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***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, forests planted on or after 1st January 1990 earn carbon credits. These credits have to be repaid when the forest is harvested. This paper analyses the effects of this scheme on the value of bareland on which radiata pine is to be planted. A real options method is developed and applied, assuming stochastic carbon and timber prices. We find that land value increases by about 73%, with the rotation age lengthened. The optimal harvest price thresholds are useful in deciding whether to harvest or to wait.

Keywords for paper: Emissions Trading Scheme (ETS); Climate change policy; Kyoto Protocol; Real options; carbon forestry; tradable permits;

JEL CODES: Q23, Q28, Q54

I 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 engage in more desirable and sustainable behavior. It is designed to reflect international climate change rules (New Zealand Government, 2010). It allows for a transition period between 1st July 2010 and 31st December 2012, during which emitters from the non-forestry sector (such as the energy sector) have the option to buy emission units (carbon credits) either at market prices from the carbon market or at a fixed price of NZ\$25 per unit (in July 2012 one NZ\$ was about US\$0.8) from the New Zealand government. In this context one unit equals one ton of carbon dioxide equivalent. In addition, non-forestry emitters will have to surrender only one emission unit for every two tons of emissions they produce during this period. In July 2012, the government has further announced that both this two-for-one unit obligation and the NZ\$25 fixed price option will continue beyond 2012, with no end date specified at present (Ministry for the Environment, 2012).

For the forestry sector, new forests established on or after 1st January 1990 are eligible to earn carbon credits¹. Known domestically as post-1989 forests, these forests can earn carbon credits for increases in carbon stocks from 1st January 2008². If in a post-1989 forest the carbon stock decreases (for example, due to harvesting), emission units must be surrendered (i.e. harvest liabilities). These post-1989 forestry rules have been designed into the NZETS to directly reflect the rules of afforestation and reforestation under Article 3.3 of the Kyoto Protocol (UNFCCC, 1998).

After receiving the credits, forest owners can accumulate them or immediately sell them in domestic and international carbon markets. Upon harvesting post-1989 forests, the proportionate amount of carbon credits must be surrendered. The required credits could be purchased from domestic or international carbon markets at the market price (Ministry of Agriculture and Forestry, 2011a). These rules produce a clear revenue stream from carbon credits and introduce harvest liabilities. They hence

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.

alter the traditional timber-only cash flow business model, and affect the harvesting decision by forest owners. We report here research results that explore these changes.

This paper briefly reviews the literature on infinite rotation forestry valuation methods, namely net present value/land expectation value (NPV/LEV) and real options. This is followed by a review of the carbon forestry literature, with a focus on carbon forestry modeling work in New Zealand. Then the methodology employed in this paper is described, along with data and assumptions made. Valuation results are presented and discussed.

The novel methodological contribution of this paper is the development of a binomial tree with two stochastic prices, one for carbon and one for timber. The binomial tree is used for the valuation of real options to analyze and predict the effects of carbon forestry in New Zealand. This method is advantageous as it enables simultaneous stochastic and dynamic modeling of both the carbon and timber prices in a simplified fashion.

II FORESTRY VALUATION METHODS

Probably the best known, and still quite widely adopted, approach to forestry valuation was proposed by Faustmann in 1849, whereby the value of the forest investment is determined by forecasting expected future cash flows and discounting them at a specific discount rate using a net present value (NPV) approach. Riskiness in the investment and time value of money is generally captured by the discount rate, which is assumed to be constant throughout the forest's lifetime.³ The method is relatively simple numerically and easy to implement, but has a few notable weaknesses. The NPV approach does not account for flexibility due to the assumption of a fixed investment path and duration, where the rotation decision is made in advance, and remains unchanged, even when unexpected favorable or unfavorable events arise. It also ignores the value that alternative opportunities and choices bring to the investment such as deferring or bringing forward the timber harvest or the choice of conversion to agriculture land.

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

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*".

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 the expected harvest (i.e. it is decided upfront when the trees are first planted). The decision to replant will also have to be made immediately after cutting, according to 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 unexpectedly low at harvest time, the "loss" in profits is also permanently irreversible.

Forest owners face uncertainty in future prices and irreversibility in the consequences of their decisions. It is hence advantageous for them to remain flexible about the timing of forest harvesting decisions. If timber prices are low at harvest time forest owners may want to delay it and wait-and-see before making a harvesting decision. Likewise, if timber prices are unusually high before the planned harvest time then 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 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 (henceforth RO) approach offers such flexibility.

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 RO theory by Myers (1977). He was the first to argue 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. In short, RO are investments in real 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 RO valuations: partial differential equations (henceforth PDE), simulations, and binomial trees.

The PDE approach treats time as a continuous variable and expresses the present value of a cash flow stream as the solution to a set of PDEs. This is the standard and most widely used RO valuation method in the academic literature due to its mathematical elegance and insights. 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. Large simulation programs are used to value options that are very difficult to solve using PDEs. Though powerful, this method is not very insightful because it only provides the answer hiding much of the relationships between key variables and it hence obscures the valuation

drivers. Stochastic dynamic programming is another form of simulation and shares the same shortcomings.

The binomial trees approach, also known as the Binomial Option Pricing Model, 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. The precision of this method can be improved to a very high degree by dividing the life span of an option into increasingly smaller, yet finite discrete stages. This discrete-time approach is mathematically more practical 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. The binomial trees approach 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. 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 less flexible Faustmann model. Clarke and Reed (1989) and Reed and Clarke (1990) further distinguished the stochastic uncertainty in the dimensions of timber price and 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 RO 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 process. Plantinga (1998) found that when prices follow a random walk, there is almost no option value, whereas, when prices follow a mean reverting process, there is a larger option value. Insley (2002) concluded that “*option value and optimal cutting time are significantly different under the mean reversion assumption compared to geometric Brownian motion*”. Insley and Rollins (2005) 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 based on the argument that, like many commodities such as oil and copper, timber prices should eventually revert to some mean, reflecting long run marginal costs. Gjolberg and Guttormsen (2002)

applied the RO approach to the tree-cutting problem under the assumption of mean-reverting stumpage prices. In Khajuria, Kant and Laaksonen-Craig (2009), RO theory is used to value timber harvesting in Canada using a mean reversion process with jumps.

To gather comparative insights and evaluate robustness of the results, valuations of fixed and flexible rotation ages are commonly compared using different methods: an NPV/LEV model and a RO model. In such comparisons, conducted for example by Manley and Niquidet (2010) and Duku-Kaakyire and Nanang (2004), the RO 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 sources of the differences in valuations. In Guthrie (2009) a single random variable (henceforth r.v.) binomial tree (henceforth BT) method was applied to study the optimal harvest decision of forests in Oregon (USA) using a mean-reverting timber price process. The same BT method was able to generate results for RO (flexible harvest decision) and NPV/LEV (fixed rotation), for both single and infinite rotations. The work of Guthrie (2009) is a useful point of departure for the present study as it can be used to isolate the cause of increased valuation of flexible rotations compared to those obtained with fixed length rotations.

III CARBON FORESTRY

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 to 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 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. They found that a system of subsidies to encourage tree growth and taxes to discourage timber harvesting could be a useful policy tool to increase carbon sequestration as a result of moderately longer forest rotation ages. Sohngen and Mendelsohn (2003) developed a general equilibrium model to show the interaction between carbon and timber prices. They found that large sequestration efforts would eventually have systematic effects on the price of land and price of timber. While their

work concluded that timber and carbon prices would not be independent in future, it is unclear when this will happen, particularly because the current state of carbon markets is insufficiently developed. More recently, Olschewski and Benitez (2009) investigated the optimization of joint timber production and carbon sequestration of afforestation projects covered under the Kyoto Protocol. Behan, McQuinn and Roche (2006) employed RO to explain why farmers may be slow to switch land use from traditional agriculture to forestry in Ireland.

Chladna (2007) used RO to study the impact of carbon credit payment schemes on the optimal rotation length based on a PDE model. The author was the first to provide a detailed 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 to represent the increasing marginal value of carbon stock. 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 exponential growth of 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 the analysis of 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 fixed harvest NPV/LEV methodology to analyze the impact of the New Zealand Emissions Trading Scheme (NZETS) on forest management. Revenue from annual sales of carbon credits greatly increases the valuation of post-1989 forests, and lengthens their rotations. For example, at a constant (non-stochastic) carbon price of NZ\$10, the valuation increases from NZ\$4,117 (timber-only, 25 year rotation) to NZ\$5,484 (timber and carbon, 27 year rotation). If the carbon price is constant at NZ\$20, the LEV increases to NZ\$8,114 (timber and carbon, 33 year rotation).

Turner et al (2008) employed a combination of NPV/LEV and simulations to model and analyze the management of planted forests for carbon under the NZETS. This work showed that at a constant carbon price of NZ\$22, extending the fixed rotation age of carbon forests from 25 years to 70 years increases the valuation from NZ\$4,095 to NZ\$5,095.

In Meade et al (2008), results from a simulation method called bootstrapping RO analysis were

compared to results from a NPV/LEV calculation. At a NZ\$25 price, the NPV/LEV method produces a carbon forestry valuation of NZ\$3,310, whereas the bootstrapping RO method produces a valuation of NZ\$11,030.

Guthrie and Kumareswaran (2009) used PDEs to study the impact of carbon credit payment schemes over multiple rotations in New Zealand. This work modeled the timber price stochastically while keeping the carbon price constant. Due to the complexity of the PDE method, only one of the two prices is modeled stochastically in order to keep the mathematics tractable.

In these papers, we note a convergence in conclusions that carbon revenue significantly increases the valuation of post-1989 forests in New Zealand, with a general lengthening of optimum rotation age. However, these existing works are constrained by the untenable assumption of constant price, applied to either or both timber and carbon. Both carbon and timber prices influence the forest owners' harvesting decision and both are subject to uncertainty. It is therefore necessary to take into account the stochastic fluctuations of both these prices in order to compare the valuations of the timber-only forests with those of the carbon and timber forests in a more accurate manner. The accuracy is particularly important, because the difference between the two valuations will determine the amount of new lands that will be brought into forestry, and hence, the effectiveness of the NZETS in increasing the long term carbon sequestration of New Zealand. This forms the basis of our motivation in developing a model that incorporates both stochastic timber and stochastic carbon prices. Here, we focus our efforts on the valuation of flexible harvest forests.

IV METHODOLOGY

The binomial tree method of Guthrie (2009) is used as the foundation of our model development. In subsequent sections, the single random variable (r.v.) binomial tree method is explained. Because it only has one r.v., this method can model only one stochastic price. A double r.v. model is hence developed to account for the stochastic nature of both timber and carbon prices endogenously, allowing for a joint optimization of the harvest decision.

Single Random Variable Price Binomial Tree

The basic parameters of a price binomial tree (BT) are the following. $X(i,n)$ denotes the price, where i is the number of downward price moves and n is the time step; $X(0,0)$ denotes the present price; U is the upward price move multiplicative factor; D is the downward price move multiplicative factor (D

$= 1/U$); $\theta_U(i,n)$ denotes 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 BT labeling convention is shown in Figure 1 for $n = 2$. Each $X(i,n)$ node on the BT 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 $X(i+1,n+1) = X(i,n)D$. A mean-reverting price process is assumed. The technique for calibrating the BT for a mean reverting price is described in Guthrie (2009).

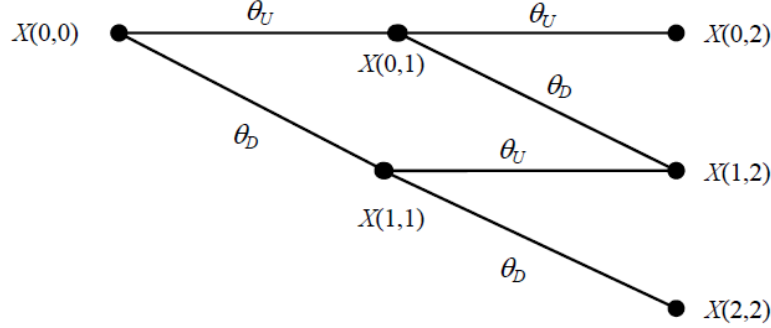


Figure 1: The Binomial Tree labeling convention.

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":

$$\begin{aligned}\Pi_U &= \theta_U - MRP_{Adj} \\ \Pi_D &= 1 - \Pi_U = \theta_D + MRP_{Adj}\end{aligned}\tag{1}$$

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 price BT are applied to the valuation BT, 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 price.

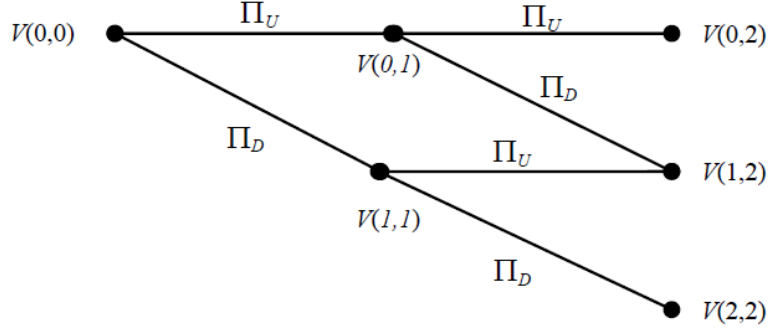


Figure 2: Single r.v. valuation Binomial Tree.

In contrast to the price BT which is calculated forward using $X(0,0)$, U and D , the valuation BT 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 denoted as:

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

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

Applying the Single r.v. Binomial Trees to a Flexible Harvest Decision (Real Options)

When calculating the valuation (backwards), a decision on whether or not to harvest is re-evaluated at each node, where a node is a harvesting opportunity presenting itself at predefined regular time intervals (e.g. every 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:

$$V(i,n) = \max \left\{ \begin{array}{l} (1-T)((X(i,n) - H)Q(n\Delta t_m)) + B, \\ (1-T)(-M_T) + \frac{\Pi_U(i,n)V(i,n+1) + \Pi_D(i,n)V(i+1,n+1)}{R_f} \end{array} \right\} \quad (3)$$

where T is the tax rate, H is the harvesting cost, $Q(n)$ is the timber volume at time step n , Δt_m is the time step size of the binomial tree, 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 valuation BT 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 $V(0,0)$:

$$B = V(0,0) - (1 - T)G \quad (4)$$

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. RO valuation for the 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 iterated a number of times (e.g. 10 iterations), the bareland value converges to a steady state value (i.e. it no longer changes with subsequent iterations). This convergence value is the valuation for an infinite rotation forest with flexible harvest (i.e. RO valuation for infinite rotation).

With some minor modifications, this valuation method can be applied to a fixed harvest (Guthrie, 2009).

Development of a Double r.v. Binomial Tree

Let X^T be the timber price, X^C denote the carbon price, Π^T be the probability of the timber price process and Π^C denote the probability of the carbon price process. For the case of $n = 1$, the single r.v. price BT for timber and carbon are shown below in Figure 3.

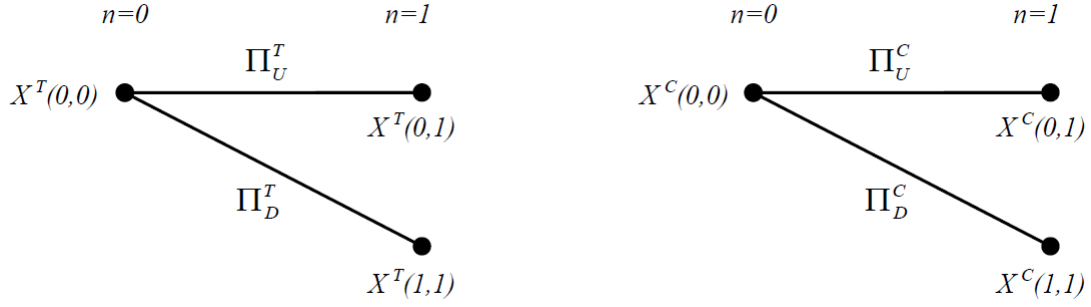


Figure 3: Single r.v. price Binomial Trees for timber (left) and carbon (right).

Two single random price binomial trees can be combined to construct a BT with two random prices, one for carbon and one for timber, as shown in Figure 4, where each node consists of a pair of timber and carbon prices. For a single r.v. BT, the number of nodes increases with n at the rate of $(n+1)$, whereas for a double r.v. BT, the number of nodes increases with n at the rate of $(n+1)^2$. This increase adds to the computational complexity of the double r.v. BT method. The corresponding double r.v. valuation BT is shown in Figure 5.

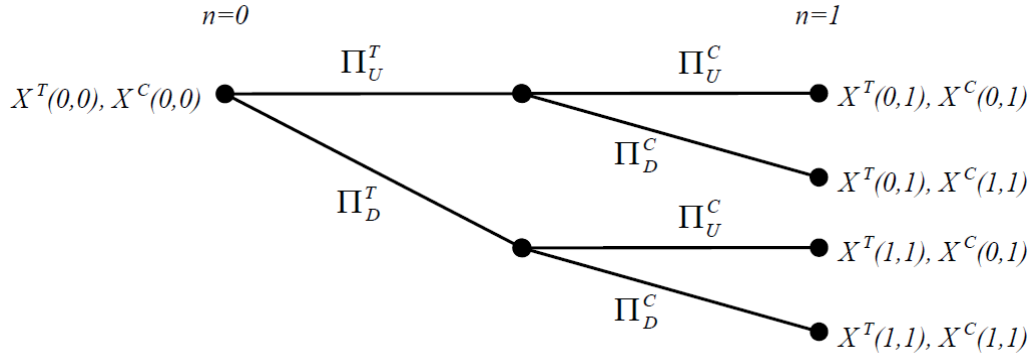


Figure 4: Double r.v. price Binomial Tree for timber and carbon.

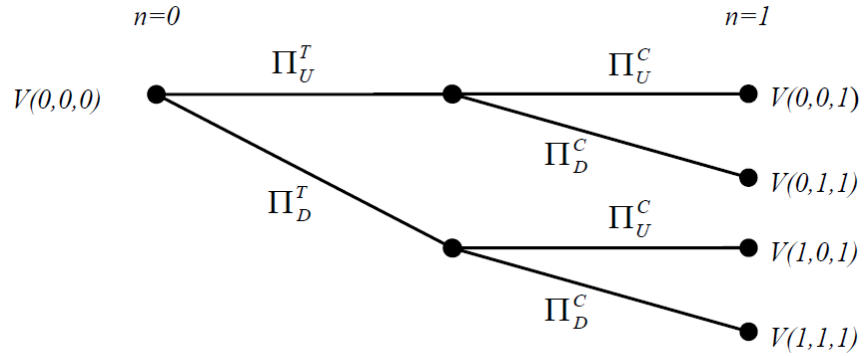


Figure 5: Double r.v. valuation Binomial Tree for timber and carbon.

In the same way as for the single r.v., 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:

$$V(0,0,0) = \frac{\Pi_U^T \Pi_U^C V(0,0,1)}{R_f} + \frac{\Pi_U^T \Pi_D^C V(0,1,1)}{R_f} + \frac{\Pi_D^T \Pi_U^C V(1,0,1)}{R_f} + \frac{\Pi_D^T \Pi_D^C V(1,1,1)}{R_f} \quad (5)$$

Valuation Function of the Double r.v. Binomial Tree

For the double r.v. BT, the real option valuation function is:

$$V(i,j,n) = \max \left\{ \begin{aligned} & \left[(1-T) \left([X^T(i,n) - H^T] Q^T(n) - X^C(j,n) Q^C(n-1) - M^C \right) \right. \\ & \quad \left. + B, \right. \\ & \left. (1-T) \left(-M^T - M^C + X^C(j,n) [Q^C(n) - Q^C(n-1)] \right) \right. \\ & \quad \left. + R_f^{-1} \left(\begin{aligned} & \Pi_U^T(i,n) \Pi_U^C(j,n) V(i,j,n+1) + \\ & \Pi_U^T(i,n) \Pi_D^C(j,n) V(i,j+1,n+1) + \\ & \Pi_D^T(i,n) \Pi_U^C(j,n) V(i+1,j,n+1) + \\ & \Pi_D^T(i,n) \Pi_D^C(j,n) V(i+1,j+1,n+1) \end{aligned} \right) \right] \end{aligned} \right\} \quad (6)$$

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.

V DATA AND ASSUMPTIONS

Table 1 shows the yield by log grade for radiata pine of various ages (source: Future Forests Research Limited, 2010).

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 grade⁴ yield of various timber ages (in percentages).

The average log grade yield is used as weight in aggregating the log grade prices (Ministry of Agriculture and Forestry, 2011b) into a single proxy timber price series. This is further adjusted using the Consumer Price Index (CPI) from Statistics New Zealand (2011) to result in the CPI-adjusted timber price series as shown in Figure 6. 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

⁴ Pruned logs are logs without knots, having a small end diameter size of 300 mm and above. S1 (400 mm and above), S2 (300-399 mm) and S3 (200-299 mm) are unpruned structural logs with maximum knot size of 60 mm. L1 (400 mm and above), L2 (300-399 mm) and L3 (200-299 mm) are unpruned industrial logs with maximum knot size of 140 mm. Pulp are unpruned logs with small end diameter of 100 mm. (Ministry of Agriculture and Forestry, 2010).

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 independent⁵.

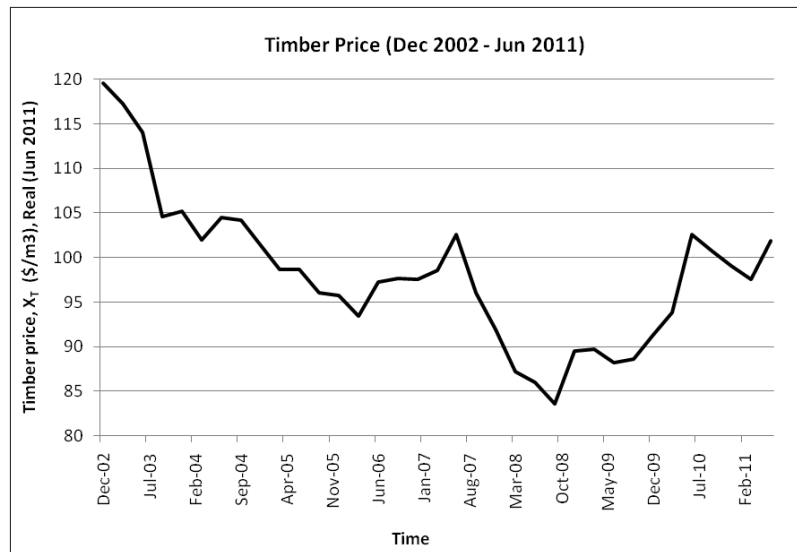


Figure 6: Timber price (CPI adjusted).

⁵ Historically and till the present time, timber in New Zealand has been predominantly supplied by pre-1990 plantation forests, which do not earn carbon credits nor incur harvest liability under the NZETS. This is in large part due to the young age of post-1989 forests (e.g. forest planted in 1991 is only 21 years of age in 2012 whereas a typical harvesting age for fixed rotation timber-only forest is 27 years). As a result, domestic timber in New Zealand is supplied from pre-1990 forests, which influences the timber price. Post-1989 forests are affected by the carbon price, which is linked to the global carbon price. While the domestic timber price may be related to the global timber price, there is presently no strong linkage between the global timber price and the global carbon price. The majority of carbon credits in the global market have to date been supplied from non-forestry sources, such as the non-forestry Clean Development Mechanism (CDM) scheme and trading/sale of Assigned Amount Units (AAUs). CDM forestry projects in emerging markets and developing countries have only had limited uptake due to problems such as permanence (relating to the loss of temporarily stored carbon) and accounting (measurement and monitoring). REDD+ mechanisms to reduce deforestations in emerging markets and developing countries, such as Indonesia, Brazil and Africa, have yet to be implemented for similar reasons. Therefore, the assumption of independence in analyzing the NZETS is a reasonable one, at least for the present time.

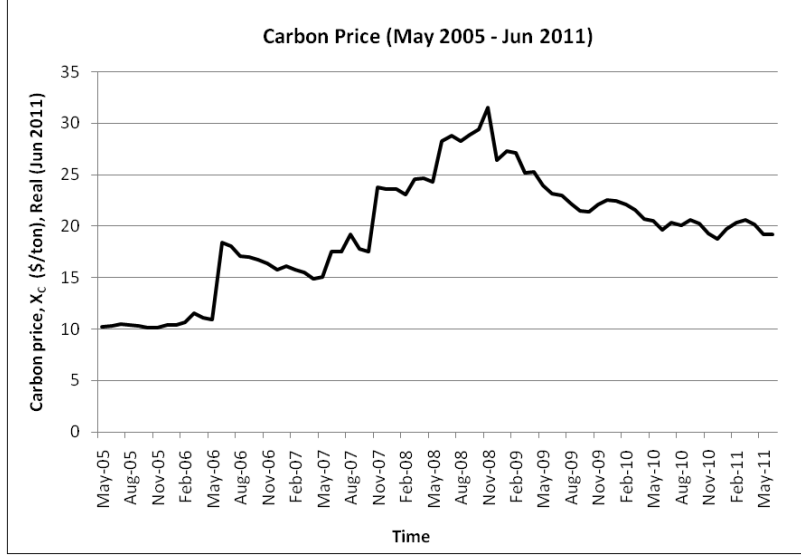


Figure 7: Carbon prices (CPI adjusted).

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

Timber price series

$$\hat{a}_T = 0.7996 \text{ (0.3298)}$$

$$\hat{b}_T = 4.5564 \text{ (0.0320)}$$

$$\hat{\sigma}_T = 0.0732 \text{ (0.0090)}$$

$$R^2 = 0.8229$$

$$U_T = 1.0213$$

$$D_T = 0.9791$$

$$e^{\hat{b}_T} = \text{NZ\$}95.24 \text{ (long run price)}$$

Carbon price series

$$\hat{a}_C = 0.7540 \text{ (0.3898)}$$

$$\hat{b}_C = 3.0659 \text{ (0.1728)}$$

$$\hat{\sigma}_C = 0.2971 \text{ (0.0247)}$$

$$R^2 = 0.9285$$

$$U_C = 1.0895$$

$$D_C = 0.9178$$

$$e^{\hat{b}_C} = \text{NZ\$}21.45 \text{ (long run price)}$$

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.

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

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. 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.

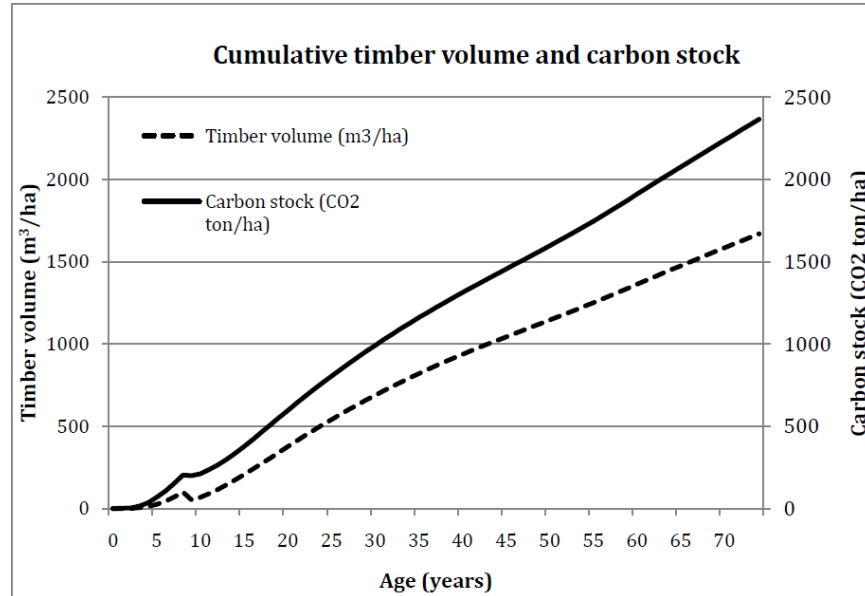


Figure 8: Cumulative timber volume and carbon stock functions for site index of 28.3 meters, with 850 stems planted per ha.

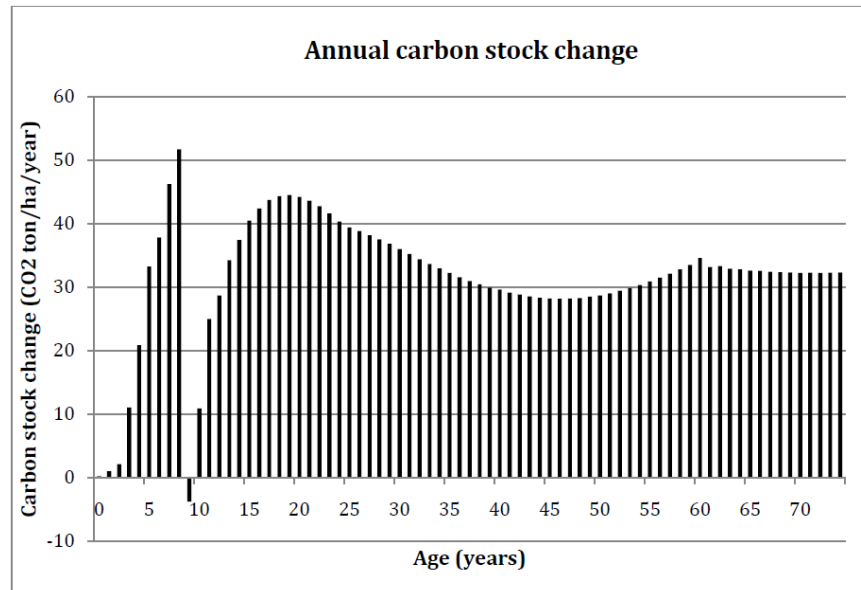


Figure 9: Annual carbon stock change.

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.

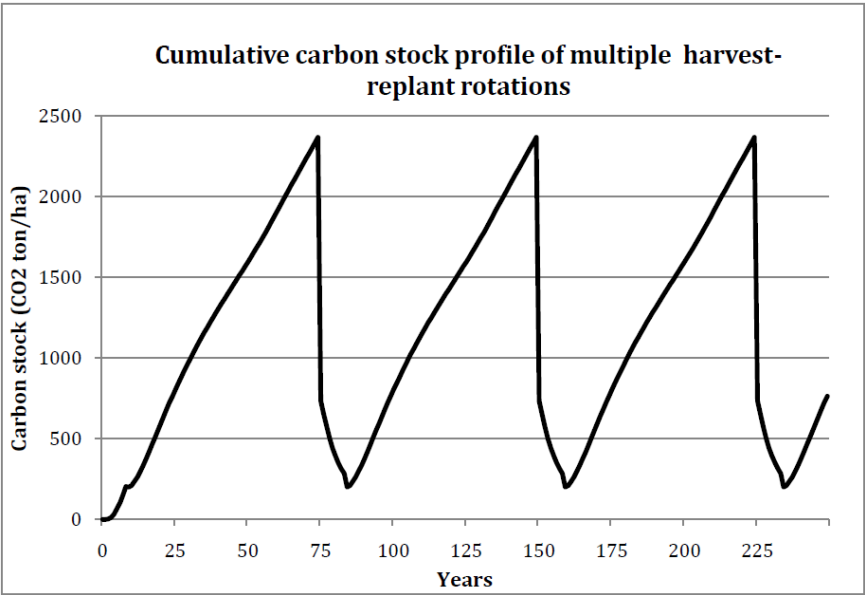


Figure 10: Cumulative carbon stock profile of a 75 year fixed rotation forest, over multiple harvest-replant rotations.

The establishment and operational costs 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 NZ\$40/m³.

	Years											Harvest year
	0	1	2	...	5	6	7	8	9	10	...	
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

Table 2: Establishment and operational costs of carbon forestry (per hectare).

VI RESULTS

Valuation Results

Figure 11 compares the RO (flexible harvest) valuation of timber-only forestry and carbon forestry, using the double r.v. BT method. The carbon forestry valuation of NZ\$14,290 is about 73% higher than the timber-only forestry valuation of NZ\$8,280.

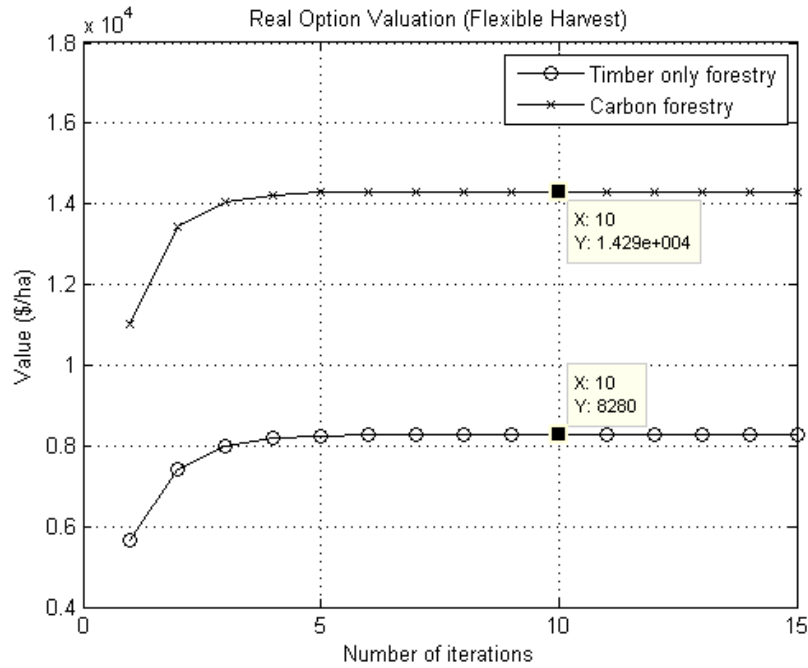


Figure 11: RO (flexible harvest) valuation of timber only forestry and carbon forestry using the double r.v. Binomial Tree method.

Timber-Carbon Price Thresholds for Optimal Harvest Decisions

The timber price is a key driver of revenue for harvest: 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, prior to harvest, it is a source of annual revenue). Due to the large carbon harvest liabilities (i.e. paying back all the carbon credits lock in the timber harvest), 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 the 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 r.v. BT method.

In Figure 12, 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 12, the combination of NZ\$120 timber price and NZ\$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.

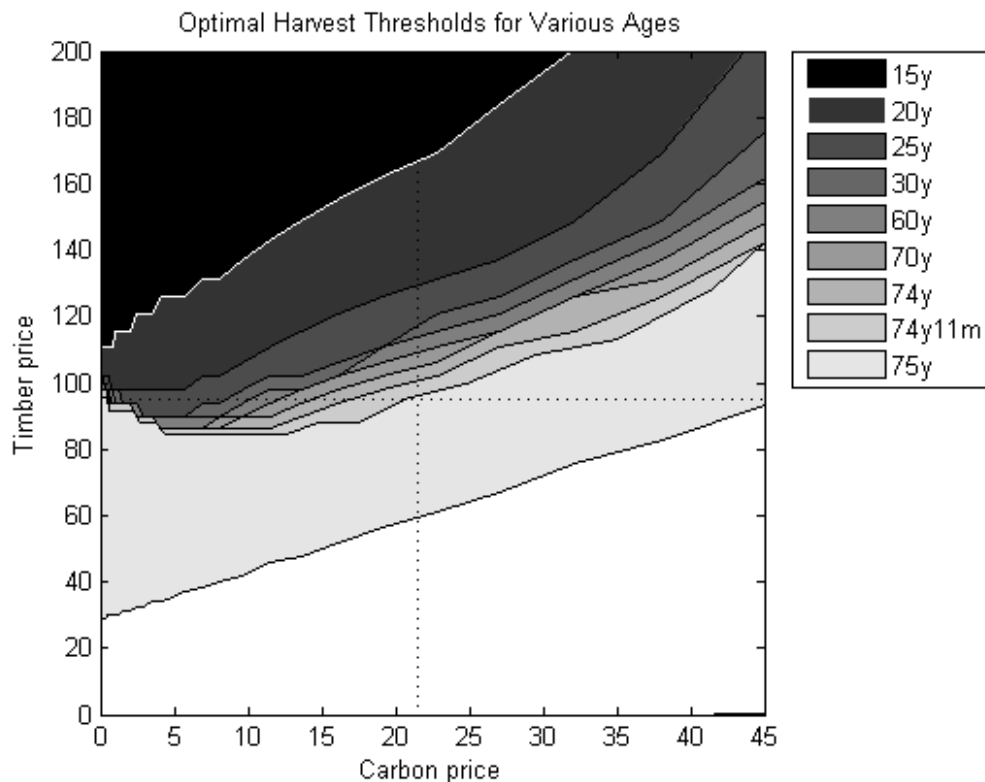


Figure 12: Timber-carbon price thresholds (double r.v.) for optimal harvest decisions for forest ages 15 to 75 years, stacked into a single graph⁶.

⁶ 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.

In Figure 12, 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: the top-left quadrant representing high timber price and low carbon price; the top-right quadrant representing high timber price and high carbon price; the bottom-left representing low timber price and low carbon price; the bottom-right quadrant representing low 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).

VII CONCLUSIONS

In this paper, a standard binomial tree (BT) approach to estimate forest value and harvest timing with stochastic timber price has been extended to also include a stochastic carbon price. This method combines two binomial trees, each with a stochastic price variable, into one model wherein at each node, instead of one price variable that can go up or down, there are two price variables (assumed to be independently distributed), each of which can go up or down. This double r.v. BT approach is applied to analyze the effects of the New Zealand Emissions Trading Scheme (NZETS) on the value of bareland. The analysis found that the NZETS is expected to increase the bareland valuation of carbon forestry by about 73% compared to timber-only forestry for radiata pine plantations. This means that, over a long time horizon, there should be a net increase in carbon sequestration that is associated with the conversion of bareland into carbon forestry. The NZETS is expected to be an effective policy in encouraging such conversions, thereby 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 set the harvest time when this combination happens. The optimal harvest price thresholds generated from the double r.v. BT method are also useful tools for both forest owners and policy makers.

A potential caveat of this work is in the assumption that timber and carbon prices in New Zealand while recognized as stochastic are assumed to be independent. This assumption seems safe at this stage because the carbon market is relatively undeveloped and is dominated by the energy industry. Post-1989 forests supply carbon credits to the New Zealand carbon market. In future, as post-1989 forests become mature for harvesting, they could also significantly supply timber to the New Zealand market. Because harvest decisions for post-1989 forests are dependent on timber and carbon prices in New Zealand, some form of dependence between the timber and carbon prices in New Zealand may arise. Such dependence

may not be trivial, as suggested in Sohngen and Mendelsohn (2003). As a suggestion for future work with this approach, it would be interesting to study the consequences of this dependence on the size and timing of future new plantings once carbon market conditions allow a better empirical understanding of such interactions.

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