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Optimal selection of plantation tree species accounting for climate change

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Abstract: The Australian plantation forestry industry, including the manufacture of forest products will be affected directly by climate change, since changes in weather variables such as temperature and rainfall directly impact timber yields. Furthermore, increased CO_2 concentrations and risk of fire are also likely to directly result in altered yields from forested land. This analysis aims to examine the future viability and profitability of the two most widely planted and financially important plantation species in Australia, *Pinus Radiata* and *Eucalyptus Globulus*. These two species of plantation tree have proved successful in the environment of Australia; however whether this continues to be the case in a changing climate is unclear. Examination of this question is facilitated through the use of a Central Victorian case study.

The most recent National Plantation Inventory (1996) of the Bureau of Rural Sciences (BRS) defines Central Victoria as the region "located immediately west of Melbourne, stretching from the Otway Ranges, north to Castlemaine, and to just west of the Grampians". The main areas of significance for plantation centre on Ballarat, Beaufort, Colac and Geelong which are also major centres for timber processing (and shipping in Geelong). Central Victoria has a reported total plantation area of 57,185 hectares, of which the two most planted species are *Pinus Radiata* which comprise 53.7 % of plantation land, and *Eucalyptus Globulus* which constitutes 43.2 % . Australia wide the two most widely planted plantation species are also *Pinus Radiata* which accounts for 42.6 % of the total land in Australia under plantation, and *Eucalyptus Globulus* which accounts for 21.6 % of total plantings in Australia . The data used in this study concentrates on these two species since they are central to the plantation industry in the region and in the country as a whole.

The expected long-run value of the two species, Pinus Radiata and Eucalyptus Globulus, are estimated, in two ways: first assuming current growing conditions continue indefinitely; and secondly assuming changing growing conditions as a result of projected climate change. The plantation region considered is Central Victoria, split into three productivity areas based on historical seasonal rainfall. Estimates of the effect of climate change, represented by changes in atmospheric carbon dioxide concentration, ambient temperature and rainfall, on timber yields for the two species are used in the second part of the study.

Maximum net present values of plantation returns with respect to rotation length are determined in the first part based on the Faustmann formula for infinite rotations with no changes in growth parameters. In the second part, maximum net present values are calculated with respect to rotation length the same for each rotation, over 20 rotations, allowing for changing growth parameters. For the base rate of discount of 3 per cent per annum the net present values over a planning horizon of 20 rotations closely approximate the present values over infinite rotations.

Plantation returns include payments from carbon sequestration calculated for a range of carbon prices. Allowance is made for the changing probability of fire destroying a plantation in any year by adding a suitable element to the rate of discount.

It is concluded that for the base case climate-change scenario, Eucalyptus Globulus dominates Pinus Radiata as the preferred species, but this is subject to a number of caveats. The modelling of how the net present value (**NPV**) of each species changes under climate change provides insight for management practices (including selection of plantation species) to better anticipate the challenges of climate change.

Keywords: *Climate change, plantation species selection, probability of fire, carbon sequestration*

1. INTRODUCTION

The future comparative viability and profitability of the two most widely planted and financially important plantation species in Australia, *Pinus Radiata* and *Eucalyptus Globulus* is examined. These two species of plantation tree have proved successful in the environment of Australia; however whether this continues to be the case in a changing climate is unclear. Examination of this question is facilitated through the use of a Central Victorian case study.

The method of calculating the maximum NPV of returns from the two plantation species, before allowing for climate change affecting timber yields and for fire as a hazard, is explained. Methods for incorporating climate change, the risk of fire, and allowance for carbon sequestration rents are introduced in Section 2. In Section 3 results are presented of the comparative NPVs of the two species for various combinations of climate change, risk of fire and returns from carbon sequestration.

1.1. Timber Yields

Data on average annual yield per hectare for each species were obtained for the region of Central Victoria for low, medium and high productivity sites. Yields are split between volume of pulpwood and sawlogs for *Pinus Radiata*, and given as pulpwood volume for *Eucalyptus Globulus* since this species is usually only farmed for pulpwood (Burns et al., 1999). High productivity yield data are shown in Table 1 because results in Section 3 show interesting differences between the NPVs of the two species on high productivity sites.

Table **1**: Mean timber yields by age for Eucalyptus Globulus and Pinus Radiata (High productivity sites)

	Eucalyptus Globulus	Pinus Radiata	
Age (years)	Pulpwood (m^3/ha)	Sawlog (m^3/ha)	Pulpwood (m^3/ha)
8	276	–	–
9	332	–	–
10	382	19	165
11	428	41	199
12	477	76	218
13	517	111	235
14	550	151	257
15	582	143	140
16	–	184	143
17	–	225	144
18	–	267	149
19	–	309	155
20	–	375	134
21	–	436	117
22	–	482	117
23	–	390	67
24	–	437	63
25	–	480	59
26	–	524	53
27	–	563	52
28	–	601	53
29	–	641	52
30	–	677	52
31	–	717	50
32	–	753	47
33	–	788	49
34	–	829	42
35	–	861	44

1.2. Timber Prices and Establishment Costs

The prices for pulpwood and sawlog used in the model are stumpage prices, those charged by foresters when logs are lifted from the forest site. Since the yield and cost data obtained from ABARE are for 1999, this is the base year for modelling (Prices for *Pinus Radiata* logs were \$37/m^3 and \$10/t for pulpwood in 1999. The price of *Eucalyptus Globulus* pulpwood in 1999 was \$23/t . It is usual to estimate one tonne as equivalent to a green cubic metre and is the conversion rate used here.

Establishment costs are \$1,800 per hectare for *Pinus Radiata* compared to \$1,200 per hectare for *Eucalyptus Globulus* (Burns et al., 1999).

1.3. The rate of discount

A social discount rate not based on current market interest rates is used. The rationale is that the present values of net returns from the alternative species are calculated over very long planning horizons, and that it is desirable to consider intergenerational equity. The social rate of discount is given by (1):

$$r = u + ge \tag{1}$$

where u is the utility discount rate, g is the optimal rate of growth of per capita income, approximated by the long run per capita growth in real GDP; and e is the elasticity of the social marginal utility of consumption with respect to per capita consumption. A review of estimates of u and e by Boardman et al. (2006) suggests that values of 1% p.a. and 1 are good proxy values respectively. The value of g is set at 2% p.a. based on per capita growth in real GDP for Australia over the years 1970-2006 . This gives a social discount rate of 3% p.a., which is adopted for the base case.

1.4. Calculating the NPV of a forest rotation

The NPV (2) of cash flows occurring over one rotation of length *t* years is:

$$NPV_t = -c_{re} + ((p_p - c_{cf})v_{pt} + (p_l - c_{cf})v_{lt})/(1+r)^t \quad (2)$$

where c_{re} is the one-off cost of replanting or establishing a new stand starting from bare land; p_p and p_l are the unit prices of pulp and log products; c_{cf} is the unit cost of clear felling; and v_{pt} and v_{lt} are the volumes of pulpwood and sawlog harvested when the trees are *t* years old.

1.5. Calculating the NPV of infinite forest rotations

The aim is to compare the NPVs of returns per hectare across infinite rotations for each species, based on recent climate continued into the indefinite future. Determination of the NPVs to infinity is straightforward if the problem is stationary, and is the basis of the Faustmann formula. For the problem to be stationary, all functions (timber price, cost, timber yield and stochastic event) must be the same for all decision stages, in this case for all years. This is assumed for finding NPVs to infinity in the absence of climate change. The calculation of NPV of infinite rotations of length *t* years (NPV_∞) is given by (3):

$$NPV_\infty = NPV_t(1-(1+r)^{-t})/r \quad (3)$$

The optimal rotation length (t^*) is the Faustmann rotation where NPV is maximised with respect to rotation length *t*.

1.6. Comparative NPVs for the two species in the absence of climate change and fire hazard

For a discount rate greater than 4.3 % the NPV of *Eucalyptus Globulus* is higher on all sites. The discount rate must fall below 2% for medium productivity sites of *Pinus Radiata* to have a higher NPV than *Eucalyptus Globulus* and below 1% for low productivity sites to yield a higher NPV.

2. NPVs IN THE PRESENCE OF CLIMATE CHANGE AND RISK OF FIRE

To determine NPVs under climate change comparable to those under no climate change, the planning horizon must be finite but sufficiently long. The planning horizon may be judged long enough if the NPV of the finite horizon solution is not much lower than that for the infinite planning horizon. Tests showed that the length of the time horizon should be at least 20 rotations.

An approximate method was used to find the near-optimal policy under climate change. The method allows for climate change to affect yield across all years of the planning horizon, but requires that the length of all rotations across the planning horizon be the same. This enables the effect of climate change to be modelled, but the degree of accuracy of the method is still to be determined. This would entail the use of finite-stage stochastic dynamic programming. The solution for the climate change problem is the rotation length that maximises NPV. This is found by inspection after total enumeration of all feasible rotation lengths.

2.1. Expected changes in timber yields as a result of climate change

Declines of 0 to 25% for *Pinus Radiata* are expected in most areas of central Victoria. The magnitude of the changes (namely a doubling of CO2, a rise in temperature by 3 degrees Celsius and a 20% decline in rainfall) modelled by Kirschbaum (1999) is not likely until 2070 and only then given a scenario of continued economic growth and reliance on fossil fuels. This conclusion is drawn by matching Kirschbaum's modelled assumptions to forecasts outlined in CSIRO and BOM (2007). The decline is mainly due to the higher than optimal temperatures in which *Pinus Radiata* is currently planted. Most sites in central Victoria will be at the top end of the range of suitable temperatures, due to the hot average temperatures (particularly in summer) for those plantations around Balart and Beaufort. A decline of 0.25% in yields per annum fits this scenario resulting in a compounded decline of around 19% by 2070 (base year 1999). This figure holds for the base case.

For *Eucalyptus Globulus* the modelling predicts a gain for most "generic Eucalypt" species in southern Australia under the conditions outlined above of 0 to 25% . An increase in annualised yields by 0.25% is added to the yields of *Eucalyptus Globulus* in the climate change scenario (as with *Pinus Radiata* compounded from the base year of 1999 results in an increase of around 19%), for the baseline case. These increases are due largely to longer growing seasons and the CO_2 fertilisation effect.

2.2. Adjusting the discount rate to account for the risk of loss trees from catastrophic fire

The risk of catastrophic fire in most areas of Southeast Australia is projected to increase from 1 in 42 (2.4%) odds at present, to 1 in 38 (2.6%) for low levels of climate change , to as high as 1 in 12 (8.3%) for high levels of climate change (Cary, 2002). If the risk of catastrophic fire is the same for all tree ages, the solution to the problem of the planned age at which to fell trees (recognising that the trees may be lost at any age below the planned age of felling), is obtained from the deterministic solution by adding a suitable fire risk premium to the rate of discount. Clark (1990) shows that the risk adjusted discount rate is (4):

$$r' = (r + \lambda)/(1 - \lambda) \tag{4}$$

where r is the actual discount rate and λ is the probability that a fire destroys the stand in any year.

2.3. The Emissions Trading Scheme and a price on carbon

In July 2008 the Australian federal government released a green paper roughly detailing its proposed introduction of a national carbon pollution reduction scheme, commonly referred to as an emissions trading scheme (**ETS**), set to be introduced in 2010 (Department of Climate Change, 2008). The paper proposes the inclusion of forestry activities from the outset of the scheme's introduction and includes both reforestation and land planted for the purposes of commercial forestry, on a voluntary basis .

This paper follows Spring et al. and considers the effect of these two possible policy settings, here named policy A and policy B. Under policy A the amount of carbon released is simply the amount of carbon contained in timber used for pulpwood, whilst the carbon in timber used for saw logs is assumed to be sequestered for ever. The present value of extra revenue from the interest gained from temporary sequestration and the income from permanent sequestration is then added to the revenue streams for each rotation to gain new NPV figures. Under policy B (the most likely policy scenario), no differentiation is drawn between pulp and sawlog, so on harvesting the stand all carbon is assumed to be released and must be paid for. In this case only interest payments are added to the revenue since the forester cannot keep credits for sawlog timber. The revenue (R_c) each year from carbon sequestration is therefore (5):

$$R_c = p_c d_w \beta \tag{5}$$

where p_c is the price of carbon and d_w is the dry weight timber in tonnes which locks up carbon over the year and β is the carbon in tonnes per tonne of dry weight timber. To find d_w (6), the dry weight of each cubic metre of wood (basic density) (d) for each species must be multiplied by the total volume of wood (pulp (v_p) and log(v_l)), such that:

$$d_w = d(v_p + v_l) \tag{6}$$

The basic density of each species varies with the age of the tree but the basic density of wood for each species is relatively constant at a typical time of harvest. These are 480 kg/m^3 for *Pinus Radiata* and 790 kg/m^3 for *Eucalyptus Globulus* .

Since the ETS is not yet in place it is unclear what the carbon price will be. A price of $20/tonne is cited as a likely price when the scheme is introduced and is also suggested as a fixed price for the introduction of the scheme in the Garnaut Climate Change Review . This price is used in the base case.

3. RESULTS

Table 2 reports the NPV of each species on a high productivity site, in dollars per hectare. The length of the optimal maximum rotation is shown in brackets. Maximum rotation length is the rotation length for a plantation always subject to some constant annual probability of loss by fire when no fire has actually occurred. The first part of the table shows the results for the stationary system outlined above. The table also details how these values change once climate change, the risk of fire and the two sequestration policies are accounted for.

Table **2**: The NPV ($ per ha) and (optimal maximum rotation length) for each species: For high productivity site, discount rate = 3% p.a. and carbon price = $20 per tonne.

Scenario	*Eucalyptus Globulus*	*Pinus Radiata*
No climate change No fire risk No returns from sequestration	$7,276/ha (13 years)	$8,645/ha (27 years)
Changing climate No fire risk No returns from sequestration	$8,220/ha (13 years)	$7,300/ha (27 years)
Changing climate Risk of fire = 2.6% p.a. No returns from sequestration	$2,859/ha (12 years)	$1,580/ha (24 years)
Changing climate Risk of fire = 2.6% p.a. Sequestration Policy A	$3,507/ha (13 years)	$3,556/ha (24 years)
Changing climate Risk of fire = 2.6% p.a. Sequestration Policy B	$3,507/ha (13 years)	$1,939/ha (24 years)

3.1. The NPV of each species without climate change

For discount rates greater than 4.3 %, *Eucalyptus Globulus* has a higher NPV on all sites. The discount rate must fall below 2% for medium productivity sites of *Pinus Radiata* to have a higher NPV than *Eucalyptus Globulus* and below 1% for low productivity sites to yield a higher NPV.

3.2. The effect of climate change on NPV

Table 2 shows how the NPV for each species is affected by the projected changes in yields, arising from climate change. It shows that the projected effects of climate change on these two species is enough to make the NPV of optimal rotations of *Pinus Radiata* fall below that of *Eucalyptus Globulus* on the high productivity sites.

3.3. The effects of a carbon price and sequestration policy on NPV

The proposed ETS, depending on its form (Department of Climate Change, 2008), will have the effect of favouring one species or the other. Firstly Policy A allows for a more realistic treatment of carbon stored in sawlogs, where carbon stored in sawlogs is assumed to be sequestered forever more. Policy B allows plantation owners to claim carbon credits but only for temporary sequestration. That is, once the stand is cut it is assumed that the carbon stored within is released. Table 2 shows the NPV of optimal rotations of each species on high productivity sites under each policy with a 3% discount rate, the fire regime of low level climate change, the projected climate yield effects and a carbon price of $20 per tonne.

Policy A improves the NPV of *Pinus Radiata*, so that a $20 per tonne price on carbon is just enough to make it comparable with the NPV for *Eucalyptus Globulus*. The price of $20 is a threshold price for high productivity sites: prices above $20 result in a higher NPV for plantations of *Pinus Radiata*. This is because *Eucalyptus Globulus* is not generally used for saw logs and this policy allows the plantation owner to keep credits for carbon locked up in saw logs. In short, a policy of this nature could, with a price on carbon over $20 per tonne, make the NPV of *Pinus Radiata* greater than that of *Eucalyptus Globulus* on high productivity sites. In contrast, Policy B results in larger gains in NPV for *Eucalyptus Globulus*.

4. CONCLUSION

Climate change will have significant effects on Australia’s plantation forests over the next few rotations. By undertaking anticipatory measures to adapt to climate change the forester can both reduce vulnerability to negative impacts and take advantage of any positive impacts that may arise. Economic modelling can help the forester understand what measures are best to take, given different possible scenarios.

The results shown in the base case scenario suggest that it may be optimal for foresters considering which species to plant, to switch current plantations of *Pinus Radiata* over to *Eucalyptus Globulus,* and for new plantations to consist more of *Eucalyptus Globulus.* This tentative conclusion comes with a number of caveats that arise from a sensitivity analysis. The NPV of *Pinus Radiata* falls below *Eucalyptus Globulus* on high productivity sites when: a) the discount rate is above 4.3%; b) *Eucalyptus Globulus* experiences a gain in yields greater than 0.25% p.a. above that of *Pinus Radiata*; or c) Policy A is adopted to account for carbon sequestration and the price of carbon is above $20 per tonne.

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