Robust decisions in a climate of change: what should you do tomorrow if you do not know what will be happening in 30 years?

Cris Brack, Professor and Chair of Forestry
School of Forestry, Wood Processing and Biotechnology
Waiariki Institute of Technology
Cris.Brack@waiairiki.ac.nz

Abstract

Climate variability and the political uncertainty around possible carbon trading systems have focused attention on the impact of risk on long term planning. Researchers have published comparisons of short/long plantation regimes and integrated or simple grazing/cropping regimes under different "future scenarios" and made qualified conclusions about the expected discounted value or land rent under different scenarios. However, a plantation or a farming enterprise is not the result of a single, irrevocable decision or action. Each year or season, the manager can decide to continue the current land use and scheduled activities, change the land use or proposed sequence of activities, or invest more time/effort into making a decision. Good management should minimise the loss of options for that land and should not result in the scheduling of activities that "lock" land into poor uses. Essentially, managers should be choosing robust decisions or activities that are likely to lead to good outcomes under a wide range of potential futures.

This presentation examines a system for determining robust decisions and quantifying the different aspects of risk that have the greatest impact on the outcome of the decisions that need to be made in the immediate future.

Introduction

Changing political landscapes, changing markets and even changing understanding of climate variability have focused attention on the difficulties involved in long term decision making for forests. Growers are being given access to additional markets involving carbon trading, but there are major differences in the forecasts of these markets - the unit price may increase substantially or it may become worthless; the way the commodity is quantified may change (measured, modelled or standard values introduced); carbon from some areas may be excluded or included from yet to be finalised agreements. These uncertainties add to those already present in long term forest management. Marshall (1987) classified sources of uncertainties in forest management as:

- **Internal**. These uncertainties include those caused by simplifications required by the models used in planning; inaccuracies in the databases (e.g. inventory of current standing stock) and imprecision or bias in growth and yield projections.
- **External**. The sources for these include the changing nature of the desired forest estate (i.e. what does the manager want the forest to "look" like at some future reference point); improper specifications of the returns; potential changes in political or policy decisions.

Despite these uncertainties, managers of land that currently has trees or land that has the potential to grow trees must make decisions on whether to continue or to start growing a forest, and if so, what needs to be do in the immediate, medium and long-term. A common approach is to assume that everything is actually known for certain - the growth and yield models are correct, the returns for wood products and carbon are exactly as predicted and policy decisions are "fixed in stone". Numerous analyses of the profitable nature of forest establishment make these assumptions, although the best analyses do note that these assumptions have been made and that the conclusions may change if the assumptions prove to be incorrect.

Reed and Errico (1986), Lohmander (1990) and others have concluded that optimal decisions on yield regulation or long term sustainable yield levels will change when uncertainty is explicitly recognised in a management problem. Many analysts note that uncertainty about yield, prices and policy increases the further you project the problem into the future and therefore introduce a "discounting" of future values derived from the forest. This discount is not just related to the time cost of money (i.e where a $1 now is worth, say $1.07 next year), but also attempts to reduce the importance of accurate forecasts of yield and future unit prices. The discount factor is usually a constant fraction applied against the predicted outputs or net value or a standard economic discounting rate. Linear Programming (LP) and its derivatives have been used extensively in forest management to determine optimal regimes or long term sustainable yield levels. However, because an LP algorithm assumes no uncertainty (e.g. yield is known without error), the returns from the forest are discounted by a factor assumed to relate to the level of internal and external uncertainty and the LP objective is to maximise the sum of this discounted value through time.

Although commonly used in manufacturing or investment decision-making where the expected return horizon is only measured in months or a few years, the use of discount factors may distort immediate as well as long-term management decisions in forest activities. Cast (1983) and McKenney (1990) used multiple LP models with different assumptions about internal and external errors to attempt to overcome the distortion of management decisions, but the large model formulation needed in forest management scheduling remained a problem.

This paper reports on approaches to developing optimal decision making in the presence of risk or uncertainty. These focus on the need of the manager to be very confident of the actions needed in the immediate future without compromising good options in the intermediate and longer term future.

Table 1: Regimes included as possible alternatives in the model farm forest.

Regime Name	Description
Std-30-yr	A “standard” clearwood regime with an initial establishment at 800 trees ha-1, 2 pruning lifts and a non-commercial thinning at 7 years. Final harvest is between 25 - 30 years.
Early5-30yr, Early10-30yr, Early15-30yr	As above - established as if for a standard clearwood regime except final harvest is 5 or 10 years early (i.e. age 20 - 25 or 15 - 20 respectively) with subsequent progressive loss of higher grade sawlog recovery.
Plant-leave	Initially establish at 800 trees ha-1 and then leave with no additional management .
Plant-5-leave, Plant-10-leave	As above but delay the establishment for 5 or 10 years respectively.
Regen	Allow natural regeneration to occur. Assumed to have no management costs and grow at 15 t CO2e yr-1
Pasture	Maintain current non-forest landuse activity
Late-5-30yr, Late-10-30yr, Late-15-30yr	As for Std-30-yr but delay establishment for 5, 10 or 15 years respectively. While delayed continue to manage as Pasture
Conv-std-30yr	Initially establish as for Std-30-yr, but after one rotation return to Pasture
Conv-early5, Conv-early10, Conv-early15	Return to Pasture after one rotation of Early5-30yr, Early10-30yr or Early15-30yr respectively

Method

A simple “model” farm forest estate is defined where the manager has the option of continuing with a nominal farming/grazing land use that returns (net) \$2,000 ha^{-1} yr^{-1}, or converting to, initially, a forest clearwood regime. Deterministic yields (i.e. yields that are assumed to be known without error and not subject to any uncertainty due to climate variability) are defined for a restricted but realistic range of land uses (e.g. Figure 1) (Table 1). The value of the returns are initially assumed to be deterministic, and reflect current assumptions of the value of CO_2 equivalent tonnes (CO_2-e) and various log grades. Costs and yields of logs are based on Evison (2008).

For the sake of simplicity, a 5% discount rate is assumed. Also for simplicity, it is assumed that the current landuse has no CO_2-e value, either because it is carbon neutral of because it does not enter the market unless there is a land use change.

The optimal land use and long term management of the estate is determined using LP with minimal constraints the manager may wish to apply. This optimal decision under deterministic conditions is compared to LP runs under assumptions of various internal and external uncertainties. The internal uncertainty is represented by variation in the yield models. The trees were modelled as growing in

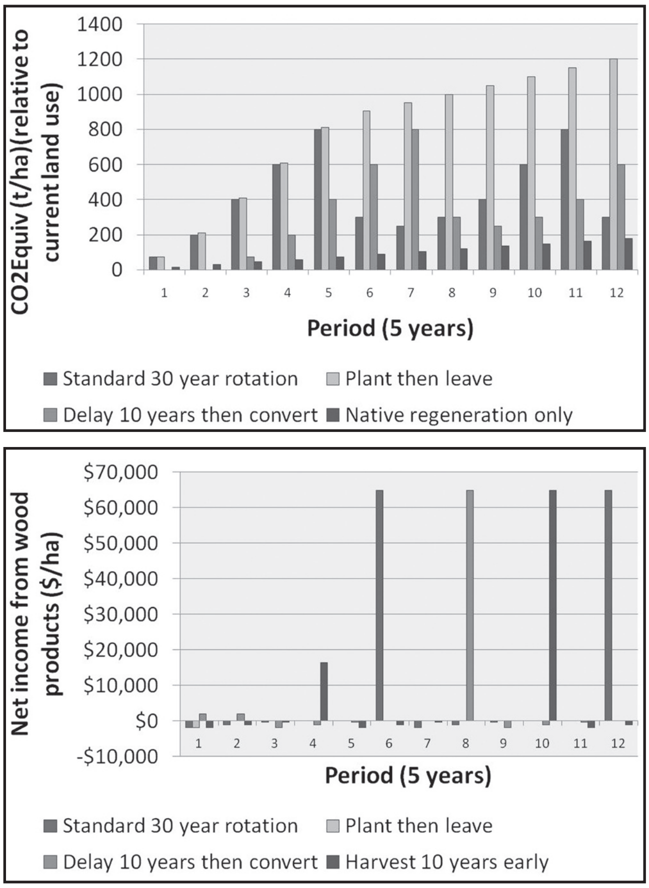


Figure 1: Representative regime yields (a) CO_2 equivalent (b) Net (non-discounted) returns

value (a function of volume, quality and unit price) between 75% - 150% of the deterministic value in each period (overall mean of all periods and all runs was 100%), with each period independent of the previous one (and with no allowance for climate change induced mortality or disease). This variation reflects only that of the original inventory and growth model parameters. The asymmetrical variation in yield predictions has been found in separate studies of error budgets for estate-wide modelling (Merrit and Brack, 2005). Externally sourced uncertainty was introduced via random variation in the unit prices for CO_2-e (75% - 200%) but increasing mean (overall mean of all periods and all runs was 140%). There was also a 10% chance that the market or acceptability for carbon sales on that land will cease sometime after 20 years (average length of time before market/price ceased was 50 years). The Solver Add-In in Microsoft Excel is used for the LP analysis. A planning horizon of 60 years or 12 5-year periods was selected.

Results

A simple LP designed to optimise the net discounted value of wood products (with no value for CO_{2-}e) concludes that 100% of the estate should be converted from the current land use to the clearwood (std-30-yr) regime with a rotation of six periods (i.e. final harvest and sizable net income in 25 - 30 years). The discounted net value (DNV) of this strategy is $15,676 although the initial three periods have a net cost to the manager.

Introducing a constraint that there can be not net loss in any period, caused the DNV of the optimal strategy to drop to $12,690 with only 44% of the estate being initially converted to forest with the cost of conversion met by the income of the existing land use on the remaining land. The rest of land is converted over the next three periods, again using the income from remaining non-forest land to fund the conversion.

The introduction of a carbon market where the manager can opt in to sell carbon (initially $30 t^{-1} CO_2-e) up to a maximum of the current standing stock in a given period (and buy up any shortfall caused by earlier sales at 125% of current period value, initially $38 t^{-1} CO_2-e) means that the manager has an additional choice of how much carbon to offer each period as well as the original decision on land use changes. Under this scenario, the optimal LP solution is once again to convert almost the entire estate (97%) into a standard clearwood regime and use the carbon sales to initially offset any costs of establishment. The LP solution sold 73 t in the first period (out of 75 t available) then an additional 118 t in the second period and 16 in the third (totalling just over 50% of the available CO_2-e by the end of the third period) with a DNV of $20,687. This scenario and strategy was then defined as the base deterministic run.

Twenty-five LP solutions, run under the stochastic or random changes in internal and external variables previously mentioned resulted in changes in the optimal allocation of land to various regimes and the amount of CO_2-e sold. The DNV varied from $15,600 to $30,400 with over-representations of values less that $17,500 (Figure 2).

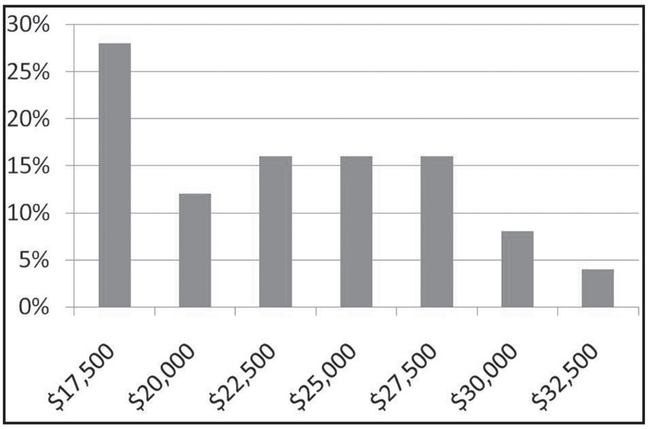


Figure 2: Distribution of DNV ($ ha^{-1}) from stochastic LP runs that maximise DNV subject to a constraint of no net loss in any period.

None of the stochastic runs selected any area with regimes of: continuing existing pasture over the planning period, allow natural regeneration only, plant and leave immediately or plant up to 10 later then leave for carbon credit income. The standard clearwood regime with a rotation age of 25 - 30 years was selected for the majority of the estate area in most of the stochastic runs, although one quarter of the time, the percent of the estate was less than 47% and on one occasion it was allocated to only 2% of the estate area. Figure 3 summaries the distribution of the percentage area allocated to the regimes selected at least occasionally by the LP analyses.

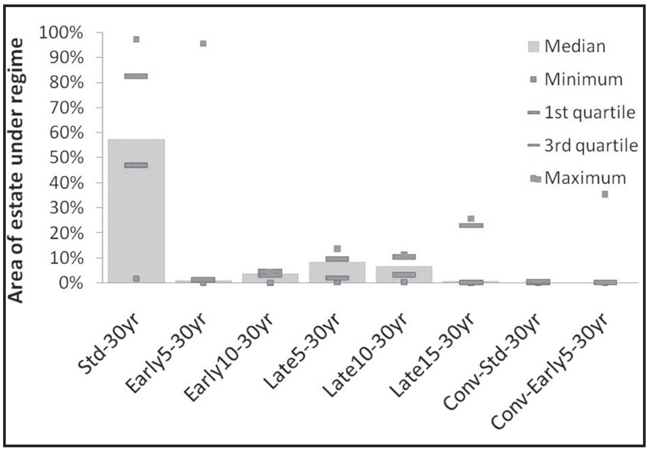


Figure 3: Distribution of the percent area of the estate allocated to the various regimes during the stochastic LP runs.

Similarly, there is a wide variation in the quantity of CO_2-e sold in each period (Figure 4) although the majority of the sales are usually in the first two periods.Simple linear correlations between the DNV, areas allocated to specific regimes and quantities of CO_2-e sold against the

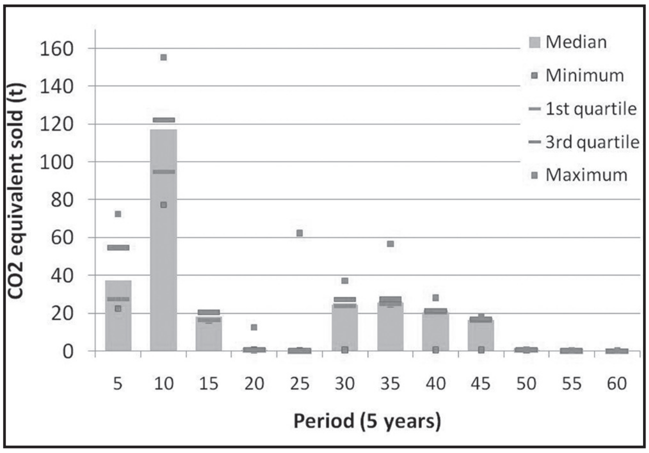


Figure 4: Distribution of the CO_{2e} ($t\ ha^{-1}$) allocated for sale by the various regimes during the stochastic LP runs.

stochastic variables used to represent internal and external uncertainties were ranked (see Figure 5 over page). Some of these correlations were significant ($p<0.05$) and positive. Values between -0.3 - 0.3 may be defined as "small" are unlikely to be significant. For example DNV and the variation in growth and yield in period 6 are logically correlated because period 6 is when the maximum yield of high quality sawlog is being produced in the standard 25-30 year regime (Std-30yr) which largely dominates most solutions - if above average growth occurs then, the DNV will increase. There is a weaker but still positive relationship between DNV and variation in growth and yield in period 8, but an equally as strong negative correlation between DNV and the length of time until carbon trading ceases.

Discussion

The DNV and "optimal" combination of regimes for this simple farm forest problem change substantially when uncertainty is introduced. Very rarely would the optimal strategy allocate as much of the land to a standard clearwood regime with a 25-30 year rotation as the 97% allocation suggested under the base deterministic run (Figure 3). Similarly, rarely do the stochastic runs indicate it be optimal to sell almost 70 t CO_2-e in the first period, although selling almost 120 t CO_2-e in the second period is quite common (Figure 4).

The maximum DNV also ranges quite substantially around the base deterministic value of $20,687 (Figure 2), but this variation is not evenly distributed. More significantly, if the base strategy of establishing 97% of the land under the standard clearwood regime (Std-30yr) and selling 73 and 118 t CO_2-e in the first two periods respectively were adopted under the various stochastic runs, the DNV could falls to as little at $3,000 and the constraints for non-negative net returns in any period are frequently violated. The base deterministic strategy is clearly not optimal and rarely even feasible.

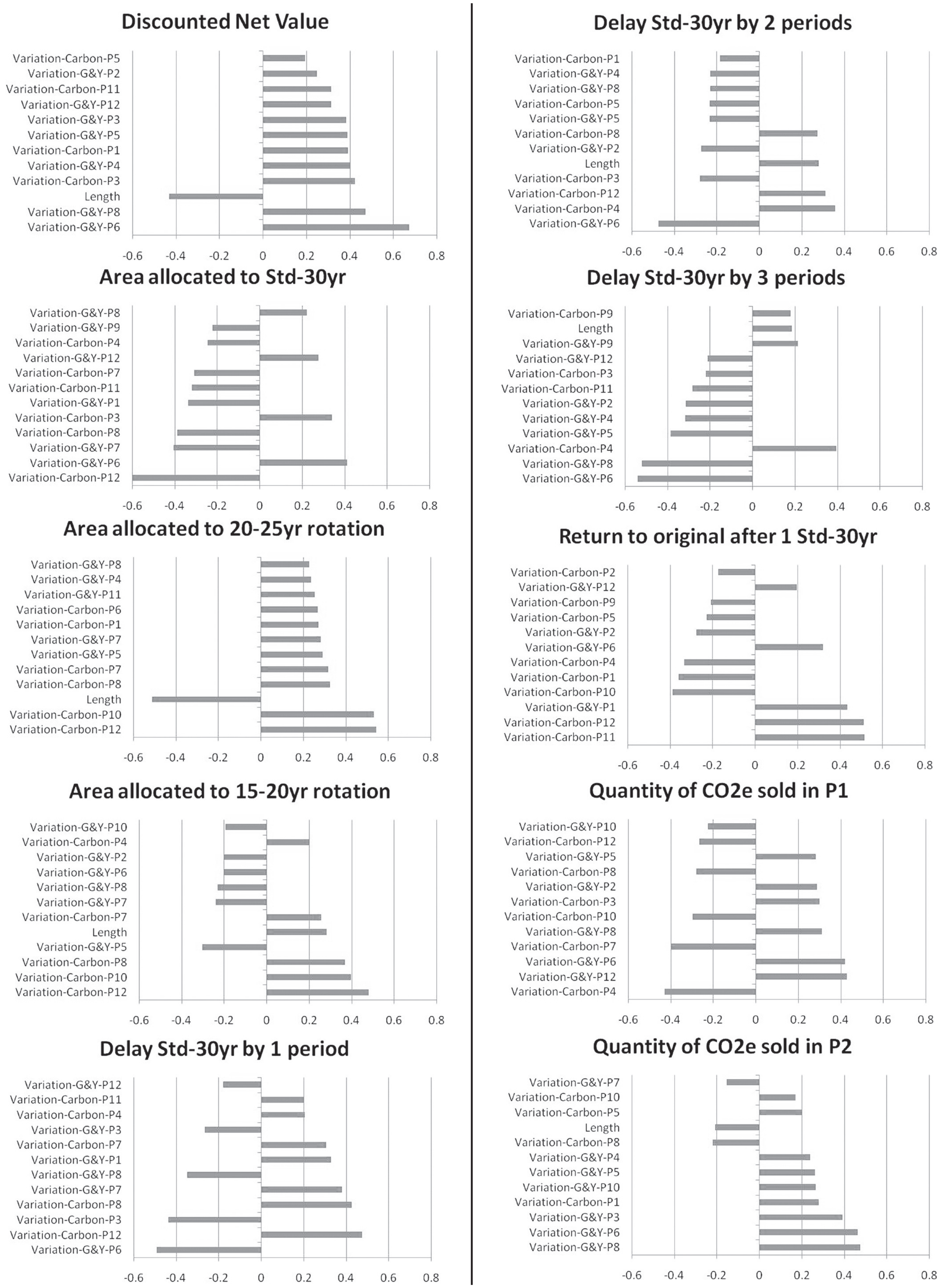
Of the possible regimes provided, those that appeared in at least one stochastic run included: standard clearwood regimes with final rotation lengths of 25 - 30, 20 - 25, or even 15 - 20 years or delayed by 5, 10 or 15 years before being established. Surprisingly given the low nominal return for non-forest land use, there were some stochastic solutions where the standard clearwood regime was only used for one rotation and then the estate returned to the non-forest land use - even one occasion when over 40% of the estate started with a standard regime that was subjected to an early final harvest before return to non-forest use (Figure 3).

Figure 5 summarises the linear correlation between the optimal decisions and variation in internal or external parameters. The stochastic variables that appear to have most effect on DNV appear logical when above expected growth or carbon price leads to an increase in DNV. The significant negative correlation with length of time the carbon retains a value suggests that if carbon ceases to be a commodity or attract a price as soon as possible after the 20 years restriction (i.e. decrease length), then DNV will increase. This negative correlation may seem counter intuitive until consideration of the fact that if trading ceases, the manager will not have to buy back any carbon sold earlier but then subsequently harvested.

Similarly, it may appear counter intuitive that the variation in the unit price of carbon in the twelth period is significantly correlated with the optimal areas allocated to 6 of the 8 regimes appearing in some LP solutions. It may have initially been expected that any price variation would have been reduced to insignificance by the effect of 60 years of discounting at 5% y^{-1}. Closer inspection however shows that the relationship is negative for the standard 30 year regime and positive for all the other regimes, which means that when less area is planted to the standard 30 year regime, then more must be planted elsewhere. The negative correlation for the standard 30 year regime is due to the final harvest (of the second rotation) in the twelth period, resulting in a large "loss" of CO_2-e that may have been either sold earlier (and therefore needs to be purchased back at a premium) or had to forego an earlier sale. The purchase back could also cause problems with the constraint that the (non-discounted) net revenue could not be negative in any period.

The option to return the land to non-forest use after a single 25 - 30 or even 20 - 25 year rotation is normally unlikely, but there are circumstances when it was selected in the LP optimisation runs. The area allocated to these regimes increases with better growth in first and sixth periods, but also with increased carbon prices in the eleventh and twelth periods. The increase in the Convs-regimes with increased growth in the sixth period again makes sense as this is when the sales from the wood products are maximised. The effect of the carbon prices in the final two periods must be an indirect one as, for the purposes of this model, the non-forest activity is carbon neutral, but also without any net cost. Interestingly, the

Figure 5: Simple linear correlations (r) between the 12 most important internal or external variations against DNV and area allocation or CO_{2e} sales.



re-conversion of plantation to non-forest has happened in New Zealand, as evidenced by the photographic sequence captured by Stevenson and Mason (2008). This actual change was likely to have been prompted by substantially more than an expected net return of \$2,000 ha^{-1} yr^{-1} from the non-forest use, but may also be reflecting a manager's response to uncertainty in the growth or relative carbon prices.

So, what should the manager do next year? It is very unlikely that converting 97% or more of the non-forest estate to a standard clearwood plantation with a fixed 30 year rotation will be the best strategy. However, in three-quarters of the simulations made here, at least half the estate should be so converted, with another 5% established but with an expectation that they may not go through to a full 25 - 30 year rotation. More than half the estate should be planted up when there is an expectation that the growth and yield is being underestimated for the end of the 1st or 2nd rotation (possibly due to climate forcing). An increase in the price of carbon in period 3 could also increase the area established because that price increase would negate the extra costs of standard clearwood management (e.g. thinning). Under very rare conditions, the majority, if not all of these plantings would be felled and the land returned to non-forest use, but the manager does not need to "worry" about these decisions until after 15 - 20 years when hopefully a better understanding of the carbon pricing is available. The remaining area is left until the next period when a decision is made to possibly convert more land to a forest landuse. The amount converted in subsequent periods will depend on the success of the initial establishment, but unfortunately if the initial planting is very successful and there is an expectation that the yields in the sixth period will be higher than initially modlled then the ideal action would be to not delay establishment by that one period.

The amount of CO_2-e sold in the first period is a function of the amount of area to be planted as well as being influenced by the actual growth rates and future prices. However in most cases, the bulk of the CO_2-e from the estate is sold by the end of the second period to provide for an early return or to pay for the conversion of more land.

In practice, at the end of each period, the manager could re-run the LP models but with an estate that no longer starts as a uniform non-forest area - some would be planted one or more periods prior and some may still be non-forest. The constraints will be different depending on how much carbon was actually sold in the preceding periods and uncertainties about carbon prices and growth in the immediate future will probably be lessened.

Conclusions

Ignoring uncertainty from internal or external sources is almost guaranteed to result in a biased decision to establish a sub-optimal area of plantation on a farm estate. It is also likely to result in the sale of a sub-optimal amount of CO_2-e, which may cause problems with future cash flow.

This paper introduces a method that takes advantage of commonly available LP software to identify robust decisions on the amount of land to plant and CO_2-e to sell, while simultaneously identifying the aspects of uncertainty that are most influential on decision-making.

References

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