TIMING THE NEXT FOREST INVENTORY

INCORPORATING FOREST OWNER PREFERENCES AND FOREST DATA QUALITY

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PROBLEM OVERVIEW

- In addition to developing a management plan, the forest owner also wants to decide when to re-inventory the forest

- The issue is primarily about data quality
  - the quality degrades over time, so one way to look at it is as an optimization problem:
    - Conduct a new inventory when improvements to the objective function are maximized
      - (If an inventory was conducted later, it will produce a lower objective function value)

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PROBLEM OVERVIEW

- A theoretical case study based on real data will be used as an example:

- 47.3 ha, mainly Scots pine and Norway spruce (some birch)
  - Fairly even age class distribution.
- The forest owner wants to maximize net present value while minimizing deviations from even-flow style constraints (measured as the conditional value at risk).
- The planning horizon is 30 years, six 5-year periods.

- Uncertainty sources: inventory error (+-10% standard deviation – Basal Area and height), growth model error an AR(1) model (Pietilä et al. 2010).

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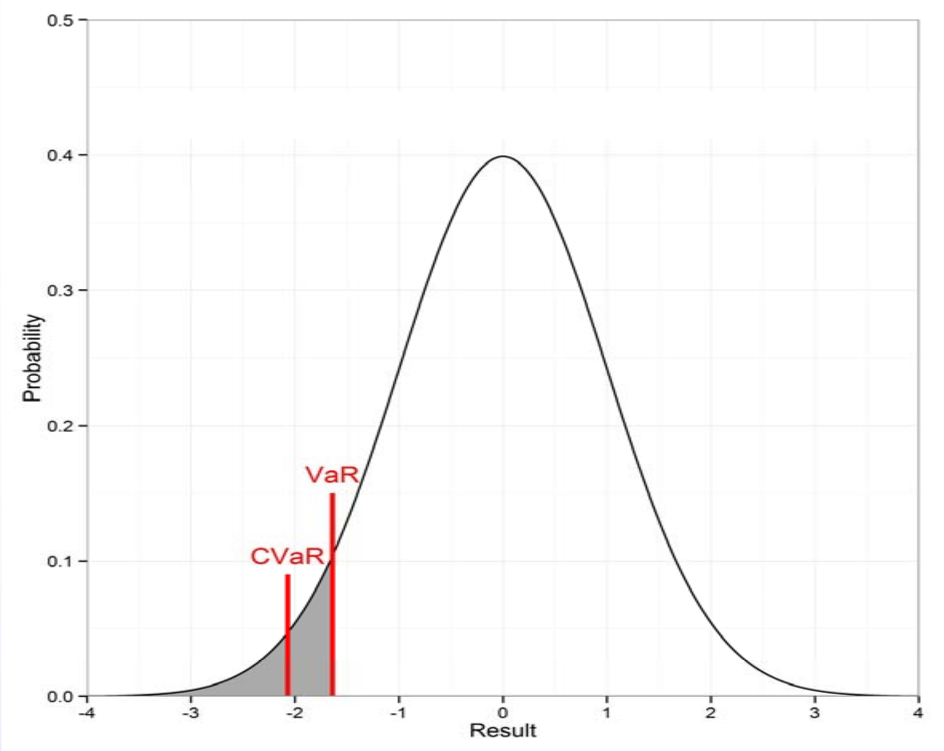
WHAT IS CVaR:

- CVaR is a measure of risk, evaluated as the average loss exceeding a specific probability.
- Directly related to the Value at Risk (VaR) – which is the expected loss at a specific probability.



HOW TO EVALUATE CVaR:

- CVaR can be evaluated in a stochastic programming framework. Rockafellar and Uryasev (2000) have shown how to utilize it in an optimization framework. CVaR can be used as a constraint or as a part of the objective function.

$$CVaR = Z + \frac{1}{(1-\alpha)N} \sum_{n=1}^{N} [L_n - Z]^+$$

- where:

Z - is the VaR (a decision variable) L_n - Loss of scenario *n*

α – is the probability N – total number of scenarios

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KEY CHALLENGES:

- This problem required a shift from
  - two-stage stochastic programming with simple recourse
    - to:
  - two-stage stochastic programming with recourse

- Requires a method of resolving part of the uncertainty while maintaining the total uncertainty of the problem.

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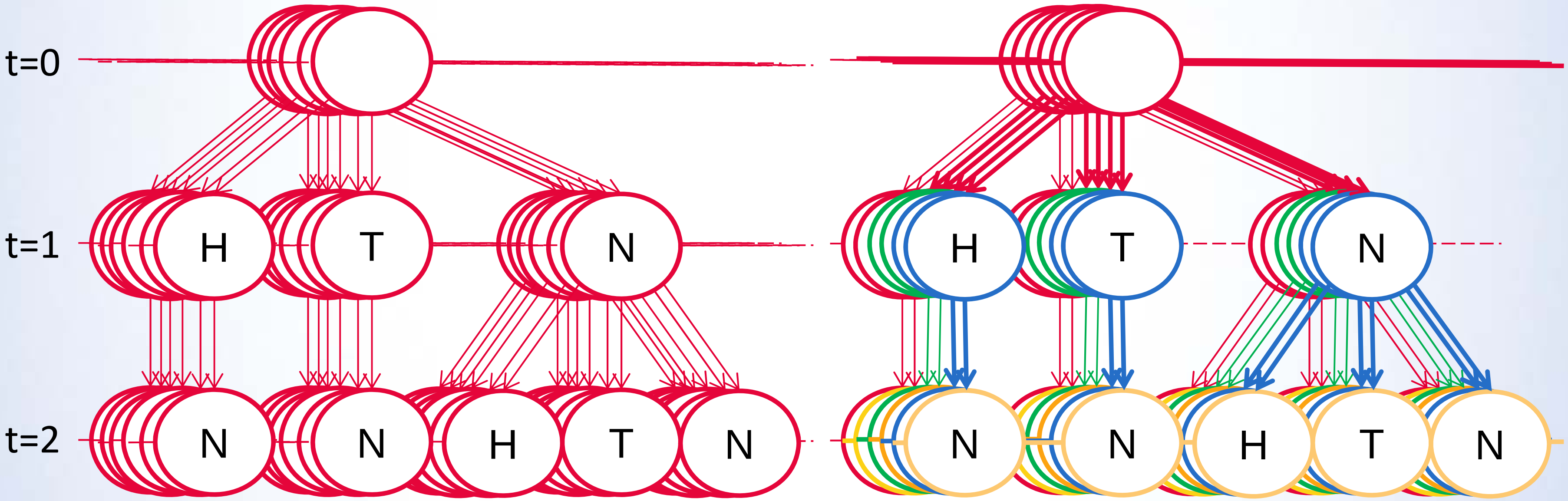
WHAT IS THE DIFFERENCE?

- Stochastic programs can be approximated through a large number of scenarios. From LP to SP: H – harvest, T – Thin, N – Do nothing.



With simple recourse – evaluated as penalties

With recourse possibilities at t=1 and t= 2. Requires sorting of scenarios based on remaining uncertainty

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PROBLEM FORMULATION:

Objective function:

$$\max \sum_{n=1}^{N} p_n NPV_n - \lambda \sum_{t=1}^{T} \frac{CVaR_t}{T}$$

Subject to:

$$[1]\ NPV_n = \sum_{t=1}^{T} \frac{I_{nt} - w_t q}{(1+r)^{(t*5-u)}} + \sum_{j=1}^{J} \sum_{k}^{K_j} \frac{PV_{n6}}{(1+r)^{30}}, \forall\, n = 1, \dots, N$$

$$[2]\ L_{nt} = [I_{nt} - w_t q - b_t]^+, \forall\, n = 1, \dots, N, t = 1, \dots, T$$

$$[3]\ CVaR_t = \left(1 - \sum_{p=1}^{t} w_p\right)\left(Z_t + \frac{1}{(1-\alpha)N} \sum_{n=1}^{N} [L_{nt} - Z_t]^+\right)$$

$$+ \left(\sum_{p=1}^{t} w_p\right) \sum_{f=1}^{F} \frac{1}{F}\left(Z_t + \frac{1}{(1-\alpha)N_f^t} \sum_{n \in N_f^t} [L_{nt} - Z_t]^+\right), \forall\, t = 1, \dots, T$$

$$[4]\ \sum_{k=1}^{K_j} (x_{jkf} - x_{jkg}) s_{jkt} - \sum_{p=1}^{t} w_p * M \le 0, f \in F, g \in F, j \in J, t = 2, \dots, T, f \neq g$$

$$[5]\ \sum_{k=1}^{K_j} (x_{jkg} - x_{jkf}) s_{jkt} - \sum_{p=1}^{t} w_p * M \le 0, f \in F, g \in F, j \in J, t = 2, \dots, T, f \neq g$$

nonanticipativity constraints

$[6]\ \sum_{t=1}^{T} w_t \le 1$ $\quad$ $[7]\ I_{nt} = f(x_f)$ $[8] PV_{n6} = f(x_f)$ $[9]\ x_{jkf} \in \{0,1\}, w_t \in \{0,1\}\ for\ all\ t \in T, f \in F, j \in J, k \in K$

I - Income

PV - Productive value

x - decision

L – Loss

q – cost of inventory

b – periodic target

s – actions in schedule

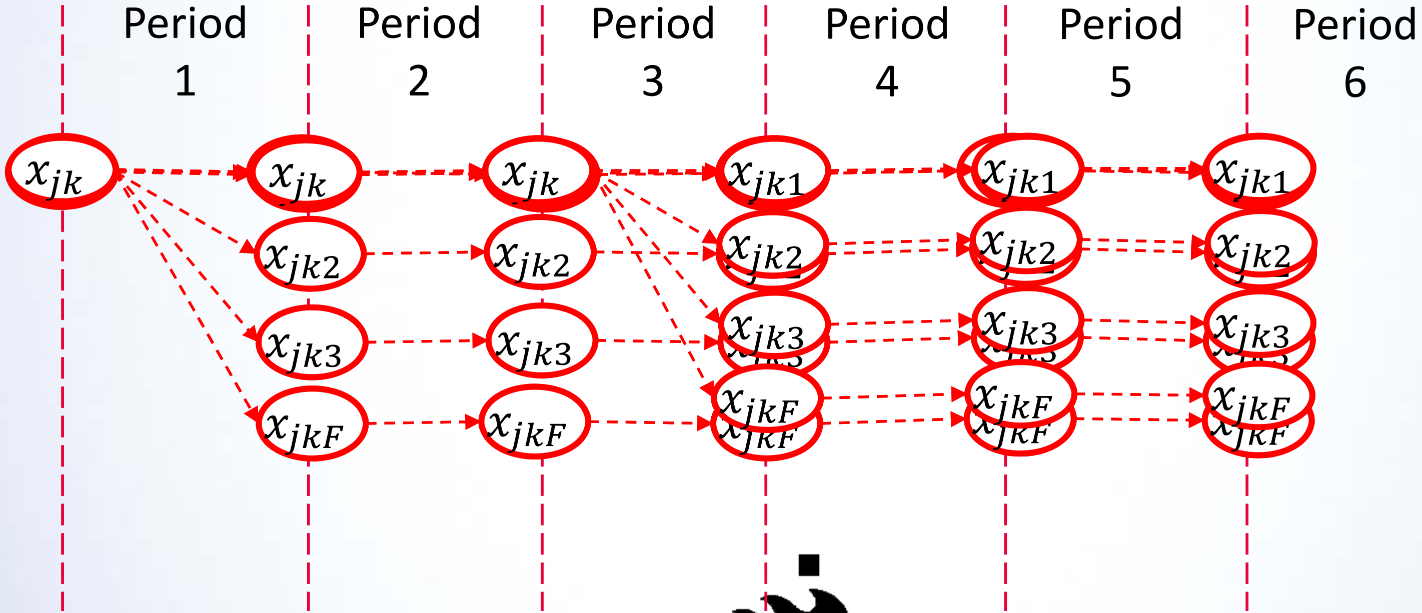
M – Large number

λ – risk parameter

F – number of subsets

MANAGEMENT DECISIONS:

- Depending on the optimal timing will determine the shift from first stage to second stage.



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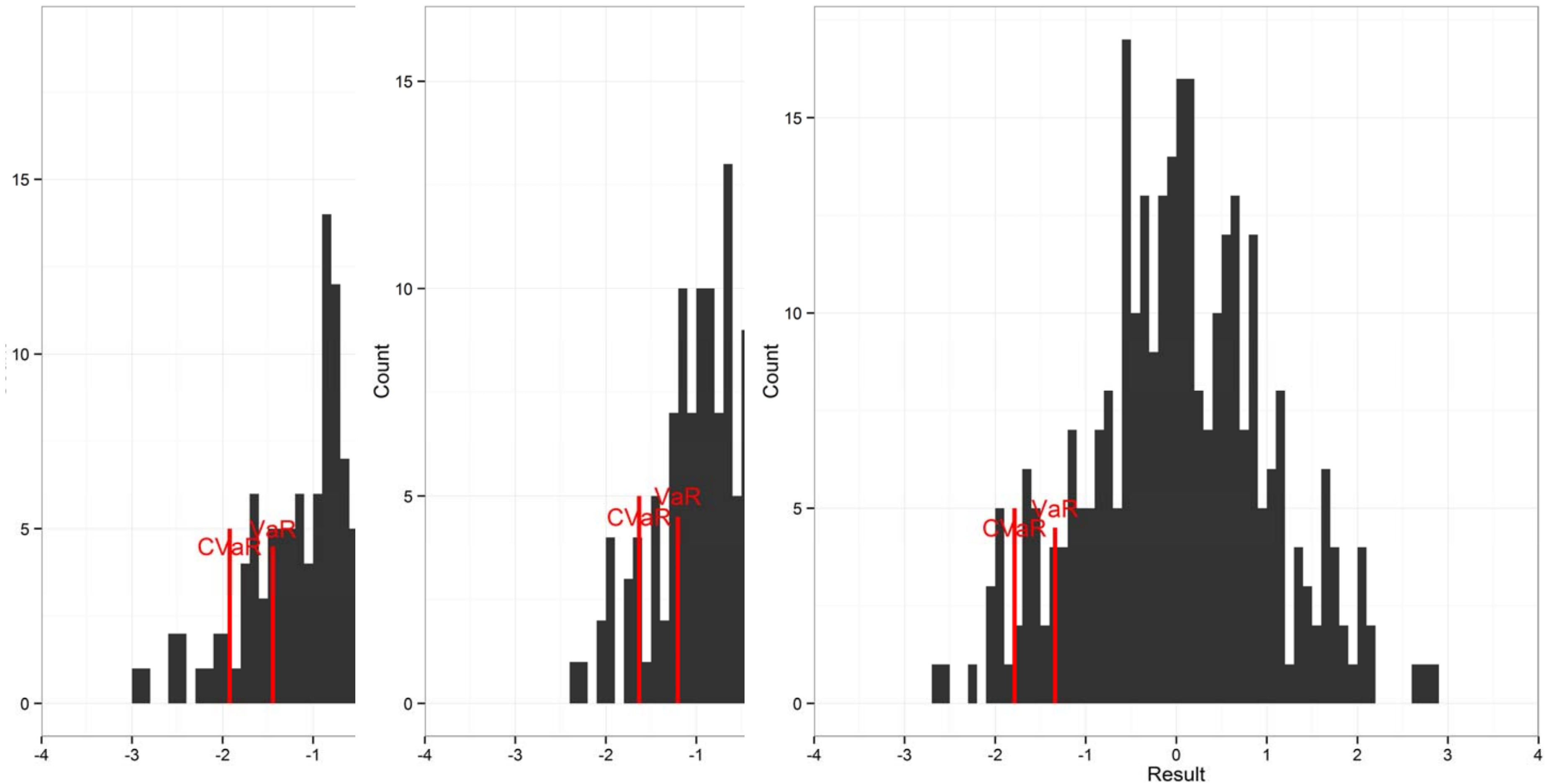
MANAGEMENT DECISIONS:
CVaR ISSUES.



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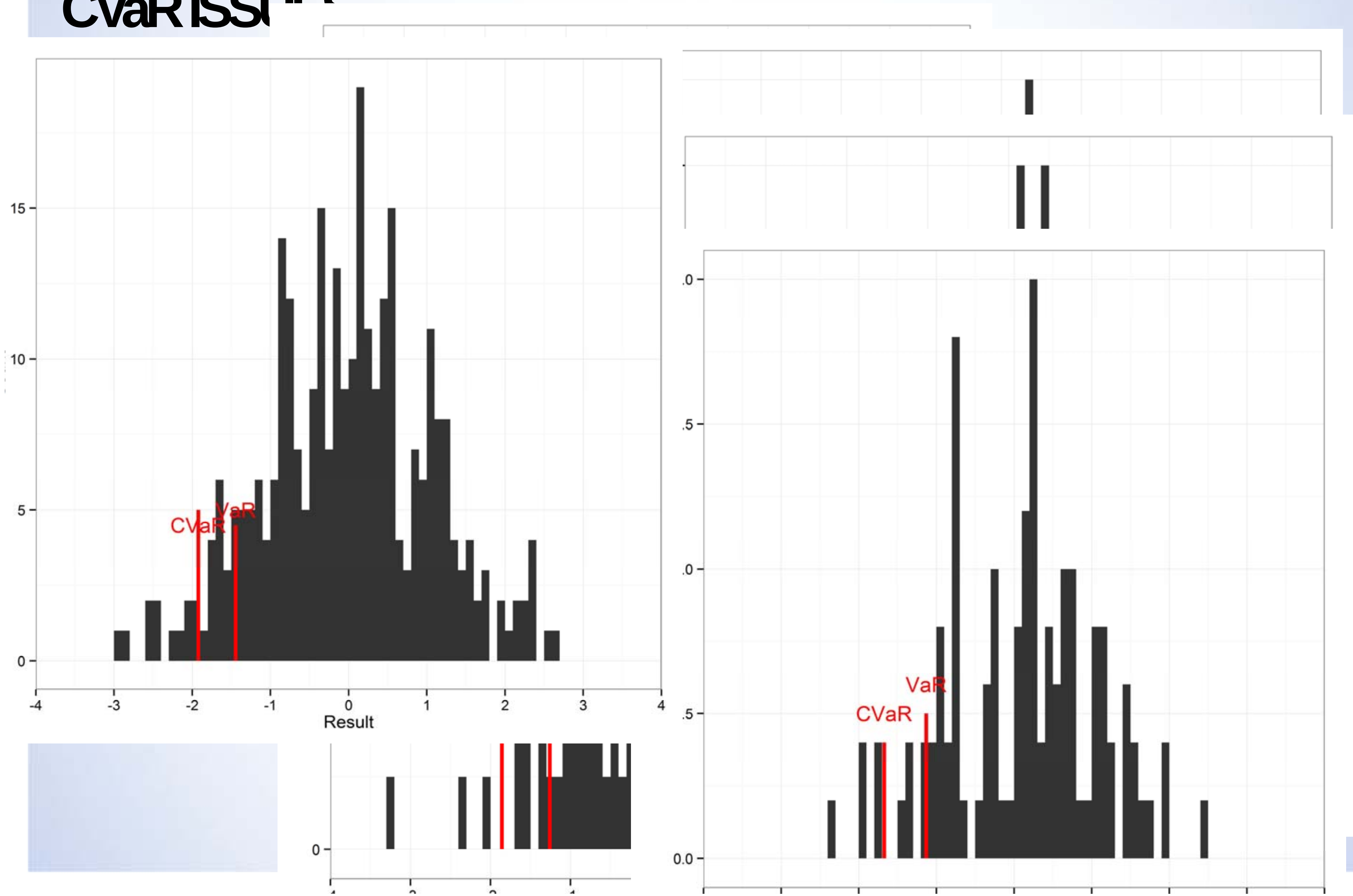
MANAGEMENT DECISIONS:
CVaR ISSUES



RESULTS:

- Four parameters of the model can be adjusted based on the preferences of the decision maker and current economic situation:
  - λ – risk parameter (varied from 0.1 – 2)
  - b_t - Periodic income target (60,000€ / period)
  - r – Interest rate (4%)
  - q – Inventory costs (500 €) – roughly 11€ / ha
- To highlight the shift, for each λ all possible options for conducting inventories were solved.

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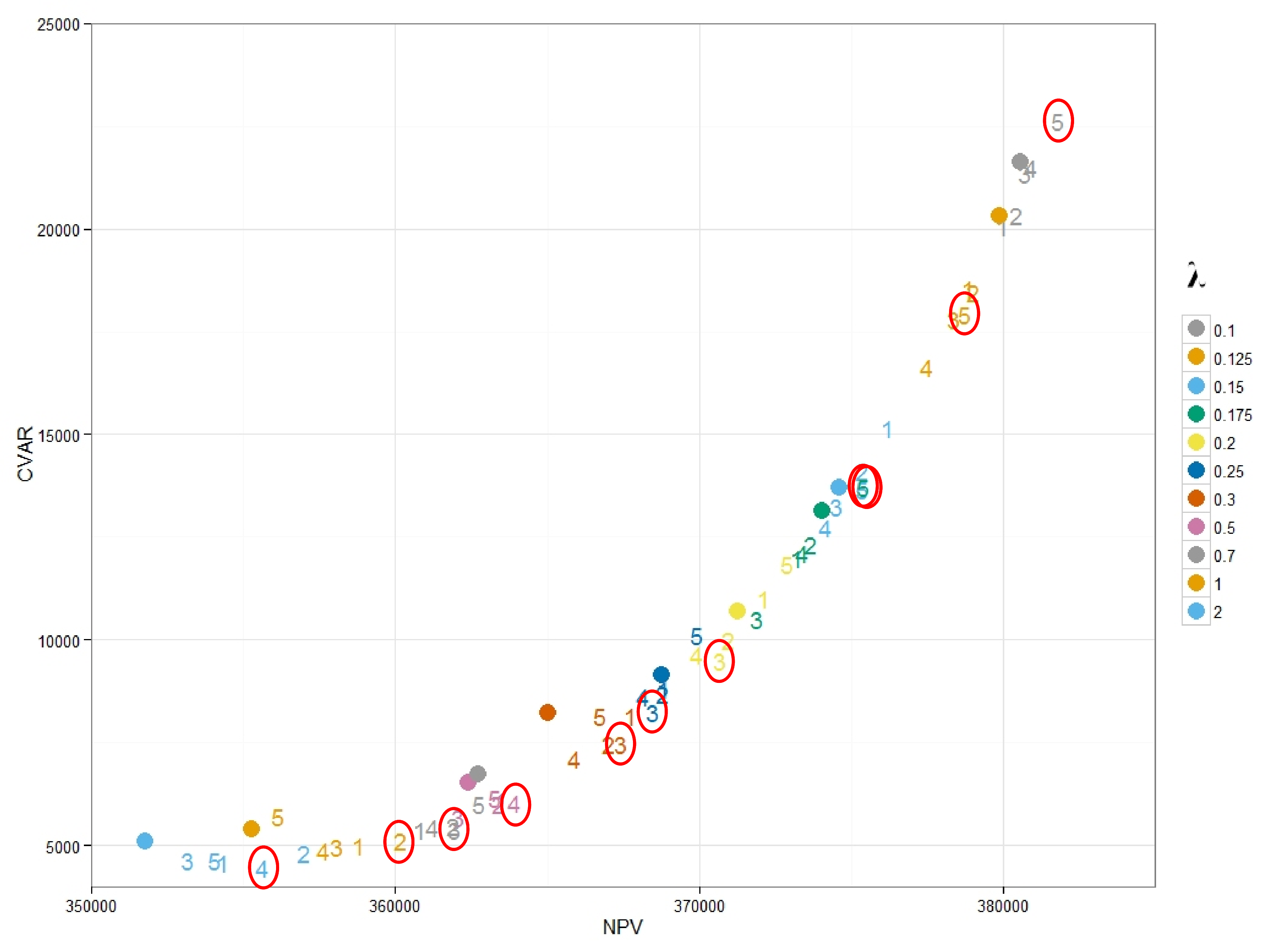
RESULTS:



CVAR
NPV
25000
20000
15000
10000
5000
350000
360000
370000
380000
λ
0.1
0.125
0.15
0.175
0.2
0.25
0.3
0.5
0.7
1
2

CONCLUSIONS / MOVING FORWARD

- Demonstrated a two-stage stochastic programming with recourse
  - Allows for a resolution of uncertainty during the planning horizon.

- For this case:
  - With a near risk neutral DM ($\lambda = 0.1\ to\ 0.175$), delay inventory until end of planning period.
  - With a moderately risk averse DM ($\lambda = 0.2\ to\ 0.3$), delay inventory until middle of planning period

  - Changing interest rate, costs of inventory will also cause a shift.

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MOVING FORWARD

- Some assumptions made could be relaxed
  - (Which for a small holding may be true, but for a large holding may not...)
- Complete re-inventory → Partial re-inventory
  - select an area which benefits most from a new inventory
- Improvement in inventory method – reduction in uncertainty
  - future inventory methods may have improved accuracy

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REFERENCES

- Rockafellar, R. T., and Uryasev, S. 2000. Optimization of conditional value-at-risk. J. Risk, **2**: 21-42.
- Pietilä, I., et al. (2010). Influence of growth prediction errors on the expected losses from forest decisions. Silva Fennica 44(5): 829-843.

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SORTING TO CREATE SECOND STAGE DATASETS:

- Large set of all scenarios:
  - N – red square
- 1st opportunity to inventory
  - N_f^1 – blue, yellow, green rectangles
- 2nd opportunity to inventory
  - N_f^2
- Last opportunity to inventory
  - N_f^6

- N_f^t is a subset of N,
- $N_{f_1}^t \cap N_{f_2}^t = \emptyset \; for \; all \; f_1 \neq f_2 \; and \; \cup_{f \in F} N_f^t = N$

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