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Robust optimization of water-flooding in oil reservoirs using risk management tools

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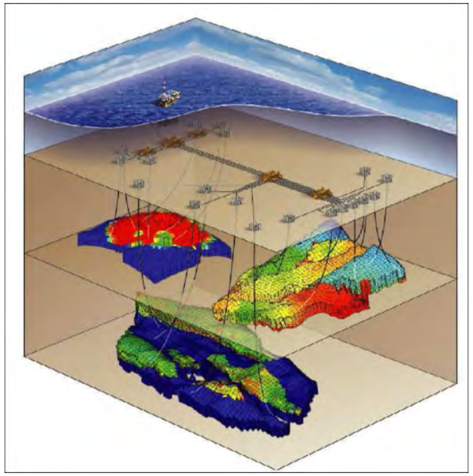
Where innovation starts

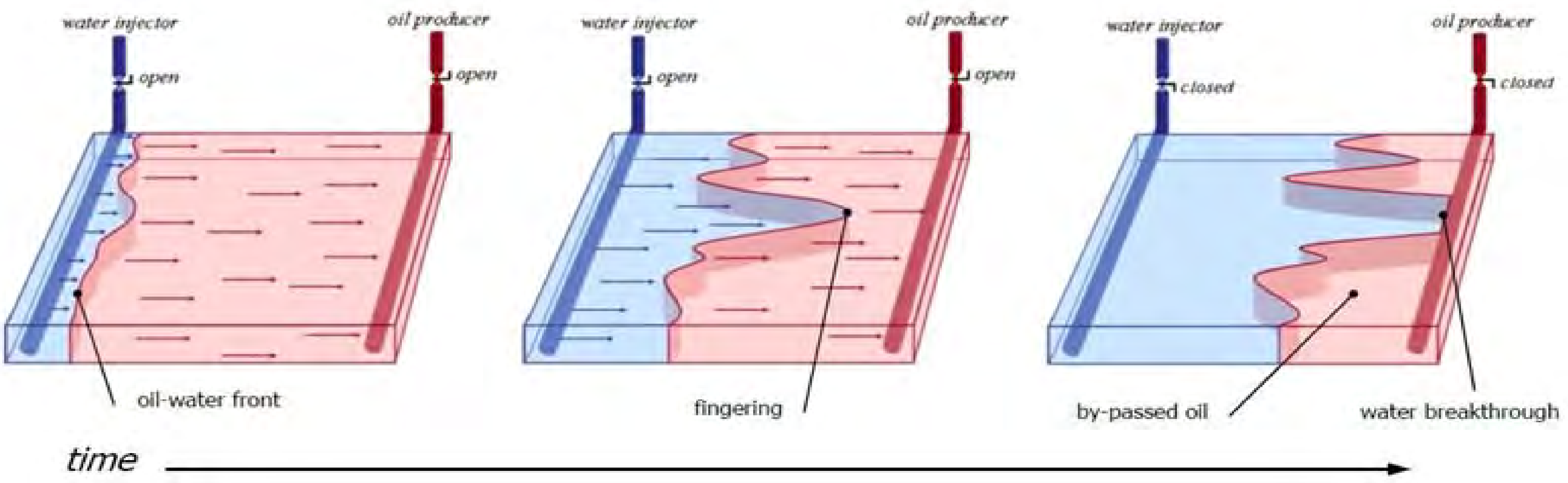
Oil Production

- Production from Oil reservoir
  - Porous rocks with oil in pores
  - 10^1 to 10^4 km^2 in size
  - Geological structure heterogeneous
    - Very different rock properties within reservoir
  - Life cycle of 10 – 100 years



- Oil production phases
  - Primary production (5-15%)
  - Secondary production (Water-flooding)
  - Tertiary production

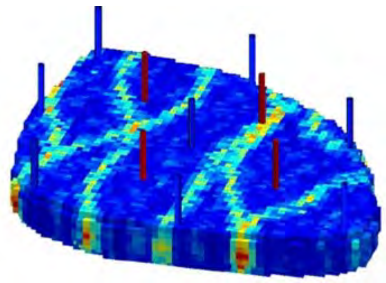
Van Essen et al. (2010)

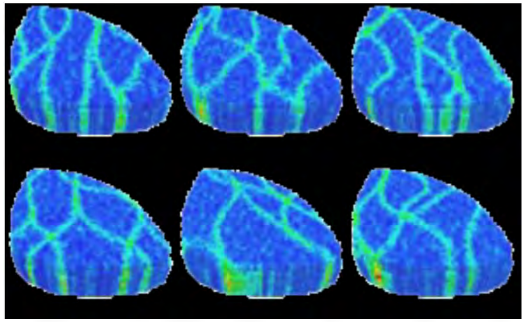


Challenges

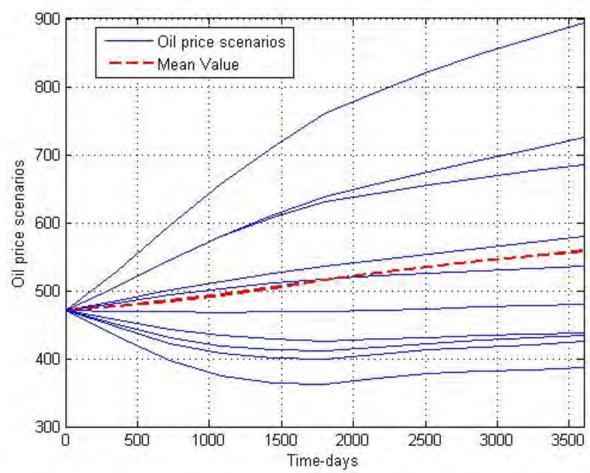
- Large-scale, non-convex and non-linear optimization

- Uncertainty
  - Parametric uncertainty





  - Economic uncertainty
    - Varying oil prices



Decision making (model-based economic optimization) under geological parametric and economic uncertainty

Contents

- Introduction
- Model-based economic optimization and Reactive strategy
- Handling risk of uncertainty
- Risk management
    - Worst-case optimization
    - Conditional Value-at-Risk (CVaR) optimization
    - Semi-variance optimization
- Conclusions and future work

Model-based optimization and Reactive strategy

- Net Present Value (NPV)

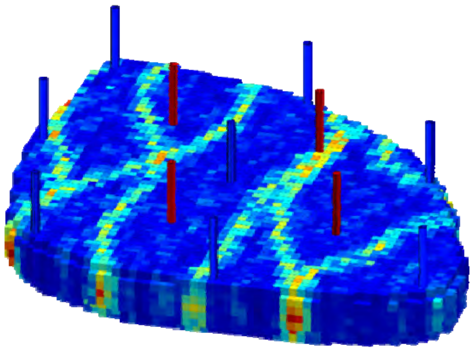
$$J_K(\boldsymbol{u}) = \sum_{k=1}^{K} \frac{\Delta t_k \ [r_o q_{o,k} - r_{wp} q_{wp,k} - r_{wi} q_{wi,k}]}{(1+b_\tau)^{\frac{t_k}{\tau}}}$$

- Gradient obtained by solving an adjoint equation

- Reactive strategy:
  - Injection with maximum rates and shut-in production wells when it is no longer profitable.

- Experiment with ‘the standard egg model’

Jansen et al. (2014)



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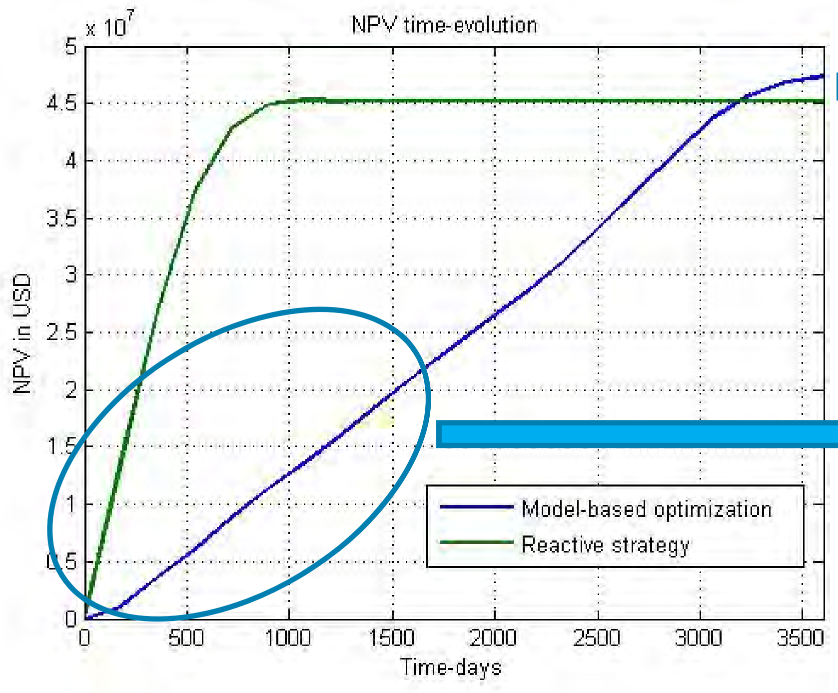
Model-based optimization and Reactive strategy

Nominal model-based optimization and reactive strategy



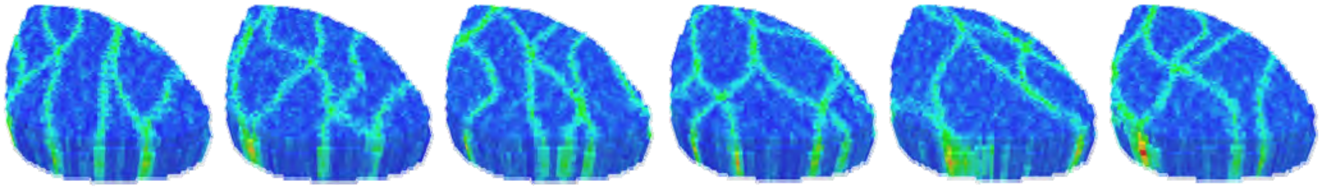
Long-term gains

Short-term gains

It is desirable to include uncertainty in the model-based optimization

Handling risk of uncertainties
Literature Survey

Ensemble of uncertainty realizations:



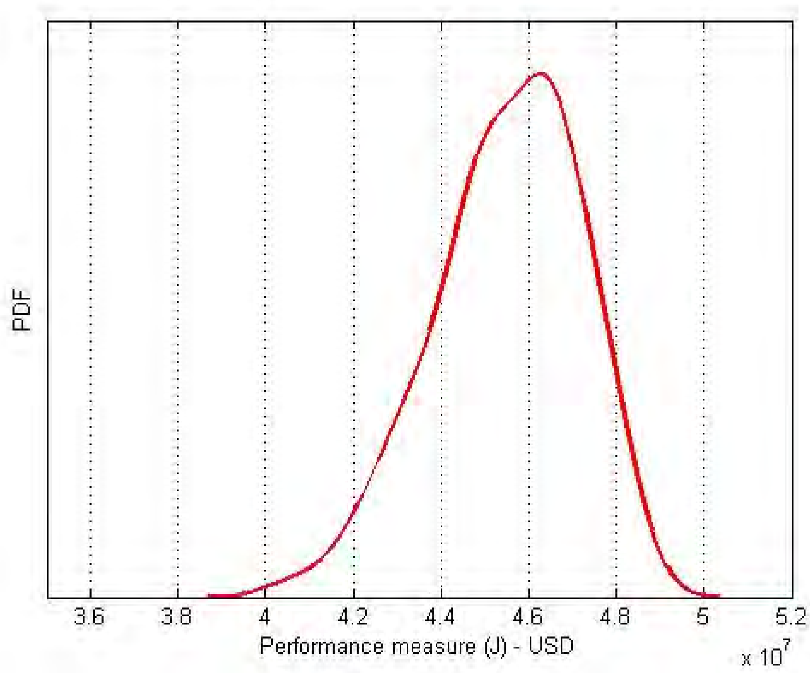
A mean optimization (MO) approach

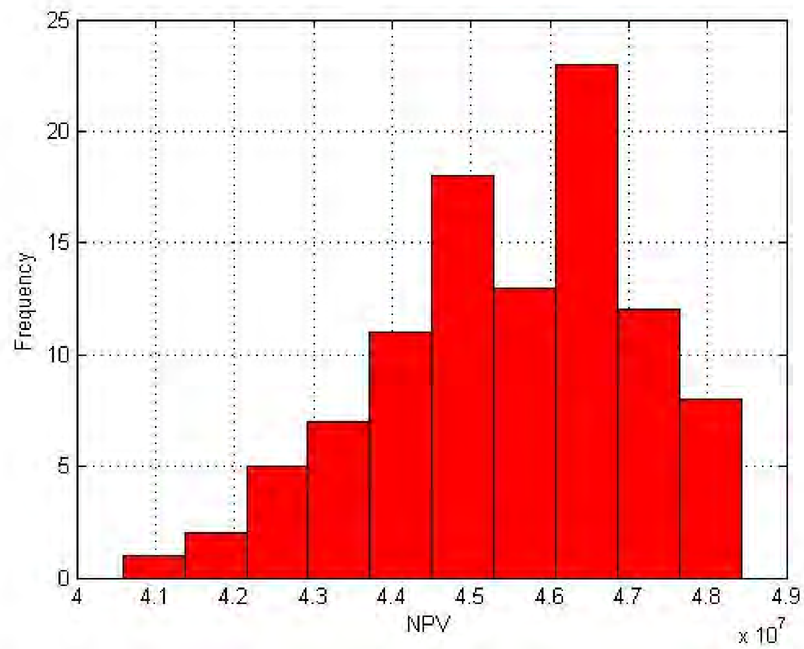
Van Essen et al. 2009a

$$J_{MO} = \frac{1}{N_r}\sum_{i=1}^{N_r} J_i(u, \theta_i)$$

Handling risk of uncertainties
Literature Survey

$$\max_{u} J_{MO} = \max_{u} \frac{1}{N_r} \sum_{i=1}^{N_r} J_i(u, \theta_i)$$





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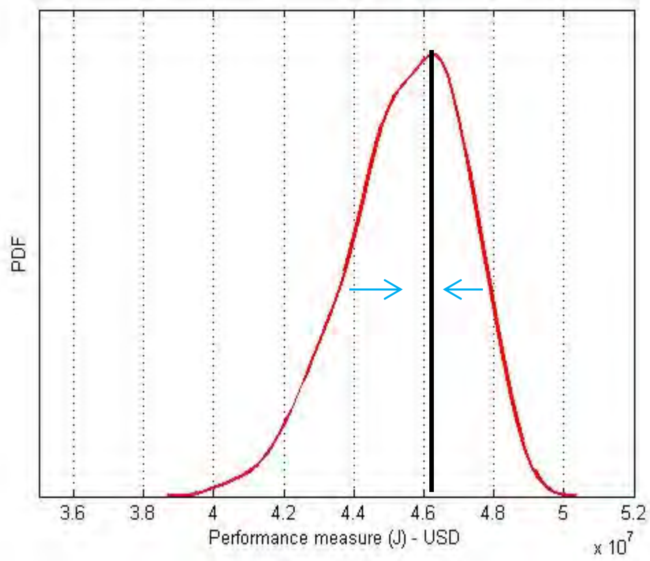
Handling risk of uncertainties
Literature Survey

A mean-variance approach

H. Markowitz (1952),
Capolei et al. (2015a),
Siraj et al. (2015)

$$J_{MVO} = J_{MO} - \gamma J_V$$

- A symmetric measure of risk
- It penalizes the best cases
- The decision maker is mainly concerned with the worst cases



Using asymmetric risk measures to improve the worst cases without heavily compromising the best cases

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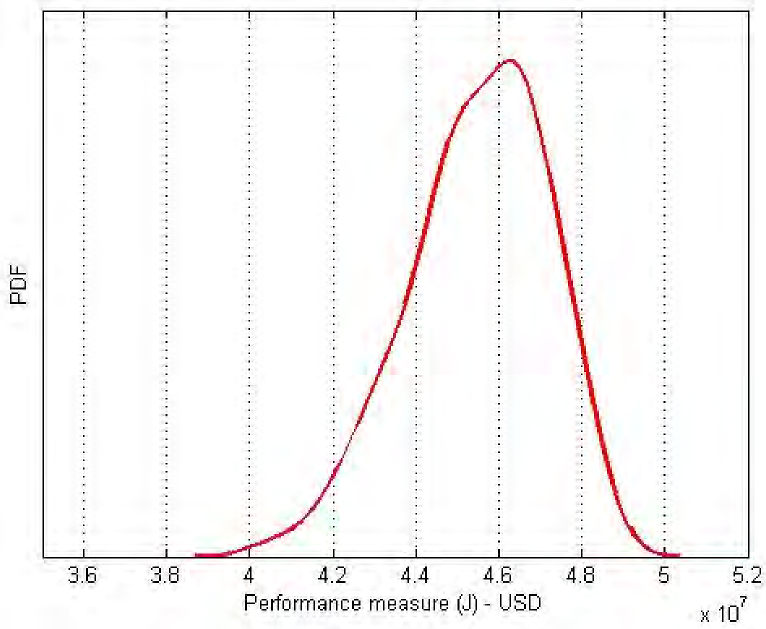
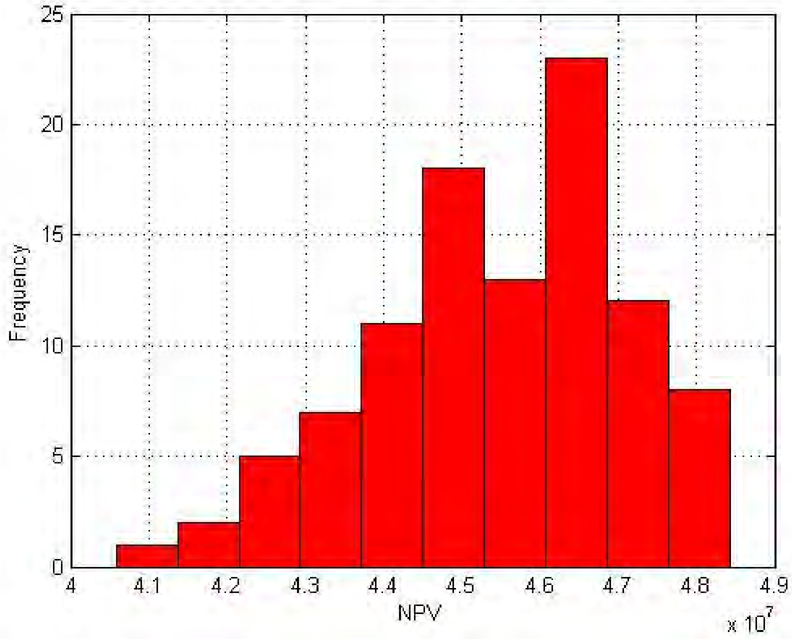
Risk management

H. Markowitz (1952), Rockafellar et. al (2000), Capolei et al. (2015b),

Risk is unpredicted variability or a potential loss of the expected economic objective.

Risk management is the shaping of gain\loss distribution.





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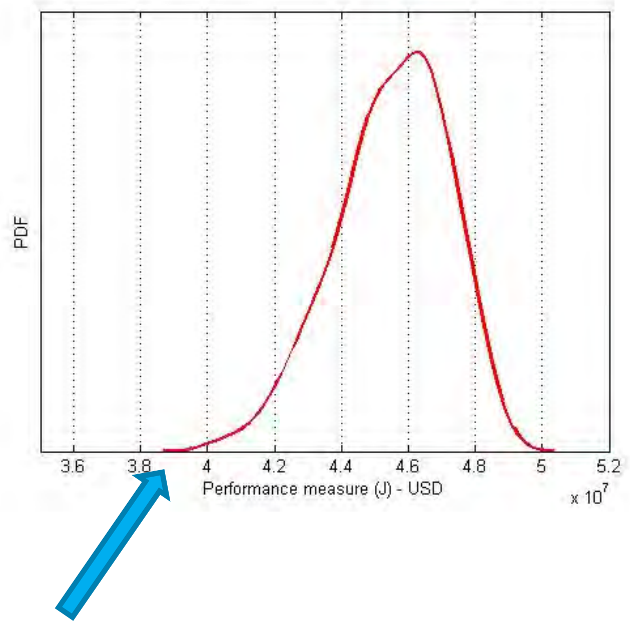
Risk management

Asymmetric Risk and deviation measures

Worst-case (Robust optimization):

$$\max_{u} \quad \min_{\theta_i} \; J(u, \theta_i)$$



Reformulation:

$$\max_{u} z$$

$$s.t \qquad z \leq J(u, \theta_i) \qquad \forall i$$

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Risk management

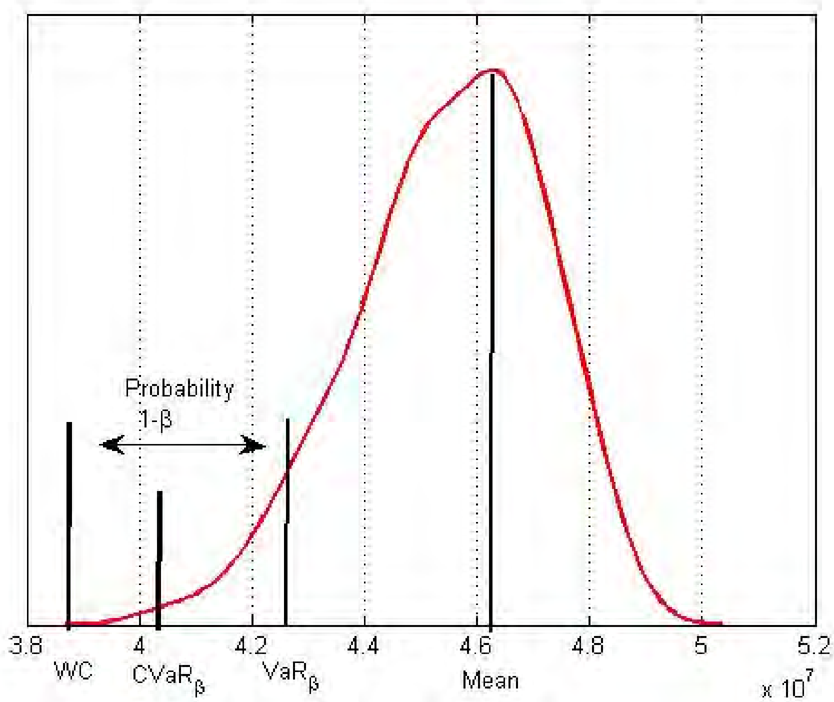
Asymmetric Risk and deviation measures

Value at Risk (VaR):

$$VaR_\beta(X) = \min\{z \,|F_X(z) \leq \beta\}$$

Conditional Value at Risk (CVaR):

$$CVaR_\beta(X) = E\,[X\,|X \leq VaR_\beta]$$

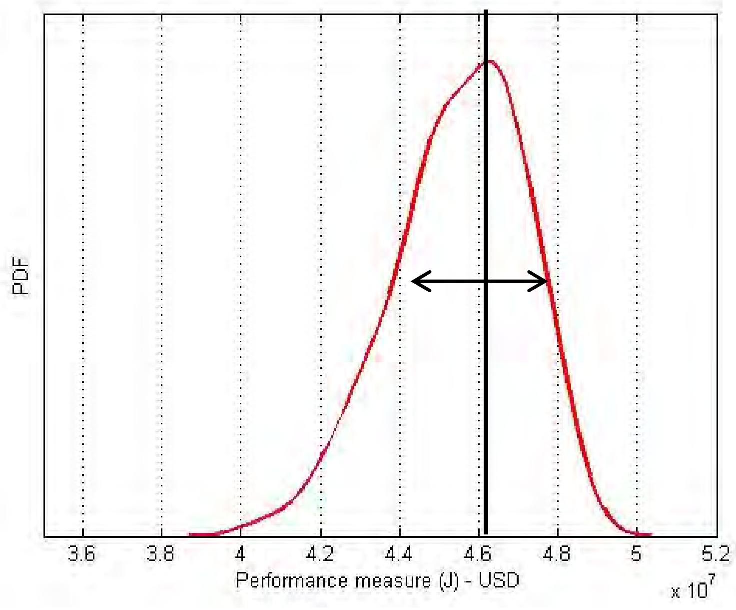


Risk management

Asymmetric Risk and deviation measures

Standard semi-deviation:

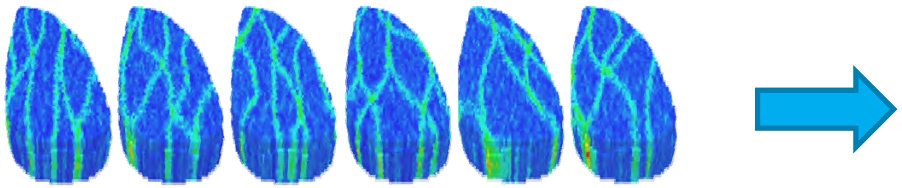
$$\sigma_+(X) = (E[\max\{X - EX, 0\}]^2)^{\frac{1}{2}}$$
$$\sigma_-(X) = (E[\max\{EX - X, 0\}]^2)^{\frac{1}{2}}$$

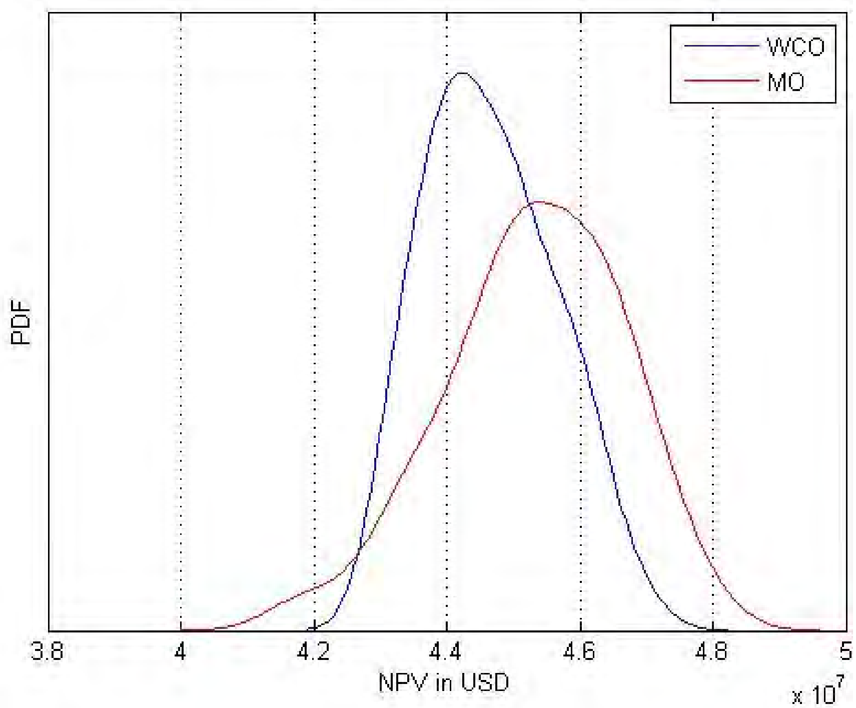


Worst-case robust optimization

Handling geological uncertainty

$$\max_{u} z$$
$$s.t \qquad z \leq J(u, \theta_i) \qquad \forall i$$





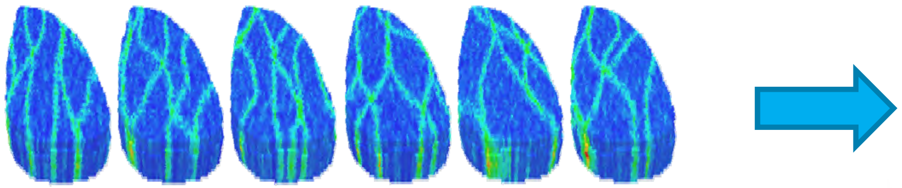
Worst-case increase: 3.60%
Average decrease: 1.54%

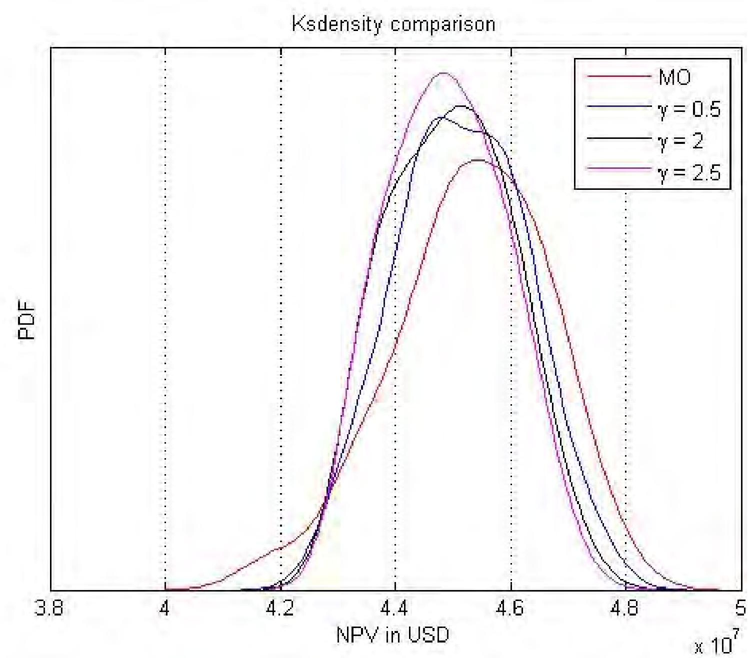
Conditional value-at-Risk (CVaR) optimization

Handling geological uncertainty:

$$\max_{u} \quad J_M - \gamma J_{CVaR}$$

- $\beta = 0{,}8$

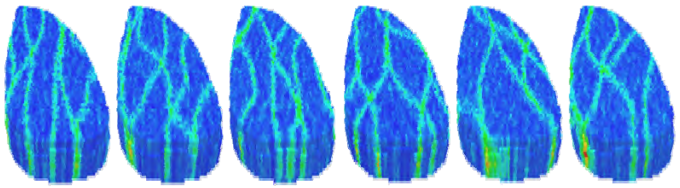


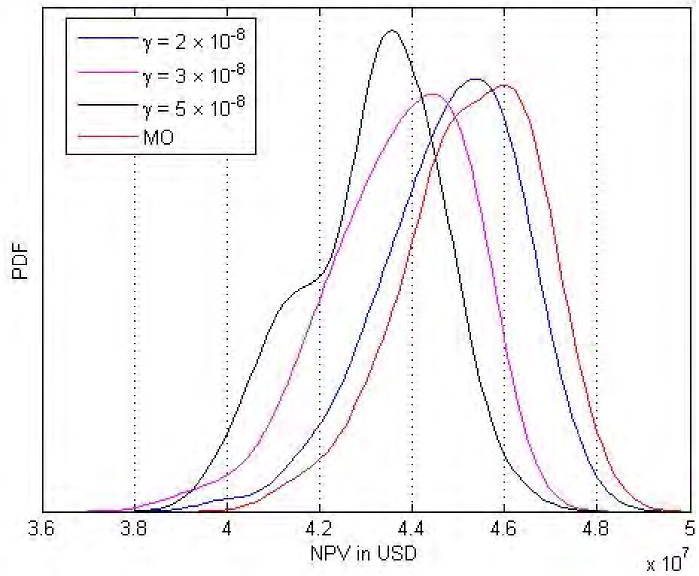


Semi-variance optimization

Handling geological uncertainty:

$$\max_u \; J_M - \gamma J_{SV}$$





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Take-~~home~~ office messages

- Asymmetric risk management using concepts from the theory of risk
- Results highly dependent upon the chosen uncertainty quantification (uncertainty ensemble)
- CVaR and worst-case optimization provide significant improvement in the worst cases specially with geological uncertainty
- Results can be extended to include economic uncertainty

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Thank you!