Forest Management and Wildfire Prevention under Forest Carbon Policy Schemes

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Background

- Forest Wildfire
  - Recent ten years:
    - more burned acreage per fire
    - more massive fires
  - The suppression cost has exceeded 1 billion dollars per year since 2006.
  - Wildfires release more than 200 million metric tons CO_2 on an annual average, equivalent to approximately 4–6% of annual anthropogenic emissions in the U.S. (Wiedinmyer and Neff, 2007).

Background

- Prescribed fire
  - A cost effective forest management tool for landowners to improve forest health conditions and reduce catastrophic damage of wildfire (Lotti et al., 1960; Dubois et al., 1999);
  - Annually,14 thousand prescribed fires burn more than 2 million acres;
  - A two-fold issue under the consideration of forest carbon:
    - The implementation of a prescribed fire can reduce the damage and carbon release in wildfires.
    - However, a prescribed fire is also a process of carbon release.

Background

- No existing carbon policies have specified the accounting system on the relationship between wildfire and prescribed fire.
  - Clean Development Mechanism: only temporary or long-term certified emission reductions can be issued for CDM activities;
  - California Air Resources Board: unintentional reversals, such as wildfires, are insured against by contributing a percentage of ARB offset credits to a Forest Buffer Account;
  - Principles of existing carbon mitigation mechanism: second effect of silviculture activities should be quantified and accounted.

Objective and Significance

- Gap
  - No research has been done to examine the interactions among timber production, carbon sequestration, wildfire, and prescribed fire comprehensively with Faustmann model.
- Objective
  - To examine how differently assumed forest carbon policy schemes on fire can influence landowners' forest management decisions
- Significance
  - To provide information to landowners about how to adjust forest management decisions for gradually built up carbon market in future;
  - To help policy makers designing effective fire carbon policies.

Methodology

- A revised Faustmann model with wildfire risk to maximize the land expectation value.
- Assumptions:
  - Four control variables: harvesting rotation T, planting density d, year of prescribed burning s, intensity of the burning z;
  - Prescribed fire is applied at most once in one rotation; no thinning; growth function does not change after burning; all the prices and costs are constant.

Landowner Decision Model

- Basic Faustmann: land expectation value maximization

$$\max_{T} \frac{rY(T)}{1 - e^{-rT}}$$

where $Y(T)$ denotes the net present value of a stand of forest and r is the discount rate.

- When fire risk is included, considering the control variables:

$$\max_{T,d,s,z} \frac{E(e^{-rx}Y(x))}{1 - E(e^{-rx})}$$

Landowner Decision Model

- Three states:
  - (1) Wildfire occurs before prescribed burning: $x < s$; all the timber burns down.
  - (2) Wildfire occurs after prescribed burning, but before harvesting age is reached: $s \leq x < T$; partial timber can be salvaged.
  - (3) Wildfire did not occur before harvesting age is reached: $x = T$. All the timber is harvested.
- Landowners problem becomes:

$$\frac{\int_0^s \lambda(X) e^{-m(X)} e^{-rX}\, Y_1 \,\mathrm{d}X + \int_s^T \lambda(X) e^{-m(X)} e^{-rX}\, Y_2 \,\mathrm{d}X + e^{-m(T)} e^{-rX} Y_3}{r \int_0^T e^{-m(X)-rX} \,\mathrm{d}X}$$

Component functions

Type	Function	Assumed Form
Timber volume	$Y(x,d)$	$e^{\alpha - \frac{\beta_1}{dx} - \frac{\beta_2}{xS} - \frac{\beta_3}{x^2} - \frac{\beta_4}{S^2}}$ $(S = 80)$
Carbon release of harvesting	$g(x)$	$m_0 - m_1 x + m_2 x^2$
Average fire arrival rate function	Constant average arrival rate, λ	$\frac{t_0}{t_b - t_a}$
	Rising average arrival rate, $\lambda(x)$ with $\lambda' < 0$	$2t_0 \frac{(x - t_a)}{(t_b - t_a)(t_c - t_a)}$
	Falling average arrival rate, $\lambda(x)$ with $\lambda' > 0$	$2t_0 \frac{(t_b - x)}{(t_b - t_a)(t_b - t_c)}$
Planting costs	Unburned land	$c_1 d$
	Burned land	$c_2 d$
Timber and carbon salvage	$k(d,z)$	$k_0(1 - e^{\frac{-k_1(k_2+z)}{d}})$
Cost of prescribed fire	$C_3(z)$	$c_0 + c_3 z$
Carbon release of prescribed fire	$f(d,z,s)$	$\mathrm{f(d,s,z)} = n_0 z(n_1 + n_2 \ln(d) + n_3 \ln(s))$

Carbon Policy Schemes

- Scheme 1: considering only benefit of carbon sequestration; not punishing landowners for any activities attributed to carbon release;
- Scheme 2: including carbon release of normal harvesting; excluding any carbon release of fire;
- Scheme 3: penalizing carbon release in either wildfire or final harvesting; excluding carbon release involved in the process of prescribed fire;
- Scheme 4: quantifying and penalizing carbon releases of prescribed fire, wildfire and normal harvesting.

Moderate

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Rigorous

Simulation Results

- Results without carbon sequestration

Model	t_0	T^*	d^*	s^*	z^*	Expected Rent
Faustmann		21.9	400			630
Constant arrival	1	23.1	364	7.8	818	435
	2	25.2	312	7.7	1029	312
	3	27.4	269	7.8	1032	199
Rising arrival	2	22.3	394	8.5	980	483
	4	23.6	371	8.1	1279	413
	7	25.3	347	7.8	1393	321
Falling arrival	0.6	23.3	362	7.6	707	435
	1.3	25.8	296	7.6	928	288
	2.1	29.1	234	7.8	884	137

Simulation Results

- Results of scheme 1

Model	t_0	T^*	d^*	s^*	z^*	Expected Rent
Scheme 1						
Constant arrival	1	22.9	436	7.7	910	658
	2	24.8	378	7.5	1189	506
	3	26.9	331	7.5	1222	365
Rising arrival	2	22	469	8.5	1081	718
	4	23.3	443	8.0	1453	634
	7	25	416	7.7	1600	523
Falling arrival	0.6	23	434	7.5	783	658
	1.3	25.4	361	7.4	1080	474
	2.1	28.5	293	7.5	1073	283

Simulation Results

- Results of scheme 2

Model	t_0	T^*	d^*	s^*	z^*	Expected Rent
Scheme 2						
Constant arrival	1	23.9	406	8.0	831	547
	2	26.1	349	7.8	1084	409
	3	28.4	303	7.8	1104	282
Rising arrival	2	23	438	8.8	1013	600
	4	24.5	412	8.3	1351	522
	7	26.4	387	8.0	1476	419
Falling arrival	0.6	24	404	7.8	703	548
	1.3	26.7	332	7.7	973	382
	2.1	30.2	266	7.9	954	211

Simulation Results

- Results of scheme 3

Model	t_0	T^*	d^*	s^*	z^*	Expected Rent
Scheme 3						
Constant arrival	1	23	398	8.2	563	525
	2	24.3	327	8.4	694	360
	3	25.6	272	8.6	668	217
Rising arrival	2	21.4	429	8.8	640	572
	4	21.2	388	8.6	778	458
	7	20.8	345	8.4	778	320
Falling arrival	0.6	23.5	398	8.0	482	532
	1.3	25.7	312	8.4	647	341
	2.1	28.8	236	8.8	597	158

Simulation Results

- Results of scheme 4

Model	t_0	T^*	d^*	s^*	z^*	Expected Rent
Scheme 4						
Constant arrival	1	22.2	381	8.3	264	475
	2	25.2	298	8.7	587	310
	3	27.7	248	9.1	644	181
Rising arrival	2	20	416	8.8	246	514
	4	22	352	8.9	661	394
	7	23.3	311	9.0	800	271
Falling arrival	0.6	22.7	385	8.0	174	489
	1.3	26.5	285	8.6	528	295
	2.1	30.9	216	9.2	562	129

Simulation Results

- Rotation
  - Rotation ages are at the similar level with the traditional model under carbon policy scheme 1, and are extended about one year under scheme 2;
  - The situations under scheme 3 and 4 depend on fire arrival patterns and assumed fire risks;
  - The longest rotation age appears when wildfire risk is high and in falling arrival pattern under policy scheme 4.

Simulation Results

- Planting density
  - Planting densities increase when scenarios are under scheme 1, 2 and 3, but averagely decrease under scheme 4 comparing to the traditional model.
- Burning intensity
  - Burning is much lighter when a carbon penalty is levied on fires, i.e., under policy scheme 3 and 4, especially under scheme 4.

Simulation Results

- Expected rent
  - Scenarios under scheme 1, 2 and 3 gain higher expected rents than the traditional scenarios.
  - Scheme 4: rents keep at similar level with the traditional model when wildfire risks are low, but fall below traditional level when wildfire risks are higher.

Sensitivity Analysis

- Higher carbon prices ($20/ton and $50/ton):
  - Rotations are slightly shortened under scheme 1 and 4 but prolonged under scheme 2;
  - No burning becomes a strategy under some scenarios of scheme 3 and 4, especially when fire risk is low.

Sensitivity Analysis

- Higher timber prices ($200/MBF):
  - Landowners tend to respond higher timber price with longer rotations when wildfire risk is high, but with greater planting densities when wildfire risk is low;
  - Burning intensities increase.

Discussion

- Scheme 1 and 2: moderate policies
  - Larger densities and higher expected rents comparing to the traditional model without carbon;
  - Scheme 2 ends up with relatively longest rotations.

Discussion

- Scheme 3: a compromise
  - State 2 (the salvage state) is less attractive than it is under scheme 1 and 2. Thus, harvesting rotation are sometimes shortened and years of burning are postponed, both to decrease the relative length of state 2;
  - Planting densities are less than those under scheme 1 and 2;
  - As a result of changes on rotations and densities, landowners do not need to burn as intense as in scheme 1 and 2.

Discussion

- Scheme 4: rigorous policy
  - Landowners would rather to shorten rotations, reduce densities and/or give away some salvage, but not to prescribed-burn intensively when the fire risk is not high;
  - When the wildfire risk is high, landowners use prescribed burning anyway, but they have to prolong the rotation to compensate the extra cost on carbon release brought by the prescribed burning; but the expected land rents are declined below no-carbon scenarios.

Conclusion

	Advantage	Drawback
Moderate policy	Landowners gain better rents from forestland so they participate in the projects voluntarily.	The policies do not strictly satisfy the discipline of additionality or verifiability.
Rigorous policy	Satisfying the disciplines	• Responses go against common suggestions for forest carbon sequestration; • No prescribed burning can be a stategy when carbon price is high; • Landowners' welfares are worse off under some scenarios: voluntary projects may not attract landowners anymore.

Take Home Messages

- Penalty on carbon release of prescribed fire may reduce the use of prescribed fire, increase losses in wildlife, and drive forest management patterns to an undesirable direction for carbon sequestration;
- Carbon policy makers should be more cautious and conservative when dealing with forest fire issues.

Limitation

- This research considers only one forest stand, but does not take consideration of wildfire spread or prescribed fire escape, especially under extreme cases.


Thanks!
Questions and comments are more than welcome!
Source: http://www.fs.fed.us/fire/fmt/contest/2006-firstwinners.html