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# Climate Change Mitigation Policy: The Effect of the New Zealand Emissions Trading Scheme on New Radiata Pine Forest Plantations in New Zealand

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**Abstract**

Climate change is one of the toughest challenges facing the world today. Putting a price on carbon emissions is an important step towards climate change mitigation. A cap and trade system is one of the ways to create a carbon price. The New Zealand Emissions Trading Scheme (NZETS) is the world's first economy-wide cap and trade system that covers all sectors and all 6 greenhouse gases. Forestry is a major part of the NZETS, allowing foresters to earn carbon credits for new forests planted on and after 1st January 1990 (afforestation and reforestation). At the same time, the NZETS also makes foresters liable for harvesting new forests planted on and after 1st January 1990, and deforesting forests existing on and before 31st December 1989. In this paper, we perform an economic analysis of how a carbon price will likely affect the returns and forestry management behaviour in new forests in New Zealand.

Previous works have used the NPV/LEV (fixed harvesting) analysis where the forest is assumed to be harvested (in future) at the estimated optimal rotation age regardless of timber prices at that time. Other works have employed the Real Options approaches (flexible harvesting) where sophisticated models such as Partial Differential Equations and simulations analyse the effects of bringing forward the harvest decision if timber prices are favourable, and deferring the harvest decision if timber prices are unfavourable. Often, these methods tend to have higher data requirements, employ different assumptions and are much more complex to estimate. Because of these differences, it may be difficult to compare the results of NPV/LEV analysis with Real Options.

Our work here applies the binomial tree method, which is a relatively simple method that can generate both LEV (fixed harvesting) and Real Options (flexible harvesting) results on a common model with the same data requirements and assumptions. This allows for better comparability of forestry management behaviour and effects of carbon price. The forestry valuations are analysed under a stochastic timber price and a constant carbon price. This paper concludes with some implications on policy in New Zealand.

## 1.0 Overview of the New Zealand Emissions Trading Scheme (NZETS)

The Kyoto Protocol is an international climate change agreement that sets binding greenhouse gas (GHG) reduction targets for 37 industrialized countries and the European Community. The collective reduction target amounts to an average of 5% against 1990 emission levels over the 5-year period of 2008-2012. It covers 6 greenhouse gases, namely, carbon dioxide ($C0_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride ($SF_6$). These emissions are categorized under 5 sectors/sources – energy, industrial processes, agriculture, waste, and solvent (and other product use). [UNFCCC (1997)].

New Zealand's GHG emissions for 2008, broken down by each sector, are shown in Figure 1. The 2 major emitting sectors are agriculture and energy. Land Use, Land Use Change and Forestry (LULUCF) are a major source of carbon sinks. [Ministry for the Environment (2010)].

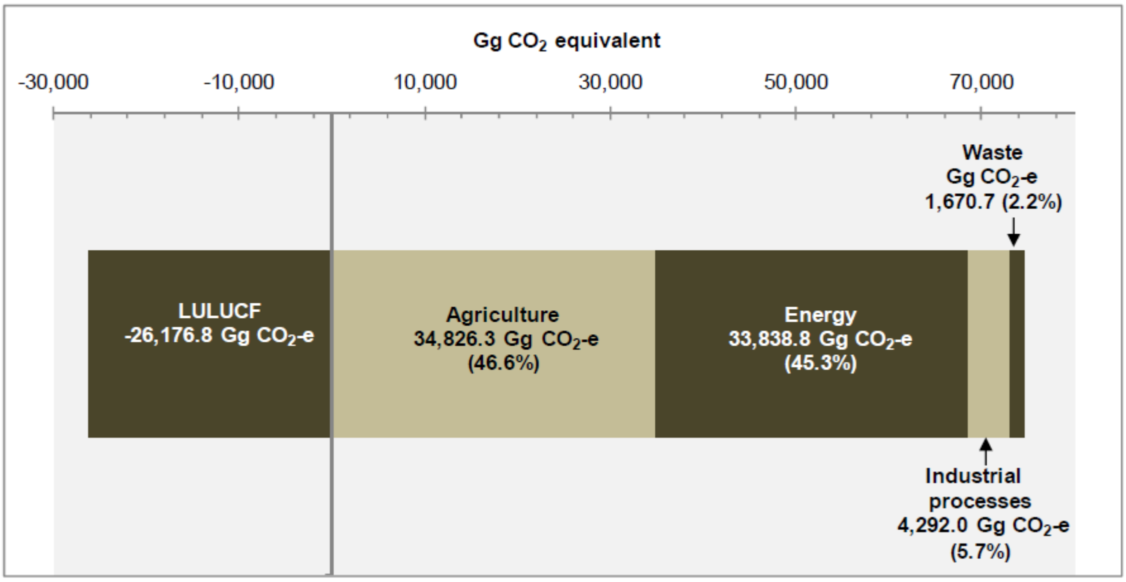


Figure 1: New Zealand's GHG emissions by sector in 2008.

To meet New Zealand's Kyoto Protocol commitments, the government has passed a cap and trade legislation, called the New Zealand Emissions Trading Scheme (NZETS) to put a carbon price and create incentives for businesses and consumers to change behaviour. The NZETS is the first economy-wide cap and trade system that covers all sectors and all gases. It is internationally linked and reflects international climate change rules. [New Zealand Government (2010)].

The NZETS has a transition period between 1st July 2010 and 31st December 2012, during which emitters will be able to buy emission units (carbon credits) from the New Zealand government for a fixed price of $25. 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, only new forests established on and after 1st January 1990 are eligible to earn carbon credits. Known as post-1989 forests, these forests can earn units for increases in carbon stocks from 1st January 2008[1]. If the carbon stock in a post-1989 forest decreases (for example, due to harvesting), emission units must be surrendered (i.e. harvest liabilities). Participation in the NZETS for post-1989 forests is voluntary (i.e. post-1989 forest owners who do not choose to participate in the NZETS do not receive carbon credits nor harvest liabilities).

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

The new revenue stream from carbon credits and harvest liabilities alters the traditional timber-only cash flow business model for foresters, and affects the harvesting decision of forests. Upon receiving the credits, they can be accumulated or immediately sold in domestic and international carbon markets, thereby, generating a new set cash flow for foresters. Upon harvesting of the post-1989 forests, the proportionate amount of carbon credits must be surrendered by the forester. These credits could be purchased from domestic or international carbon markets at the market price for surrendering. [Ministry of Agriculture & Forestry (2010)].

## 2.0 Timber Forestry Valuation Methods

*Fixed Rotation Forestry Valuation*

Faustmann (1849) approached the problem of valuing a single forest stand assuming it is destined to an infinite succession of rotations by identifying the problem as "choosing the harvest period to maximize the NPV value of a series of future harvests". He showed that the NPV of a forest can be expressed as a sum of discounted net cash flow over an infinite time horizon. [Esa-Jussi (2006)]. Until recently, the NPV approach has been widely accepted as the key method in investment decision-making. However, the NPV approach does not account for flexibility due to the assumption of a fixed investment path where decisions are made in advance, and remain unchanged, even when unexpected favourable or unfavourable events arise. It ignores the value that alternative (unexpected) opportunities and choices bring to the investment.

*Flexible Rotation Forestry Valuation*

Flexibility in decision-making is valuable when investors face risks and uncertainties about the future, especially when there is a degree of irreversibility attached to the decisions being made [Dixit and Pindyck (1995)]. Given that forest managers face uncertainties and irreversibilities, it may be optimal for them to remain flexible about the harvesting decisions and do not commit to a fixed rotation length. If timber prices are low at the "expected" time of harvest, foresters may want to delay harvest (lengthen the rotation period) so as to wait-and-see if timber price improves before making a harvesting decision. Likewise, if timber prices are unusually high before the "expected" time of harvest, foresters may want to harvest earlier than planned to take advantage of the high prices. Uncertainties and irreversibilities of an investment decision cannot be easily introduced into the NPV approach. In order to better manage the true potential of the returns, foresters should use a framework or tool that can accommodate a flexible investment decision. The Real Options approach offers such flexibility.

*The Real Options Approach to Valuation*

In the early seventies, financial economists Black and Scholes (1973) and Merton (1973) pioneered a formula for valuation of a financial option, and their methodology 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 firms' 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, 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 3 approaches to 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. This is the standard and most widely used Real Options valuation method in academic research due to its mathematical elegance and insights.

- 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. Large simulation programs are being used to value options that are very difficult to solve using PDEs. Though powerful, this method only provides solutions without offering much insight into the relationships between variables and key drivers of value.
- Binomial Trees (also known as Binomial Option Pricing model): Developed by Cox, Ross and Rubinstein (1979), this approach 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 level 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.

*The Real Options Valuation Applied to Timber Forestry*

Traditionally, Faustmann harvesting ignores the 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. Their results suggest that a 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 uncertainties of the timber price and the timber growth.

Miller and Voltaire (1983) were two of 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. This author 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.

Gjolberg & 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. 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.

Duku-Kaakyire and Nanang (2004) compared a forestry investment using the Faustmann NPV model and the binomial tree approach. Their results demonstrated the weakness of the Faustmann approach, namely, the lack of managerial flexibility to adjust for shocks, risks and uncertainty.

Valuations of fixed and flexible rotation ages are commonly compared using different and separate methods: an NPV/LEV model and a Real Options model. For example, Manley and Niquidet (2010) compared 3 real option valuation methods with the Faustmann method. In such a comparison, the Real Options models tend to have higher data requirements, employ different assumptions and is much more complex to estimate compared to NPV/LEV. Because of these differences, it may be difficult to isolate the cause of the increased valuation.

In Guthrie (2009), the author applied the binomial tree method 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. In Tee et al (2010), the authors applied this method to study New Zealand forestry.

## 3.0 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 first to integrate the carbon sequestration lifecycle in the context of climate change 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 are 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, not the level of timber volume. Hence, it is not the age of trees or standing timber volume that is important, but rather, the rate of tree growth. 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 first to provide a detailed (PDE) numerical analysis that employs both stochastic wood prices and stochastic carbon prices. This work only considered a single rotation (after which the land is assumed to have zero value).

Turner et al (2008) employed a combination of NPV/LEV and simulations to analyze the effect of carbon forestry in New Zealand. In Meade et al. (2008), results from a simulation method called Bootstrapping Real Options Analysis (BROA) was 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. Their work allowed for the possibility of future deforestation. Due to the complexity of the PDE method, the timber price is assumed to be stochastic whereas the carbon price is assumed to be constant in order to keep the mathematics tractable.

In this paper, we extend the radiata pine timber-only binomial tree analysis in Tee et al (2010) to include carbon pricing effects. Optimal valuations for both fixed and flexible rotations are generated assuming a mean-reverting timber price and a constant carbon price. This method uses the same data, with the same assumptions for both valuations. By holding everything equal, the difference in valuation is solely attributable to the fixed versus flexible harvesting decisions, rather than partially attributing the differences to the methodologies (arising from the use of two separate models, data or assumptions). As such, we are able to better compare the effects of a carbon price on fixed and flexible forest management behaviours.

## 4.0 Overview of the Binomial Tree Method

### *Price Binomial Tree*

The basic parameters to a price binomial tree are:

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

An example of the binomial tree labeling convention is shown in Figure 2 for n = 2.

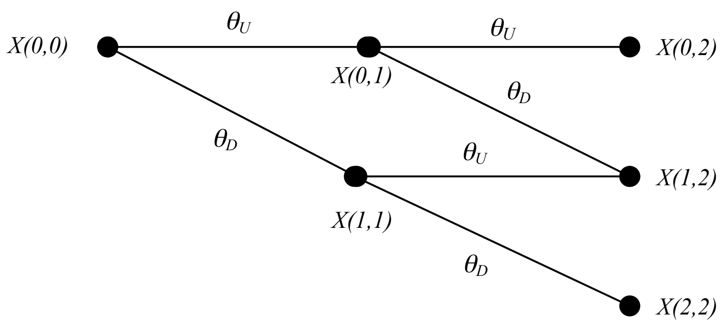


Figure 2: The binomial tree labeling convention.

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 $X(i+1,n+1) = X(i,n)D$.

An Ordinary Least Squares (OLS) regression of the historical price data series is performed to estimate the rate of mean reversion ($\hat{a}$), the long-run level ($\hat{b}$), and the volatility of the Ornstein-Uhlenbeck process ($\hat{\sigma}$) [Guthrie (2009)]. From these parameters, *U*, *D* and $\theta_U(i,n)$ are calculated as:

$$U = e^{\hat{\sigma}\sqrt{\Delta t_m}}$$

$$D = e^{-\hat{\sigma}\sqrt{\Delta t_m}}$$

$$\theta_U(i,n) = \begin{cases} 0 & if\ \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b} - \log(X(i,n)))}{2\hat{\sigma}\sqrt{\Delta t_m}} \leq 0 \\ \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b} - \log(X(i,n)))}{2\hat{\sigma}\sqrt{\Delta t_m}} & if\ 0 < \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b} - \log(X(i,n)))}{2\hat{\sigma}\sqrt{\Delta t_m}} < 1 \\ 1 & if\ \frac{1}{2} + \frac{(1-e^{-\hat{a}\Delta t_m})(\hat{b} - \log(X(i,n)))}{2\hat{\sigma}\sqrt{\Delta t_m}} \geq 1 \end{cases}$$

where $\Delta t_m$ is the time step size of the binomial tree.

***Valuation Binomial Tree***

Binomial trees are also used to implement valuation. The probability of an Up move ($\theta_U$) and probability of a Down move ($\theta_D$) in the price binomial tree are applied to the valuation binomial tree, as shown in Figure 3 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.

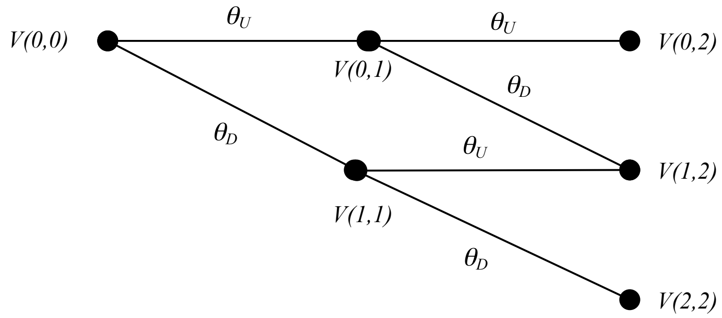


Figure 3: Valuation binomial tree.

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 $V(i,N)$.

We define $V(i,N)$, the harvest valuation function at terminal node $N$, as:

$$V(i,N) = [X_T(i,N) - H_T]Q_T(N) - X_C Q_C(N-1) - M_C + B$$

where $X_T(i,N)$ is the price at time step $N$, $H_T$ is the harvesting cost, $Q_T(N)$ is the timber volume at time $N$, $X_C$ is the constant carbon price, $Q_C(N\text{-}1)$ is the carbon stock at time $N$-1, $M_C$ is the ETS compliance cost and $B$ is the bareland value.

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

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

where $R_f$ = (1+discount rate). This valuation process traverses backwards systematically until it ends at $V(0,0)$.

In addition to the discount rate, we can use the Capital Asset Pricing Model (CAPM) to further reflect a market risk premium into the valuation. A Market Risk Premium Adjustment ($MRP_{Adj}$) is subtracted from the $\theta_U$ to produce the so-called Risk Neutral probability $\Pi_U$ [Guthrie (2009)]:

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

The $MRP_{Adj}$ is obtained by regressing timber price changes on stock market returns on an index such as the NZX 50 Total Returns Index [Guthrie (2009)]. We note here that valuation using binomial tree could also be performed without the CAPM element (i.e. using $\theta_U$ and $\theta_D$ instead of $\Pi_U$ and $\Pi_D$). In such a case, one would incorporate the appropriate level of risk premium by simply choosing a higher factor rate ($R_f$).

***Incorporating Flexible Harvesting Decisions in the Valuation (Real Options Valuation)***

When calculating the valuation (backwards), a decision on whether to harvest or not is re-evaluated at each and every node. If the cash flow from harvest at each node is more than 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 higher than the present value of the cash flows from harvesting, then, the optimal decision is to not harvest, and the valuation at the node equals the present value of the corresponding expected future cash flows. That is:

$$V(i,n) = \max\begin{Bmatrix} (1-T)\left([X_T(i,n) - H_T]Q_T(n) - X_C Q_C(n-1) - M_C\right) + B, \\ (1-T)\left(-M_T - M_C + X_C[Q_C(n) - Q_C(n-1)]\right) + \dfrac{\Pi_u(i,n)V(i,n+1) + \Pi_D(i,n)V(i+1,n+1)}{R_f} \end{Bmatrix}$$

where $T$ is the tax rate, $M_T$ 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 highlighted previously, the valuation process traverses backwards from $n = N$ to $n = 0$, ending at $V(0,0)$. This represents the single rotation valuation. This process is implemented backwards recursively over multiple iterations to produce infinite rotation valuations. Each iteration represents 1 harvest and replant rotation. During the calculation for the first iteration, the Bareland value, $B$, is assumed to be zero. At the end of the first iteration, a Bareland value is estimated by deducting the cost of replanting the forest from V(0,0):

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

where $G$ is the cost of replanting the forest. This first iteration Bareland value is then fed into the second iteration (i.e. during the 2nd iteration of valuation calculations, $B$ in the $V(i,n)$ function of Equation 11 is no longer zero). This iterative process is repeated (e.g. 15 iterations) until the Bareland value converges to a steady state value (i.e. it no longer changes with subsequent iterations), which is the valuation for an infinite rotation forest with flexible harvesting age (i.e. real option valuation).

Details of applying this valuation method to a fixed harvest age are found in Tee et al (2010).

## 5.0 Data Used and Assumptions Made

### *Timber price*

Figure 4 shows the New Zealand Ministry of Agriculture and Forestry radiata pine price data [Horgan (2010)] aggregated into a single proxy timber price series, adjusted with the Consumer Price Index from Statistics New Zealand (2010).

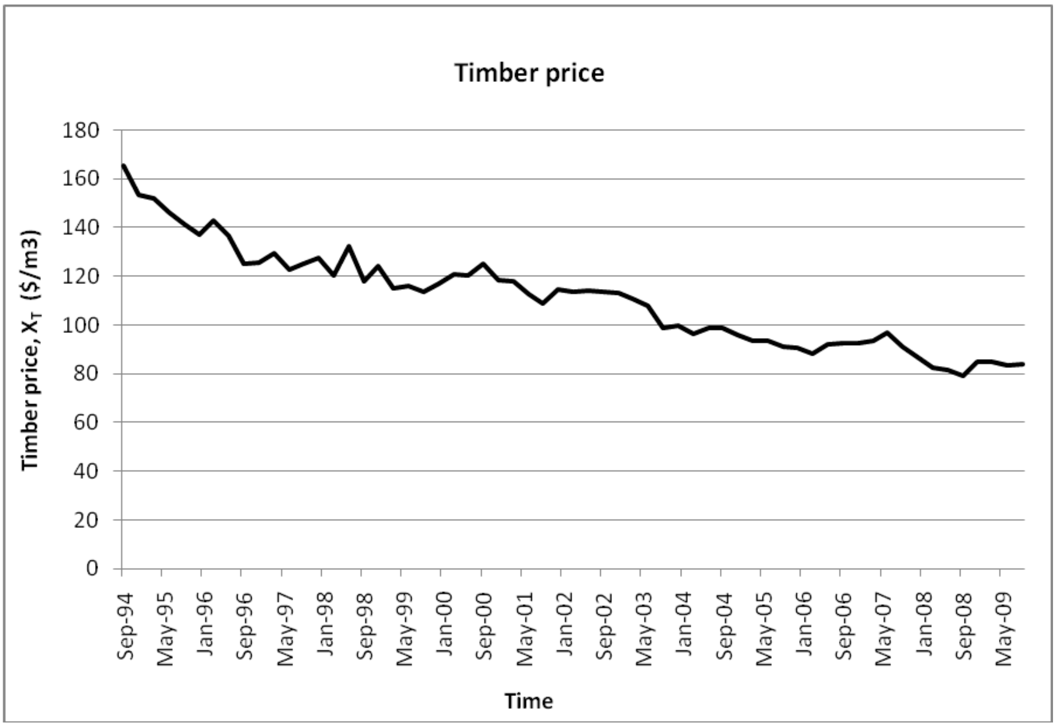


Figure 4: Proxy timber price, CPI adjusted.

The Ordinary Least Squares (OLS) regression of the proxy timber price series produced:

$$\hat{a} = 0.216006$$

$$\hat{b} = 4.482340$$

$$\hat{\sigma} = 0.080705$$

From these values, $U$ and $D$ are estimated as 1.0236 and 0.9770 respectively, which are used to calculate $X(i,n)$ and $\theta_U$ of the price binomial tree. The long run timber price is $e^{\hat{b}} = \$88.44$.

A Market Risk Premium of 5.5% is assumed, and $MRP_{Adj}$ is estimated to be -0.0008, which is used to calculate $\Pi_U$ and $\Pi_D$ of the valuation binomial tree.

### *Timber volume and carbon stock*

For this work, the cumulative timber volume and carbon stock functions (tables) up to 75 years of age were sourced from the R300 Radiata Pine Calculator model from Kimberley et al (2005), as plotted in Figure 5.

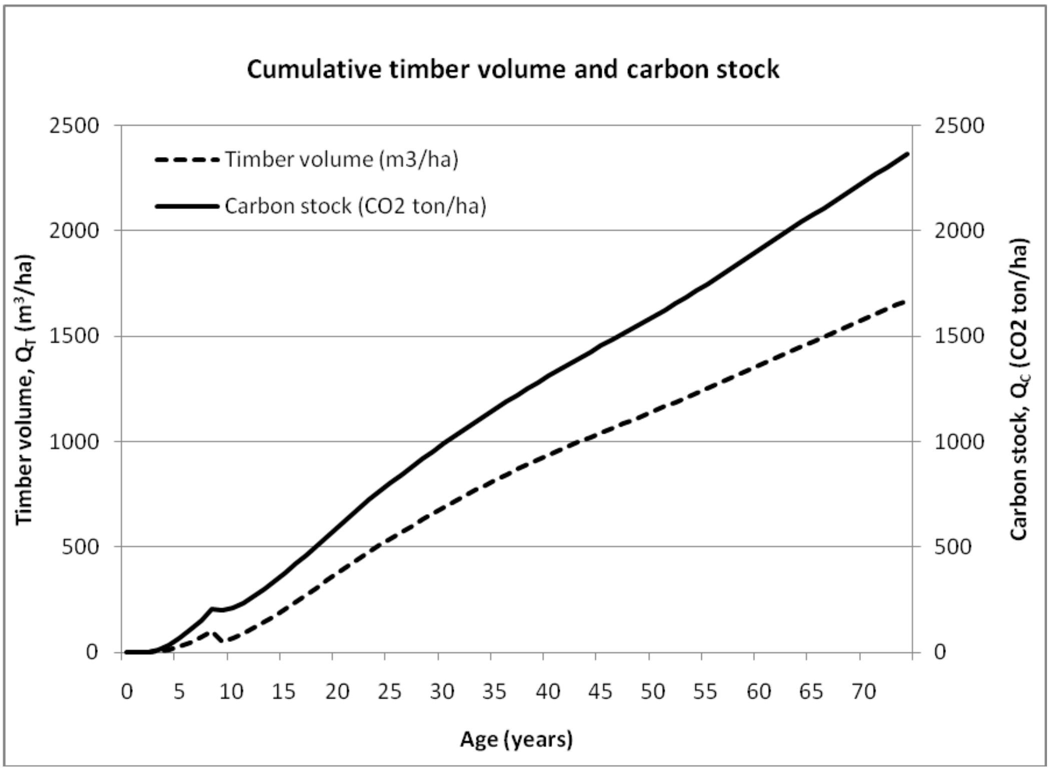

Figure 5: Cumulative timber volume and carbon stock functions.

The annual carbon stock change is shown in Figure 6. This represents the amount of carbon credits that is received every year throughout the life of the forest. In this work, it is assumed that carbon credits received every year are sold during the same year, thereby, generating annual carbon revenues.

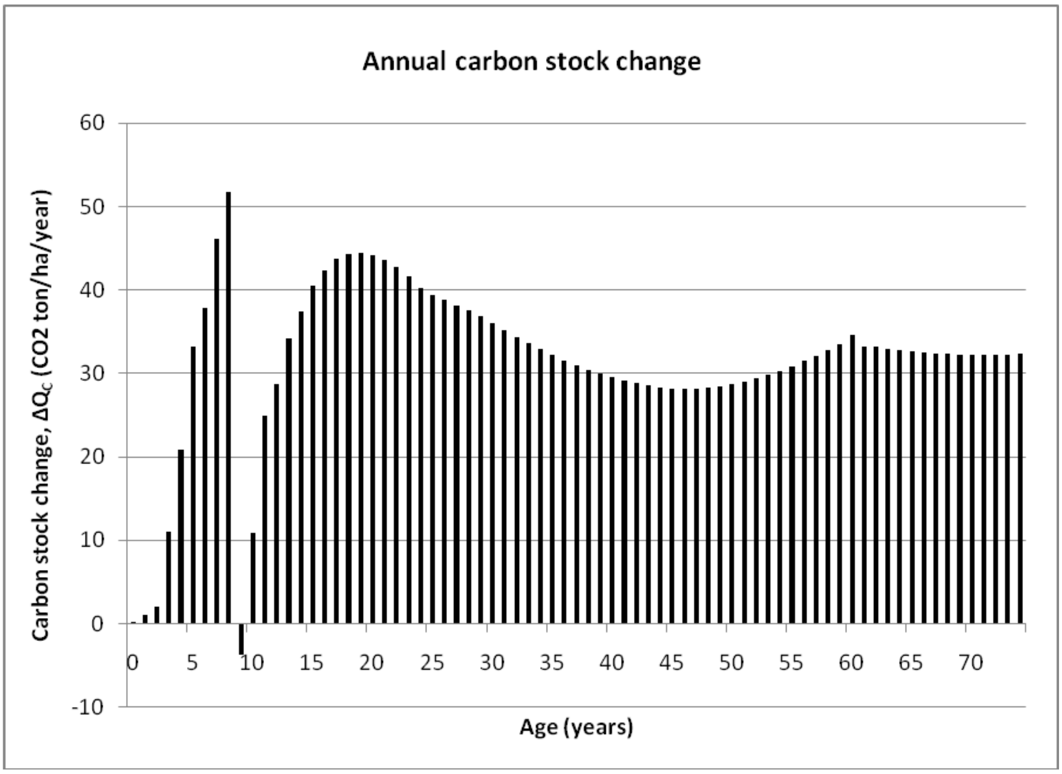

Figure 6: Annual carbon stock change.

When the forest is harvested, the carbon stock in the forest decreases sharply before it gradually increases again upon subsequent replanting. Figure 7 shows the carbon stock profile of the 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.

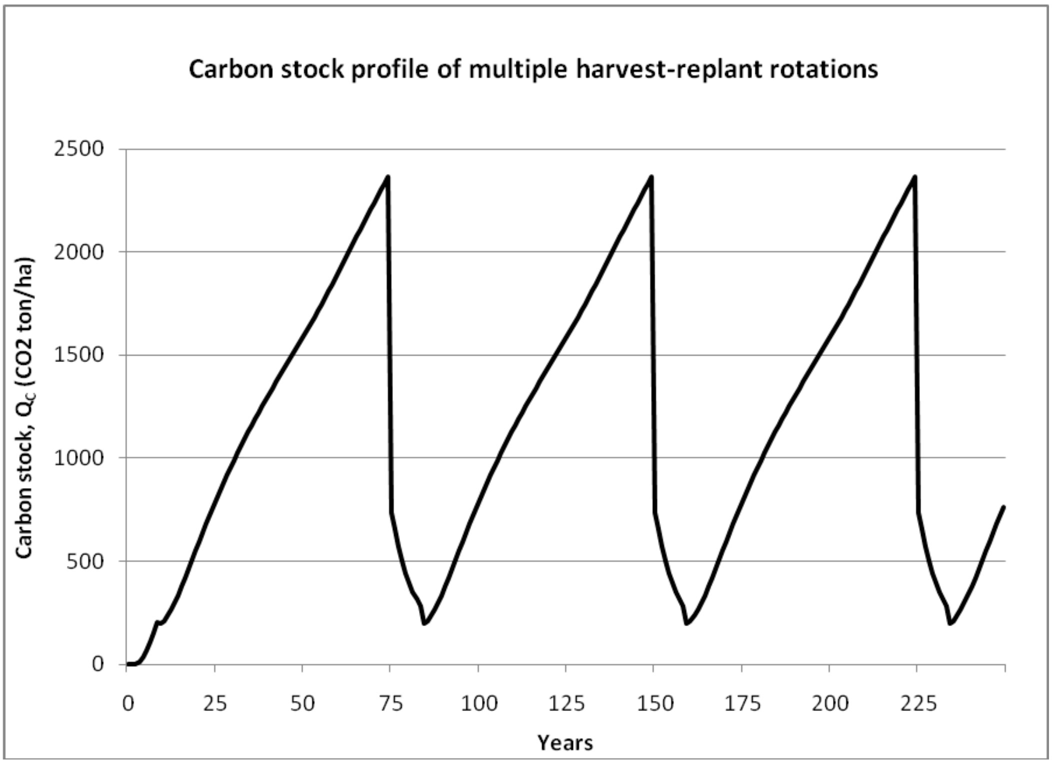


Figure 7: Carbon stock profile of multiple harvest-replant rotations.

## *Costs and Cash Flow*

Forest management costs are assumed to be:

- Planting costs, $G$ = \$1,251/ha
- Pruning costs = \$473/ha (age 6), \$674/ha (age 7), \$684/ha (age 8)
- Thinning costs = \$370/ha (age 9)
- Forest maintenance cost, $M_T$ = \$50/ha/year
- ETS compliance cost, $M_C$ = \$60/ha/year
- Harvesting cost (clearfell logging), $H_T$ = \$40/m$^3$

The tax rate, $T$, is assumed to be 28%. The cash flow discount rate is assumed to be 4%, such that $R_f$ = 1.04. The overall cash flow of carbon forestry is summarized in Table 1.

| | Years | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | . . . | 5 | 6 | 7 | 8 | 9 | 10 | . . . | Harvest year |
| Forest planting costs | -\$1,251 | | | | | | | | | | | |
| Forest pruning costs | | | | | | -\$473 | -\$674 | -\$684 | | | | |
| Forest thinning costs | | | | | | | | | -\$370 | | | |
| Forest maintenance costs, $M_T$ | -\$50 | -\$50 | -\$50 | -\$50 | -\$50 | -\$50 | -\$50 | -\$50 | -\$50 | -\$50 | -\$50 | |
| ETS compliance costs, $M_C$ | -\$60 | -\$60 | -\$60 | -\$60 | -\$60 | -\$60 | -\$60 | -\$60 | -\$60 | -\$60 | -\$60 | -\$60 |
| Timber revenue, $X_TQ_T$ | | | | | | | | | | | | \$ |
| Timber harvest costs, $H_TQ_T$ | | | | | | | | | | | | -\$ |
| Carbon revenue, $X_C\Delta Q_C$ | \$ | \$ | \$ | \$ | \$ | \$ | \$ | \$ | \$ | \$ | \$ | \$ |
| Carbon liability, $X_CQ_C$ | | | | | | | | | | | | -\$ |

Table 1: Cash flow of carbon forestry.

## 6.0 Results of Analysis

Valuation results are presented for timber forestry (stochastic timber price, $0 carbon price) and carbon forestry (stochastic timber price, constant carbon price). In addition, fixed harvest results are also compared with flexible harvest results. All values are in New Zealand dollars.

### *6.1 Results for Timber Forestry (stochastic timber price, $0 carbon price)*

Fixed harvest timber forestry generates a valuation of $5,503 with an optimal rotation age of 27 years as shown in Figure 8. This valuation is the estimated market value of one hectare of bare land that is about to be planted in trees. For flexible harvest timber forestry, the valuation is higher at $7,060 as shown in Figure 9.

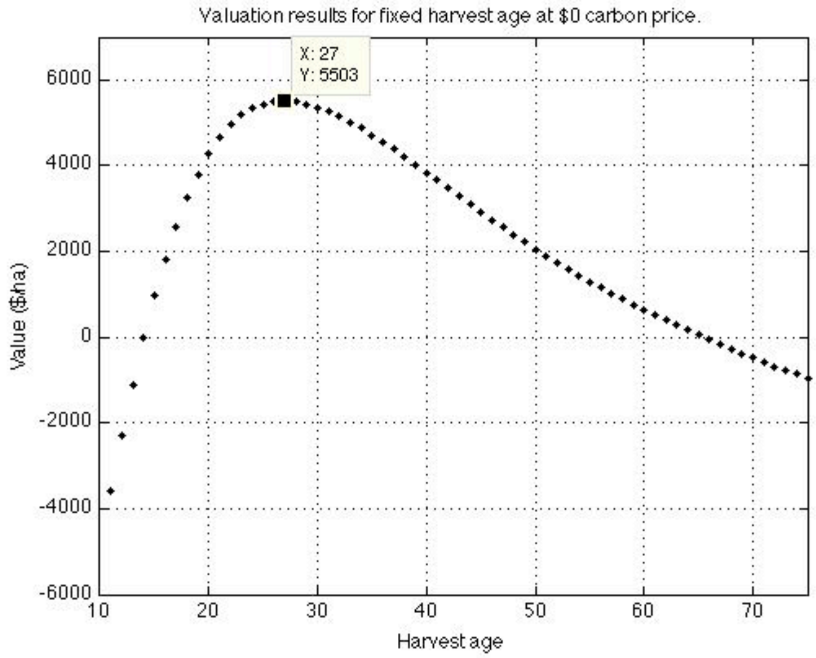


Figure 8: Valuation results for fixed harvest timber forestry.

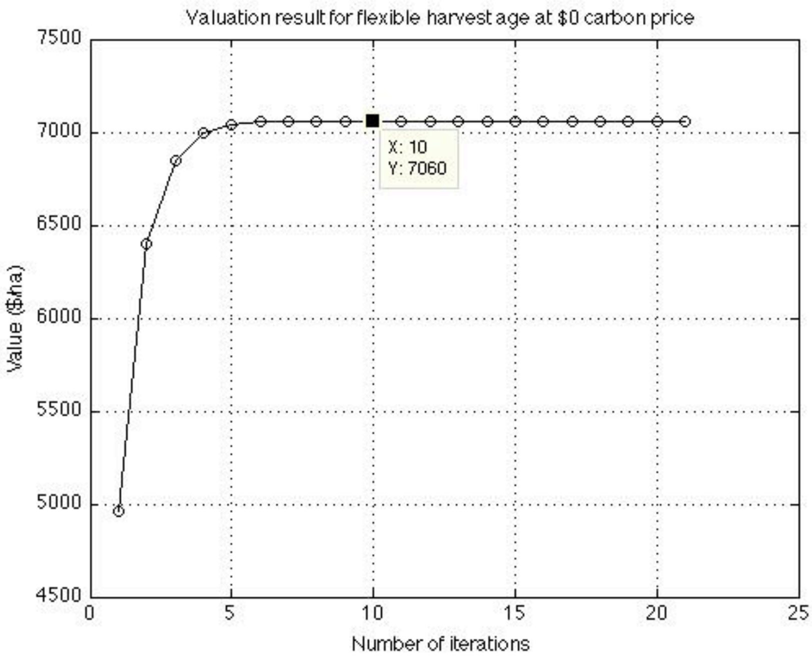


Figure 9: Valuation results for flexible harvest timber forestry.

Figure 10 shows the threshold timber prices for optimal flexible harvesting of timber forestry. The area above the dotted lines shows the timber prices that favour a harvest decision for a given forest age. As an example, the threshold for a 30 year old timber forest is $101.10 such that if the timber price is above this threshold when the forest reaches age 30, it would be optimal to harvest. If the timber price is below this threshold when the forest reaches age 30, it would not be optimal to harvest, and the optimal decision would be to defer harvest until the price is above the threshold for the respective age.

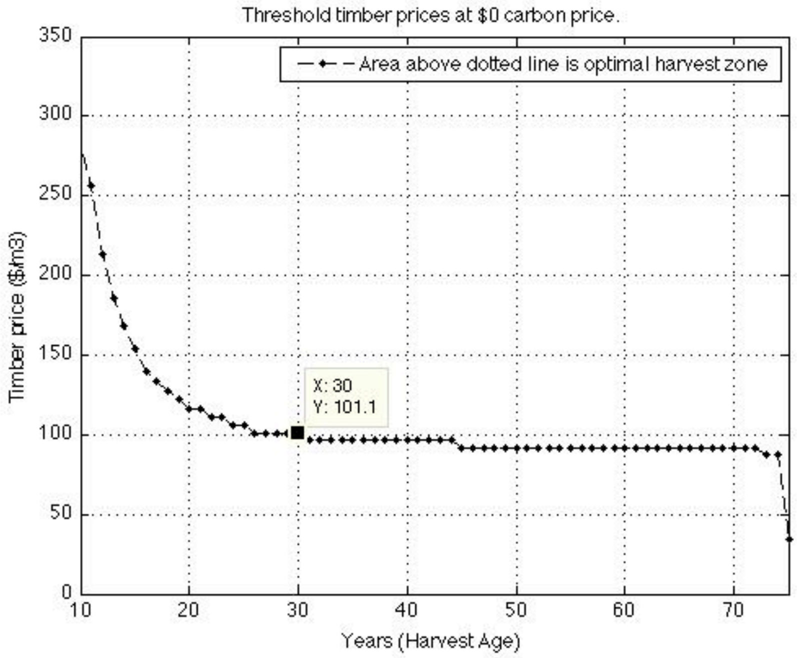


Figure 10: Threshold timber prices for optimal flexible harvesting of timber forestry.

***6.2 Results for Carbon Forestry (stochastic timber price, $25 carbon price)***

Figure 11 shows that fixed harvest carbon forestry generates a valuation of $11,060 with an optimal rotation age of 37 years. This valuation is about twice the valuation of timber forestry ($5,503).

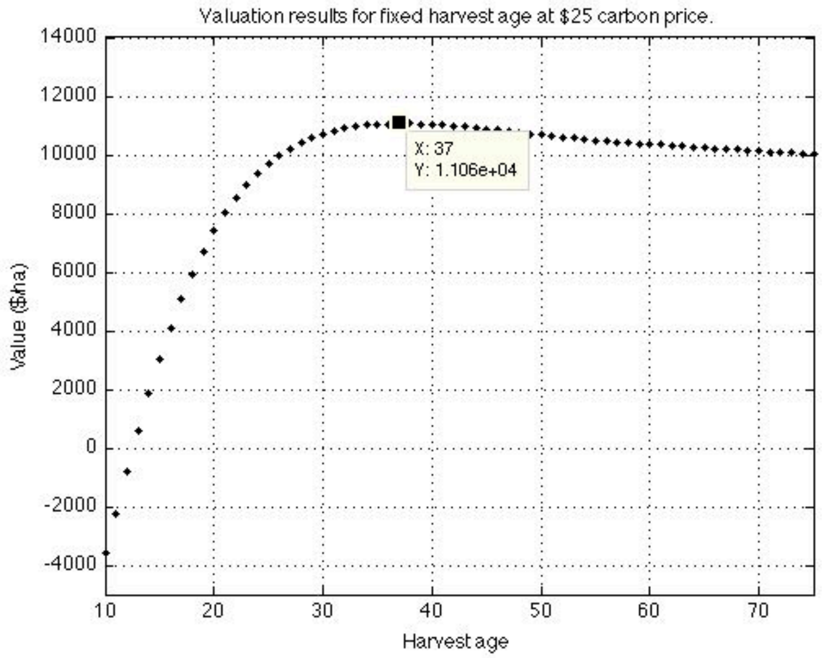


Figure 11: Valuation results for fixed harvest carbon forestry.

Figure 12 shows that flexible harvest carbon forestry generates a valuation of $13,350, which is 89% higher than the valuation for flexible harvest timber forestry and 21% higher than the valuation for fixed harvest carbon forestry.

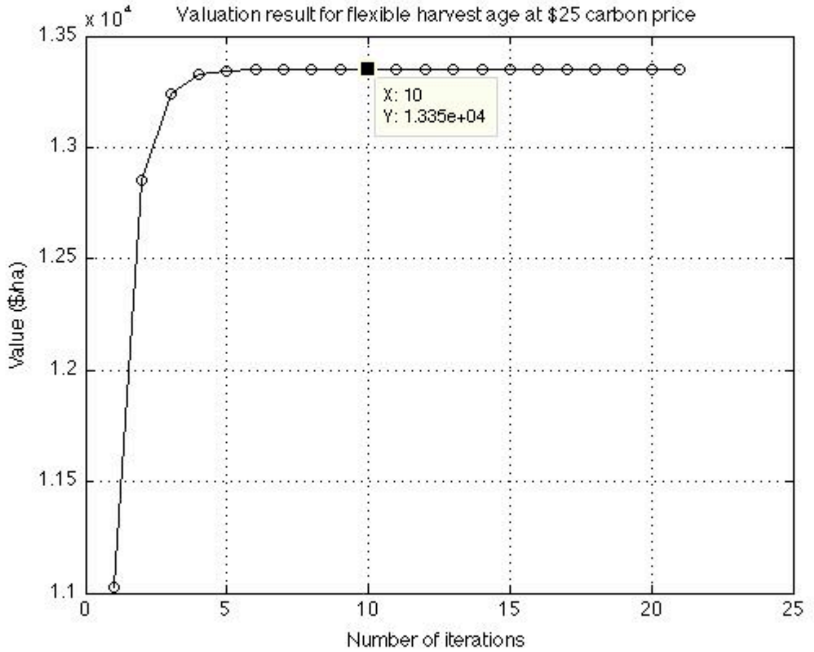


Figure 12: Valuation results for flexible harvest carbon forestry

Figure 13 shows the threshold timber prices for optimal flexible harvesting of carbon forestry. Compared to timber forestry, the threshold level is higher. For example, at age 30, the threshold for carbon forestry is $111, which is higher than the $101.10 threshold of timber forestry. This will have the effect of lengthening rotations, since foresters will need to wait longer for the timber price to reach the higher level (of $111) when the carbon price is $25, than they had to wait to reach the lower level (of $101.10) when the carbon price is zero.

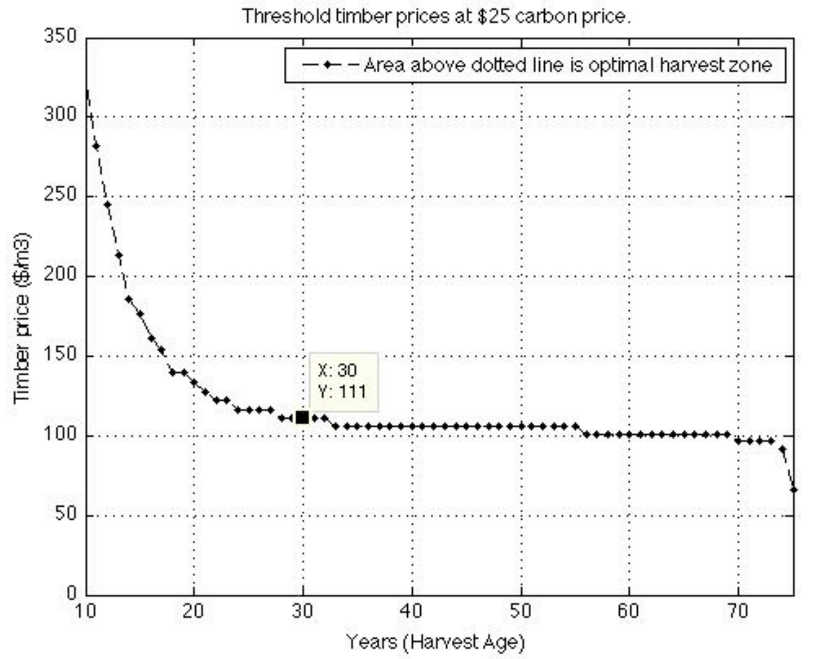


Figure 13: Threshold timber prices for optimal flexible harvesting of carbon forestry.

### ***6.3 Further Results (stochastic timber prices, at $0, $10, $25, and $50 carbon price points)***

Figure 14 compares the fixed harvest carbon forestry valuation at different carbon price points. As the carbon price increases from $0 to $10, $25 and $50, the valuation increases from $5,503 to $7,493, $11,060 and $21,000 respectively. It is also worth noting that as the carbon price increases, the shape of the valuation graphs evolve from a Faustmann-type “parabolic” profile to an “exponential” profile, due to the effects of the annual carbon revenue on the valuation. At a $50 carbon price, the graph trends towards a conclusion of significantly delaying harvest. That is, if the allowable harvest age is extended beyond 75 years, the rotation length is likely to increase as well.

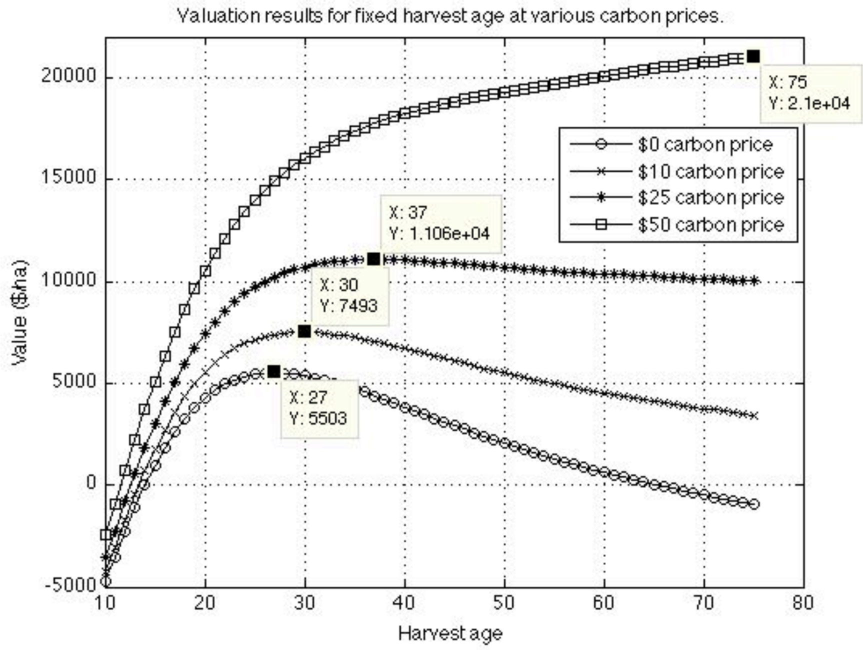


Figure 14: Valuation results for fixed harvest carbon forestry at different carbon price points.

For flexible harvest carbon forestry, the valuations at the corresponding carbon price points are shown in Figure 15. As the carbon price increases from $0 to $50, the valuations rise from $7,060 to $21,920.

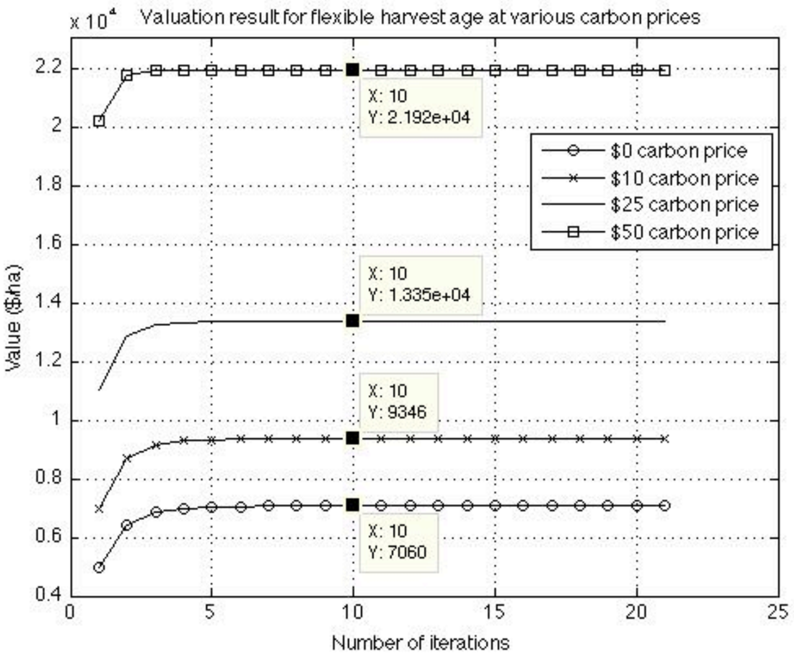


Figure 15: Valuation results for flexible harvest carbon forestry at different carbon price points.

It is worth noting that, at a $50 carbon price, the $21,000 valuation for fixed harvest is quite close to the $21,920 valuation for flexible harvest. Indeed, at an extreme carbon price of $150, valuations are virtually the same at $64,900 and $64,920, respectively (not plotted in the graphs here). We conclude that when the carbon price is sufficiently high, the choice of fixed versus flexible harvesting is one and the same, because both leads to the same optimal rotation length.

Figure 16 shows the threshold timber prices at carbon price points of $0, $25 and $50. At age 30, the threshold timber price increases from $101.10 to $127.60 as the carbon price increases from $0 to $50. This means that as the carbon price increases, there is a greater likelihood of deferring harvest, thereby keeping carbon sequestered in the forest.

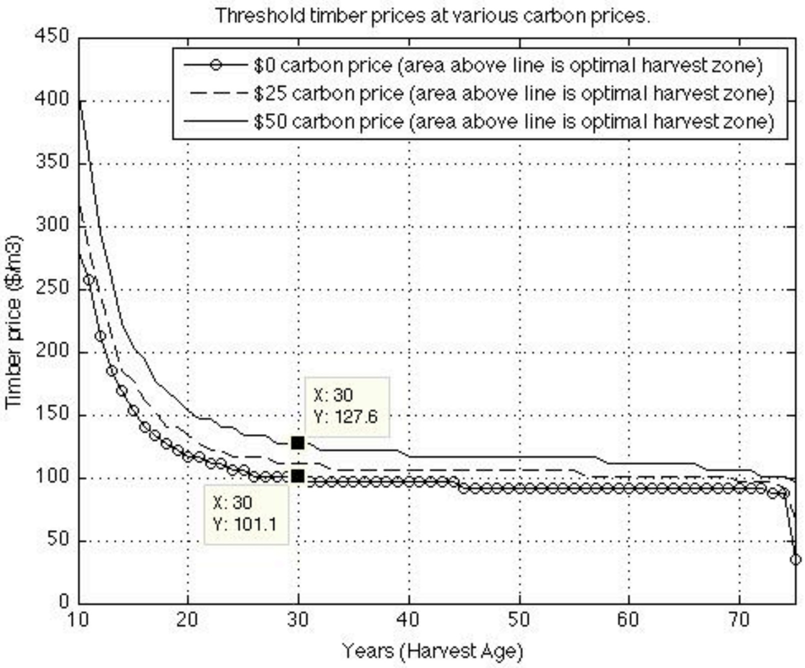


Figure 16: Threshold timber prices for optimal flexible harvesting of carbon forestry at various carbon price points.

## 7.0 Implications for Policy in New Zealand

Results of this analysis conclude that by putting a price on carbon via the New Zealand Emissions Trading Scheme, carbon forestry provides a significantly higher return compared to traditional timber forestry. This higher return comes with the cash flow advantages of annual revenues from the sale of carbon credits. Even at a modest carbon price of $10, which is approximately half of the current carbon price, the value of land employed in forestry (planted on and after 1st January 1990) increases significantly. Such forestry land will become more valuable, and some land not currently used for this purpose will switch land use. We have shown that the NZETS provides a strong economic incentive to foresters to plant new forests.

The increased returns will most likely result in a switch in forest management behaviour from timber forestry to carbon forestry by simply deferring harvest. As carbon prices increase over time, it will become even more economically attractive to do so. This effect will contribute positively towards climate change mitigation in New Zealand.

Forestry has a long investment cycle. It is therefore absolutely crucial for the New Zealand government to provide and maintain policy certainty to the forestry sector in order to encourage carbon forestry investments. This certainty can be provided by ensuring that the NZETS remains in place for the foreseeable decades ahead.

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