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Optimal Forest Management with Stochastic Prices & Endogenous Fire Risk

Jana Szolgayová[1,2], Michael Obersteiner[1], Sabine Fuss[1]

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Stresa, Italy

1) IIASA, Laxenburg, Austria;
2) Comenius University, Bratislava, Slovakia

Motivation

- Need to establish mechanisms to accelerate fire extinguishing, evacuation & fire prevention ⇒ information about incidence & location need
- Khabarov et al (2008): estimate of the benefits of a finer grid of weather stations/more frequent patrols in forest areas ⇒ addition of more weather stations reduces fraction of area burnt by wild fires ⇒ occurrence of extreme fire events decreases.
- Expected decreased fire occurrence. ⇒ influence on forest management ⇒ Value of Information

Methodology Choice

- Irreversible decision-making (harvesting) under uncertainty (fire risk, biomass price) ⇒ Real Options (RO) Modeling (e.g. Dixit & Pindyck, 1994)
- In the face of uncertainty, postponing harvest has "waiting" value. ⇒ Option will only be exercised if immediate benefits/profits ≥ value of waiting.
- Fire risk assumed increasing with stand age and density which depend on management decisions ⇒ endogenous fire risk
- Evaluate benefits from more/better EO, which can decrease fire risk (i.e. reduce burnt area) as difference in expected profits and decision structure

Case study – loblolly plantations in southern US

- Data : Descriptive Statistics Loblolly Pine, Forest Inventory and Analysis Database http://www.ncrs2.fs.fed.us/4801/FIADB/fiadb_documentation/SNAPSHOT_DB_V2pt1_JULY_2006.pdf
- Extensive plantations in southeast of US, commercially most important species

Forest Growth model

- Single tree volume growth: standard S-shaped Richard's function

$$GSV_i = a \cdot e^{b \cdot \ln^2 \frac{x_i}{c}}$$

- Extended to model a stand by employing self thinning line
- Extend the model to include the possibility of two thinnings of prescribed intensity during one rotation ⇒ volume function describes the volume for each stand age and each thinning decision possible.

GSV_i = average growing stock volume per tree on plot i depending on stand age;

a = maximum value of GSV per tree = 143 cubic feet; b = shape parameter;

c = maximum age.

Wood Price Model

- Stochastic, mean-reverting process
- Stumpage price (Timber Mart-South, TM-S) for three product classes:
  (1) pulpwood (PW) at a d.b.h. of 4-9 inches,
  (2) chip-n-saw (CNS) at a d.b.h of 9-11 inches,
  (3) saw timber (ST) with a d.b.h > 11 inches.
- < pulpwood ⇒ biomass value: 6.42 US$/ton for PW, 25.8 for CNS, 40.97 for ST and 1 for biomass
- Product price: function of diameter (using both a step-function and a continuous function to compare results).
- Estimate diameter: function of GSV per tree; increasing relationship at diminishing rate

Real Options Model

- Derive the optimal management decisions for a investor maximizing profits and facing stochastic wood prices and endogenous fire risk
- Fire risk: Poisson process, arrival rate λ; impact is the destruction of the total stock volume. Arrival rate is a function of stand age (increasing) and density (increasing)
- Decisions can be done on a yearly basis
- Solution of the model : **Optimal actions** – a table containing optimal action for each year, price and state (vector incl. stand age & thinning status),
- Results: Monte Carlo simulation of price paths and fire occurrence $\Rightarrow$ **Profit distribution, Decisions distribution**

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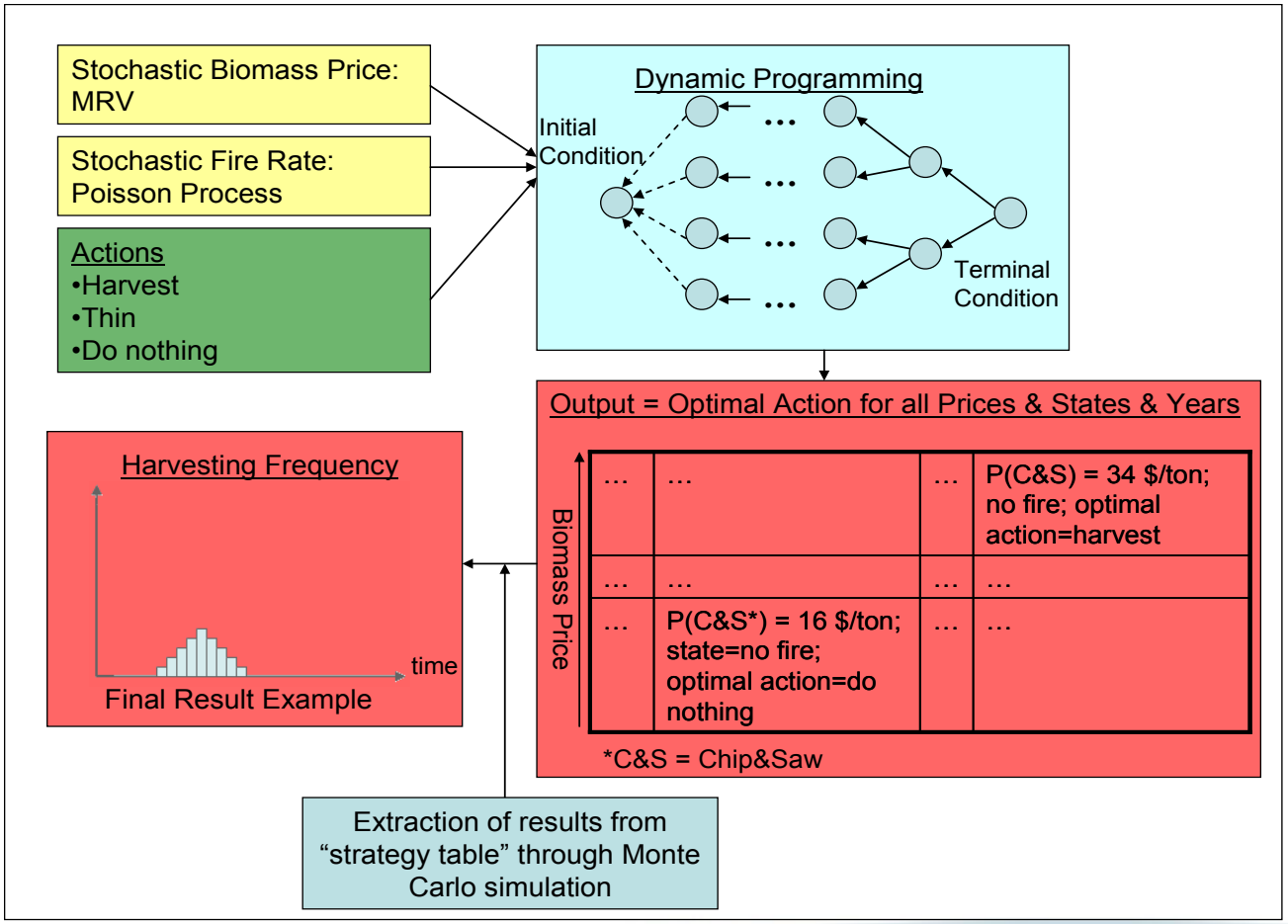
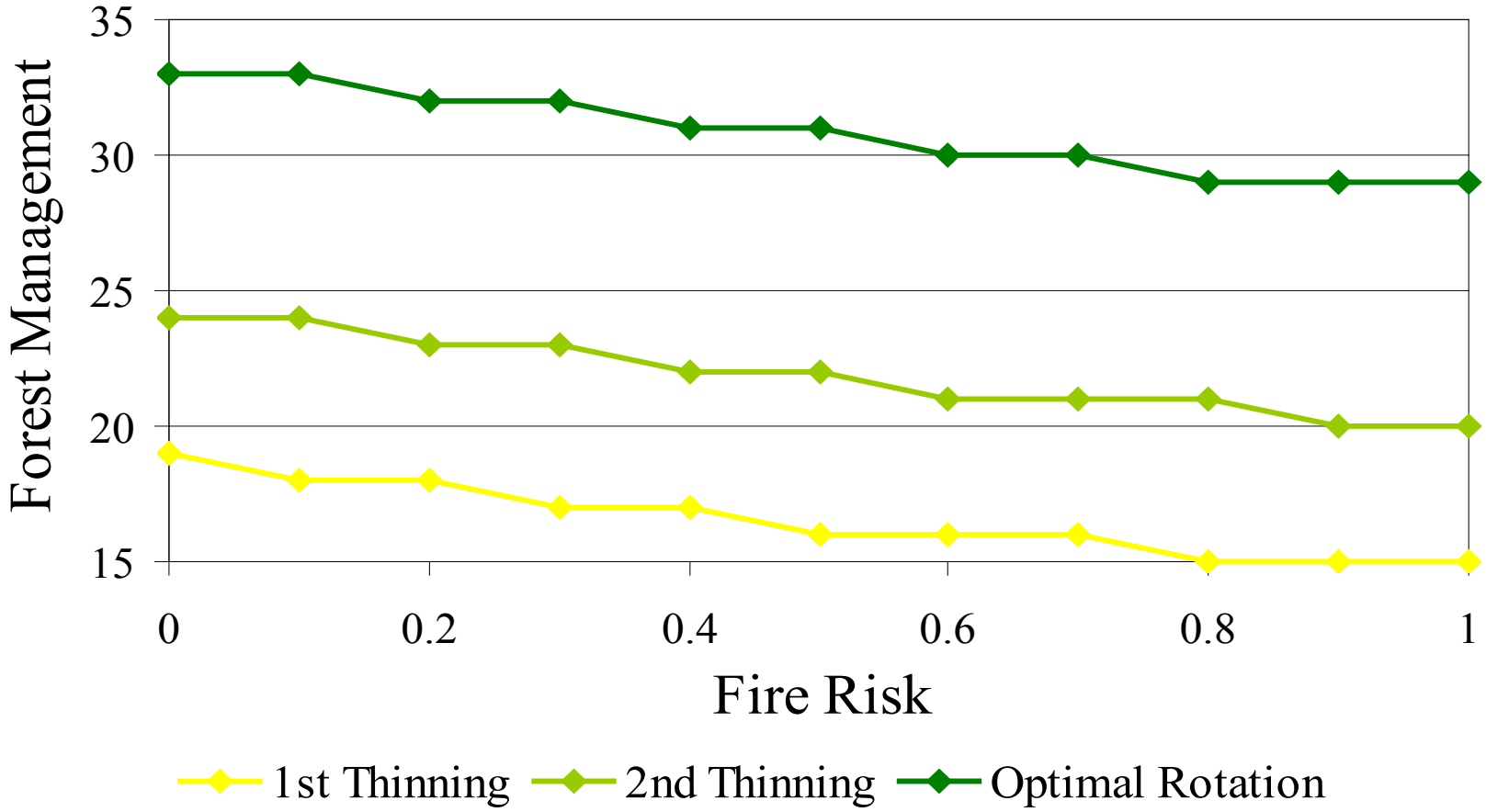
Solution method diagram



Results Analysis

- Results used in analysis: Mean Rotation (Thinning) age, category of harvested wood, expected profits, CVaR of profits
- Impact of the fire risk on optimal decisions both for stepwise and continuous price
- Impact of the fire risk on expected profits and 95% CVaR of profits (expected profits in the worst 5 % of cases)

Results: Fire Risk Impact, Continuous Price



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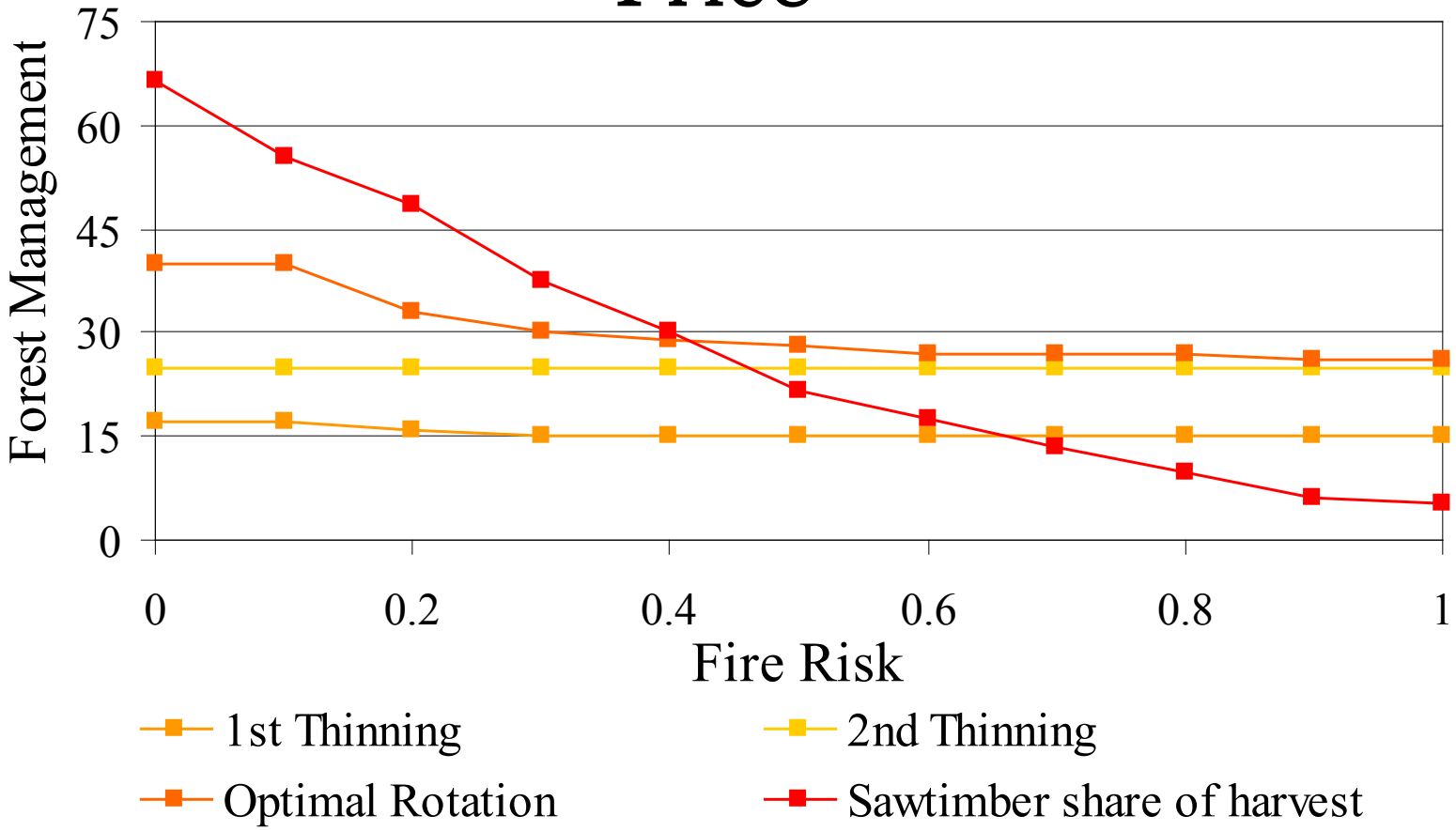
Results: Fire Risk Impact – Step-wise Price



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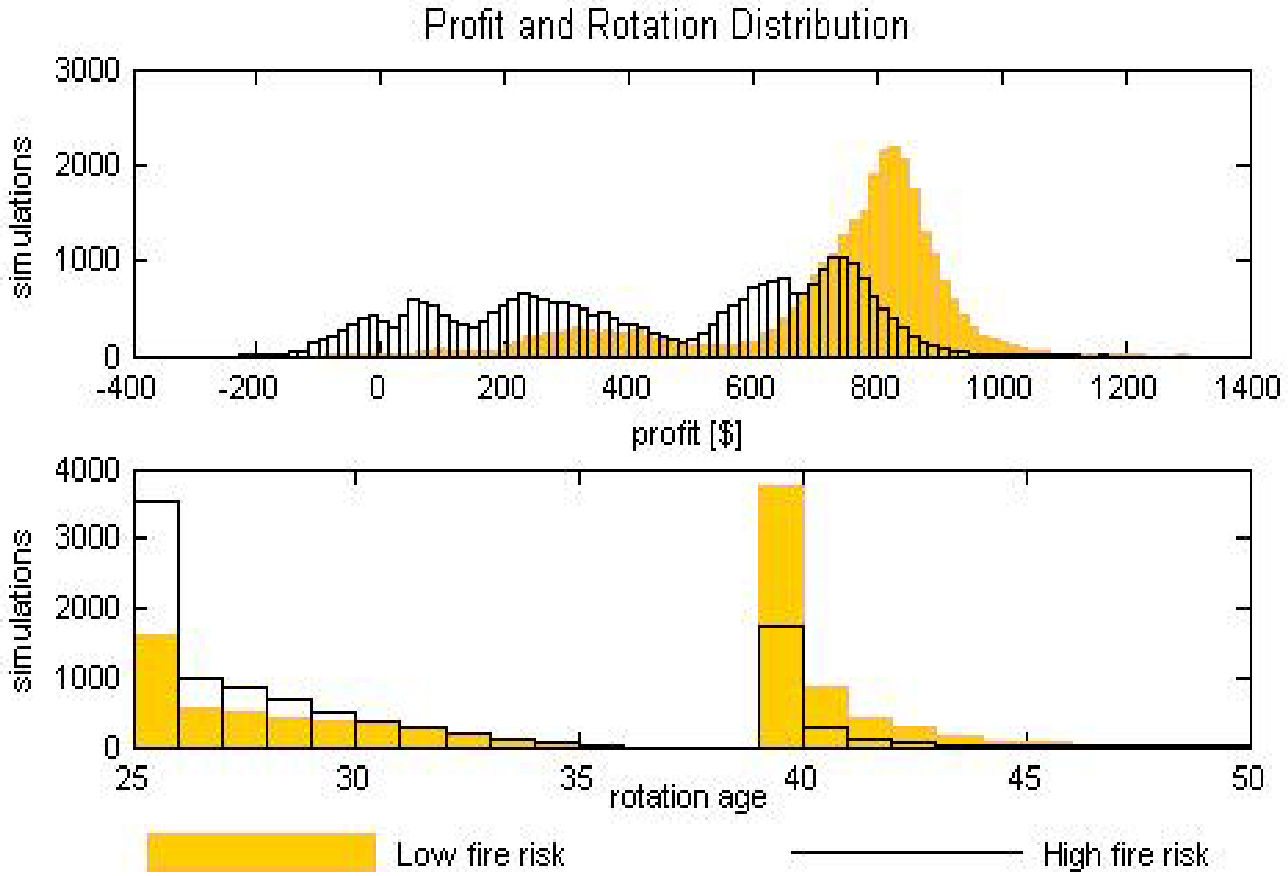
Results: Value of Reducing Risk Through EO



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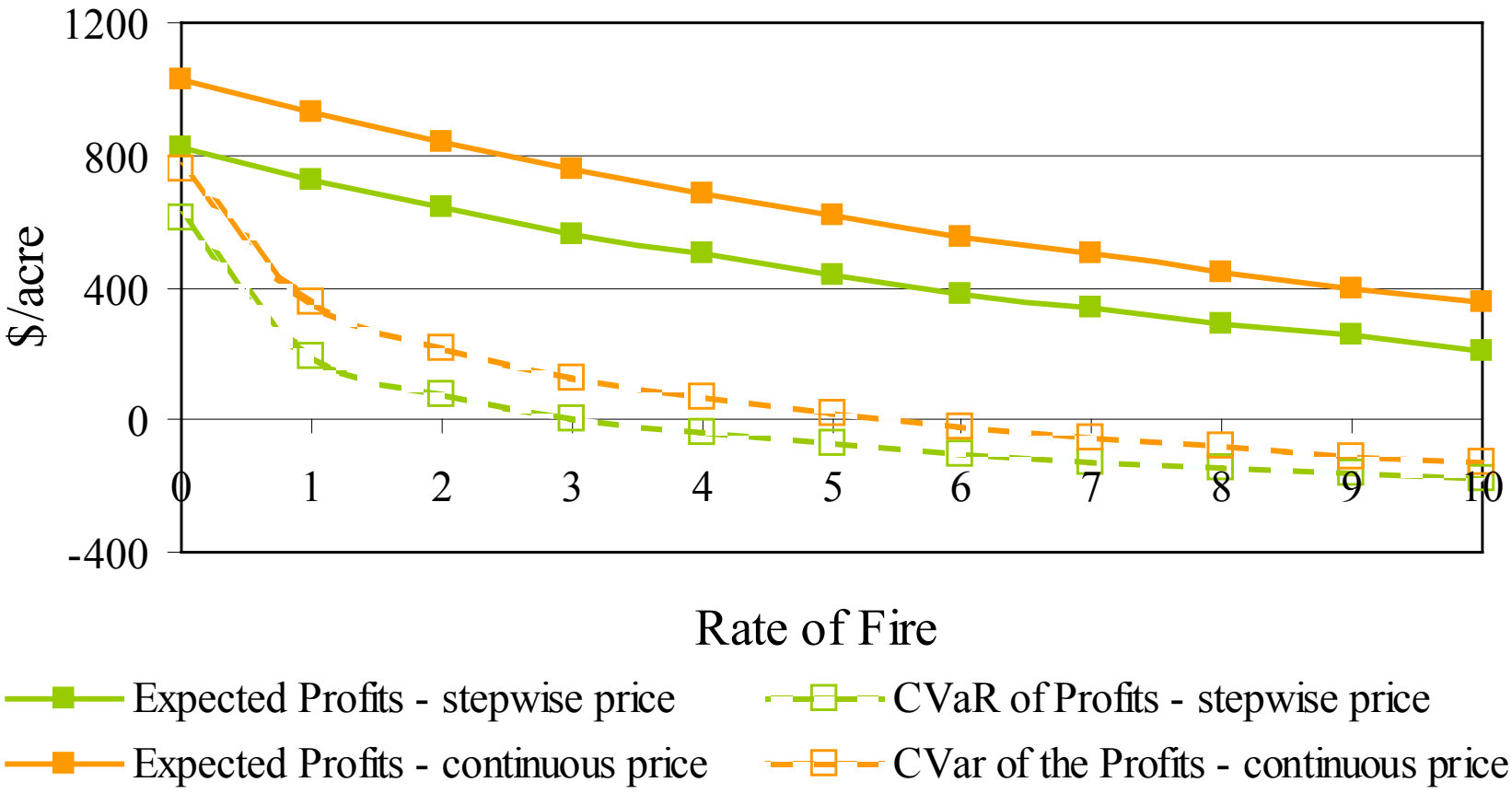
Results: Fire Risk Impact on Profits ($/acre)



Conclusions

- EO can lead to considerable gains in terms of expected profits and profit volatility by reducing the fire risk.
- Rotations will be longer as a result of more security.
- The share of saw timber can be increased substantially.

Thank you!

szolgay@iiasa.ac.at

Case study – loblolly plantations in southern US

Descriptive Statistics Loblolly Pine
(Source: Forest Inventory and Analysis Database)

Variable	Mean [std dev]
Growing stock volume [cubic feet/acre]	1333.5 [1110.89]
Stand age [years]	18 [7.771]
Stand density [100 trees/acre]	3.92 [3.396]
Site productivity class [-]	3.8 [0.992]

http://www.ncrs2.fs.fed.us/4801/FIADB/fiadb_documentation/SNAPSHOT_DB_V2pt1_JULY_2006.pdf