Valuation of Carbon Forestry and the New Zealand Emissions Trading Scheme: A Real Options Approach Using the Binomial Tree Method

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Abstract

Under the New Zealand Emissions Trading Scheme, new forests planted on/after 1st January 1990 can earn carbon credits. These credits have to be repaid upon forest harvest. This paper analyses the effects of this carbon scheme on the valuation of bareland, on which radiata pine is to be planted. NPV/LEV and Real Options methods are employed, assuming stochastic timber and carbon prices. Valuation increases significantly and rotation age is likely to be lengthened. We include a scenario analysis of potential implications of rotation age lengthening on carbon stock management in New Zealand.

1 Introduction

In order to meet New Zealand's Kyoto Protocol commitments, its government passed cap-and-trade legislation, called the New Zealand Emissions Trading Scheme (NZETS), to create a carbon price and put in place incentives for businesses and consumers to change their behaviour. The NZETS is the world's first economy-wide cap-and-trade system that covers all sectors and all gases. It is internationally linked as it reflects international climate change rules (New Zealand Government, 2010). The NZETS legislation includes a transition period between 1st July 2010 and 31st December 2012, during which emitters have been able to buy emission units (carbon credits) from the New Zealand government for a fixed price of $25 per unit (where 1 unit = 1 ton of carbon dioxide equivalent). In addition, emitters will only have to surrender one emission unit for every two tons of emissions they produce during this period.

For the forestry sector, new forests established on and after 1st January 1990 are eligible to earn carbon credits[1]. Known domestically as post-1989 forests, these forests can earn carbon credits for increases in carbon stocks from 1st January 2008[2]. If the carbon stock in a post-1989 forest decreases (for example, due to harvesting), emission units must be surrendered (i.e. harvest liabilities). These post-1989 forestry NZETS rules have been designed to directly reflect the rules of afforestation and reforestation under Article 3.3 of the Kyoto Protocol (UNFCCC, 1998).

For forest owners, the new revenue stream from carbon credits and harvest liabilities alters the traditional timber-only cash flow business model, and affects the harvesting decision. After receiving the credits, they can be accumulated or immediately sold in domestic and international carbon markets, thereby, generating a new cash flow stream for forest owners. Upon harvesting of the post-1989 forests, the proportionate amount of carbon credits must be surrendered by the forest owner. The required credits could be purchased from domestic or international carbon markets at the market price (Ministry of Agriculture and Forestry, 2011a).

This paper outlines a literature review of infinite rotation forestry methods, namely NPV/LEV and Real Options. This is followed by a review of carbon forestry literature, with a focus on carbon forestry modeling work in New Zealand. The methodology employed in this paper is described, along with data used and assumptions made. Valuation results are presented and discussed. We conclude with a scenario analysis of potential implications in New Zealand.

A key original contribution of this paper to existing literature is the development of a double RV Binomial Tree (Real Options) method to analyze carbon forestry in New Zealand. This method enables simultaneous modeling of both the timber and carbon prices stochastically. A further contribution is the scenario analysis of potential implications on existing post-1989 radiata pine forests and the annual carbon stock change in New Zealand.

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[1] It is noted here that some owners of pre-1990 forest land are eligible for a free allocation of carbon credits. This type of allocation is a one-off compensation and is not considered in this paper since the focus here is on new post-1989 forests.

[2] Carbon stock accumulated between 1st January 1990 and 31st December 2007 does not earn any credits, nor does it incur any liabilities.

2 Infinite Rotation Forestry Valuation Methods

Fixed Rotation Forestry Valuation

Probably the best known and still quite widely adopted net present value (NPV) approach by Faustmann (1849), the value of the forest investment is determined by forecasting expected future cash flows and discounting them at a specific discount rate. This method attempts to account for riskiness in the investment and time value of money. It is relatively simple numerically, with a relatively easy implementation. However, it has a few notable weaknesses. Often, adjustments for risks are captured by the discount rate, which is assumed to be constant throughout the forest's lifetime[3]. The NPV approach does not account for flexibility due to the assumption of a fixed investment path and duration, where the decision is made in advance, and remains unchanged, even when unexpected favourable or unfavourable events arise. It also ignores the value that alternative opportunities and choices bring to the investment such as deferring harvest or conversion to agriculture land.

Flexible Rotation Forestry Valuation

Flexibility in decision-making is valuable when investors face risks and uncertainty about the future, especially when there is a degree of irreversibility attached to the decisions being made (Dixit and Pindyck, 1995). Consider the situation in forestry where forest owners must decide when to harvest. Under the Faustmann NPV approach, the harvesting decision (based on the optimal rotation age calculated from the NPV) is made regardless of the timber price at the time of expected harvest (i.e. it is already pre-decided upfront when the trees were first planted). The decision to replant will also have to be made immediately after cutting, as per the optimal rotation plan. In addition, the harvesting decision is irreversible. Once harvested, trees of that age and size cannot be put back into the ground. If the timber price is low during the harvest, the *"loss"* in profits is also permanently irreversible. That is, an amount of money equivalent to the expected profit cannot be relied upon for any other investment.

Given that forest owners face uncertainty in future prices and irreversibility in the consequences of their decisions, it may be advantageous for them to remain flexible about the timing of forest harvesting decisions. If timber prices are low at the anticipated time of harvest, forest owners may want to delay harvest, and wait-and-see before making a harvesting decision. Likewise, if timber prices are unusually high before the anticipated time of harvest, forest owners may want to harvest earlier than planned to take advantage of the high timber prices.

Uncertainty and irreversibility of an investment decision cannot be easily introduced into and anticipated by the NPV approach. In practice, the optimal rotation age is recalculated as a stand matures, using

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[3] This is common, but is not always the case. It is noted here that the New Zealand Institute of Forestry's Forest Valuation Standards (p A4-22) specifies that "*the preferred approach in this situation is to adjust future cash flows rather than the discount rate*"**.**

updated information about timber prices as well as actual yields from the inventory (rather than the growth model) and costs. In order to better manage the true potential of the returns, forest owners should use a decision framework that can accommodate a flexible investment decision. The Real Options approach offers such flexibility.

The Real Options Approach to Valuation

Black and Scholes (1973) and Merton (1973) pioneered a formula for valuing a financial option and opened up subsequent research on the pricing of financial assets. This work paved the way for the development of Real Options theory by Myers (1977), who had the seminal idea that one can view a firm's discretionary investment opportunities as a call option on real assets, in much the same way as a financial call option provides decision rights on financial assets. As an analogy, a Real Option can have its underlying asset as the gross project value of expected operating cash flows, its exercise price as the investment required to obtain this underlying asset, and the time to maturity as the period of time during which the decision maker can defer the investment before the investment opportunity expires.

In short, Real Options are investments in real assets (as opposed to financial assets), which confer the investor the right, but not the obligation, to undertake certain actions in the future (Schwartz and Trigeorgis, 2004). There are three general approaches for implementing Real Options valuations:

- *Partial Differential Equation (PDE):* The PDE approach treats time as a continuous variable and expresses the present value of a cash flow stream as the solution to a PDE. The most famous such PDE appears in Black and Scholes (1973). This is the standard and most widely used Real Options valuation method in the academic literature research due to its mathematical elegance and insights. For example, Pindyck (1993) studied the uncertain cost of investment in nuclear power plants, from which he derived a decision rule for irreversible investments subject to technical and input uncertainties.
- *Simulation:* A simulation typically computes thousands of possible paths describing the evolution of the underlying asset's value from the start period to the end period. With simulations, one can handle complicated problems with a large number of variables (Gamba, 2003). With the advancement of computing power, large simulation programs are being used to value options that are very difficult to solve using PDEs. Though powerful, this method is not very insightful (compared to the closed form PDE solutions) because it only provides the answer (valuation) without as much insight into the relationships between variables and the key drivers for the valuation. Another form of simulation or modeling that is commonly used to analyse forestry valuation is Stochastic Dynamic Programming.
- *Binomial Trees* (also known as Binomial Option Pricing model): This approach was developed by Cox, Ross and Rubinstein (1979). It treats time as a discrete variable and expresses the present value of a cash flow stream as the solution to a system of simple linear algebraic equations. This method’s precision can be improved to a very high degree by dividing the life span of an option into more stages. This discrete-time approach is mathematically simpler than the PDE method, yet

it provides an efficient procedure for valuing options. Copeland and Antikarov (2001) applied Binomial Trees to value real projects and proved that this method is equivalent to the PDE solution. It is easy to use without losing the insights of the PDE model.

Of the three approaches, the Binomial Tree method offers a good balance between insights and complexity and for this reason it is the empirical approach adopted in this investigation.

Real Options Valuation Applied to Forestry

Traditionally, the Faustmann harvest decision approach ignores annual timber price fluctuations and prescribes harvest on the basis of expected prices. Brazee and Mendelsohn (1988) recognized the volatility of timber prices from year to year, and incorporated a stochastic timber price into their work. They concluded that the flexible price harvest policy significantly increases the present value of expected returns over the rigid Faustmann model. Clarke and Reed (1989) and Reed and Clarke (1990) further distinguished the stochastic uncertainty of timber price and the timber growth. Provencher (1995) investigated other factors affecting harvesting decisions, such as profit shocks.

Miller and Voltaire (1983) were amongst the first authors to introduce Real Options into forestry. Morck, Schwartz and Stangeland (1989) used a PDE approach to determine the optimal harvesting rate. Thomson (1992) employed a Binomial Tree to determine land rent endogenously assuming stumpage prices follow the Geometric Brownian Motion (GBM) process. Plantinga (1998) highlighted the role of option values in influencing the optimal timing of harvests. He treated an option value as a premium over the expected value of a timber stand reflecting the opportunity cost of harvesting now and foregoing the option to delay harvest until information on future stand values is revealed. His work shows that expected timber values are higher with a reservation price policy when timber prices are stationary compared to the Faustmann model with expected prices. When timber prices are non-stationary, the expected timber values are identical to Faustmann values. In other words, when prices follow a random walk, there is little to no option value. On the other hand, when prices follow a mean reverting process, there is a larger option value.

Gjolberg and Guttormsen (2002) applied the Real Options approach to the tree-cutting problem under the assumption of mean-reverting (rather than random-walk) stumpage prices. Insley (2002) investigated the role of the timber price process on the rotation length in a single-rotation model. A dynamic programming approach and a general numerical solution technique were used to determine the value of the option to harvest a stand of trees and the optimal cutting time when timber prices follow a known stochastic process. It was concluded that "*option value and optimal cutting time are significantly different under the mean reversion assumption compared to geometric Brownian motion*". In Insley and Rollins (2005), the authors extended the single-rotation work by Insley (2002) to multiple rotations, and analyzed forest stand value with stochastic timber prices and deterministic wood volume. Their work's motivation was argued on the basis that, like many commodities such as oil and copper, timber prices should eventually revert to some mean, reflecting long run marginal costs.

Duku-Kaakyire and Nanang (2004) compared a forestry investment using the Faustmann NPV model and the Real Options approach. They investigated four options: an option to delay deforestation, an option to expand the size of the wood processing plant, an option to abandon the processing plant if timber prices fall below a certain level, and an option that included all three of these individual options. Like ours, their analysis was conducted using the Binomial Tree method. The results show that while the Faustmann analysis rejected investments as unprofitable, the Real Option analysis showed that all four options were highly valuable. It demonstrated the weakness of the Faustmann approach, namely, the lack of managerial flexibility to adjust for shocks, risks and uncertainty.

Manley and Niquidet (2010) compared the Faustmann method with three Real Options valuation methods, namely, the Binomial Option Pricing model, the Stochastic Dynamic Programming model, and a new approach based on the Black and Scholes (1973) option pricing model called the Abandonment Adjusted Price model. This comparison assumed that the timber price follows a random walk process. It concluded that the increase in forest value over the Faustmann value can be substantial, but only when prices are low and close to the exercise cost, with gains quickly diminishing as price increases. This conclusion is consistent with the conclusion reached by Plantinga (1998), which is that when prices follow a random walk, there is little to no option value.

Valuations of fixed and flexible rotation ages are commonly compared using different and separate methods: an NPV/LEV model and a Real Options model. In such comparisons, the Real Options models tend to have higher data requirements, employ different assumptions and are much more complex to estimate compared to NPV/LEV. Because of these differences, it may be difficult to isolate the cause of the differences in valuations. In Guthrie (2009) a single random variable (RV) Binomial Tree method was applied to study the optimal harvest decision of forests in Oregon (USA) using a mean-reverting timber price process. The same Binomial Tree method was able to generate results for Real Options (flexible harvest decision) and NPV/LEV (fixed rotation), for both single and infinite rotations. The work of Guthrie (2009) is useful as it can be used to isolate the cause of increased valuation of flexible rotations compared to those obtained with fixed length rotations.

3 Carbon Forestry

Carbon Forestry and Climate Change Mitigation

In Englin and Callaway (1993), the authors investigated the use of forests for climate change mitigation purposes. They were the first to integrate the carbon sequestration lifecycle into the Faustmann framework of forest management and develop optimal cutting rules when both timber and carbon sequestration benefits are considered. Van Kooten, Binkley and Delcourt (1995) further investigated the effect of carbon taxes and subsidies on optimal forest rotation. Their work showed that when carbon sequestration for climate change mitigation purposes is taken into account, the optimal rotation age is no longer the Faustmann age because the rate of net carbon uptake by a forest is proportional to the growth of the forest, rather than the timber volume.

Romero, Ros, Rios and Diaz-Balteiro (1998) approached the timber and carbon problem by examining the trade-offs between the value of harvested timber and the value of carbon sequestration for climate change mitigation purposes. Sohngen and Mendelsohn (2003) developed a general equilibrium model to show the interaction between carbon and timber prices. A global timber market (pricing) model was used as a carbon sequestration cost function, whereas a separate greenhouse gas model of carbon and the world economy was used to project the carbon price. More recently, Olschewski and Benitez (2009) investigated the optimization of joint timber production and carbon sequestration of afforestation projects covered under the Kyoto Protocol.

Chladna (2007) used Real Options to study the impact of carbon credit payment schemes on the optimal rotation length. The author was the first to provide a detailed (PDE) numerical analysis that employs both stochastic wood prices and stochastic carbon prices. The analysis assumed that the timber price is mean reverting, whereas the carbon price follows a geometric Brownian motion. In the analysis, the carbon price grows exponentially at a rate 3.6%, from zero Euros/ton in the year 2000 to more than 130 Euros/ton in the year 2100. It is unclear whether the exponentially growing carbon price is a realistic assumption, particularly when the timber price is assumed to revert to a long term level (i.e. essentially remaining constant aside from the short term fluctuations). The exponential carbon price may also be a key reason why the approach taken in this work was limited to analysing a single rotation since over multiple rotations, the carbon price would have grown to very high levels, when compared to the mean reverting timber price.

Carbon Forestry in New Zealand

The investigations by Maclaren et al (2008a), Maclaren et al (2008b) and Manley and Maclaren (2009, 2010) employed the NPV/LEV methodology to analyse the impact of the New Zealand Emissions Trading Scheme (NZETS) on forest management. Turner et al (2008) employed a combination of NPV/LEV and simulations to model and analyse the management of planted forests for carbon under the NZETS. In Meade et al (2008), results from a simulation method called Bootstrapping Real Options Analysis were compared to results from a NPV (discounted cash flow) calculation. Guthrie and Kumareswaran (2009) used PDEs to study the impact of carbon credit payment schemes over multiple rotations in New Zealand. Due to the complexity of the PDE method, the timber price was assumed to be stochastic whereas the carbon price is assumed to be constant in order to keep the mathematics tractable. These works conclude that

It is a common conclusion in existing literature that carbon revenue significantly increases the profitability of forestry in New Zealand, with a general lengthening of optimum rotation age. However, existing works are constrained by the constant price assumption, applied to either or both timber and carbon prices. Our work here incorporates both timber and carbon prices in a stochastic manner, and therefore, contributes towards advancing existing literature.

4 Methodology

The works highlighted in the previous section show the broad range of methods used to analyze carbon forestry. In order to ensure comparability between timber-only forestry and timber with carbon forestry while maintaining consistency in studying fixed and flexible rotations, the Binomial Tree method of Guthrie (2009) needs some adaptation. In subsequent sections, the single random variable (RV) Binomial Tree method is explained. Because it only has one RV, this method can only model one stochastic price. A double RV model is hence developed to model both timber and carbon prices endogenously, allowing for a joint optimization of the harvest decision.

Single Random Variable (RV) Price Binomial Tree

The basic parameters of a price Binomial Tree are:

- $X(i,n)$ is the price, where i is the number of downward price moves and n is the time step
- $X(0,0)$ is the present price
- U is the upward price move multiplicative factor
- D is the downward price move multiplicative factor ($D = 1/U$)
- $\theta_U(i,n)$ is the probability of an upward price move
- $\theta_D(i,n)$ is the probability of a downward price move ($\theta_D = 1 - \theta_U$)

An example of the Binomial Tree labeling convention is shown in Figure 1 for $n = 2$. Each $X(i,n)$ node on the Binomial Tree is calculated by applying U and D to $X(i,n)$ starting with $X(0,0)$, such that $X(i,n+1) = X(i,n)U$ and $X(i+1,n+1) = X(i,n)D$.

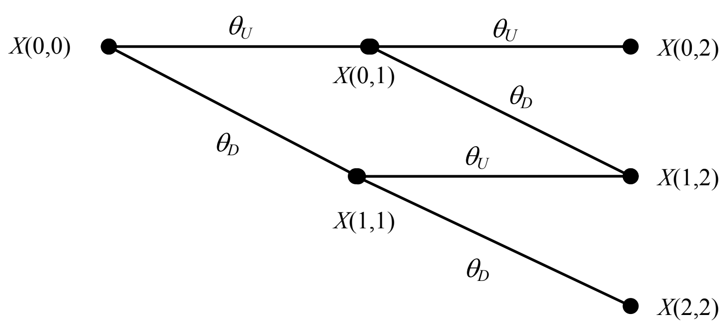

Figure 1: The Binomial Tree labeling convention.

A mean-reverting price process is assumed. The technique for calibrating the Binomial Tree for a mean reverting price is described in Guthrie (2009).

Adjusting for risk using the Capital Asset Pricing Model

In conventional NPV/LEV forestry valuations, cash flows are valued by discounting their expected value using a discount rate that equals the sum of the risk-free interest rate and a premium reflecting the cash flow's risk. Risk-adjustment models such as the Capital Asset Pricing Model (CAPM) can be used to calculate this risk premium. We adopt the (equivalent) alternative approach of adjusting for risk in the calculation of the expected value. That is, we replace the actual probabilities of up and down moves, θ_U and θ_D, with the so-called "risk neutral probabilities"

$$\Pi_U = \theta_U - MRP_{Adj}$$
$$\Pi_D = 1 - \Pi_U = \theta_D + MRP_{Adj}$$

The adjustment for risk, MRP_{Adj}, is calculated by regressing carbon and timber price changes on stock market returns as measured by changes in an index such as the NZX 50 Total Returns Index (Guthrie, 2009).

The risk neutral probabilities of up (Π_U) and down (Π_D) moves in the price Binomial Tree are applied to the valuation Binomial Tree, as shown in Figure 2 for n = 2. Each node is labeled $V(i,n)$, representing valuation at time step n, with i number of down moves in the price.

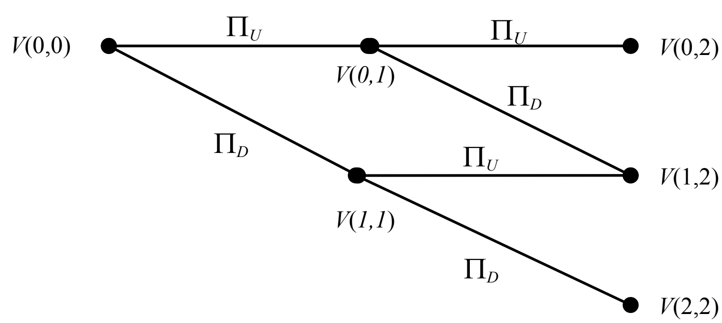

Figure 2: Single random variable valuation Binomial Tree.

In contrast to the price Binomial Tree which is calculated forward using $X(0,0)$, U and D, the valuation Binomial Tree is calculated backwards (in reverse) starting from the terminal (last) time step, N, and the corresponding terminal nodes $V(i,N)$.

Discount rates are added to the valuation calculations to reflect the time value of money. For example, valuation at node $V(0,1)$ is:

$$V(0,1) = \frac{\Pi_U V(0,2)}{R_f} + \frac{\Pi_U V(1,2)}{R_f}$$

where R_f = (1+ *risk-free interest rate*). This valuation process traverses backwards systematically until it ends at $V(0,0)$.

Applying the Single RV Binomial Trees to a Flexible Harvest Decision (Real Options)

When calculating the valuation (backwards), a decision on whether to harvest or not to harvest is re-evaluated at each and every node, where a node is a harvesting opportunity presenting itself at regular time intervals, such as for example the single year. If the present value of the cash flows from harvest at each node is more than the present value of the expected future cash flows (i.e. cash flows from not harvesting), then the optimal decision is to harvest, and the valuation at the node equals the cash flow from harvest. If the present value of the expected future cash flows (i.e. those from not harvesting) is more than the present value of the cash flows from harvesting, then, the optimal decision is not to harvest, and the valuation at the node equals the present value of the corresponding expected future cash flows. That is:

$$V(i,n) = \max \begin{Bmatrix} (1-T)((X(i,n)-H)Q(n\Delta t_m)) + B, \\ \\ (1-T)(-M_T) + \dfrac{\Pi_u(i,n)V(i,n+1) + \Pi_D(i,n)V(i+1,n+1)}{R_f} \end{Bmatrix}$$

where T is the tax rate, H is the harvesting cost, Q(n) is the timber volume at time step n, B is the value of the bare land that remains after the harvest ("Bareland value"), and M_T is the maintenance cost of the forest. The first argument of the max function represents the cash flow from harvesting, whereas the second argument represents the cash flow from not harvesting.

As mentioned previously, this process traverses backwards from $n = N$ to $n = 0$, ending with $V(0,0)$. The Binomial Tree valuation is implemented backwards recursively over multiple iterations. Each iteration represents one harvest and replant rotation. During the calculation for the first iteration, the Bareland value is assumed to be zero. At the end of the first iteration, a Bareland value is estimated by deducting the cost of (re-)planting the forest from $V(0,0)$:

$$B = V(0,0) - (1-T)G$$

where G is the cost of (re-)planting the forest. This first iteration Bareland value is the valuation for a single rotation forest with flexible harvest (i.e. Real Options valuation for single rotation).

To calculate the value for an infinite rotation forest, this first iteration Bareland value is then fed into the second iteration (i.e. during the second iteration of valuation calculations, B in the $V(i,n)$ function is no longer zero). After this process is repeated for a certain amount of iterations (e.g. 10 iterations), the Bareland value converges to a steady state value (i.e. it no longer changes with subsequent iterations). This converged Bareland value is the valuation for an infinite rotation forest with flexible harvest (i.e. Real Options valuation for infinite rotation).

Applying the Single RV Binomial Tree Method to a Fixed Harvest Decision (Fixed Rotation NPV/LEV)

To apply this valuation method to a fixed harvest, the same process is used with one modification. The harvest decision is fixed (i.e. pre-decided regardless of the price) at the node where t = fixed harvest age (i.e. use node t as the terminal node instead of N where $t < N$). All nodes on the valuation Binomial Tree to the right side of t (i.e. all nodes between $t+1$ and N) are ignored (i.e. truncated) and the backward traverse starts from node t (instead of node N as for the case of flexible rotation forest).

During each node traverse, unlike the flexible harvest case, there is no re-evaluation of a harvest decision (i.e. no harvest decision reconsidered at subsequent nodes) because there is already a fixed (i.e. pre-decided regardless of price) harvest decision at node t (= fixed harvest age). As such, the valuation for each node from $n = (t - 1)$ to $n = 0$ is:

$$V(i,n) = (1-T)(-M_T) + \frac{\Pi_u(i,n)V(i,n+1) + \Pi_D(i,n)V(i+1,n+1)}{R_f}$$

This is the only modification required to compute the fixed harvest results. The value of B after the first iteration is the single rotation NPV. After a certain number of iterations (e.g. 10 iterations), B converges to the infinite rotation LEV.

Development of a Double RV Binomial Tree

Let X^T = the timber price, X^C = the carbon price, θ^T = probability of the timber price process and θ^C = probability of the carbon price process. For the case of n = 1, the single RV price Binomial Trees for timber and carbon are shown below in Figure 3.

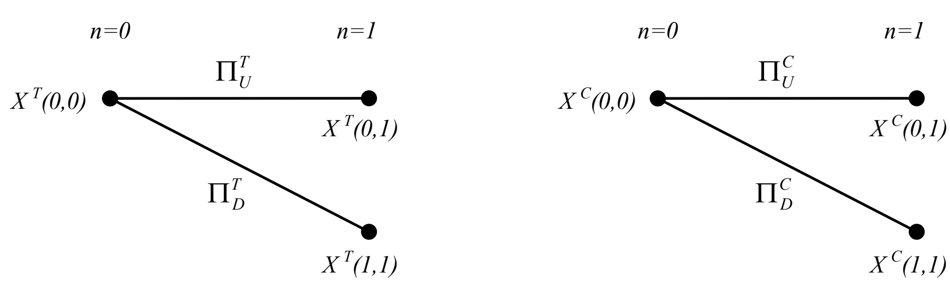

Figure 3: Single RV price Binomial Trees for timber (left) and carbon (right).

These single RV price Binomial Trees can be combined to construct a double RV price Binomial Tree as shown in Figure 4, where each node consists of a pair of timber and carbon prices.

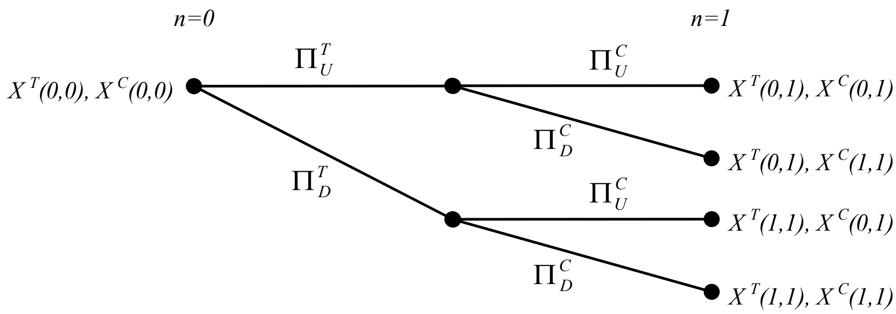

Figure 4: Double RV price Binomial Tree for timber and carbon.

For a single RV Binomial Tree, the number of nodes increases with n at the rate of (n+1), whereas for a double RV Binomial Tree, the number of nodes increases with n at the rate of $(n+1)^2$. This increase adds to the computation complexity of the double RV Binomial Tree method.

The corresponding double RV valuation Binomial Tree is shown in Figure 5.

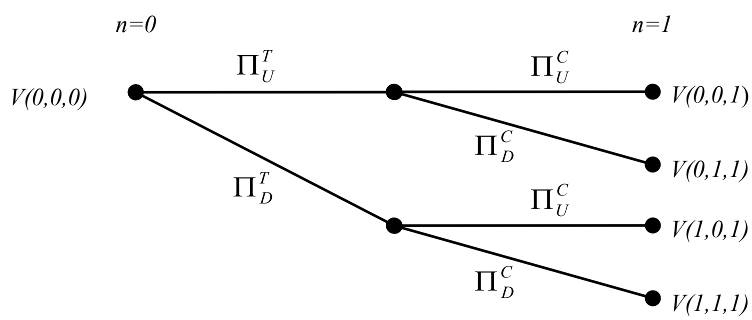

Figure 5: Double RV valuation Binomial Tree for timber and carbon.

In the same way as for the single RV, the valuation process moves systematically backwards, starting from the terminal (last) nodes $V(i,j,N)$ until it ends at $V(0,0,0)$. For $N = 1$, the valuation is:

$$V(0,0,0) = \frac{\Pi_U^T \Pi_U^C V(0,0,1)}{R_f} + \frac{\Pi_U^T \Pi_D^C V(0,1,1)}{R_f} + \frac{\Pi_D^T \Pi_U^C V(1,0,1)}{R_f} + \frac{\Pi_D^T \Pi_D^C V(1,1,1)}{R_f}$$

Valuation Function of the Double RV Binomial Tree

For the double RV Binomial Tree, the Real Options valuation function is:

$$V(i,j,n)=\max\begin{Bmatrix}(1-T)\left([X^T(i,n)-H^T]Q^T(n)-X^C(j,n)Q^C(n-1)-M^C\right)+B, \\ \\ (1-T)\left(-M^T-M^C+X^C(j,n)[Q^C(n)-Q^C(n-1)]\right) \\ +\dfrac{\Pi_U^T(i,n)\Pi_U^C(j,n)V(i,j,n+1)}{R_f} \\ +\dfrac{\Pi_U^T(i,n)\Pi_D^C(j,n)V(i,j+1,n+1)}{R_f} \\ +\dfrac{\Pi_D^T(i,n)\Pi_U^C(j,n)V(i+1,j,n+1)}{R_f} \\ +\dfrac{\Pi_D^T(i,n)\Pi_D^C(j,n)V(i+1,j+1,n+1)}{R_f}\end{Bmatrix}$$

where T is the tax rate, $X^T(i,n)$ is the price at time step n, H^T is the timber harvesting cost, $Q^T(n)$ is the timber volume at time step n, $X^C(j,n)$ is the carbon price at time step n, $Q^C(n-1)$ is the carbon stock at time step n-1, M^C is the NZETS compliance cost, B is the bareland value, M^T is the maintenance cost of the forest, Π^T is the risk neutral probability for the timber price, and Π^C is the risk neutral probability for the carbon price. The first (shorter) term of the max function represents the cash flow from harvesting, whereas the second (longer) term represents the cash flow from not harvesting.

5 Data Used and Assumptions Made

Timber and Carbon Prices

Table 1 shows the yield by log grade for radiata pine of various ages (Future Forests Research Limited, 2010). The average log grade yield is used as the weighting for aggregating the log grade prices (Ministry of Agriculture and Forestry, 2011b) into a single proxy timber price series. This is further adjusted with the Consumer Price Index (CPI) from Statistics New Zealand (2011) to result in the CPI-adjusted timber price series as shown in Figure 6.

Log Grade	Yield by Timber Age (years)										Average Yield
	25	30	35	40	45	50	55	60	65	70	
Pruned	33%	31%	28%	27%	25%	24%	24%	23%	23%	22%	26%
S1	1%	4%	7%	8%	10%	11%	14%	17%	20%	22%	11%
S2	14%	16%	16%	16%	16%	16%	16%	16%	16%	14%	16%
L1&L2	11%	16%	20%	21%	22%	24%	24%	25%	25%	26%	22%
S3&L3	26%	20%	18%	17%	15%	14%	13%	11%	9%	8%	15%
Pulp	14%	13%	11%	11%	10%	10%	9%	8%	8%	7%	10%

Table 1: Log grade yield of various timber ages.

Figure 6: Timber price (CPI adjusted).

Only historical timber prices from December 2002 onwards were included because the original Climate Change Response Act was passed in November 2002, leading to the Climate Change Response (Emissions Trading) Amendment Act being passed in September 2008.

The carbon price data is shown in Figure 7, sourced from the New Zealand Treasury (Treasury, 2011), adjusted with the Consumer Price Index (CPI) from Statistics New Zealand (2011). The carbon price data is the same data used to calculate New Zealand's net position under the Kyoto Protocol, and it provides a common reference point for analyzing the effects of the NZETS. For historical carbon prices, the earliest data available from the New Zealand Treasury is May 2005.

Both timber and carbon prices are assumed to follow a mean reverting process. It is further assumed that timber and carbon prices are independent.

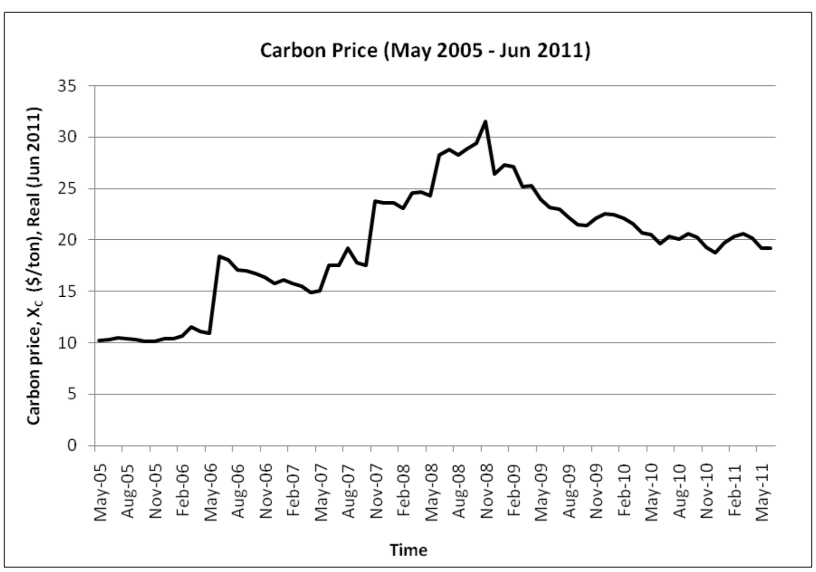

Figure 7: Carbon prices (CPI adjusted).

Price Series Parameters

Ordinary Least Squares (OLS) regression is applied individually to each of the timber and carbon price series, resulting in the following parameters:

Timber price series	*Carbon price series*
$\hat{a}_T = 0.7996$	$\hat{a}_C = 0.7540$
$\hat{b}_T = 4.5564$	$\hat{b}_C = 3.0659$
$\hat{\sigma}_T = 0.0732$	$\hat{\sigma}_C = 0.2971$
$U_T = 1.0213$	$U_C = 1.0895$
$D_T = 0.9791$	$D_C = 0.9178$
$e^{\hat{b}_T} = NZ\$95.24$ (*long run price*)	$e^{\hat{b}_C} = NZ\$21.45$ (*long run price*)

where a is the rate of mean reversion, b is the long-run level, σ is the volatility of the Ornstein-Uhlenbeck process (Guthrie, 2009). These parameters are used to calculate $X(i,n)$ and θ_U of the respective price Binomial Trees.

Market Risk Premium (MRP)

In Franks et al (2010), the authors recommended a Market Risk Premium (MRP) range between 5% and 5.7% for New Zealand. Here, an MRP of 5.5% is assumed. The resulting MRP_{Adj} for timber and carbon prices are 0.0057 and 0.0002, respectively.

Tax and Discount Rate

The tax rate, T, is assumed to be 28% and the risk-free interest rate is assumed to be 4%, so that $R_f = 1.04$.

Timber Volume and Carbon Stock

The cumulative timber volume and carbon stock functions up to 75 years of age are sourced from the R300 Radiata Pine Calculator model from Future Forests Research Limited (2010), as plotted in Figure 8.

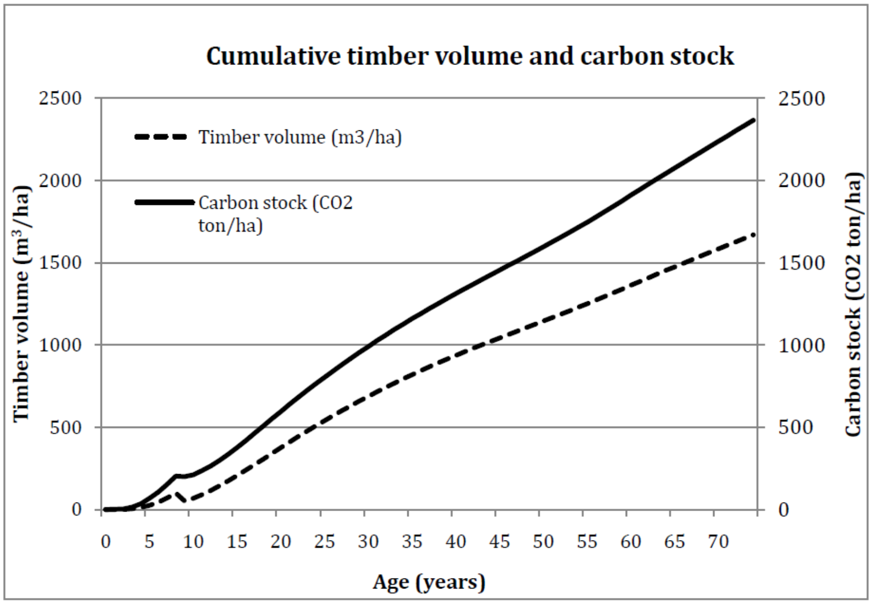

Figure 8: Cumulative timber volume and carbon stock functions for site index of 28.3 meters, with 850 stems planted per ha.

The annual carbon stock change in tons of CO2 per hectare per year is shown in Figure 9. This represents the amount of carbon sequestered, and therefore the entitlement in carbon credits every year throughout the life of one hectare of forest. It is assumed that carbon credits received every year are sold during the same year, thereby, generating annual carbon revenues.

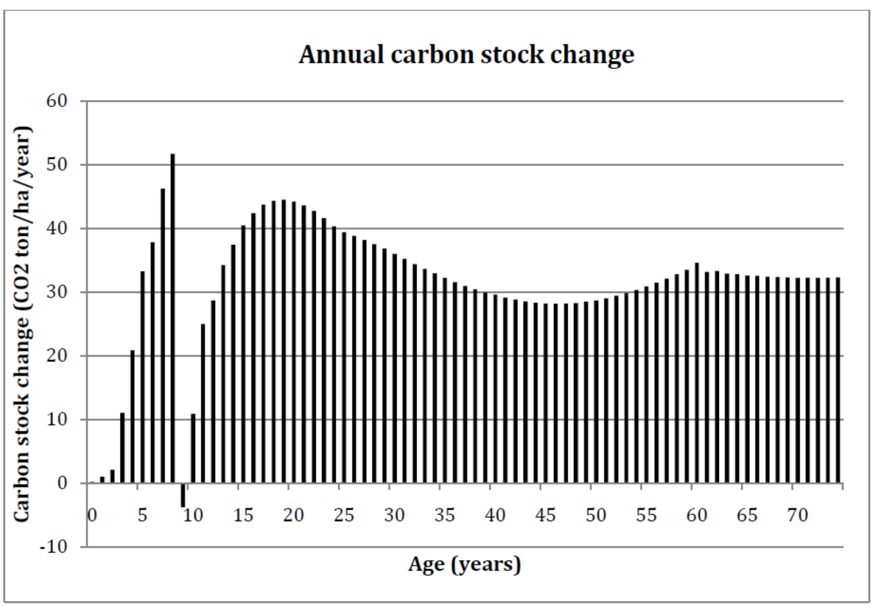

Figure 9: Annual carbon stock change.

When the forest is harvested, the carbon stock in the forest decreases sharply before it gradually increases again upon the timber growth of the subsequent replanting. Figure 10 shows the cumulative carbon stock profile of a 75 year fixed rotation forest, over multiple harvest-replant rotations. The sharp decrease represents the amount of harvest liabilities that needs to be paid at the time of harvest, as per forestry rules in the NZETS.

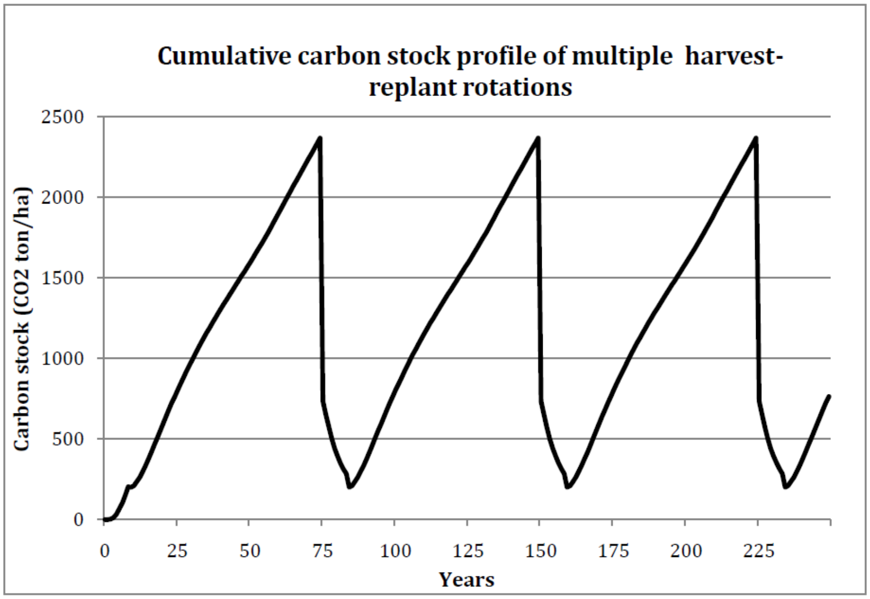

Figure 10: Cumulative carbon stock profile of a 75 year fixed rotation forest, over multiple harvest-replant rotations.

Costs and Cash Flow

The overall cash flow of carbon forestry (per hectare) is summarized in Table 2. These costs are based on Turner et al (2008) and the R300 Radiata Pine Calculator (Future Forests Research Limited, 2010). Harvesting cost (clearfell logging), H_T, is assumed to be \$40/m^3.

	Years											
	0	**1**	**2**	**. .**	**5**	**6**	**7**	**8**	**9**	**10**	**. .**	**Harvest year**
Planting costs	(1251)											
Pruning costs						(473)	(674)	(684)				
Thinning costs									(370)			
Maintenance costs, M_T	(50)	(50)	(50)	(50)	(50)	(50)	(50)	(50)	(50)	(50)	(50)	
NZETS compliance costs, M_C	(60)	(60)	(60)	(60)	(60)	(60)	(60)	(60)	(60)	(60)	(60)	(60)
Timber revenue, $X_T Q_T$												$
Harvest costs, $H_T Q_T$												($)
Carbon revenue, $X_C \Delta Q_C$	$	$	$	$	$	$	$	$	$	$	$	$
Carbon liability, $X_C Q_C$												($)

Table 2: Cash flow of carbon forestry (per hectare).

6 Results

Valuation Results for Fixed and Flexible Harvest Infinite Rotation Forests

Figure 11 compares the fixed harvest valuation of timber-only forestry and carbon forestry, using the double RV Binomial Tree method. For timber only forestry, the valuation is $6,761 per hectare, with an optimal rotation age of 27 years. For carbon forestry, the valuation is 69% higher at $11,420, with an optimal rotation age of 34 years.

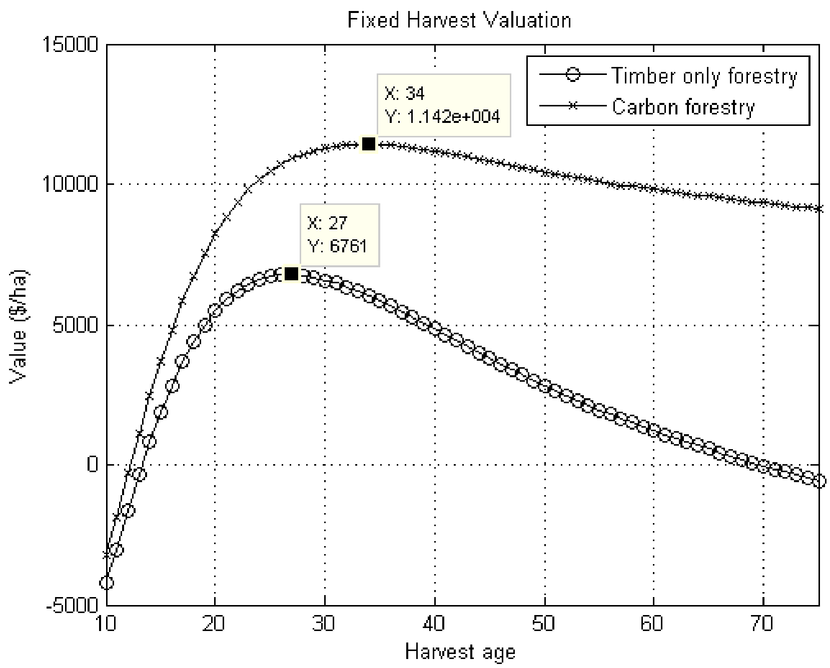

Figure 11: Fixed harvest valuation of timber-only forestry and carbon forestry using the double RV Binomial Tree method.

Figure 12 compares the Real Options (flexible harvest) valuation of timber only forestry and carbon forestry, using the double RV Binomial Tree method. The carbon forestry valuation of $14,290 is about 73% higher than the timber forestry valuation of $8,280.

Comparing the fixed harvest valuation of Figure 11 with the flexible harvest valuation of Figure 12, flexible harvest increases timber-only valuation from $6,761 to $8,280, amounting to a 22% increase. For carbon forestry, the valuation increases from $11,420 to $14,290, amounting to a 25% increase.

In summary, for both cases of fixed and flexible harvest, carbon forestry has a significantly higher valuation than timber-only valuation. In addition, adopting a flexible harvest approach further increases the valuation.

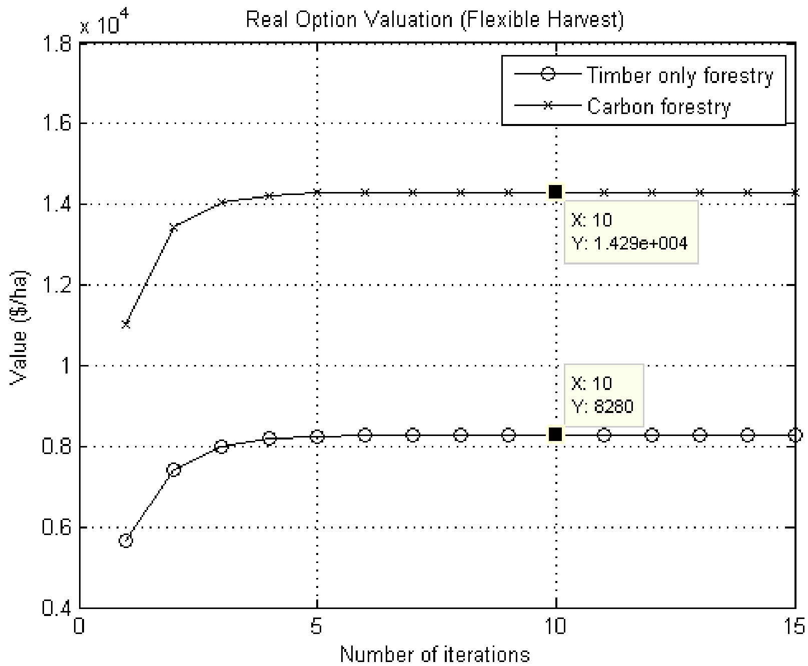

Figure 12: Real Options (flexible harvest) valuation of timber only forestry and carbon forestry using the double RV Binomial Tree method.

Timber-Carbon Price Thresholds for Optimal Harvest Decisions

The timber price is a key driver of revenue during harvest, and as such, the higher the timber price, at any given forest age, the more attractive is the harvest decision to the owner. On the other hand, the carbon price is a key driver of cost during harvest (even though it is a source of revenue annually prior to harvest). Due to the large carbon harvest liabilities (i.e. paying back all the carbon credits for harvesting), a lower carbon price will make harvest more attractive to the owner. If the carbon price is high, then, the timber price will need to be much higher in order to trigger an optimal harvest decision (in order to "offset" the harvest liabilities). At any given forest age these timber-carbon price thresholds for optimal harvest decisions can be generated by the double RV Binomial Tree method.

In Figure 13, the timber-carbon price optimal harvest thresholds for forest ages 15 to 75 years are stacked together into a single graph, showing the trend of enlarged optimal harvest zones with increasing forest age. The horizontal axis represents the carbon price, whereas the vertical axis is the timber price. The shaded areas show all carbon and timber price combinations for which it is optimal to harvest at the corresponding ages. For young forests, the thresholds to the shaded zones imply high timber prices and low carbon prices. This is due to the low timber volume of young forests, resulting in the need for the combination of relatively high timber price (revenue) and low carbon price (cost) in order to trigger an optimal harvest decision. As the forest age increases, there is more timber volume in the forests, and the timber-carbon price threshold lowers, which is made evident by the enlarged shaded parts of the graph denoting optimal harvest zones. For example, at age 15 in Figure 13, the combination of $120 timber price and $15 carbon price is in the no-harvest zone. However, at age 25, this price combination falls within the optimal harvest price zone. It is noted that the threshold for age 75 years is for a forced harvest decision (rather than the optimal harvest decision) since 75 years is the assumed maximum biological limit for tree growth, at which point harvest must take place.

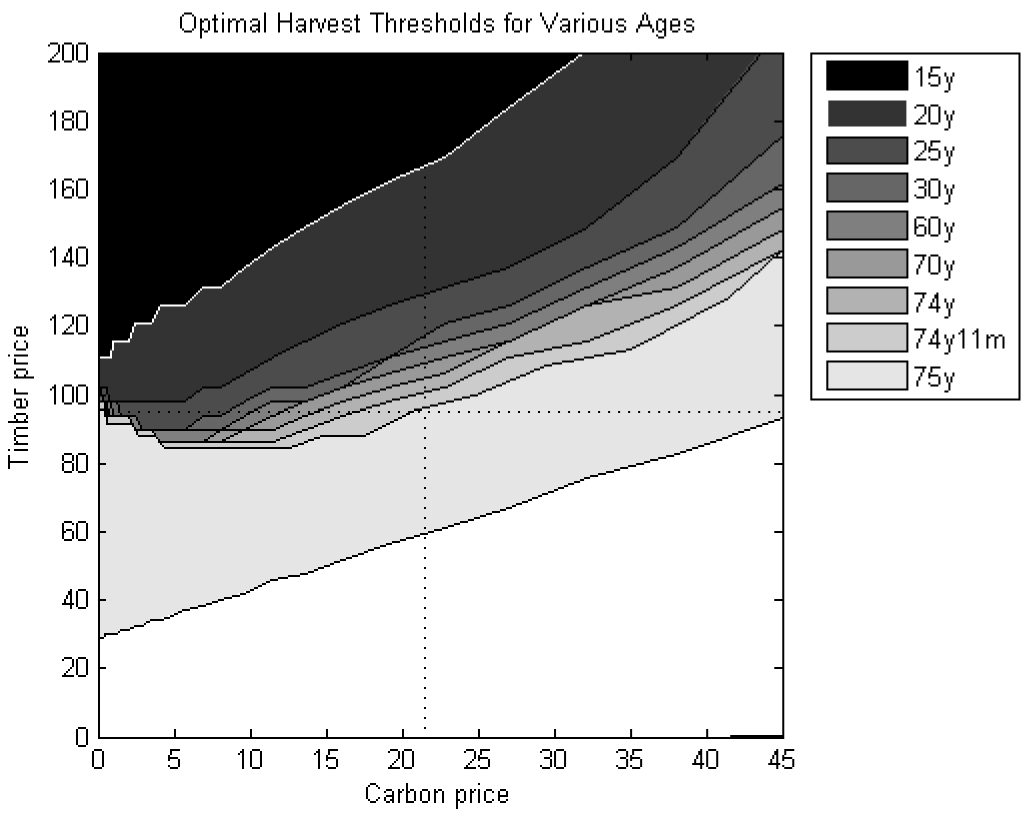

Figure 13: Timber-carbon price thresholds (double RV) for optimal harvest decisions for forest ages 15 to 75 years, stacked into a single graph[4].

In Figure 13, the long run prices for carbon (NZ$21.45) and timber (NZ$95.24) are also plotted as vertical and horizontal dotted lines, respectively. These dotted lines divide the graph into 4 quadrants:

- Top-Left quadrant: High timber price, and low carbon price
- Top-Right quadrant: High timber price, and high carbon price
- Bottom-Left quadrant: Low timber price, and low carbon price
- Bottom-Right quadrant: High timber price, and high carbon price

The Top-Left quadrant represents the best pricing conditions for an optimal harvest (i.e. high revenue from timber, and low cost of harvest liabilities), whereas, the Bottom-Right quadrant represents the worst pricing conditions (i.e. low revenue from timber, and high cost of harvest liabilities).

4 The shaded areas are optimal harvest zones for the respective ages. Note that the graph for age 75 years is for a forced harvest thresholds (rather than the optimal harvest threshold) due to maximum tree age.

Summary of Results

Results from this analysis conclude that the NZETS is expected to increase the bareland valuation of carbon forestry compared to timber-only forestry for radiata pine plantations. In addition, adopting a flexible harvest approach further increases the valuation. The NZETS is expected to be an effective policy to incentivize new forest planting to increase carbon sequestration in the forestry sector, contributing positively towards climate change mitigation in New Zealand. Given the wide window of technically feasible harvest dates (of up to 75 years), the forest owner can afford to wait for the optimal combination of timber and carbon prices, and harvest when it happens. The optimal harvest price thresholds generated from the double RV Binomial Tree method are also very useful tools for both forest owners and policy makers.

7 Potential Implications to New Zealand

Scenario Analysis

The New Zealand Ministry for the Environment periodically publishes a projection of New Zealand's Land Use, Land Use Change and Forestry (LULUCF). This publication shows New Zealand net position for the LULUCF sector under the Kyoto Protocol, for the short term period between 2008 and 2012. The most recent report was produced in April 2011 (Ministry for the Environment, 2011). A carbon price will most likely result in the lengthening of the forest rotation age from 27 years to longer rotation ages, even up to 75 years old. The scenario analysis in this section focuses on potential implications of lengthening forest rotation to carbon stock management in New Zealand over a longer term horizon beyond 2012.

Assumptions Made in the Scenario Analysis

Figure 14 shows the rate of new forest plantings between 1990 and 2008 (Horgan, 2007).

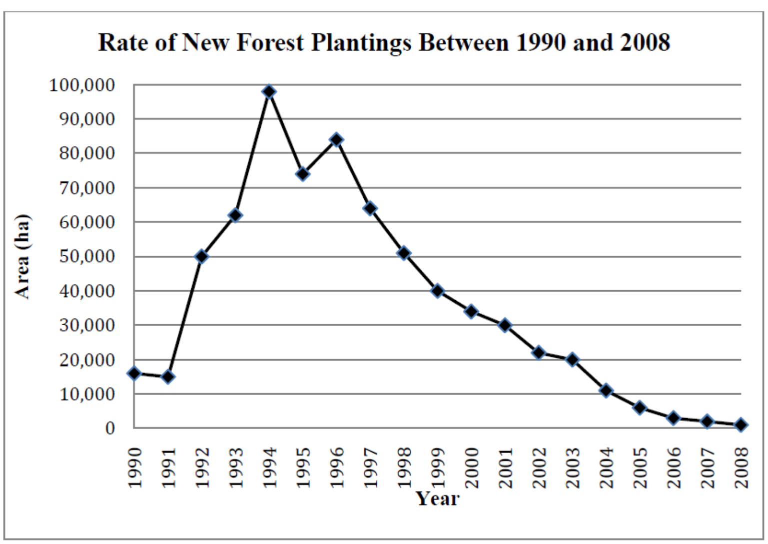

Figure 14: Rate of new forest plantings between 1990 and 2008.

In order to simplify the scenario analysis, only radiata pine post-1989 forests[5] are considered – all other forest species are excluded. It is assumed that an average of 89%[6] of all the new forest plantings in each year between 1990 and 2008 in Figure 14 are radiata pine forests. All radiata pine forests are also assumed to have characteristics that are identical to the forest modeled in this paper. Based on these assumptions, the entire post-1989 radiata pine forests in New Zealand is broken down into 19 uniform age classes, each planted in every year between 1990 and 2008 as per Figure 14.

Five scenarios of rotation age lengthening are analysed: 27, 30, 37, 50 and 75 years. In each of these scenarios, all the radiata pine forests are assumed to be harvested at the same age, at the rotation length being analysed in the respective scenarios. For example, under the 30 year rotation age scenario, all 13,350[7] hectares of radiata pine forests planted in 1991 are assumed to be harvested in the year 2021, and all 44,500[8] hectares of radiata pine forests planted in 1992 are assumed to be harvested in the year 2022, and so forth. This simplistic assumption is consistent with the approach taken by Manley and Maclaren (2009) where scenarios for 28 year, 32 year and 40 year rotations were projected[9].

The five scenarios are not intended to be a detailed and accurate projection/forecast such as the New Zealand Wood Availability Forecasts 2010-2040 (Ministry of Agriculture and Forestry, 2010). They are intended to show a hypothetical and potential effect of lengthening the rotation age on the carbon stock in New Zealand. The work here takes the projection to a more extreme level, by considering the hypothetical and potential effect of lengthening the rotation age to 50 and 75 years, which was not previously considered in Manley and Maclaren (2009).

Results of the Scenario Analysis

Figure 15 shows the projected annual carbon stock change of post-1989 radiata pine carbon forests, for the scenarios of 27, 30 and 37 year rotation ages, between the time horizon of 2008 and 2100. The positive value range of the vertical axis represents the net annual carbon sequestration, whereas the negative value range represents the net annual carbon emissions (i.e. carbon liabilities due to harvesting). A section of Figure 15 is magnified in the Figure 16 to show the horizontal axis zero crossings (marked by circles). In the near term, lengthening of rotation age prolongs the duration that annual carbon stock change of carbon forests remains in the positive territory. A 27 year rotation crosses zero at around 2021, a 30 year rotation crosses zero at around 2023, and a 30 year rotation crosses zero at around 2030.

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5 Pre-1990 forests are not included in this scenario analysis.

6 Based on data from Ministry of Agriculture and Forestry (2009), 89% of all post-1989 forests are radiata pine forests.

7 15,000 hectares x 0.89 = 13,350 hectares.

8 50,000 hectares x 0.89 = 44,500 hectares.

9 This refers to Figure 10 of Manley and Maclaren (2009). It is noted here Manley and Maclaren (2009) plotted carbon stock (i.e. the cumulative carbon stock of New Zealand's Kyoto plantations), whereas in this section, the annual carbon stock change (i.e. the amount by which carbon stock increases or decreases every year) is plotted.

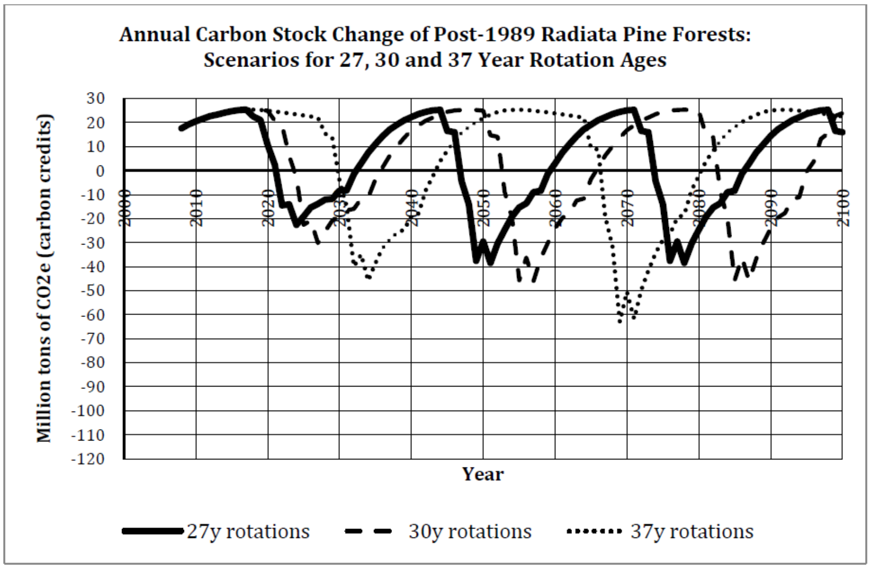

Figure 15: Scenarios of annual carbon stock change of New Zealand's post-1989 radiata pine carbon forests, for rotation ages 27, 30 and 37 years, between the time horizon of 2008 and 2100.

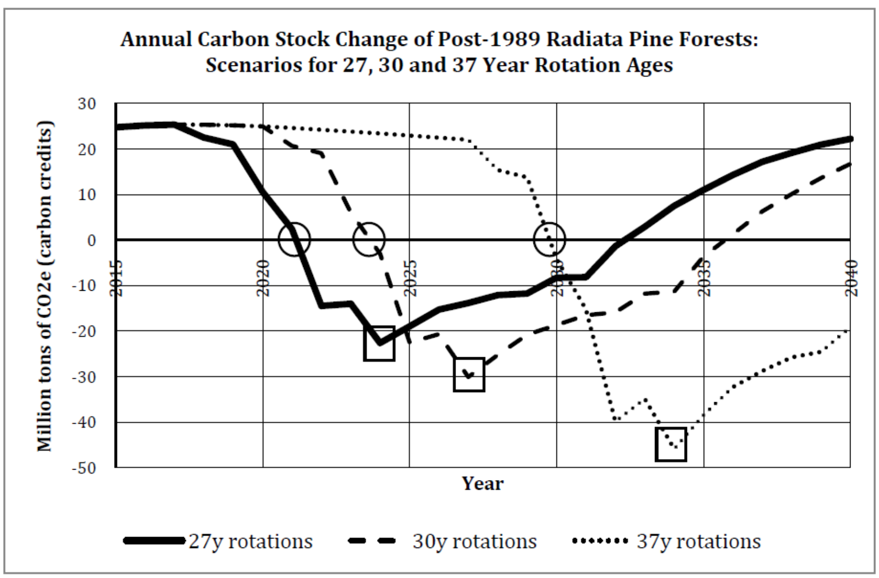

Figure 16: Magnification of Figure 15 to show the zero crossings (marked by circles) and minima points (marked by squares).

Lengthening the rotation age also results in more forest growth (i.e. a 37 year old forest has more timber than a 27 year old forest), which results in a higher accumulation of total carbon stock. This implies that when forests are harvested, because of their lengthened growth period, the magnitude of harvest liabilities is higher. For New Zealand's carbon forests, the harvest liability minima are marked by squares in Figure 16. The minimum point for 27 year rotations is about -22 million tons (occurring in the year 2024), whereas the respective minima for 30 and 37 year rotations are about -30 million tons (occurring in the year 2027) and -45 million tons (occurring in the year 2034).

Both the effects of extended sequestration and higher magnitude of harvest liabilities are significantly amplified if the rotation age extends beyond 37 years to 50 or 75 years, as shown in Figure 17. For 50 year rotation scenario, the forest keeps on sequestering carbon and only crosses zero in 2042, with a minimum point of approximately -70 million tons in 2047. For 75 year rotations, the zero crossing happens in 2067, with a much larger minimum of approximately -118 million tons in 2072.

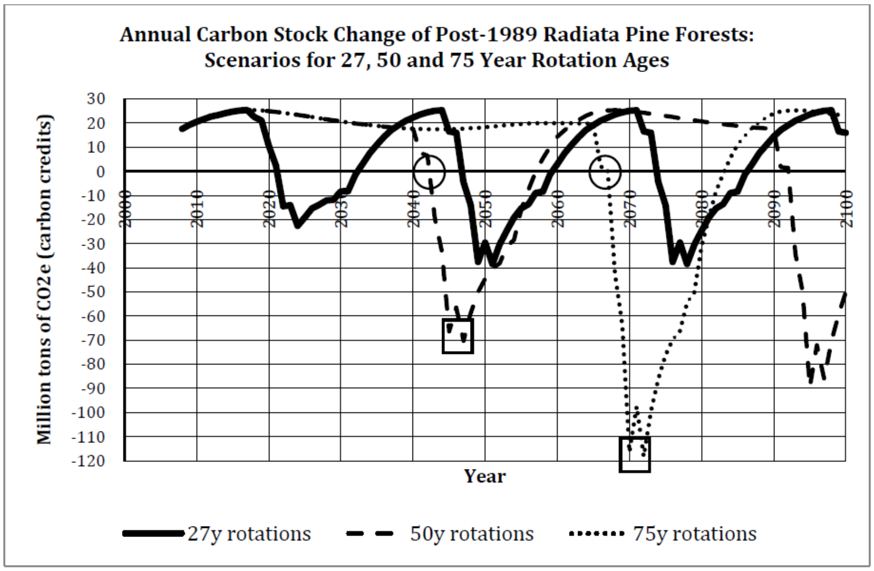

Figure 17: Scenarios of annual carbon stock change of New Zealand's post-1989 radiata pine carbon forests, for rotation ages 27, 50 and 75 years, between the time horizon of 2008 and 2100[10].

To illustrate the monetary value of such potential harvest liabilities, a $20 carbon price would mean that a harvest liability of $1.4 billion[11] in the year 2047 for the 50 year rotation scenario. For the extreme 75 year scenario, a harvest liability of $2.36 billion[12] would be incurred in the year 2072. For further comparison of the order of magnitude, New Zealand's total greenhouse gas emissions in 2008 were only approximately -75 million tons (Ministry for the Environment, 2010). This emission is of a similar order of magnitude to the potential harvest liabilities due to extending rotation lengths. As such, the lengthening of rotation age for short and medium term carbon sequestration benefits has potentially major long term implications to the overall carbon stock balance in New Zealand.

10 Zero crossings are marked by circles, and minima points are marked by squares.

11 -70 million tons x $20 per ton = -$1.4 billion.

12 -118 million tons x $20 per ton = -$2.36 billion.

Summary

Our analysis indicates that carbon forestry will introduce substantial changes in the aggregated supply of timber from radiata pine in New Zealand. The magnitudes of changes is such that it seems to be crucial for forest owners and the government to manage New Zealand's overall carbon stock with care, particularly the potentially massive harvest liabilities. Similarly to what is in place in the financial and banking system, the government may need to consider putting in place the necessary regulatory measures and contingencies in order to ensure the future stability of the carbon market in New Zealand . It is also important to recognize that while climate change mitigation via carbon forestry offsets is an effective solution, it is only a temporary one. Sooner or later, the forests will have to be harvested, and when that happens, the carbon will be at least in part re-emitted back into the atmosphere and the carbon credits will have to be repaid back (i.e. harvest liabilities). The silver lining is that carbon forestry buys time in order to allow for innovative technological solutions to greenhouse gas emissions (such as low-emission/hybrid/electric vehicles and clean electricity) to be developed and deployed widely in a cost effective manner. Other incentives should be devised to promote the lengthening of the period of time during which the carbon remains locked in timber and away from the atmosphere. For example, new buildings with timber structures could receive carbon credits from forest felling. Other industries manufacturing durables using timber could also be integrated in such a system so as to take a long term perspective on decarbonization.

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