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Resource Allocation Decisions under Deep Uncertainty, with Application to Deepwater Horizon Oil Spill Case Study

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IISE Annual Conference, Pittsburgh, PA
May 20, 2017

Deep Uncertainty

Levels of uncertainty (Walker et al. 2013)

- Level 4: Enumerate possible outcomes but no likelihoods
- Level 5: What is known is only that we don't know

Uncertain about (Lempert et al. 2003)

1. Appropriate models for interactions of variables
2. Probability distributions
3. Value the desirability of outcomes

Model / structural uncertainty

Walker, W.E., R.J. Lempert, and J.H. Kwakkel, 2013. Deep uncertainty. In *Encyclopedia of Operations Research and Management Science*, S.I. Gass and M.C. Fu, eds. New York: Springer, pp. 395-402.

Lempert, R.J., S.W. Popper, and S.C. Bankes, 2003. *Shaping the Next One Hundred Years: New Methods for Quantitative Long-Term Strategy Analysis*, MR-1626-RPC, Santa Monica: The RAND Corporation.

Models for policy analysis

- Hard to validate
- Need for flexible, adaptive decision support systems
- Policy makers posses various sources of knowledge — (some of them are) difficult to quantify

Solutions to deep uncertainty

- Resistance: plan for the worst case
- Resilience: focus on recovering
- Robustness: perform reasonably well in all circumstances
- Adaptive: change policy if situation changes

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Proposed solution

- Accounts for different types of uncertainty
  - Parameters
  - Functions
  - Risk attitudes
- Returns an interval as solution (rather than a point solution)

Proposed solution

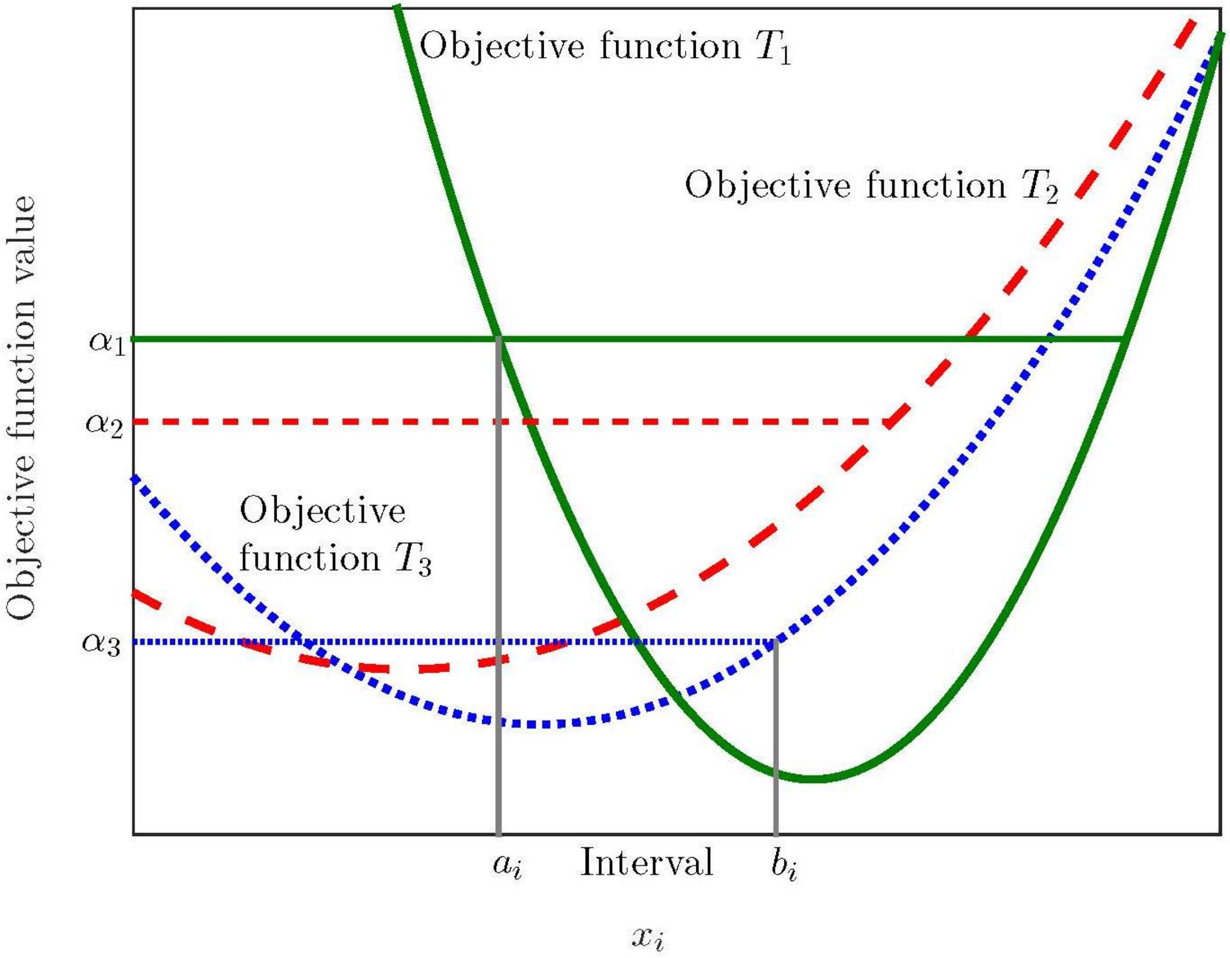
- Objective: minimize $f(x)$
- Several competing objective functions: $f_1(x), f_2(x), \dots, f_N(x)$
- x is continuous decision variable

interval width

$$\begin{aligned} &\text{maximize} && bi - ai \\ &\text{subject to} && f_i(x) \le \alpha_i \quad \text{for } ai \le x \le bi \end{aligned}$$

acceptable threshold

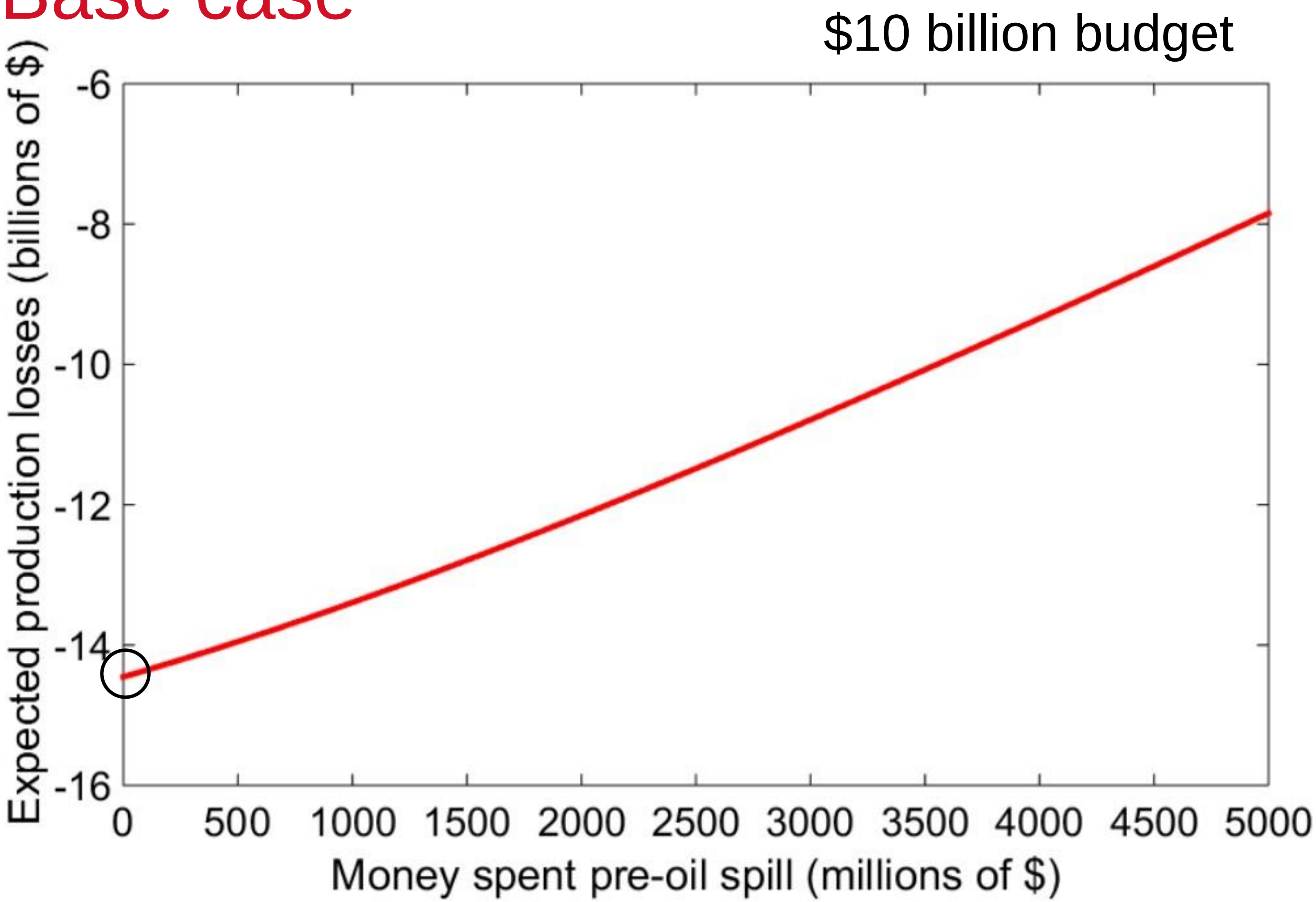
Proposed solution



Oil spill prevention, preparedness and recovery
- Deepwater Horizon Case Study

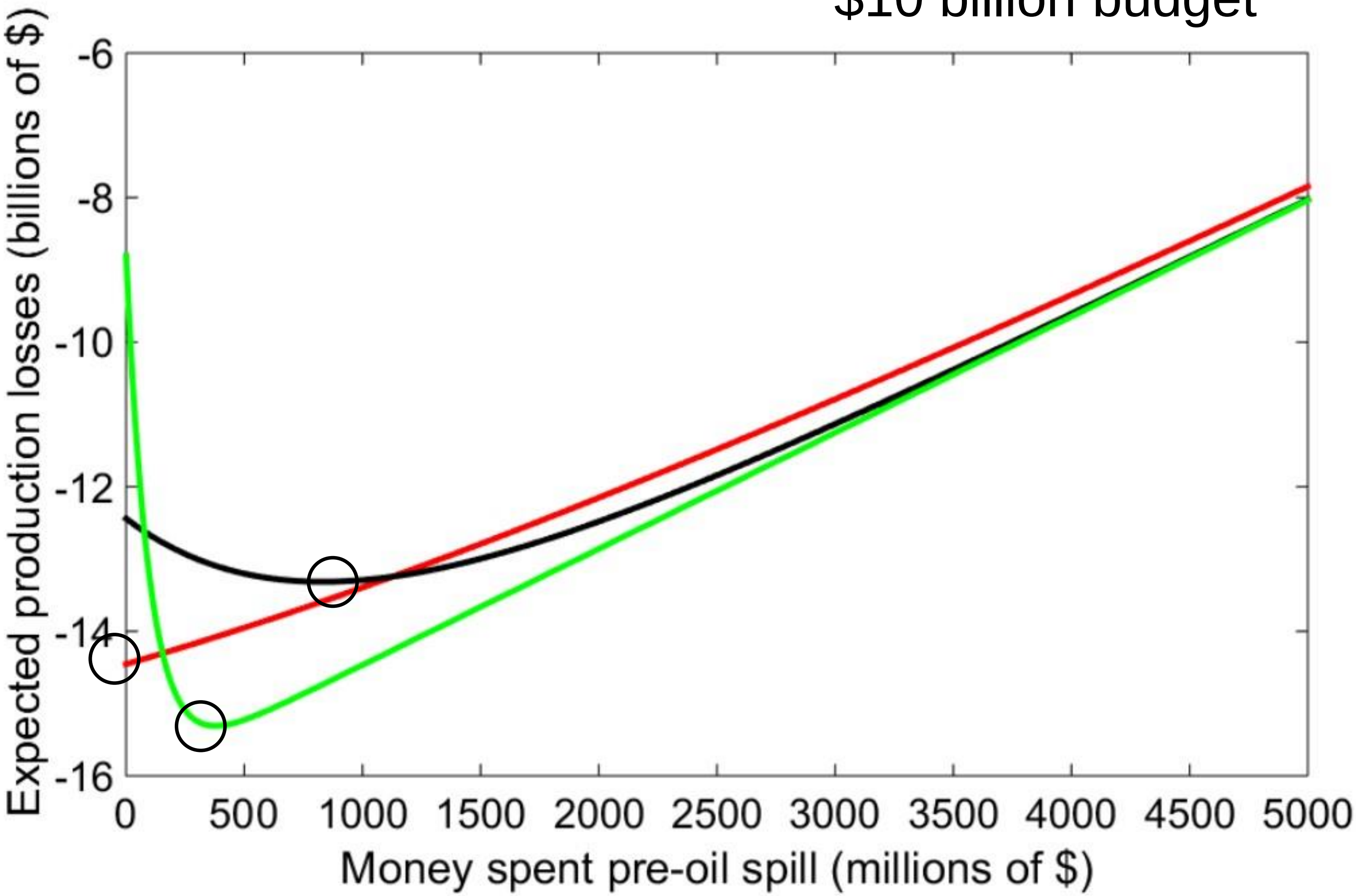
- How much money to prevent and prepare for an oil spill?
- Money that is not spent pre-disruption
  - Response and recovery if spill occurs
  - Other priorities if spill does not occur
- Objective
  - Minimize expected production losses (oil spill)
  - Maximize expected production gains (other priorities)

Base case

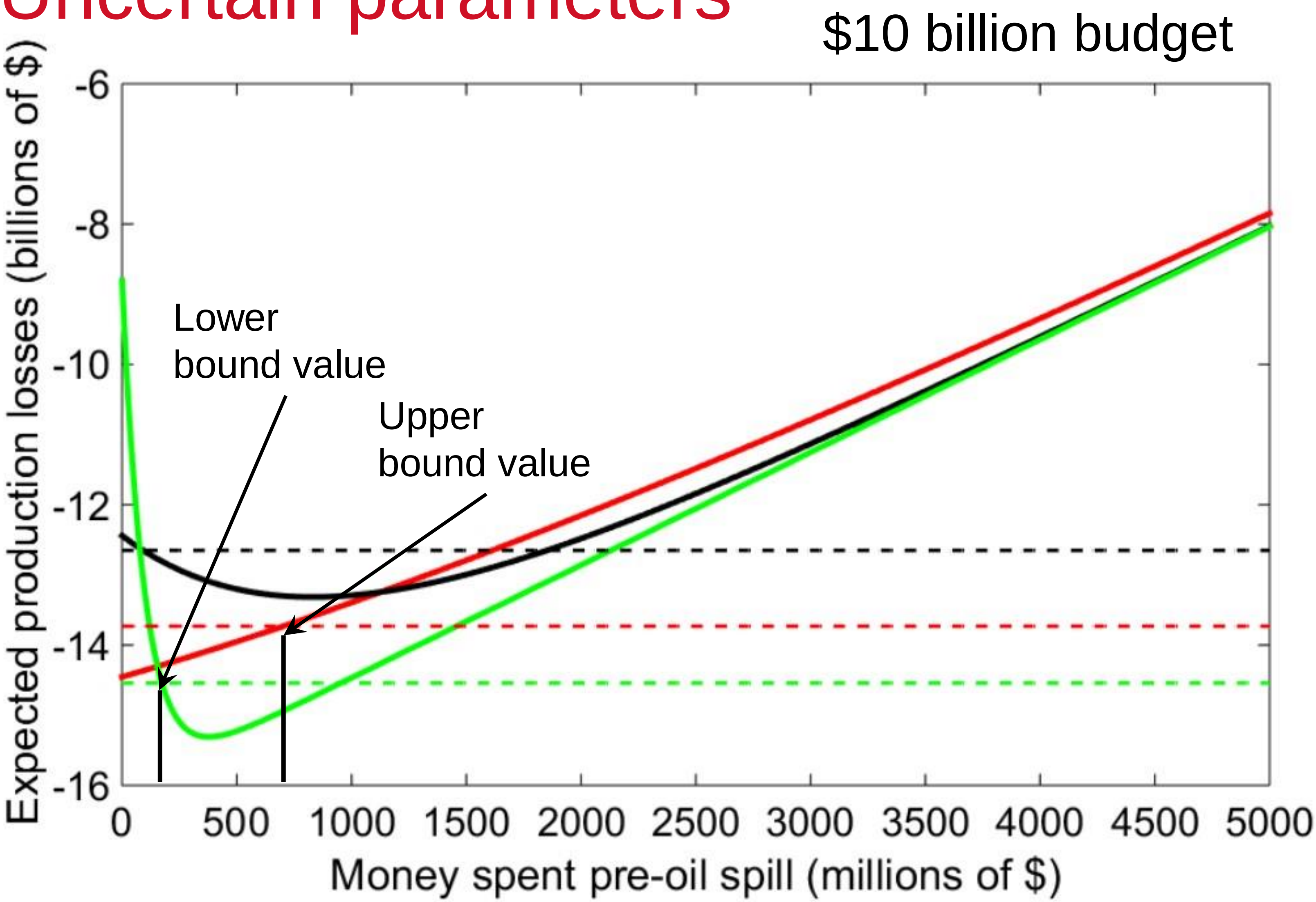

$10 billion budget
Expected production losses (billions of $)
-6
-8
-10
-12
-14
-16
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Money spent pre-oil spill (millions of $)

Uncertain parameters

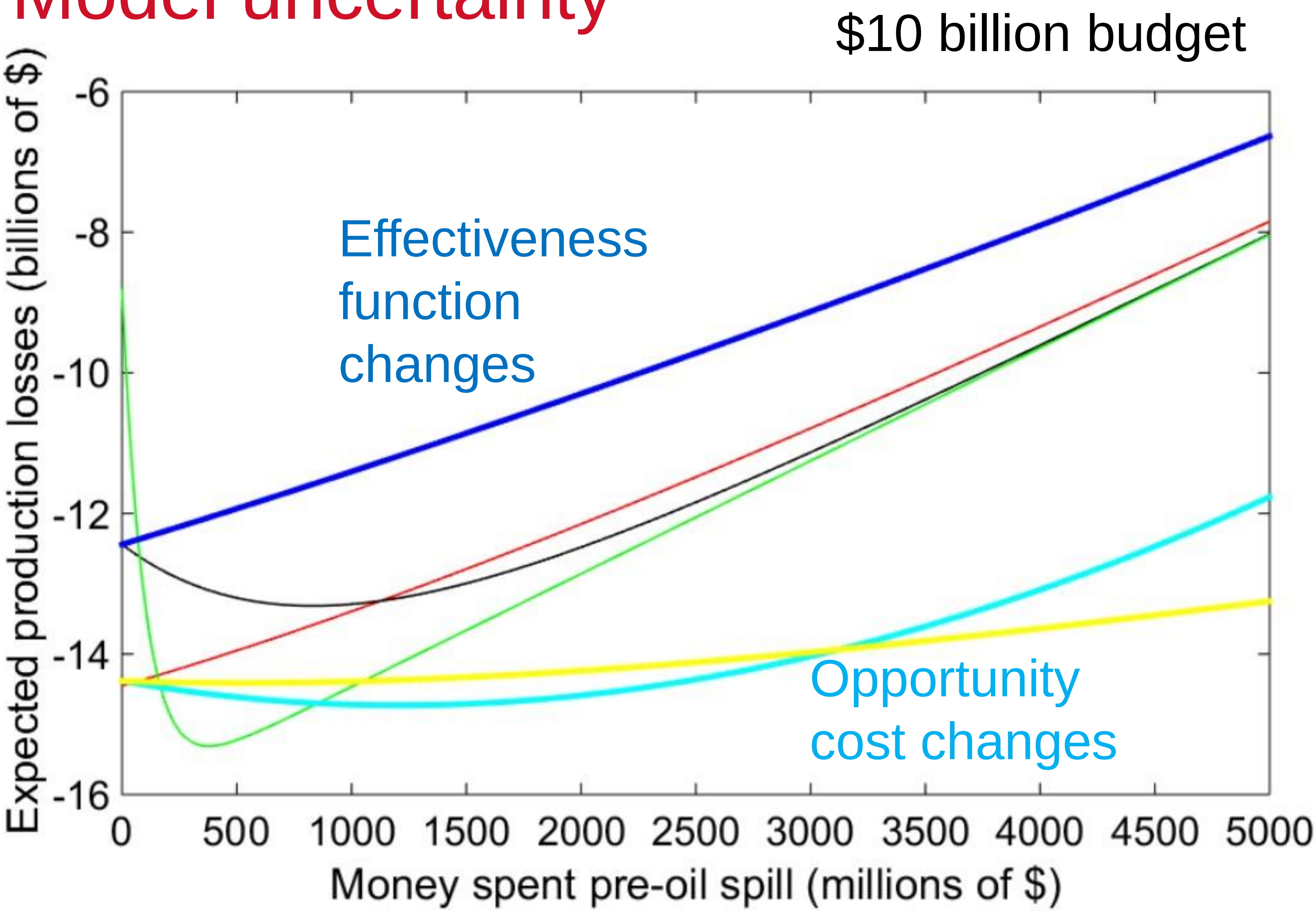
$10 billion budget



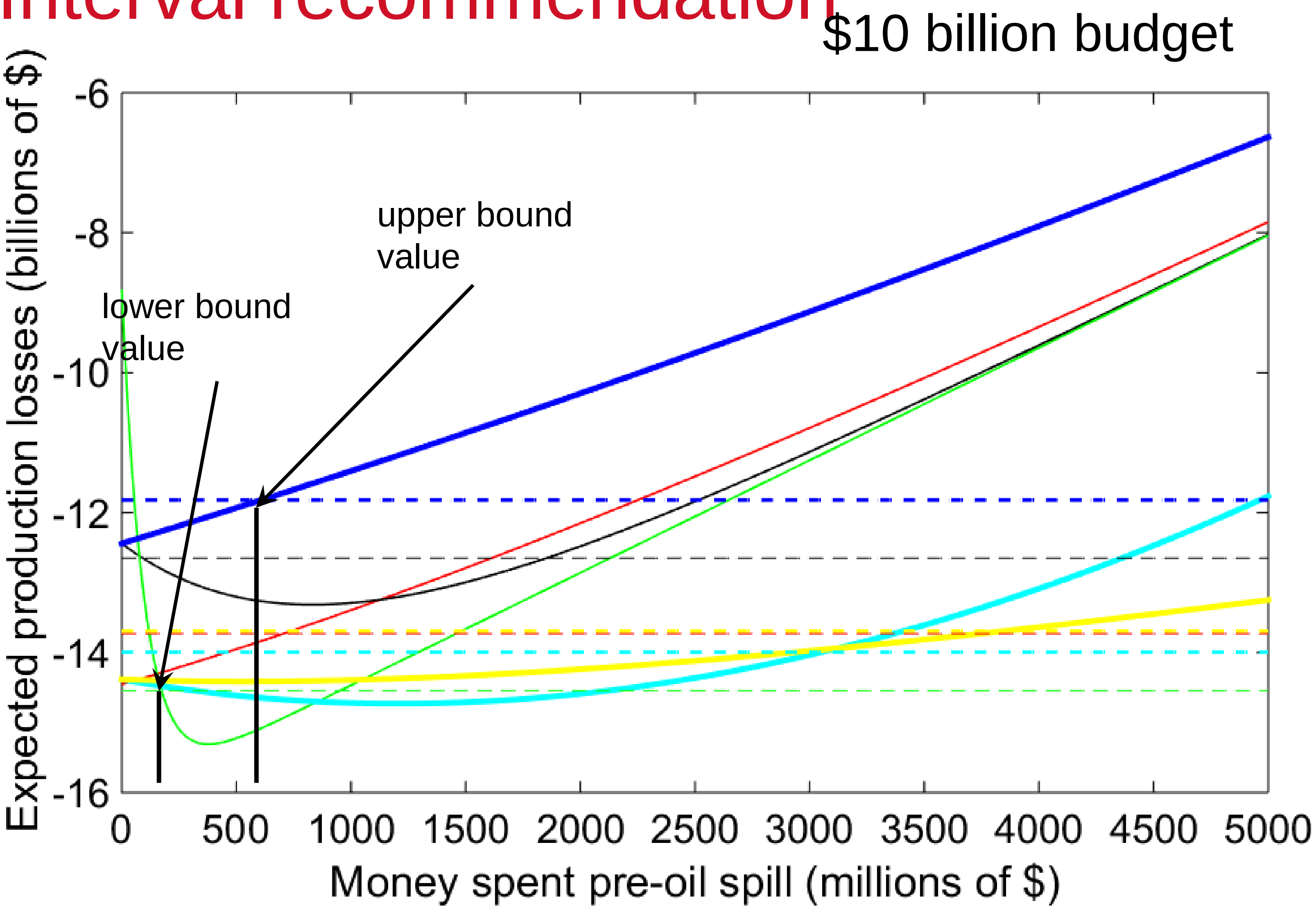
Uncertain parameters



Model uncertainty



Interval recommendation

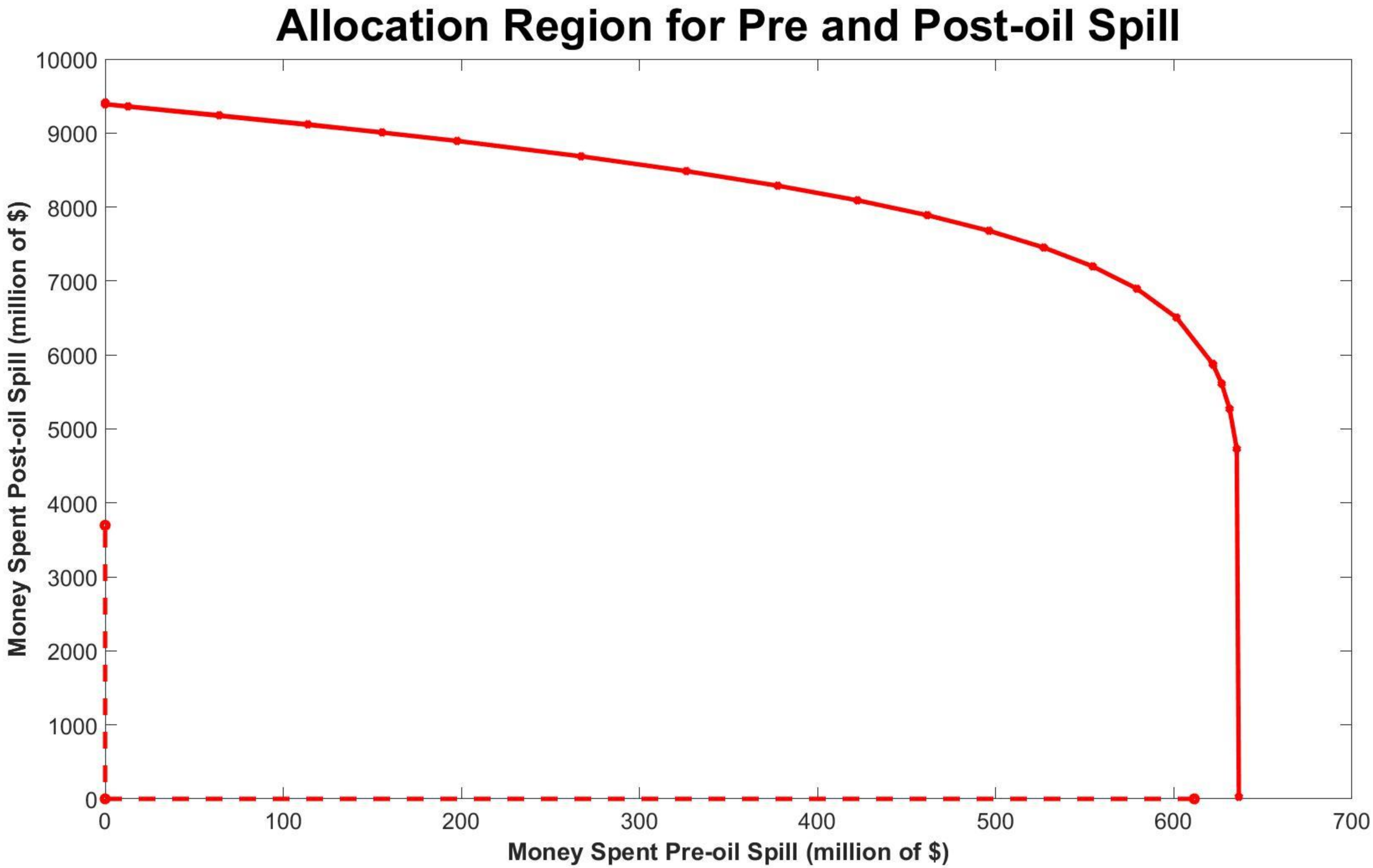


Changing threshold

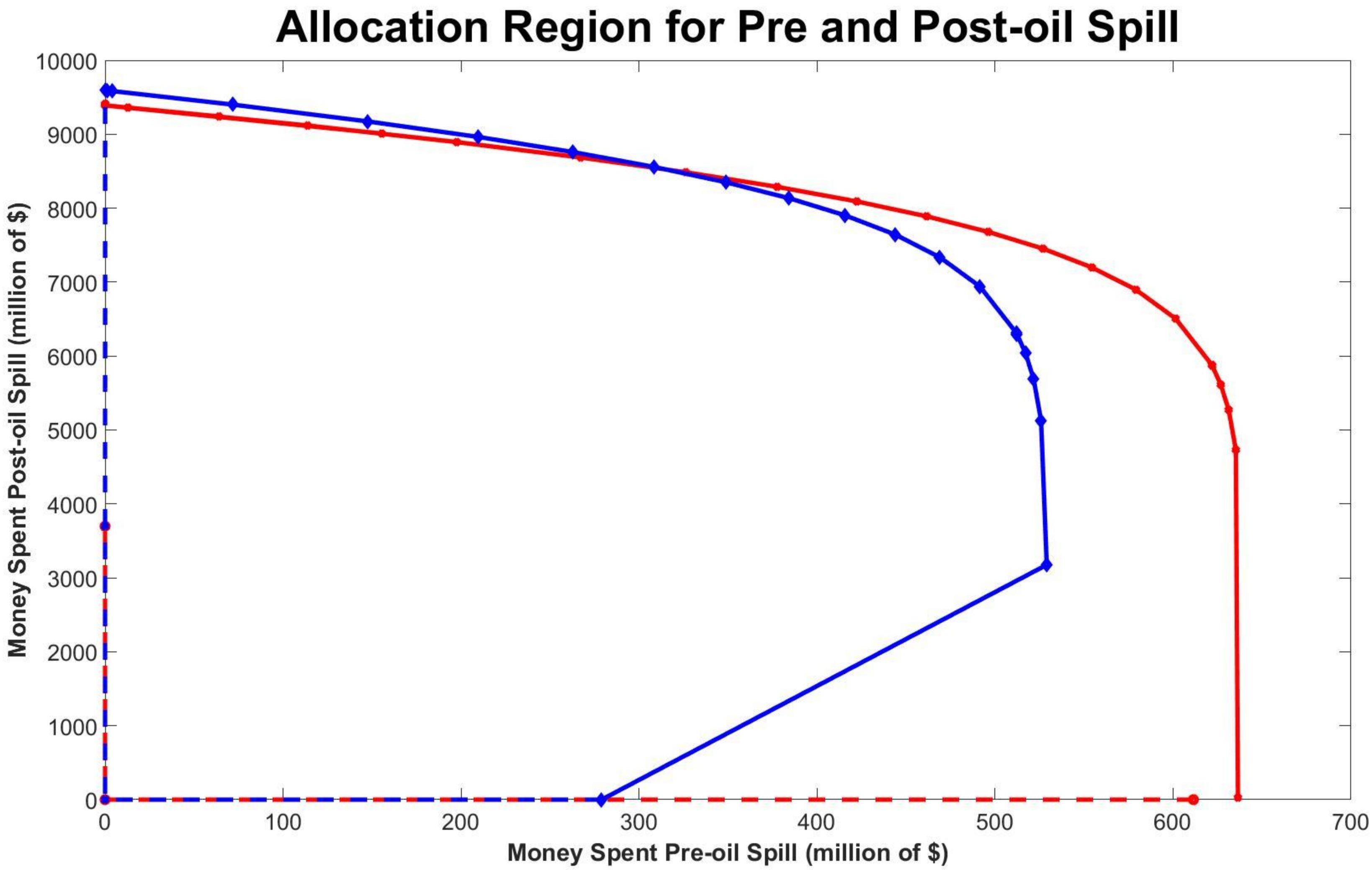
Percent of optimal value	Minimum	Maximum
93	387.22	407.52
92	312.44	467.98
91	243.83	529.04
90	180.34	590.71

millions of dollars

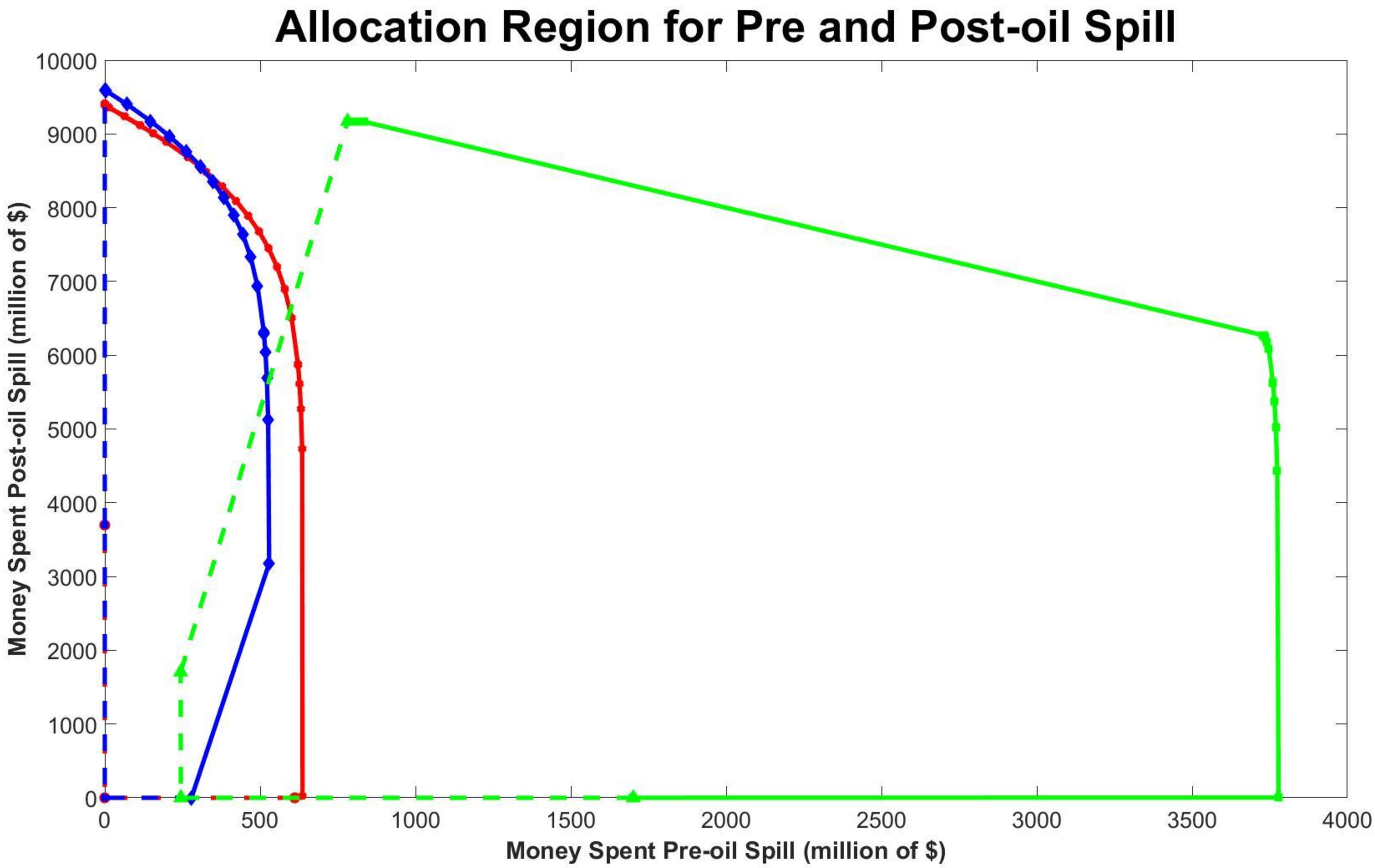
Intervals for two decision variables



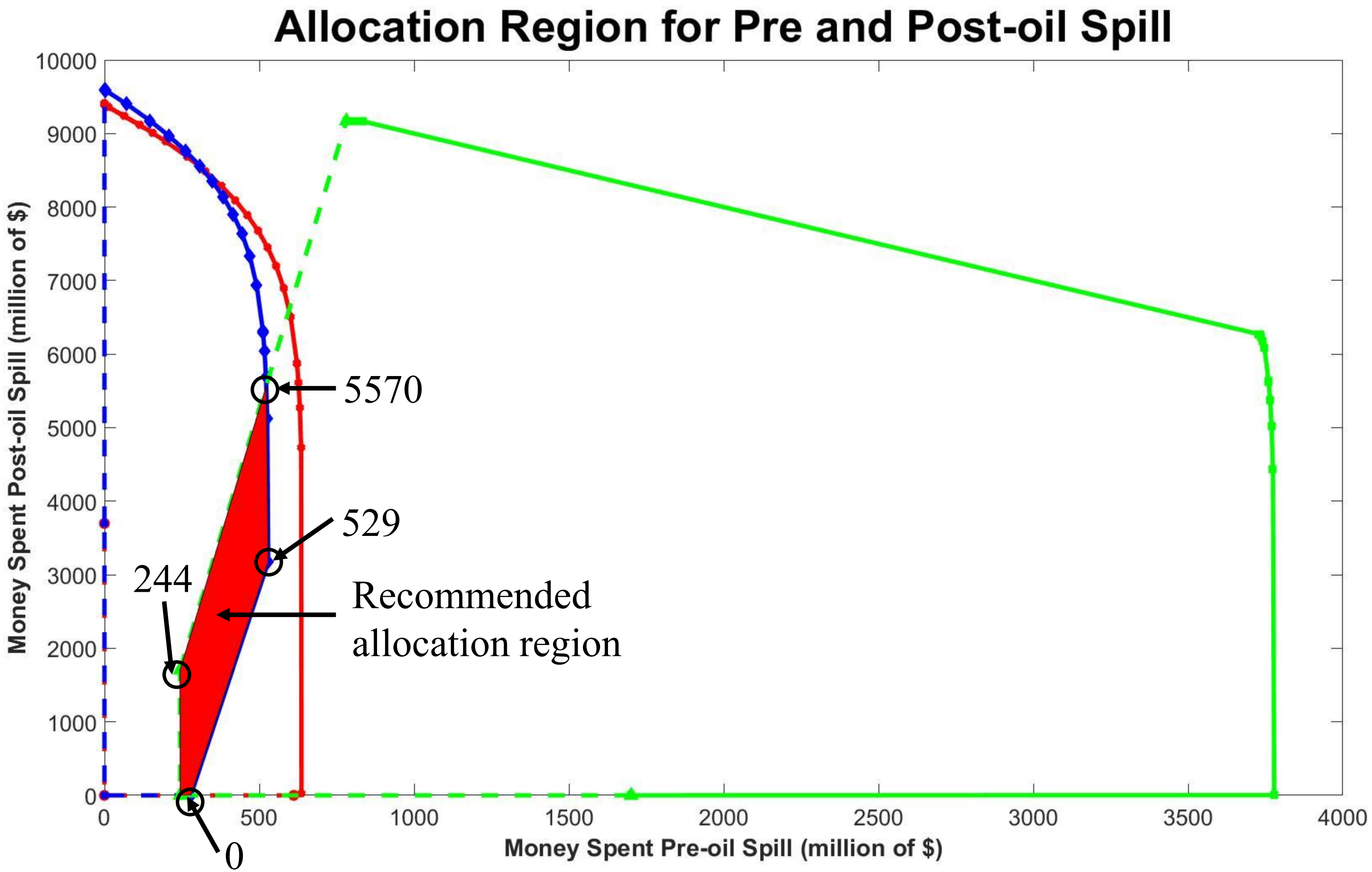
Intervals for two decision variables



Intervals for two decision variables



Intervals for two decision variables



Conclusions

Contributions

- Interval helps decision maker to allocate resources and provides flexibility
- Interval incorporate uncertainty about model, parameters and functions
- Interval provides solutions that are within threshold

Future extensions

- Different risk attitudes (utility functions)
- Multiple consequences study

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