The generalized Reed model and its application to determine the impact of hurricane risk on even-aged plantation management in southern U.S.

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BACKGROUND

- Hurricanes Hugo and Ivan: a loss of US$630 million (1989) and US$2.2 billion (2004) in the forest sector . Losses of US$ 2 to 3 billion due to Katrina and Rita (2005).
- Intensive hurricanes will remain at high levels for at least the next 40 years in the North Atlantic basin .
- Hurricanes also imply:
  - reduced carbon storage in the forest
  - altered forest structure
  - increased intensity and probability of wildfires and pest outbreak

RESEARCH GAP

- Economic models such as the Reed model (1984) incorporated constant risk from natural hazards and salvageable portions, and assessed this effect on optimal forest management.
- These two salient parameters of the Reed are likely to fluctuate after each or several rotations.

MODEL ASSUMPTION

- Two states of the world: a catastrophic event arrives before the optimal rotation age. The landowner salvages a proportion of the forest and incurs the regeneration costs associated with the new forest stand (1st state)
- 2nd state: the landowner receives the net returns from harvesting the forest stand at the optimal rotation age, and incurs the replanting costs for a new forest stand.
- Let's define for t_i year old trees at the ith timber crop:

$P_i(t_i)$: price of stumpage; $Q_i(t_i)$: the merchantable volume; C_i: the regeneration cost; C_o: initial regeneration cost; λ_i: probability of a catastrophic risk; $\bar{g}_i$: mean salvageable portion r_i: discount rate.

MODEL SPECIFICATION

- The land expectation value at the beginning of the first timber crop LEV_1 is:

$$\boldsymbol{LEV_1 = -C_0 + [P_1(T_1)Q_1(T_1) + e^{(r_1+\lambda_1)T_1}\int_0^{T_1} \emptyset_1\, dX_1]e^{-(r_1+\lambda_1)T_1} + e^{-(r_1+\lambda_1)T_1}LEV_2} \quad (1)$$

$\emptyset_1 = \lambda_1[\bar{g}_1(X_1)P_1(X_1)Q(X_1) - C_1]e^{-(r_1+\lambda_1)X_1}$ thus Eq. (1) :

- k different crops and letting $V_k(T_k) = [P_k(T_k)Q_k(T_k)]$ = stumpage value, we obtain the following first order condition with respect to T_k:

$$\boldsymbol{\frac{\partial V_k(T_k)}{\partial T_k} + e^{(r_k+\lambda_k)T_k}\emptyset_k = (r_k+\lambda_k)V_k(T_k) + (r_k+\lambda_k)LEV_{k+1}} \quad (2)$$

- The LHS of Eq. (2) represents the net marginal revenues of timber and salvage benefits by waiting extra one year. The RHS of represents the marginal cost of waiting one extra year.

IMPLICATIONS ON OPTIMAL HARVEST AGE

- Rule of harvest:; if LHS> RHS ⇒wait for one more time period, if LHS≤ RHS ⇒ harvest
- Harvest is postponed if $LEV_{k+1} < \varphi(t_k) = \frac{\partial V_k(T_k)}{\partial T_k} + e^{(r_k+\lambda_k)T_k}\emptyset_k - (r_k+\lambda_k)V_k(T_k)]/(r_k+\lambda_k)$
- A higher current risk λ implies an increase of the LHS and RHS of Eq. (2). The RHS increases more than the LHS. To restore equality $\frac{\partial V_k(T_k)}{\partial T_k}$ must also increase, implying a shortened harvest.
- A higher λ for future timber crops would only decrease future land values LEV_{k+1}. $\frac{\partial V_k(t_k)}{\partial t_k}$ would have to be decreased to hold the relationship, thus decreasing the harvest age.
- A higher current salvageable portion g implies an increase of the LHS of Eq. (3). To restore equality $\frac{\partial V_k(T_k)}{\partial T_k}$ should decrease, lengthening the harvest age.
- Higher future levels of g would increase future land values LEV_{k+1} leading to shorter harvest ages for the current timber crop.

APPLICATION TO SLASH PINE STANDS US SOUTH

- Assuming λ =0.01, g =0.85 and optimal rotation age (ORA) =22 years.
- A landowner should let the forest stand grow one more year (23 years) as long as LEV_{k+1} < $2651.0 ha^{-1}.
- At age 23, he should have to let the stand grow until age 24 if LEV_{k+1}< $1507.1 ha^{-1}.

Table 1 LEV and optimal rotation age

Age	$LEV(t)$	$\varphi(t)$
	$US ha^{-1}	
20	3415.0	4892.4
21	3465.1	3787.5
22	3474.5	2651.0
23	3448.7	1507.1
24	3393.1	377.2
25	3313.0	-721.7

APPLICATION TO SLASH PINE STANDS US SOUTH

- ORA should be age 25 if $-721.7 ha^{-1} < φ <$377.2 ha^{-1}, and 24 if $377.2 ha^{-1} < φ < $1507.1 ha^{-1}

CHANGES IN PROBABILITY OF RISK AND SALVAGEABLE PORTION

Table 2 LEV and optimal rotation age under different levels of λ and g

	λ = 0.01			λ = 0.04		
	$LEV(t)$	$\varphi(t)$	age	$LEV(t)$	$\varphi(t)$	age
	US$ ha^{-1}		year	US$ ha^{-1}		year
g = 0.85	3465.1	3787.5	21	-189.0	4223.4	17
	3474.5	**2651.0**	**22**	-65.6	3641.1	18
	3448.7	1507.1	23	8.3	3001.5	19
	3393.1	377.2	24	39.4	2313.5	20
	3313.0	-721.7	25	33.8	1591.6	21
g = 0.1	3003.7	4924.8	19			
	3069.8	3788.8	20			
	3089.6	2600.1	21			
	3069.0	1384.6	22			

[a] Regular and italicized number with straight underlines represent respectively the effect of increased current and future λ=0.04, on the current optimal harvest age
[b] Regular and italicized number with dotted underlines numbers represent respectively the effect of increased current and future g=0.85 on current optimal harvest age. The base case figures are in bold

- If all future λ =0.04, the future LEV_{k+1} =$39.4 ha^{-1}. The ORA for the current stand would be lengthened to 25 years since -$721.7 <$39.4 < $377.2 ha^{-1}.
- If the current λ = 0.04 while future λ= 0.01, the ORA for the current timber crop= 19 years since $3001.5 < $3474.5 < $3641.1 ha^{-1}.
- If all future g drops to 0.1, then the LEV_{k+1}= $3089.6 ha^{-1}. The ORA for the current crop =22 years since is $2651.0 <$3089.6 <$3787.5 ha^{-1}.
- Neither would a drop in the current g to 0.1 while future g = 0.85 change the current ORA since $2600.1<3474.5 < $3788.8 ha^{-1}.

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