illustrates the annual relative growth rate of one hectare of plantation when the products are sawlogs plus carbon sequestration.*

with longer rotation periods causing a shortage of timber, therefore driving timber prices up.

With both the timber only and timber plus carbon models, the discount rate, *r*, is crucial. Figure 1 can be visually adjusted for a change in the discount rate by shifting the whole r^* curve up or down. It may be observed, that if the rate reduced to 5%, the r^* curve would converge toward 0.05 and intersect the timber only curve at approximately 32 years, hence lengthening the rotation. An increase in the interest rate would shorten the rotation. This is because the interest rate impacts directly on the opportunity cost of delaying harvest.

Limitations of the Model

Due to the assumptions made when constructing the model and its resulting brevity, there are some limitations for its use. The model does not take account of: transport costs involved in taking timber from the plantation site to a mill; the administration costs of and risks associated with obtaining credit for carbon value; other values for which the plantation might be contributing such as watershed, aesthetics, erosion control; or carbon accumulated in soil. The model also assumes a silvicultural method which clearfells the plantation without thinning during the growing period. Whilst these factors may change the specific details of the model outcomes, their omission is not likely to affect the general conclusions drawn from the model.

IMPLICATIONS FOR GREENHOUSE POLICY

Response of the Commercial Forestry Sector

Due to the relative abundance of land available for reforestation, Australia has enormous potential to take advantage of the recognition of carbon sinks as part of the Kyoto protocol. Land owners and entrepreneurs in Australia are already responding to the recognition of carbon sinks as evidenced by the recent establishment of many individual and syndicated plantation investments. All parties are attempting to anticipate how the Australian government's Greenhouse policy will affect them under conditions of extreme uncertainty. Whilst this complicates investment decisions surrounding the use of forests as carbon sinks, it does not change the theoretical underpinnings of including carbon in the management of plantation forests.

The theory used in this paper predicts that valuing carbon sequestration will lengthen the optimal rotation of a commercial plantation. The profit maximising time to harvest varies with the price of timber relative to the price of carbon. Given the price of a carbon credit is predicted to be relatively high, it is likely that the carbon will be the dominant factor in determining the optimal rotation period. Even at the lowest carbon price estimated, the optimal rotation of the plantation is doubled. Despite this, the extent to which government policy will assist with the overall achievement of emission reduction targets will depend upon the incentives created by specific policy details such as how carbon value is measured and transferred to the owner.

Kyoto Constraints

The Kyoto Protocol introduces some institutional constraints that may alter the theoretical optimal rotation period, planting or harvesting times. How these constraints impact upon forest management depends upon how individual countries attempt to implement greenhouse policy. For example, a carbon permit trading system, to which forest owners have access, will have built-in incentives consistent with the Kyoto constraints, particularly if the number of permits are deliberately restricted during this time. Foresters will have a financial incentive to plant so that the fastest growing period is between 2008 and 2012 (to collect the largest amount of revenue) and a large disincentive to harvest during this time (to avoid a large penalty). Simulation of the model using Australian data indicates that species such as *Eucalyptus Globulus* should be planted in the year 2000. Having planted at this time, the harvest date would be well beyond the year 2012. The simulation also shows that even plantations used for sawn timber (shortest predicted rotation) planted in 1990 will not be scheduled for harvest until 2018. An alternative or complementary policy to an incentive-based system is a regulatory approach, perhaps banning harvesting during the commitment period with severe financial penalties attached. Forest managers will then either bring forward harvest time to before 2008 or postpone harvest until after 2012.

The difficulty with any specific policy to target Kyoto requirements is the uncertainty attached to both future international agreements and market prices. The timing and frequency of future commitment periods is uncertain. An over-reliance on specific policies targeting the first commitment period could be foiled by a decision to make the commitment periods consecutive. For example, a ban on harvesting during the first period may result in a large amount of harvesting in a subsequent consecutive period. Even if commitment periods are scheduled five years apart this may alter the optimal rotation period as it leaves a small window of opportunity to harvest before the next commitment period arrives.

It is likely that all countries party to the Kyoto protocol will act in a similar way, discouraging harvest during the first commitment period and perhaps encouraging planting times so that the most amount of CO_2 will be sequestered during the period. This could have significant ramifications for carbon prices, but more importantly in the case of forestry, timber prices. A five-year period without harvesting could lead to a world shortage of timber, driving timber prices up relative to carbon prices and shortening optimal rotation periods. Governments could then be in the compromising situation where it becomes optimal for forest managers to harvest during the commitment period. This scenario possibly points to the importance of having a range of policy measures in place to prevent a potential spiralling of carbon and timber prices during the commitment period.

Towards Australian Greenhouse Policy

In terms of meeting emission targets, it is in the Australian government's interest to encourage the development of forests as carbon sinks. Whilst it is recognised that carbon sinks are not single handedly going to solve Australia's greenhouse problem, they are likely to be an effective instrument in lowering the costs of abatement. Australian researchers (ABARE) have identified that the total cost of reducing net emissions would be minimised when the marginal cost of abatement across all sources is equal to the marginal cost of increasing or decreasing absorption across all sinks (Hinchy *et al.*, 1998). Stavins (1999) indicates that in the long term, the marginal cost of abatement will fall due to technological improvements, relative to the marginal cost of sequestration due to limited world wide ability to transfer agricultural land to forestry and potential for silvicultural improvements. Despite this prediction, it is concluded that "sequestration ought to be part of [an] overall portfolio of greenhouse strategies in the short term, providing a significant fraction of overall carbon reductions…" (Stavins,1999). Australia is in a better position than most countries to take advantage of the short-term advantages of carbon sequestration via reforestation, and can possibly include carbon sinks as a sustained part of the policy portfolio. It is therefore important that the particular mechanisms for incorporating carbon sequestration into forest management are clearly defined.

The simulated results presented in this paper, indicating a change in forest management, hinge critically on recognising a 'pickling factor', shown in the model as β. Without a pickling factor, forest owners will derive no net benefit from sequestering carbon over a period of time as all carbon benefits accumulated during the growing period must be relinquished upon harvest. As explained by van Kooten, assuming $\beta = 0$ gives the theoretical result equivalent to Hartman's multiple use result (van Kooten *et al*, 1995). There will, of course, be some benefit derived from receiving the stream of revenue during the growing period[4]. A recent consultancy concluded that under the various carbon accounting methods currently considered for Australian greenhouse policy, (and assuming that timber is the primary product), the benefits to forest owners was minimal over a long period of time (100 years) (Halloway, pers. comu. July 13, 1999)

The Australian government can make greenhouse policy most effective by recognising the pickling factor and establishing a clear mechanism for trade. Steps have been taken by the Australian Greenhouse Office (AGO) to provide a carbon measurement formula. This was used to calculate the conversion rate (α) and is outlined in the Greenhouse Challenge Vegetation Sinks Workbook (Australian Greenhouse Office, 1998). Either a carbon trading system or carbon tax will need to include a mechanism for forest owners to claim benefit for carbon sequestration and be charged for re-emission upon harvest.

Recognising a 'pickling factor' will reduce the penalty for harvesting a forest. Although current policy does not recognise a 'pickling factor', the AGO does classify wood products as follows:

"The Inventory separates wood products into five categories according to how quickly the product decays. These are:

- Short term (paper) – 3 years,
- Short-medium term (fiberboard) – 7 years,
- Medium term (slash from logging) – 10 years,

[4] The present value of the carbon credit received today is higher than the present value of the carbon penalty incurred upon harvest.

· Medium-long term (furniture) — 25 years

· Long term (construction material) — 50 years" (Australian Greenhouse Office, 2000).

From a policy perspective, omitting a pickling factor may discourage activity, investment and growth in carbon sinks, therefore limiting Australia's opportunity to take advantage of carbon sinks as a significant emission offset.

CONCLUSION

Various implications arise from the land use and forestry incentives caused by including carbon sequestration in the forest management decision process. On the one hand, the forestry sector of the Australian economy can take advantage of the changing face of forests, viewed not only as a source of timber but as a source of carbon sequestration. On the other hand, there are risks associated with using forests as carbon sinks — most of them stemming from the uncertainty surrounding the Kyoto Protocol itself. There lies a challenge for Australian greenhouse policy to take advantage of Australia's potential to make land use changes, by clearly specifying mechanisms to measure and transfer carbon value. There also lies a challenge for industry to develop systems that capture carbon benefits and are flexible enough to cope with the inevitable changes in global and national greenhouse rules, carbon prices and timber prices. Specific issues such as pricing of carbon rights, incorporating risk into investment decisions and the place of carbon sinks in emissions trading, all require further research.

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Appendix

Preliminary Yield Table — Australian Paper Plantations.

Site: Ma Sd Age	Total Volume (m³/ha) *E. Globulus*	MAI (m³/ha/yr) *E. Globulus*
6	65	10.83
8	116	14.51
10	164	16.43
12	210	17.49
14	253	18.07
16	294	18.35
18	332	18.44
20	368	18.41
22	403	18.3
24	435	18.12
26	465	17.9
28	494	17.65
30	522	17.39