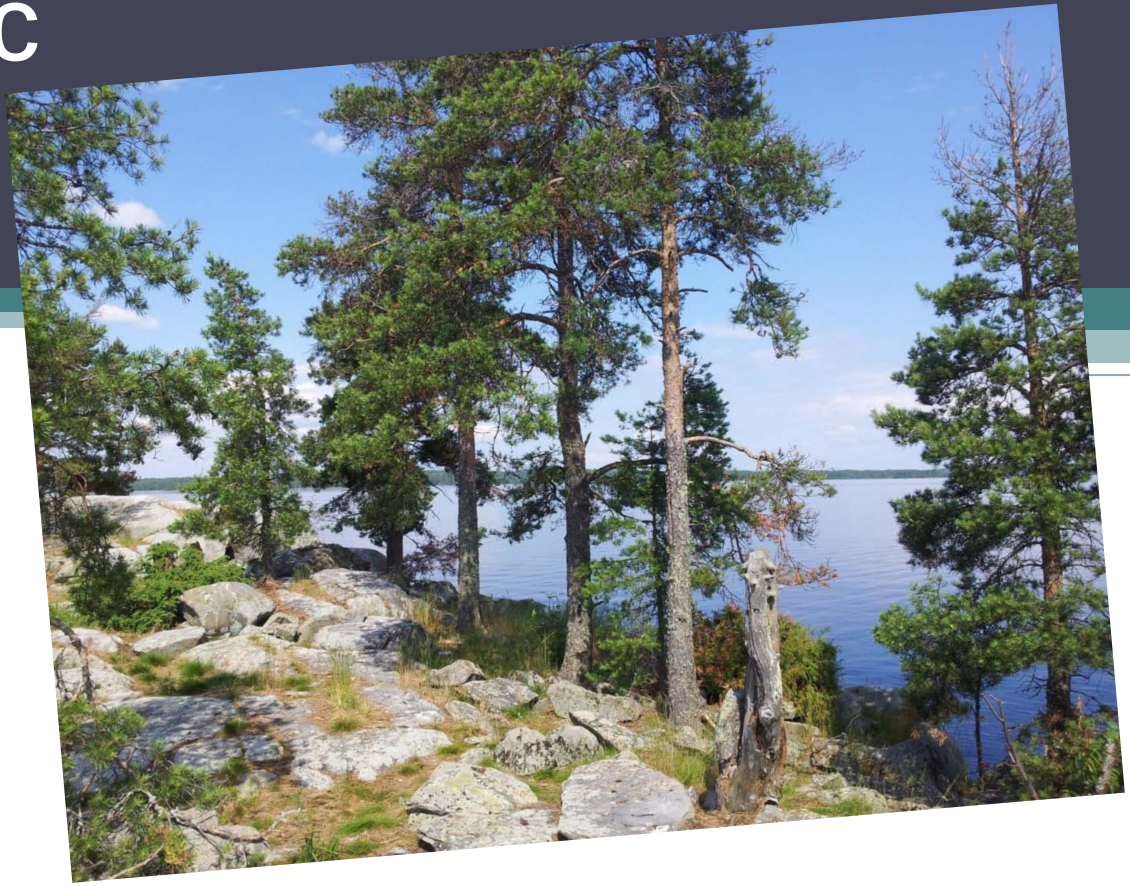
Optimizing continuous cover management when timber price and tree growth are stochastic



Timo Pukkala

Contents

- Background
- Methods
- Results
- Conclusions

Background

Some concepts

Objective

Hypotheses

Some realities

- Future timber prices are unknown
- Tree growth fluctuates: good and bad periods
- The growths of individual trees differ from model prediction
  - Affects the differentiation of tree size
  - May have a major effect on predicted stand development
- Regeneration is very erratic
  - Sometimes too little, sometimes too much

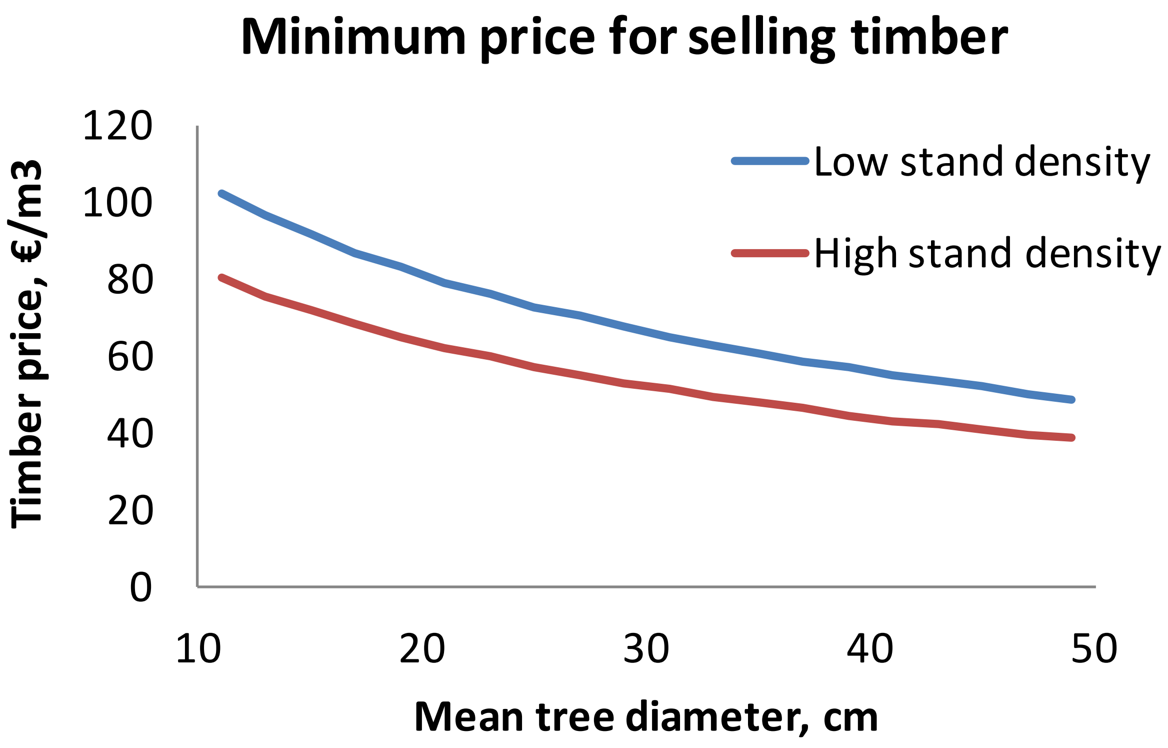
Concepts

- **State of nature**: one combination of future values of uncertain factors
- **Anticipatory optimization** finds the management, which is the best **on the average**
- **Adaptive optimization** finds a **rule** for reacting to changing states of nature
  - Example: Reservation price function

Reservation price function

- Gives the timber price that makes immediate cutting the optimal decision
- Reservation price (RP) decreases with increasing financial maturity of the stand
- RP decreases with decreasing relative value increment
- Relative value increment decreases with increasing
  - Tree size
  - Stand density

Reservation price function



Research questions

1. Effect of stochasticity (risk) on NPV and optimal management
2. Effect risk attitude on optimal management
3. Anticipatory vs. adaptive optima

In continuous cover management when the starting point (initial stand) is

- Uneven-aged stand
- Even-aged pure stand
- Even-aged mixed stand

Hypotheses

1. When growth and timber prices are stochastic, it is optimal to grow more diverse stands

2. Risk avoider keeps a more diverse stand structure than risk seeker

3. When the level of stochasticity is high, adaptive optimization leads to higher NPV than anticipatory optimization

Methods

Simulator, models
Growth scenarios
Ingrowth scenarios
Timber price scenarios
Formulation of optimization problem
Case study stands

Simulation of stand development

Pukkala et all 2013:

- Individual-tree models for diameter increment and survival
- Ingrowth model
- Variation around model prediction

Additional models:

- Individual-tree height model (Pukkala et all 2009)
- Taper model (Laasasenaho 1978)

Both even- and uneven-aged management can be simulated

Growth scenarios

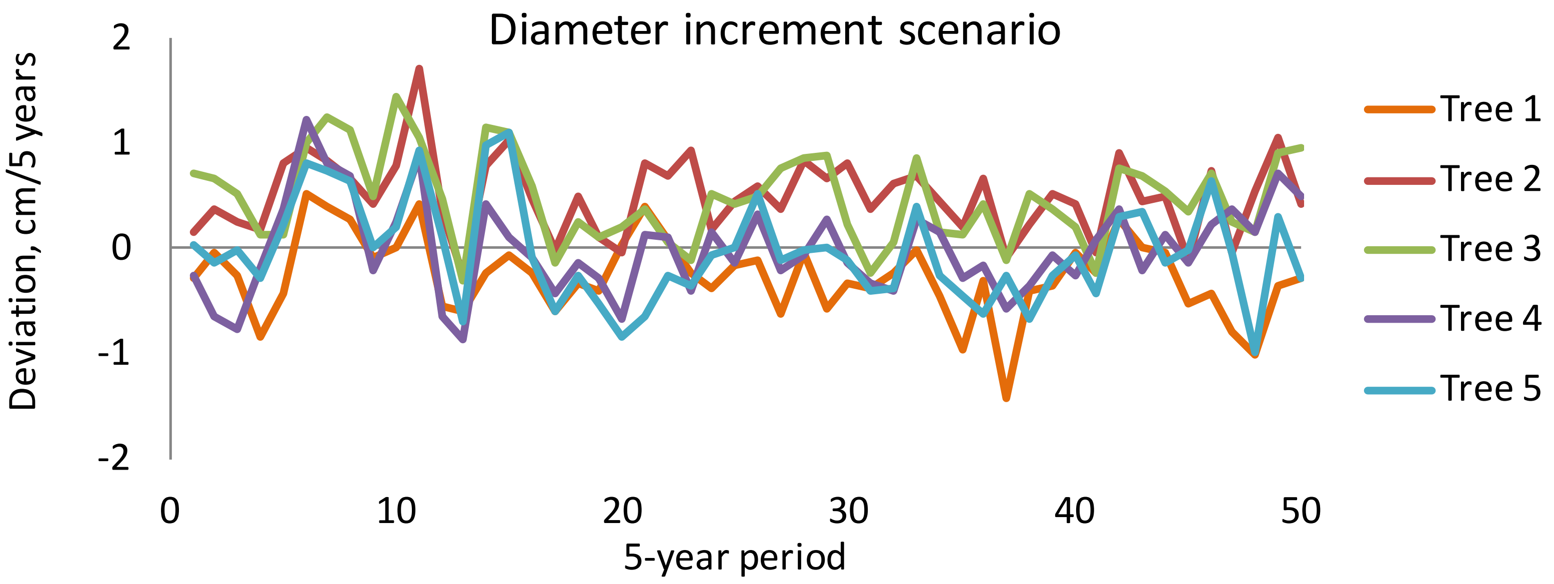
Some trees grow faster than the model predicts, others grow slower
There is also temporal autocorrelated residual variation

$$dev_{it} = a_i + v_{it}$$
$$\text{with } v_{it} = \rho v_{it-1} + e_{it}$$

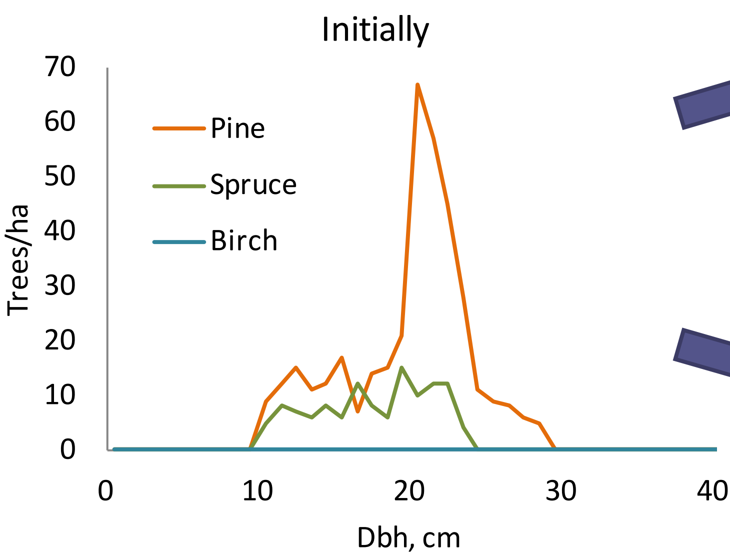
- dev_{it} deviation from model prediction for tree *i* and period *t*
- a_i random tree factor for tree *i*
- v_{it} random autocorrelated residual for tree *i* and 5-year period *t*
- ρ correlation coefficient the between residuals of consecutive 5-year periods
- e_{it} normally distributed random number, var[e_i] = var[v_{it}](1-ρ_i^2)

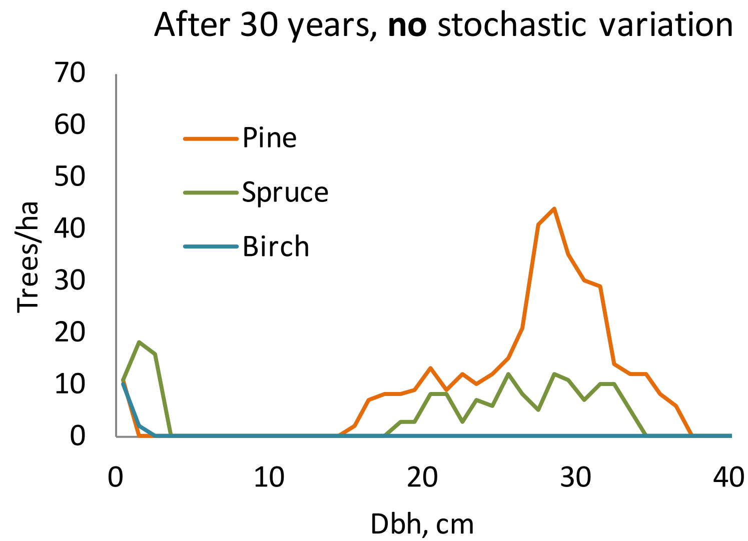
- 1/3 of *dev* accounted for by tree factors (a_i), the rest by autocorrelated residuals (v_{it})
- Correlation between the residuals of consecutive 1-year periods is 0.4–0.7
- Correlation between 5-year residuals is about half of it

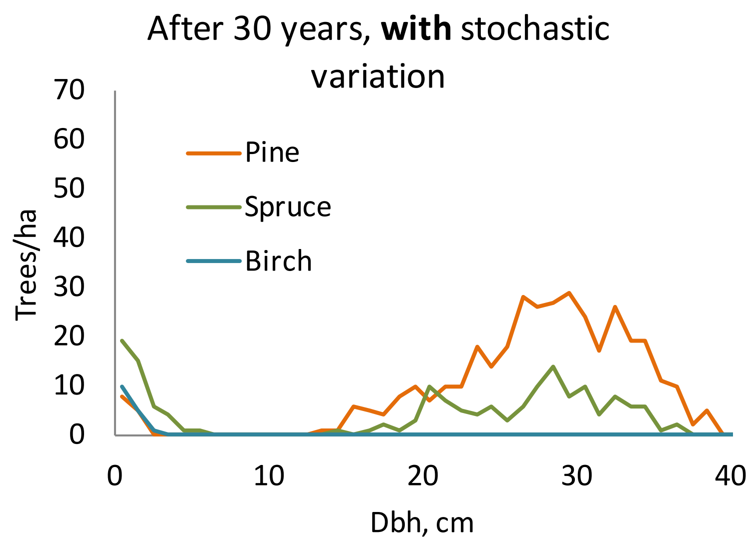
Example growth scenario



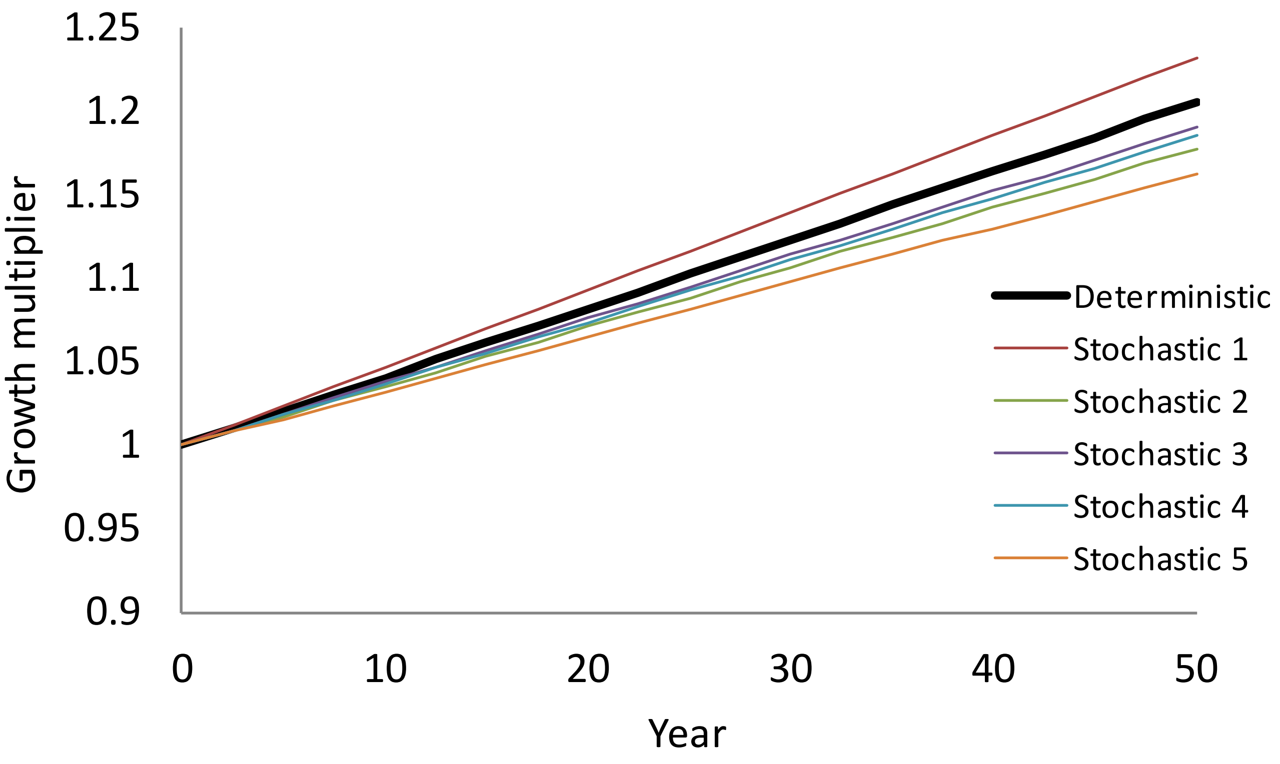
Effect of stochastic variation in dbh increment







Climate-induced growth trend assumed



Ingrowth scenarios

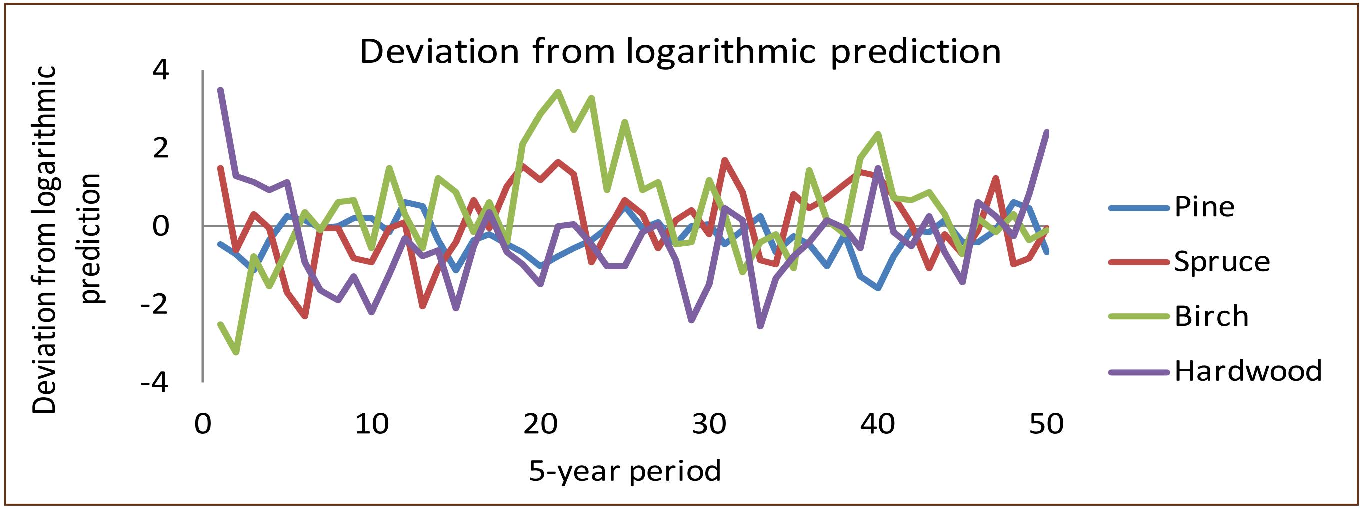
- Auto- and cross-correlated residuals of **logarithmic** species-specific ingrowth models

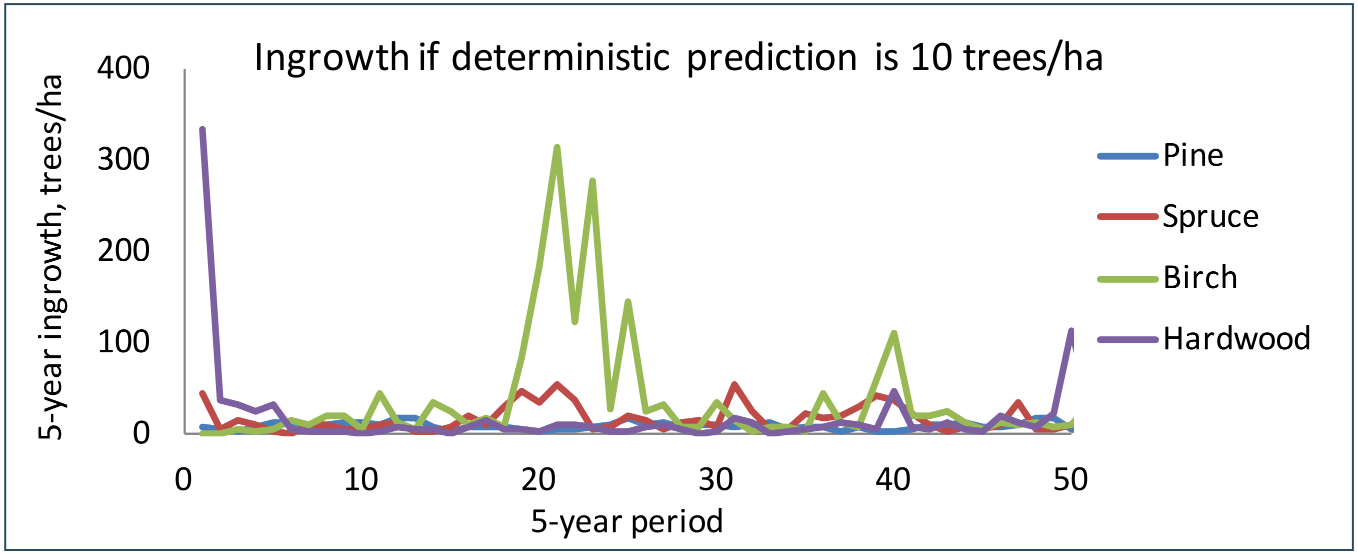
$$dev_{s,t} = \rho_s dev_{s,t\text{-}1} + se_s e_{s,t}$$

- $dev_{s,t}$ deviation from model prediction for species *s* and 5-year period *t*
- ρ_s temporal autocorrelation coefficient for species *s*
- se_s standard deviation of *e* for species *s*
- $e_{s,t}$ multi-normally distributed correlated random numbers (N(0,1))

- Correlated random numbers $e_{s,t}$ obtained from the Cholesky decomposition of the covariance matrix of the residuals of different species-specific models

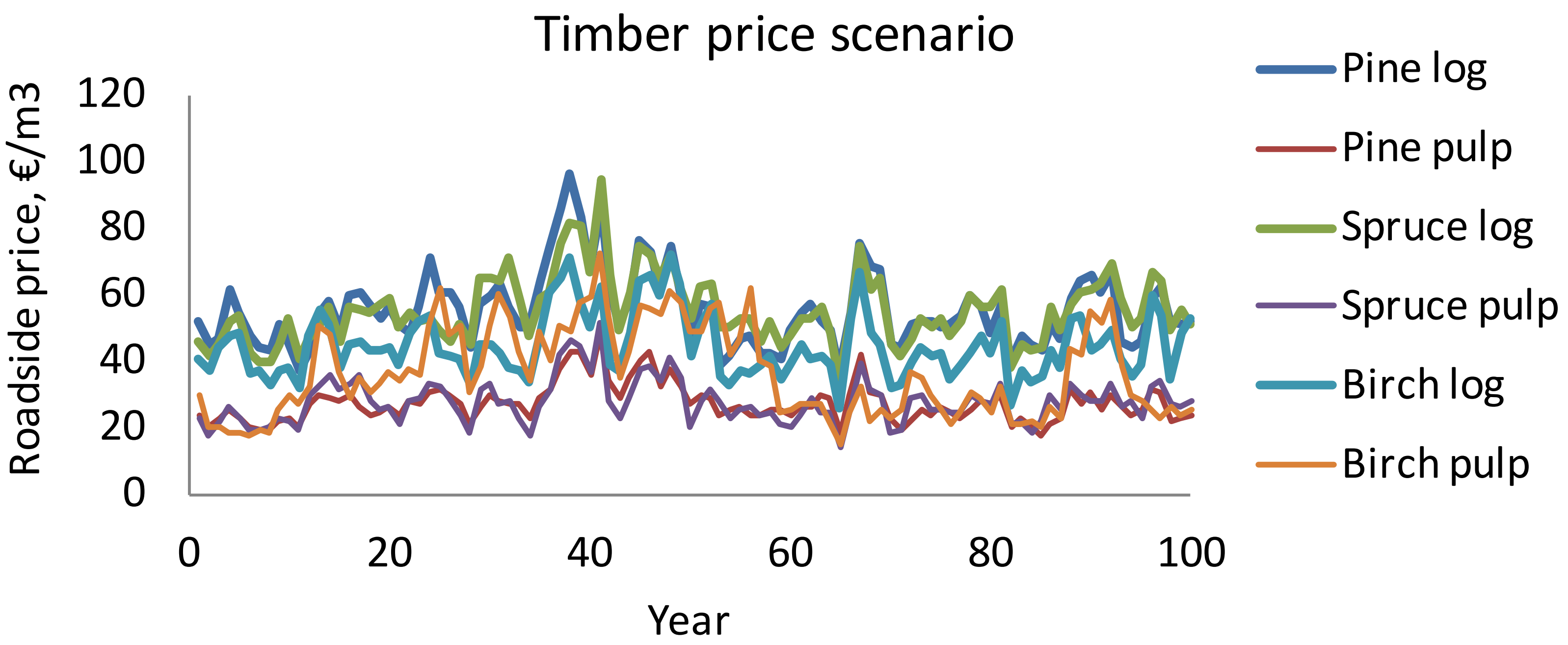
Example ingrowth scenario





Timber price scenarios

- A random walk model has been fitted to historical timber price statistics
- Auto- and cross-correlation



Optimization problem

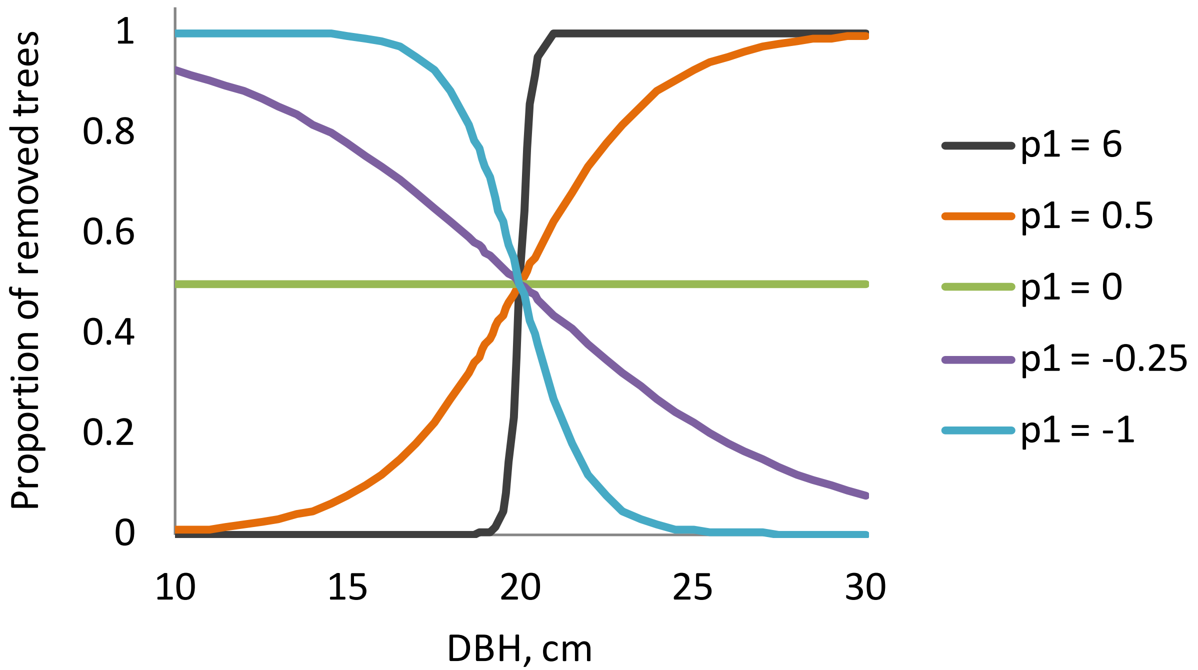
- Three next cuttings optimized

- **Anticipatory optimization**:
  - Number of years to the cutting (1 parameter per thinning)
  - Thinning intensity in different diameter classes (thinning intensity curve optimized separately for each species and cutting)
- **Adaptive optimization**:
  - Thinning years replaced by reservation price function
  - 3 parameters: $\boldsymbol{RP = \exp(p_1 + p_2\sqrt{D} + p_3\sqrt{G})}$

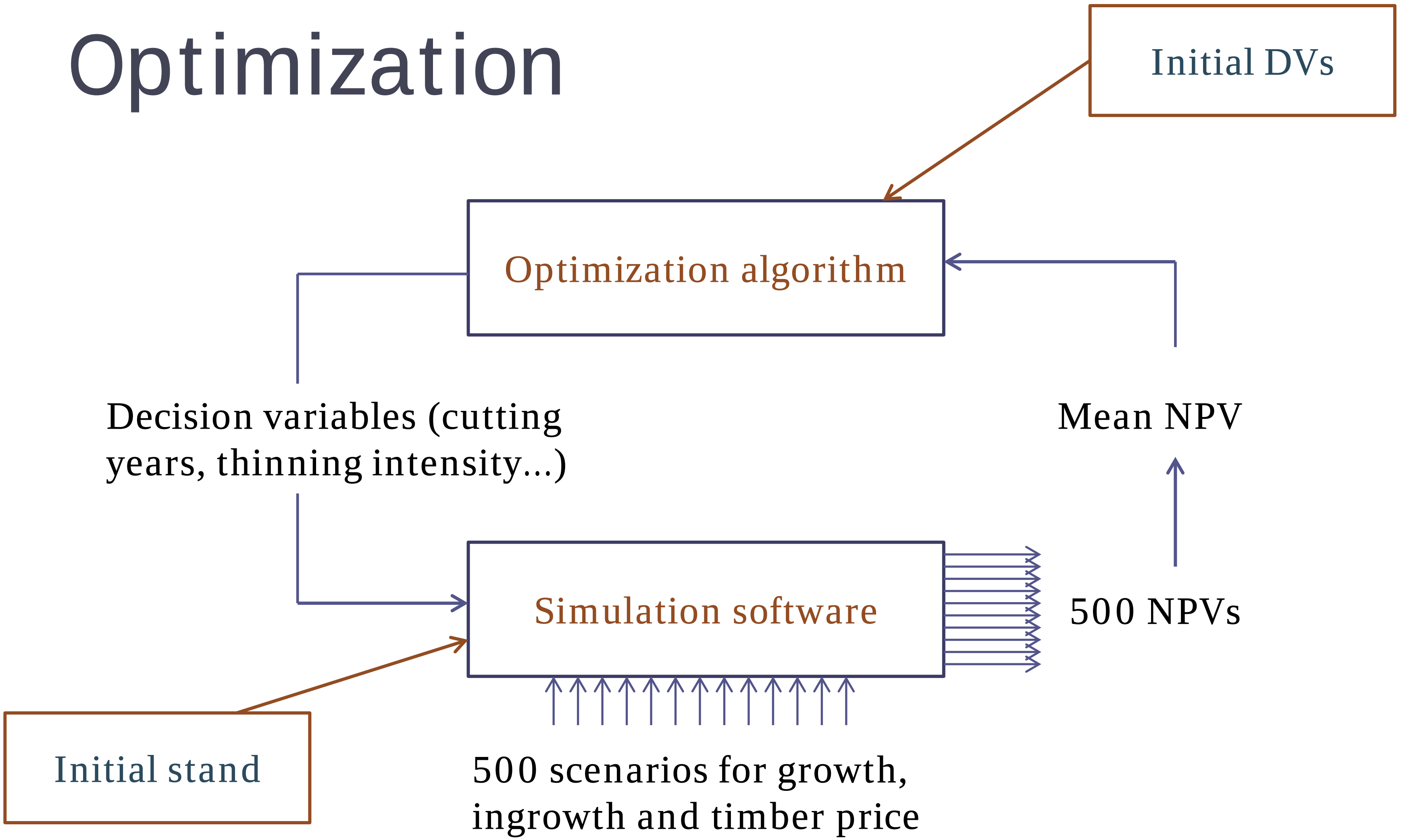
- NPV of the ending growing stock predicted with a model
- NPV to infinity maximized, with 3 first cuttings optimized
- Illegal solutions (too low post-cutting basal areas) penalized

Thinning intensity curve

$$Intensity(d) = \frac{1}{1 + \exp(p_1(p_2 - d))}$$



Optimization



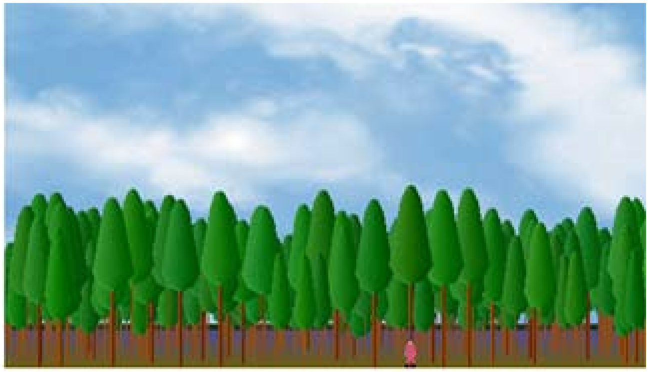
Case study stands

Uneven-aged spruce

Mature mixed

Young mixed

Pure even-aged stands

Spruce		Pine
	Young	
	Mature	

Simulation example (mature mixed stand)

Initially (2014)

After high thinning (2014)

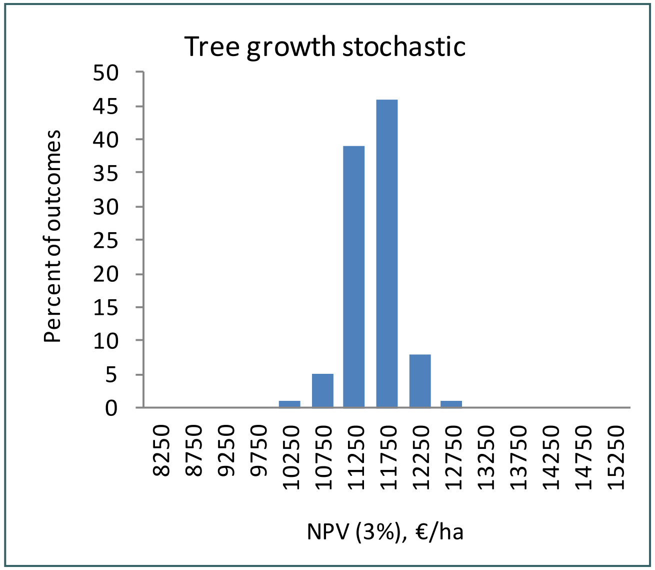
Before 3rd thinning (2054)

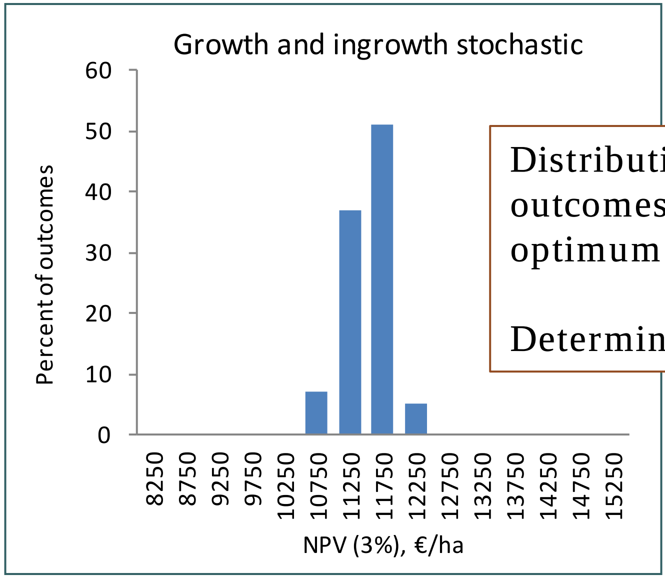
After 3rd thinning (2054)

Results

Effect of stochastic factors on NPV distribution
Effect of stochasticity on management
Effect of risk preferences on management
Comparison of deterministic, anticipatory and adaptive optima

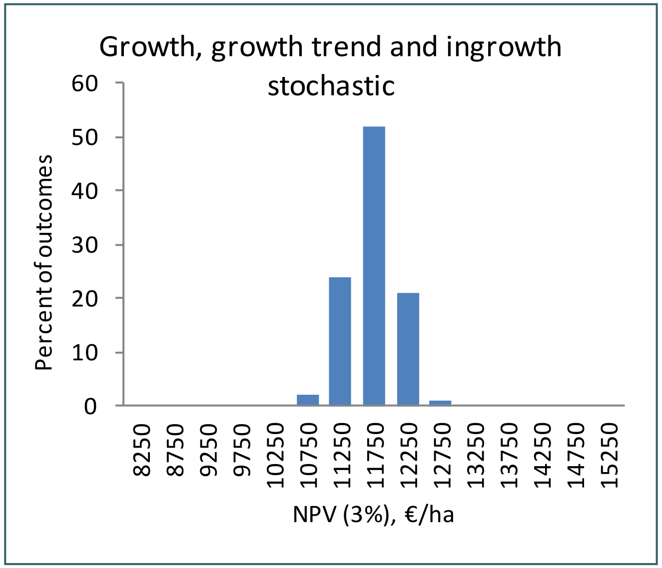
Effect of stochastic factors on NPV

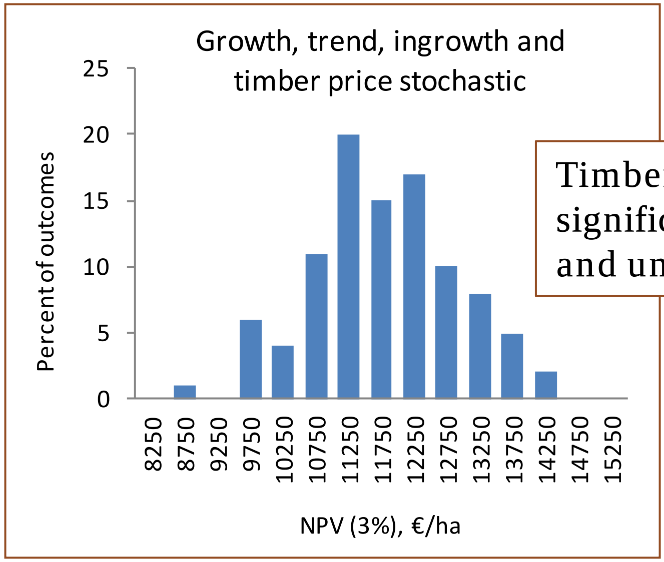




Distribution of outcomes in the anticipatory optimum for UE spruce

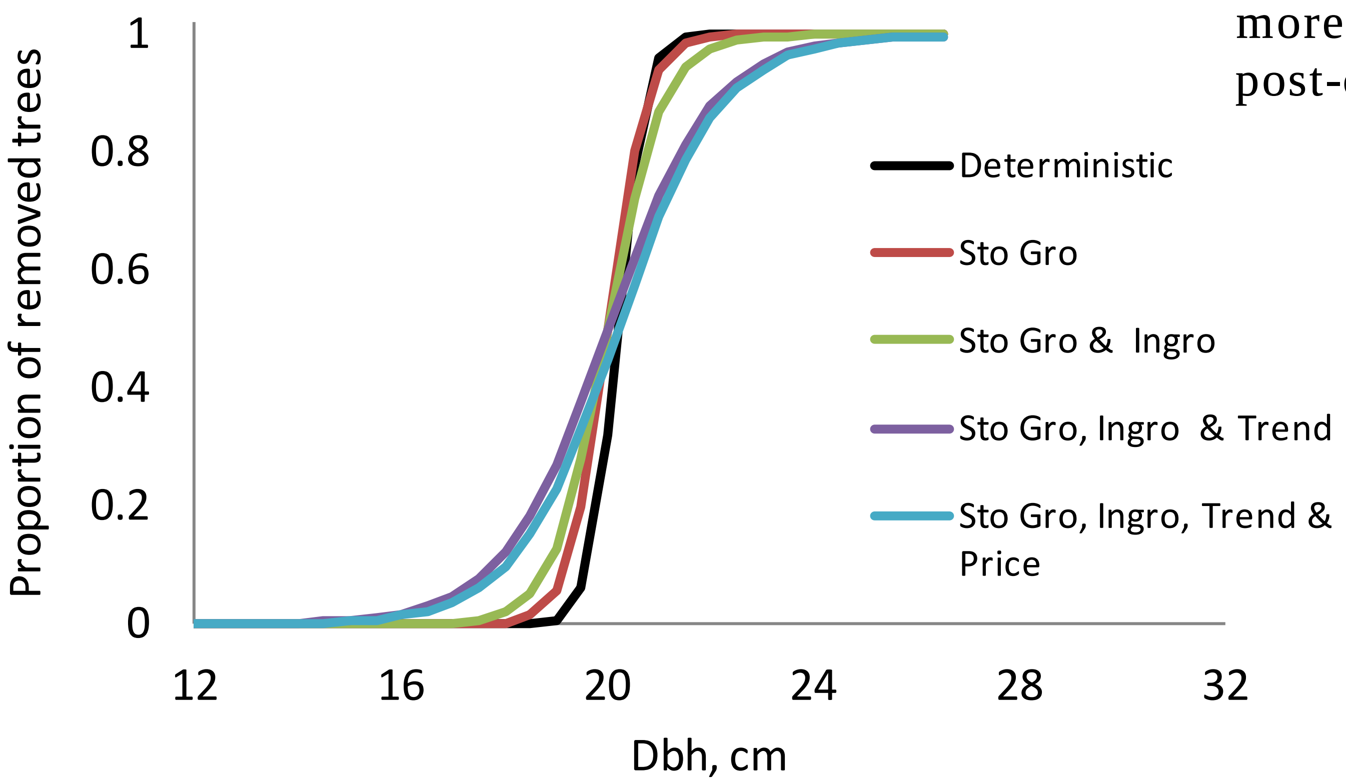
Deterministic: **11775 €/ha**





Timber price is the most significant source of risk and uncertainty

Effect of stochastic factors on management – UE spruce, 1st cutting



The higher the risk, the more dbh variation in post-cutting stand

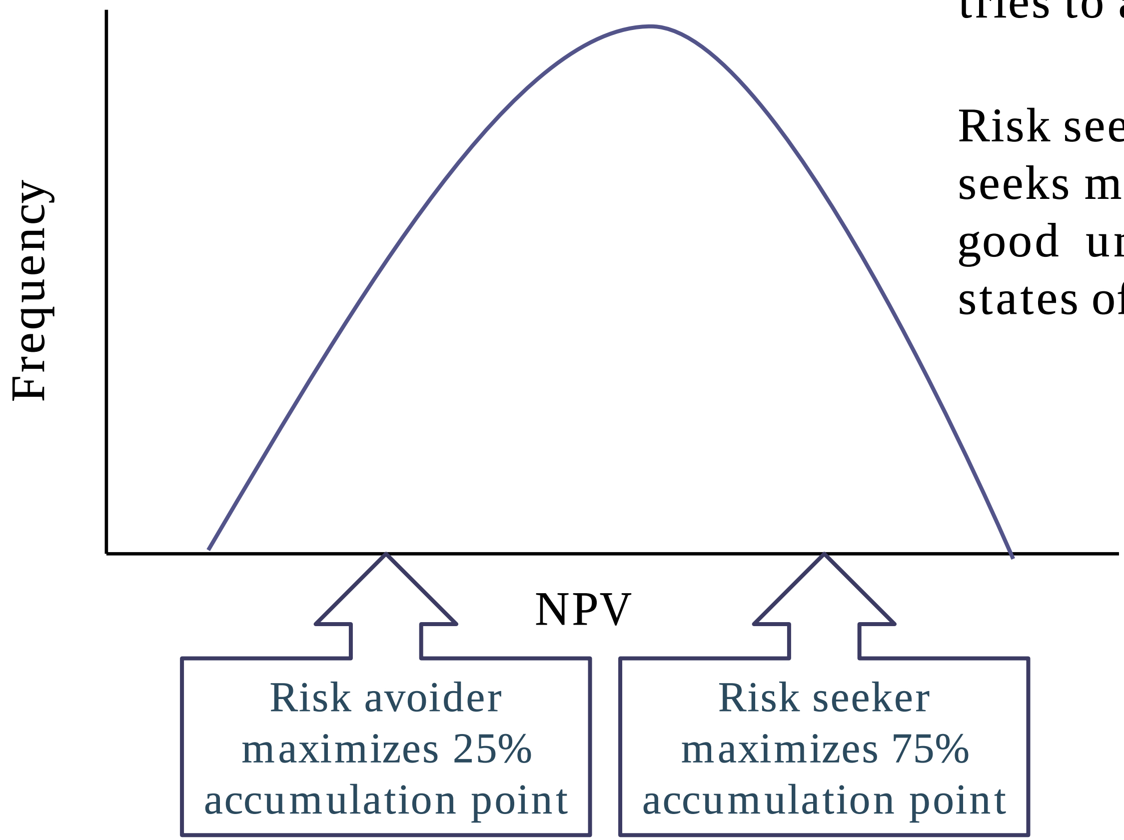
Effect of stochastic factors on management – UE spruce, cutting years

Cutting years in uneven-aged spruce stand

	Deterministic	Sto Gro	Sto Gro & Ingro	Sto Gro, Ingro & Trend	Sto Gro, Ingro, Trend & Price
1st cutting	0	0	0	0	0
2nd cutting	15	15	15	15	15
3rd cutting	25	25	25	25	25

=> No effect on cutting years

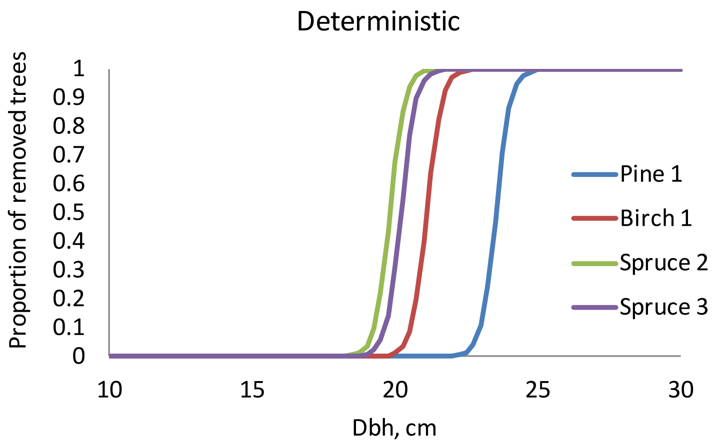
Effect of risk preferences on optimal management

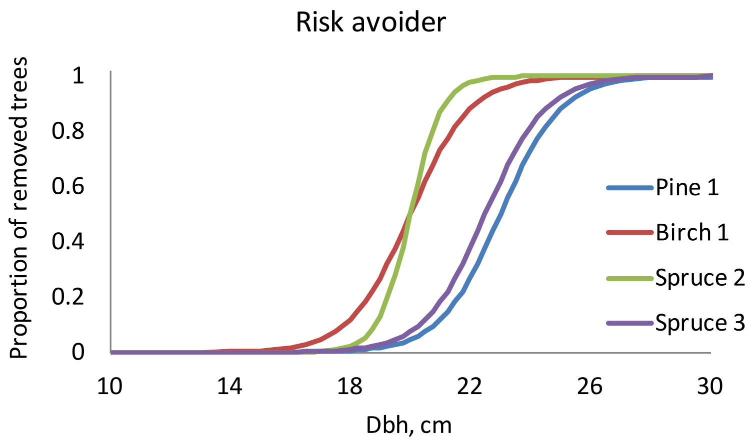


Risk avoider is pessimistic; tries to avoid bad outcomes

Risk seeker is optimistic; seeks management which is good under favourable states of nature

Effect of risk preferences: **Young** mixed stand

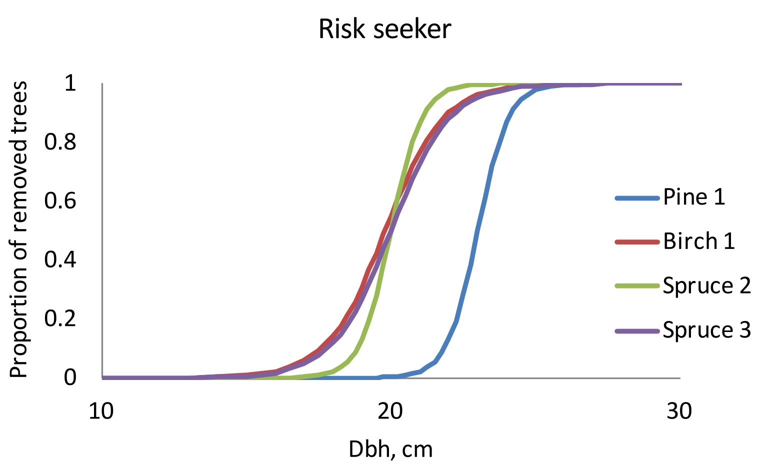




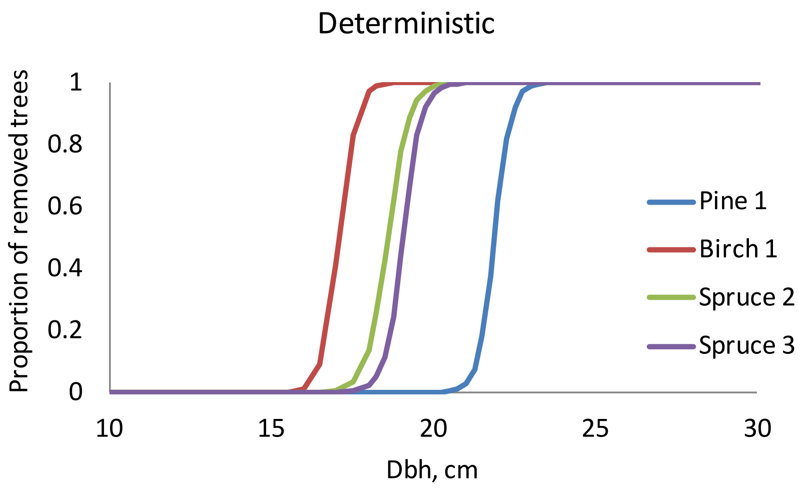
- The 1st cutting (conducted after 20 years) removes mainly pine and birch
- 2nd and 3rd cutting remove mainly spruce

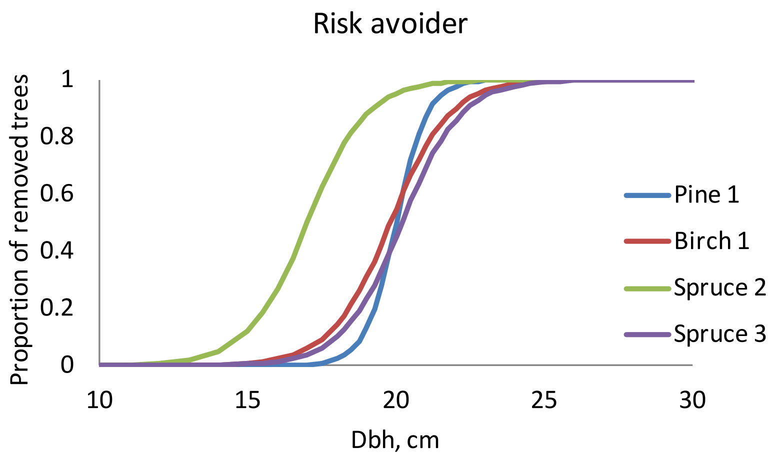
- Clear difference between deterministic and stochastic optimization

- The effect of risk attitude is small

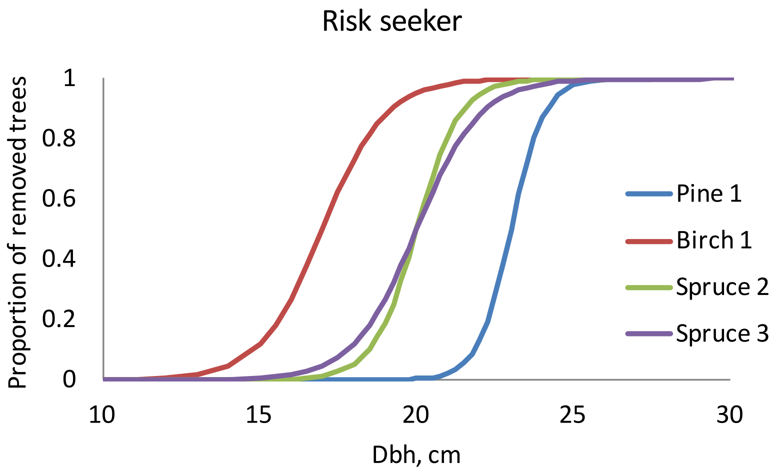


Effect of risk preferences: **Mature mixed stand**





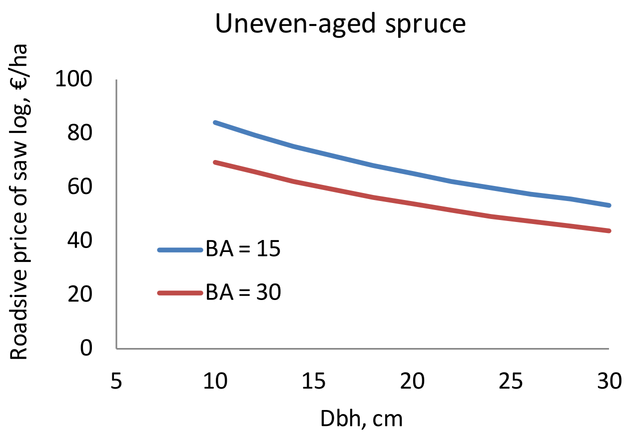
- The 1st cutting (conducted immediately) removes mainly pine and birch
- 2nd and 3rd cutting remove mainly spruce
- Clear difference between deterministic and stochastic optimization
- The effect of risk attitude is small

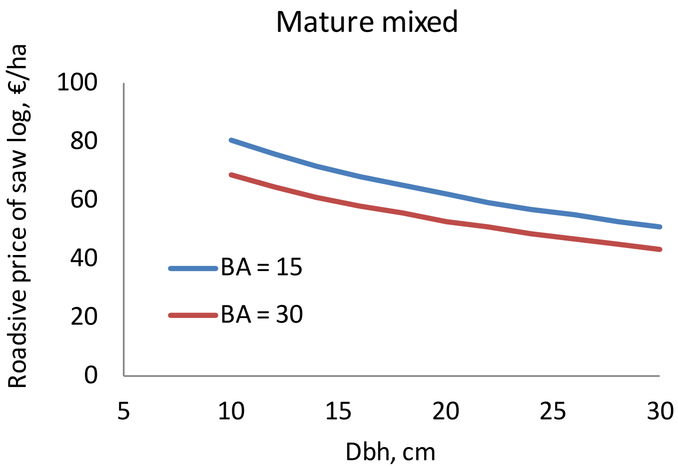


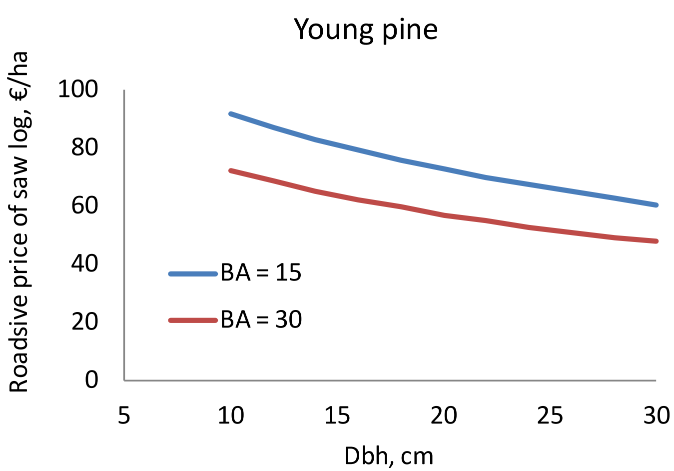
Anticipatory vs. Adaptive

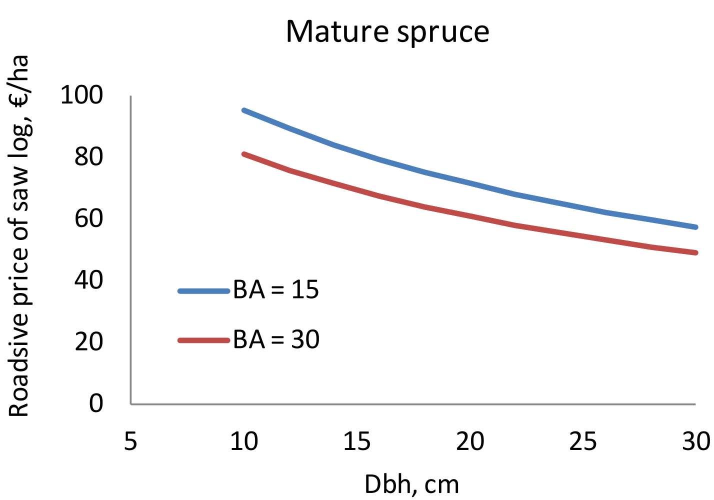
- Anticipatory optimizes
  - Cutting years
  - Thinning intensity curves
- Adaptive optimizes
  - Reservation price function
    - The same function for all cuttings
  - Thinning intensity curves
    - Separately for each cutting
- Referred to as **Semi-Adaptive**
  - Thinning intensity curves are not adaptive

Obtained reservation price functions

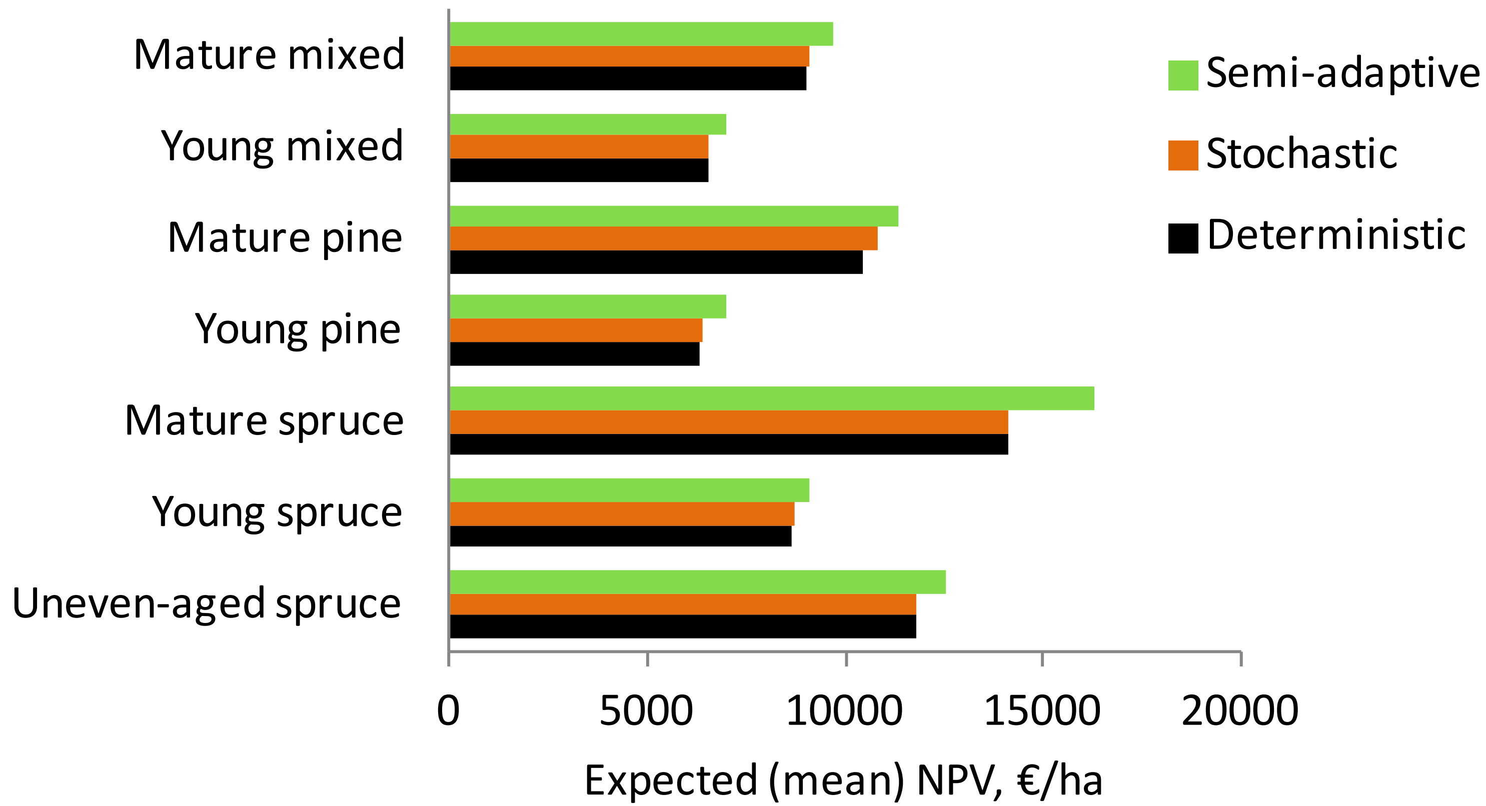








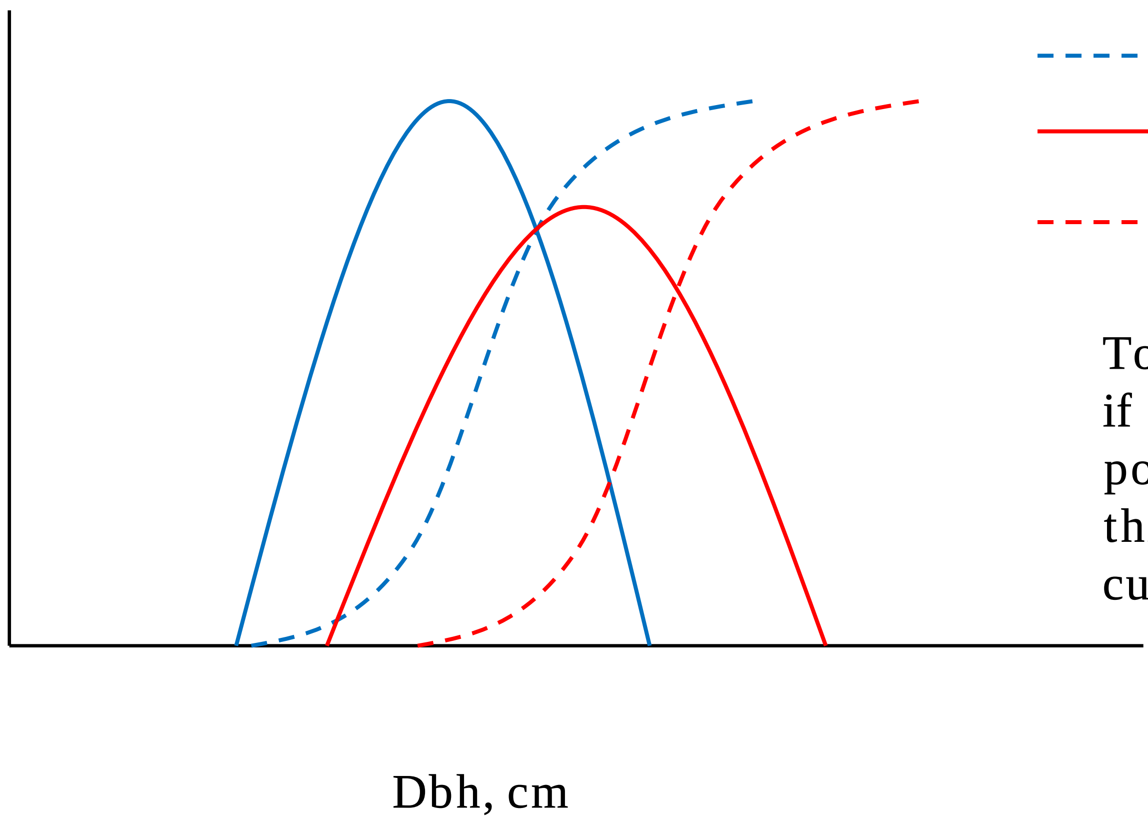
Anticipatory vs. Adaptive



Why adaptive is not “more better”?

- Thinning intensity curve is not adaptive
  - Thinning intensity curve is not moved when cutting postponed due to too low timber price
- May lead to sub-optimal post-cutting basal area
- What happens if thinning intensity curve is also adaptive?

Why is adaptive not “more better”?

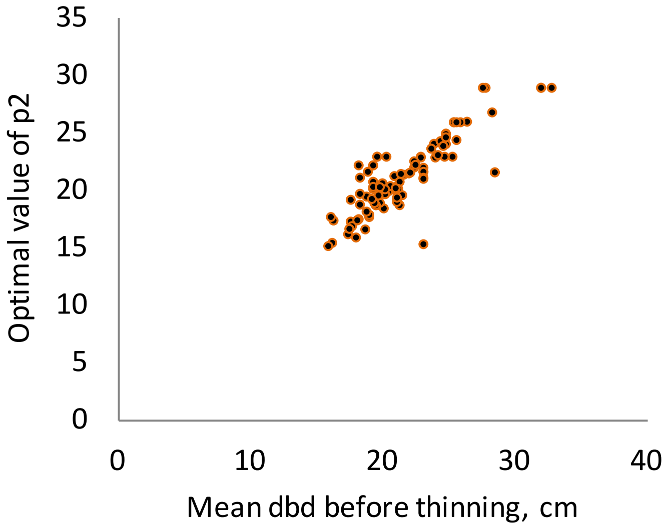


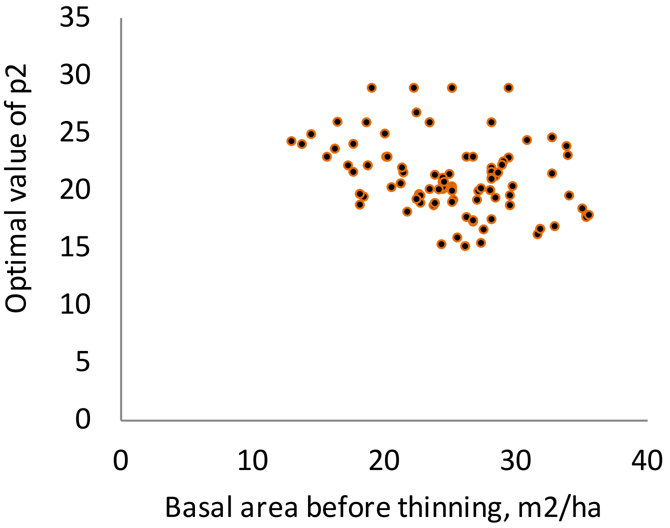
Too heavy cutting if cutting is postponed but thinning intensity curve is not moved

Thinning intensity curve

$$\text{Intensity}(d) = 1/(1+\exp(-p_1(d-p_2)))$$

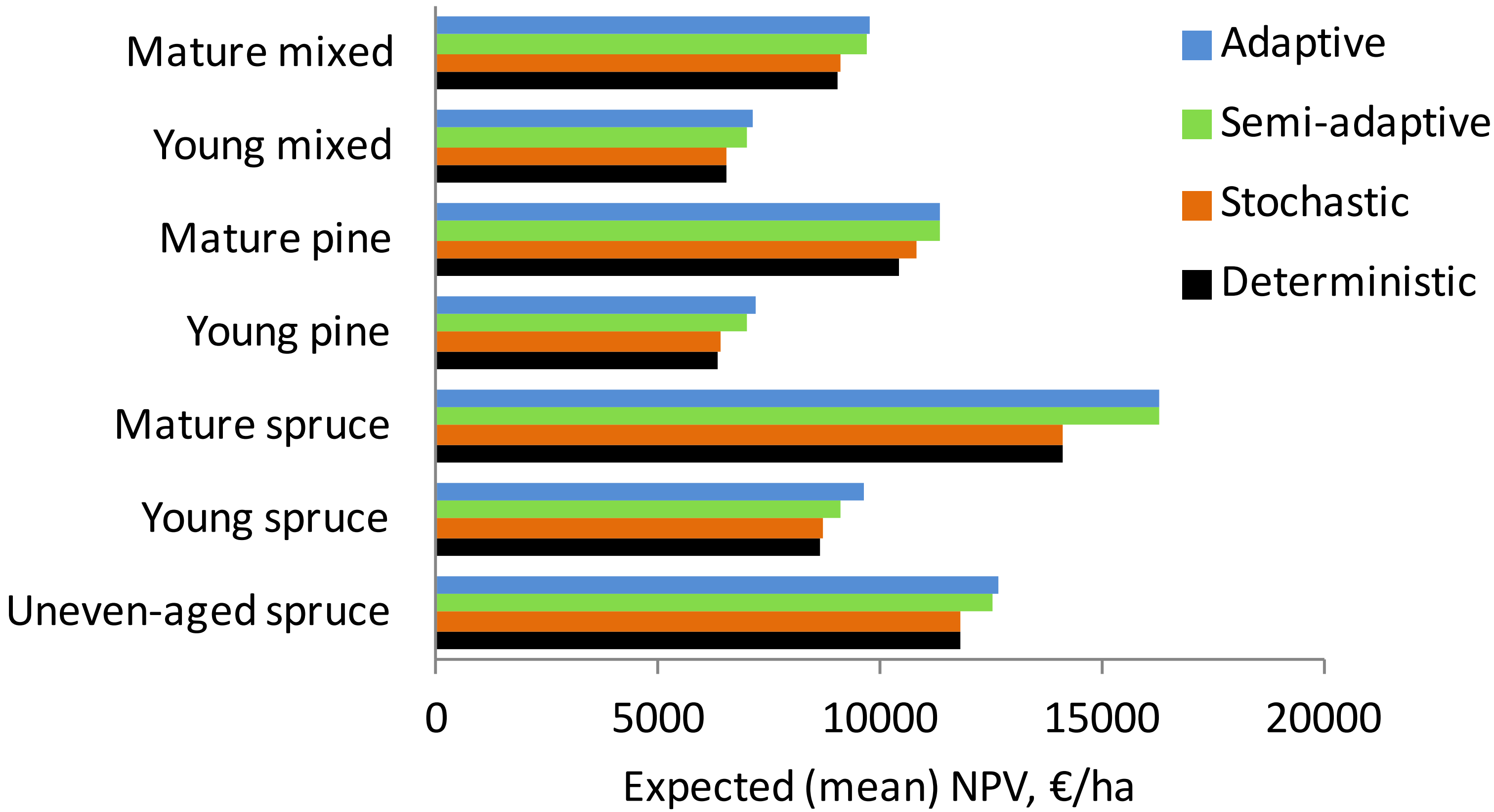
p_2 = diameter at which thinning intensity is 50%





Model for p_2 : $p_2 = 8.738 - 0.156G + 0.771D$

Adaptive = p2 calculated with model



Conclusions

Hypotheses

1. When growth and timber prices are stochastic, it is optimal to grow more diverse stands

   Supported by the results

2. Risk avoider keeps a more diverse stand structure than risk seeker

   Very weakly supported by the results

3. When the level of stochasticity is high, adaptive optimization leads to higher NPV than anticipatory optimization

   Supported by the results

What else can be concluded

1. Stochastic growth and erratic regeneration does not decrease the expected NPV of CCF, as compared to deterministic simulation and optimization

2. Timber price is a more important source of risk and uncertainty than growth and regeneration

3. Climate trend has only a small effect on NPV and optimal management
   - Affects gradually
   - Distant future has only a minor effect on NPV due to discounting

Thank you