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

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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


Models for policy analysis

- Hard to validate
- Need for flexible, adaptive decision support systems
- Policy makers possess 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

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: $f_1(x), f_2(x), \ldots, f_N(x)$
- $x$ is continuous decision variable

\[
\begin{align*}
\text{maximize} & \quad b_i - a_i \\
\text{subject to} & \quad f_i(x) \leq \alpha_i \quad \text{for} \ a_i \leq x \leq b_i
\end{align*}
\]
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 $)

Money spent pre-oil spill (millions of $)
Uncertain parameters

$10 billion budget

Expected production losses (billions of $)

Money spent pre-oil spill (millions of $)
Uncertain parameters

- Expected production losses (billions of $)
- Money spent pre-oil spill (millions of $)

Lower bound value

Upper bound value

$10 billion budget
Model uncertainty

$10 billion budget

- Effectiveness function changes
- Opportunity cost changes
Interval recommendation

$10 billion budget

Expected production losses (billions of $)

Money spent pre-oil spill (millions of $)
## Changing threshold

<table>
<thead>
<tr>
<th>Percent of optimal value</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>93</td>
<td>387.22</td>
<td>407.52</td>
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<tr>
<td>92</td>
<td>312.44</td>
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<tr>
<td>91</td>
<td>243.83</td>
<td>529.04</td>
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<tr>
<td>90</td>
<td>180.34</td>
<td>590.71</td>
</tr>
</tbody>
</table>

millions of dollars
Intervals for two decision variables

Allocation Region for Pre and Post-oil Spill

Money Spent Post-oil Spill (million of $)

Money Spent Pre-oil Spill (million of $)
Intervals for two decision variables

Allocation Region for Pre and Post-oil Spill

Money Spent Post-oil Spill (million of $) vs. Money Spent Pre-oil Spill (million of $)
Intervals for two decision variables

Allocation Region for Pre and Post-oil Spill

Money Spent Post-oil Spill (million of $)

Money Spent Pre-oil Spill (million of $)
Intervals for two decision variables

Allocation Region for Pre and Post-oil Spill

Money Spent Post-oil Spill (million of $)

Money Spent Pre-oil Spill (million of $)

Recommended allocation region

5570
529
244
0
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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