
INFRASTRUCTURE, SAFETY,
AND ENVIRONMENT

# *Robust Decisionmaking in the Face of Uncertain, Abrupt Climate Change*

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**Aspen Global Change Institute**
**Workshop on Abrupt Climate Change**
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# *Our Research Focuses on Methods and Tools to Improve Climate Change Decisionmaking*

- **Hypothesis:**
  - **Significant improvements in decision support for complex and deeply uncertain policy problems made possible by recent advances in**
    - **Computer capabilities and**
    - **Psychology of decisionmaking**
- **Key research questions include:**
  - **What are the most effective ways to represent uncertainty for decision-makers?**
  - **How can computer-based tools be designed and used most effectively to aid decision-makers?**

# *Work Aims to Improve Methods for Characterizing and Communicating Uncertainty*

- **Three research themes**
  - **Algorithm development for scenario discovery and robust decisionmaking using models at different levels of aggregation**
  - **Research in psychology of judgment and decisionmaking under ambiguity**
  - **Evaluation of decision tools in practical application**
- **Two policy areas:**
  - **Observation systems for abrupt climate change**
  - **Long-term water resources management in California**
- **Multi-year effort in collaboration with**
  - **Klaus Keller, Penn State, Abrupt Change**
  - **David Budescu, University of Illinois, J/DM**

# *Standard Decision Theory Ranks Alternative Actions Under Uncertainty According to Expected Utility*

- **Consider**
  - **Future states of the world (e.g. A,B) each characterized by some probability**
    - **frequentist or subjective**
  - **Alternative actions (e.g. 1,2,3) which have some utility in each state of the world**

| | A | B | p(B) = 1% |
|---|---|---|---|
| 1 | 20 | -500 | 15 |
| 2 | 10 | -100 | 9 |
| 3 | 5 | -10 | 4.9 |

- **Choose strategy with best expected utility (e.g. Action 1)**
- **Examine sensitivity to assumptions (e.g. Action 1 still best if p(B) = 2%).**

# *Some Decision Problems May Be Poorly Described By Traditional Framework*

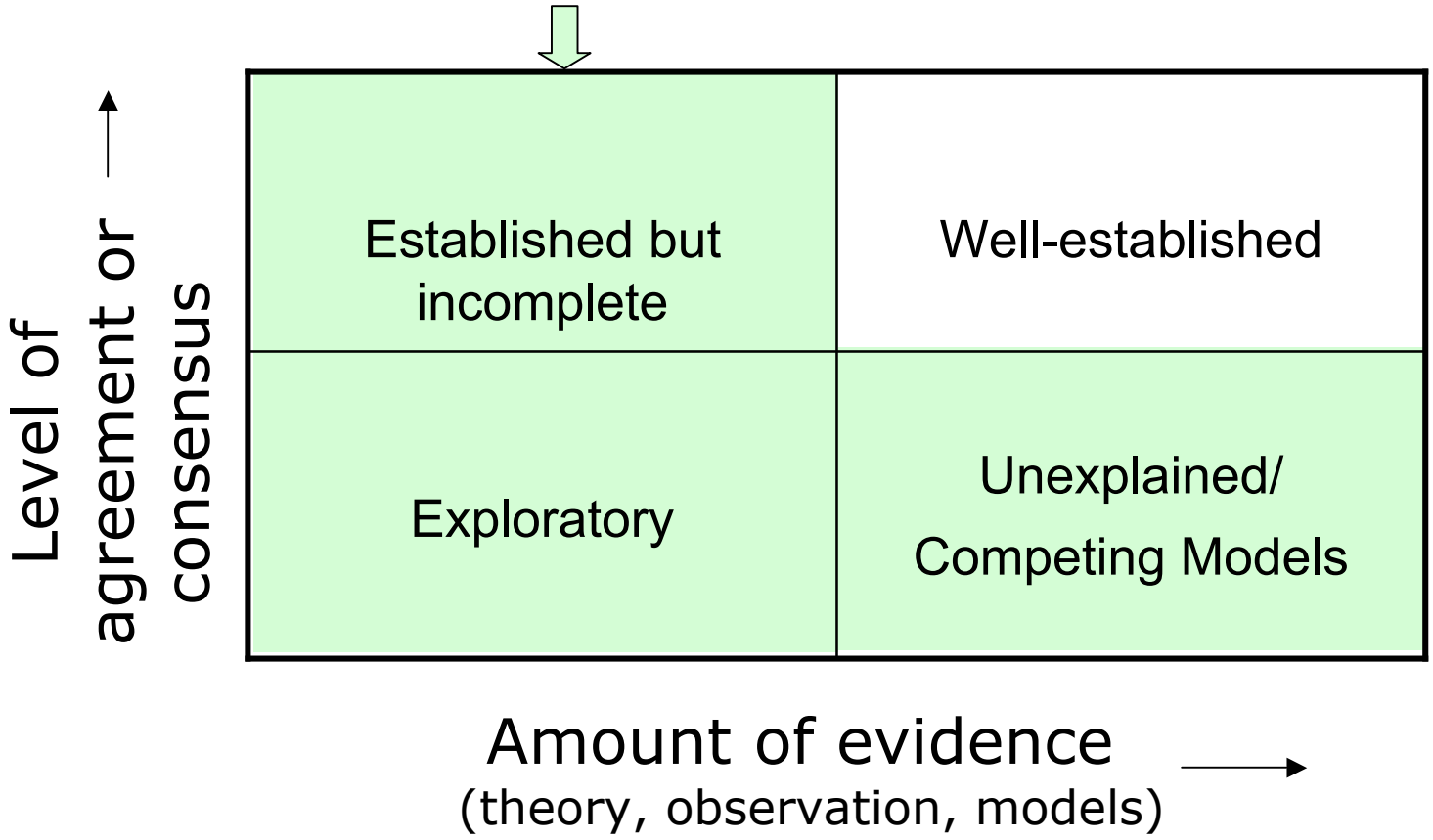
- Parties to the decision may not know, and/or do not agree on, the system model, prior probabilities, and/or "cost" function

| | A | B | C? | p(B)=? |
|---|---|---|---|---|
| 1 | 20 | ? | | |
| 2 | 10 | ? | | |
| 3 | 5 | ? | | |

We call such conditions *deep uncertainty*

# *Climate Science Often Suggests Conditions of Deep Uncertainty*

*Deep uncertainty* -- Decisionmakers do not know, and/or do not agree on, the system model, prior probabilities, and/or "cost" function

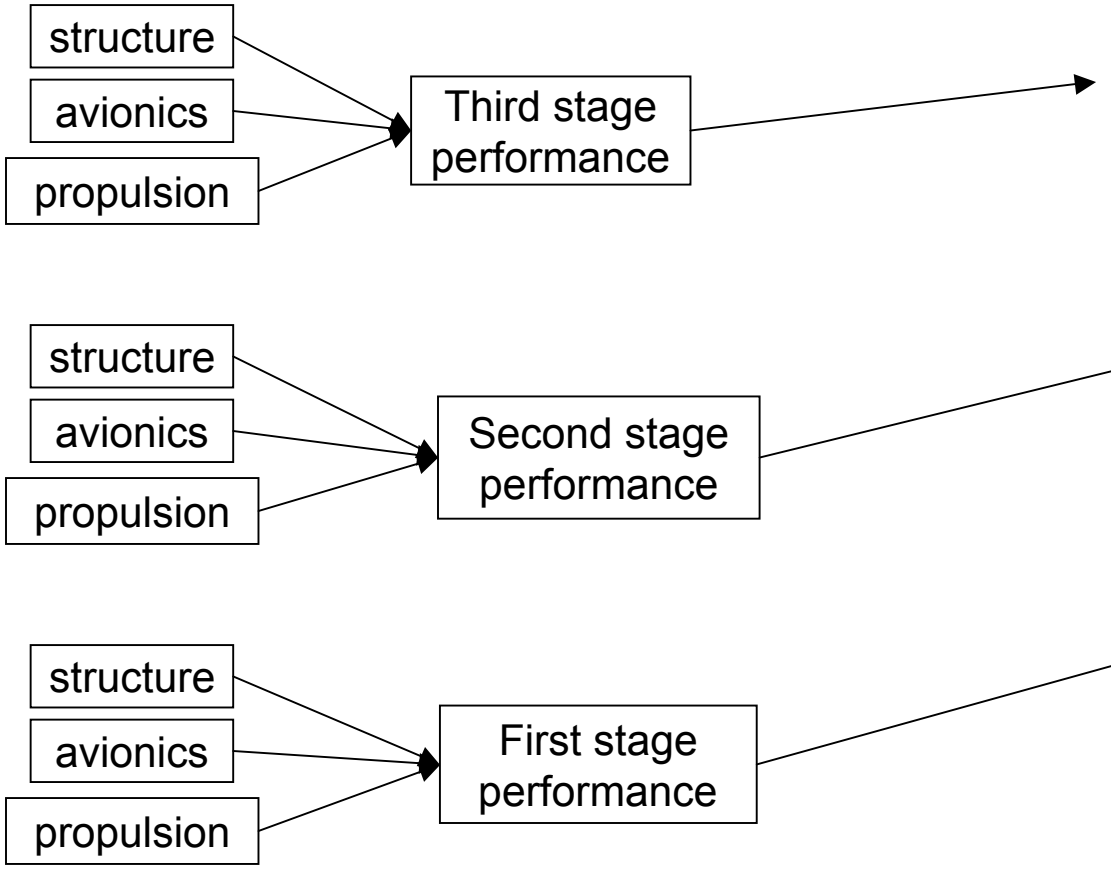


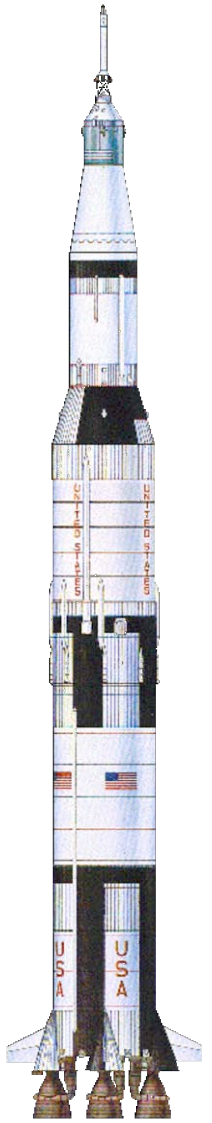
# *Traditional Decision Framework Can Prove Difficult Under Deep Uncertainty*

- Uncertainties may be underestimated
- Competing analyses can contribute to gridlock
- Misplaced concreteness can blind decision-makers to surprise
- Decision makers may reject analysis because it they believe it doesn't include all the relevant information

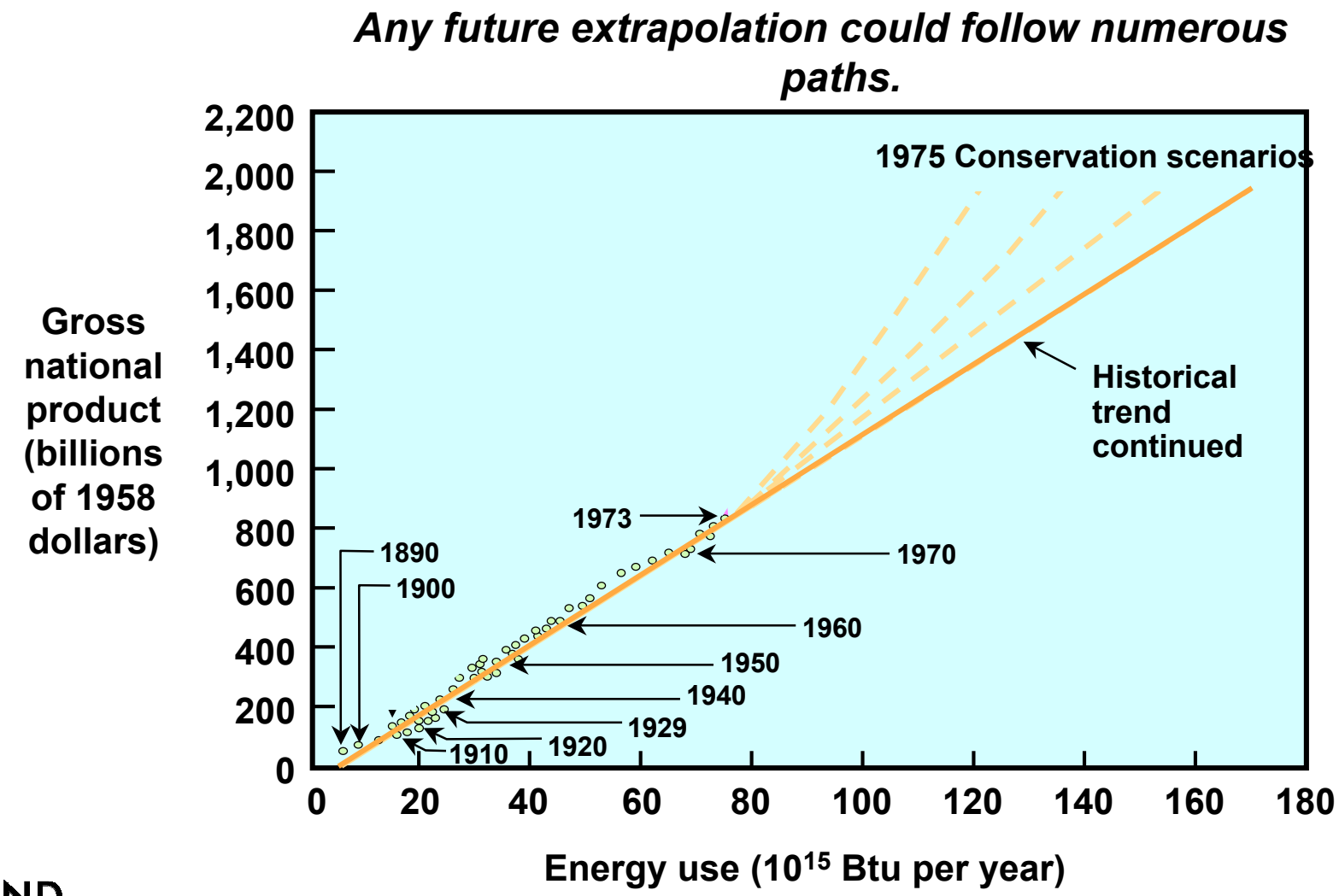
# *Quantitative Analysis Often Focuses on Complicated Systems Operating in Well-Understood Regimes*

**Good flying and engineering controls cascade of uncertainty**



# *Decisionmakers Sometimes Face Novel Situations*

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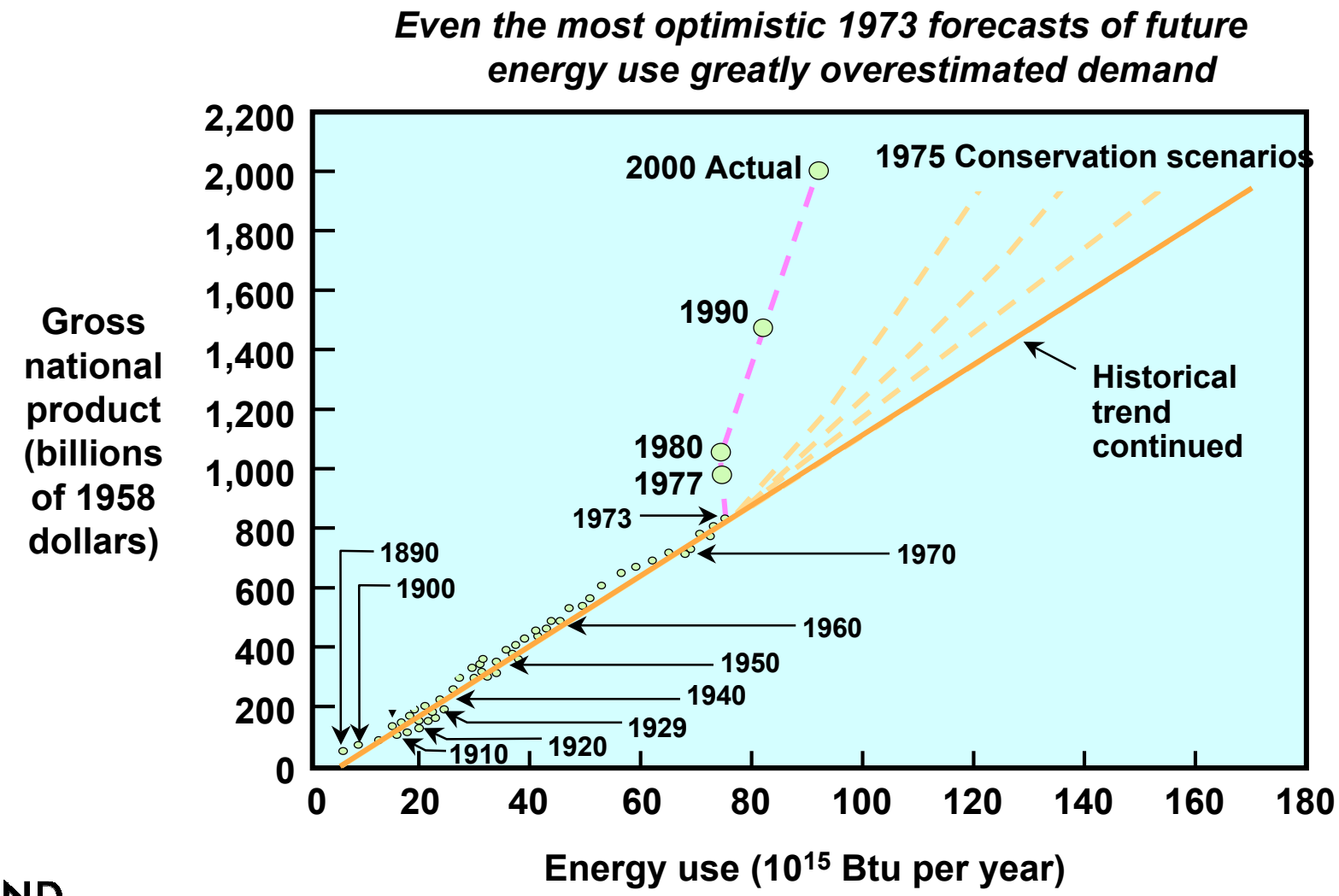


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# *Surprise Challenges Those Who Provide Information to Decision-Makers*

*Our stupendous unreadiness at Pearl Harbor…was just a dramatic failure of a remarkably well-informed government to call the next enemy move…*

*"It is not true that we were caught napping…Rarely has a government been more expectant. We just expected wrong.*

*"We were so busy thinking through some 'obvious' Japanese moves that we neglected to hedge against the choice they actually made."*

--Thomas C. Schelling:

Forward to *Pearl Harbor: Warning and Decision*

by Roberta Wohlstetter

# *Many Approaches to Decision Making Under Deep Uncertainty*

## Means to Characterize Uncertainty

- More sophisticated use of probabilities
- Adopt alternative probability calculus which can express uncertainty about uncertainty
  - Fuzzy logic, imprecise probabilities, …
- Use multiple views of the future
  - Scenarios, multiple probabilities, …

## Means to compare alternative decisions

- Optimize utility
- Efficiently meet constraints or targets
- Precautionary
- Robustness

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# *Outline*

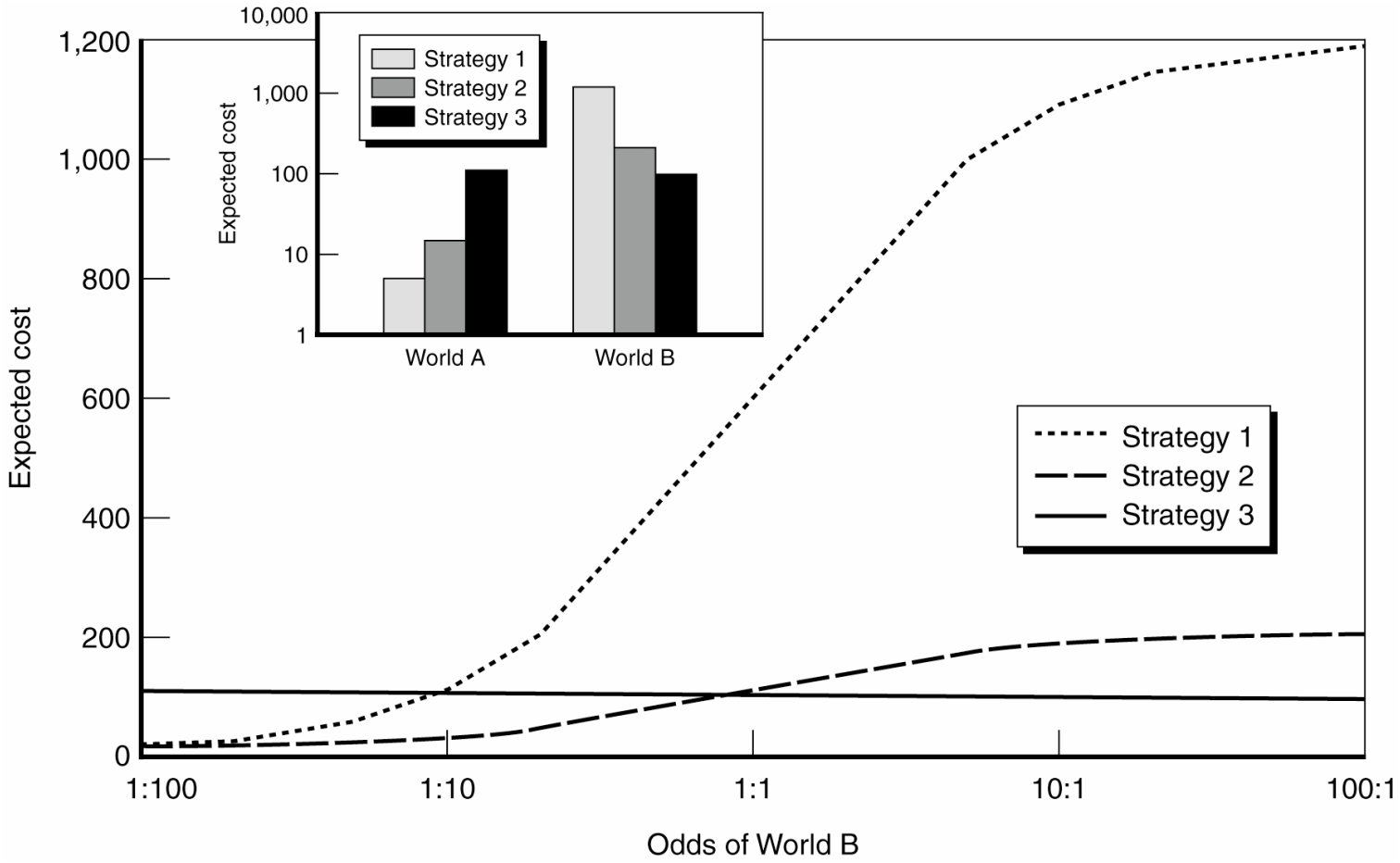
- **Robust decision making**
- **Abrupt climate change may make optimal policies sensitive to assumptions**
- **Robust policies with uncertain environmental thresholds**

# *Robust Decisionmaking Focuses on Uncertainties Most Important to Choice Among Strategies*

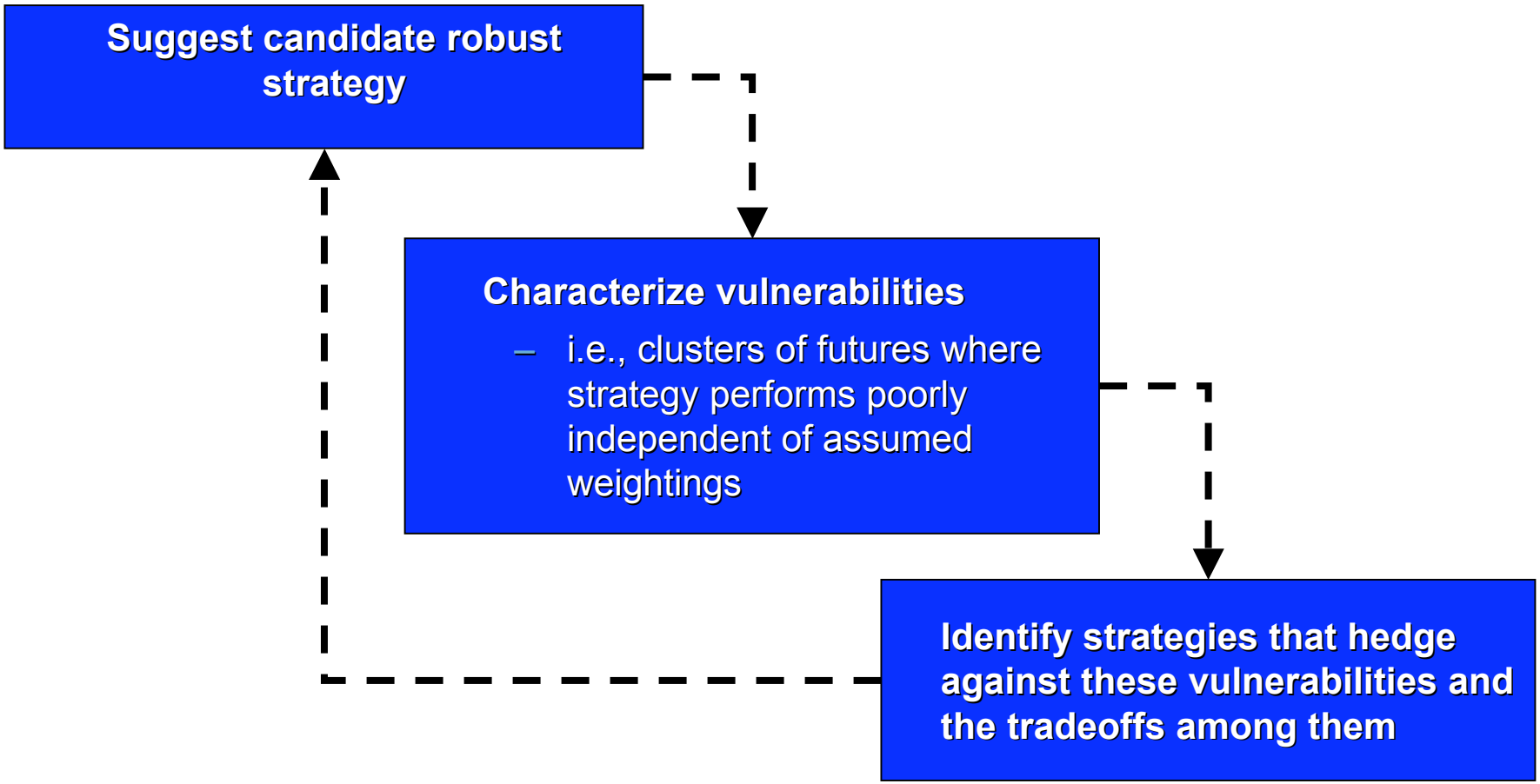
- **Under conditions of deep uncertainty, decisionmakers often rely on a choice of strategy, not on additional information, to reduce uncertainty**
  - A robust strategy performs reasonably well compared to the alternatives across a wide range of plausible futures, evaluated with a range of values

- **Robust decisionmaking (RDM) is an iterative, analytic process for**
  - identifying strategies whose acceptable performance, measured by a range of values, is largely insensitive to poorly characterized uncertainties
  - characterizing a small number of irreducible tradeoffs inherent in the choice among such robust strategies

# *People Often Intuitively Use RDM for Simple Problems*



# *RDM Identifies Robust Strategies and Key Uncertainties with Iterative Process*



# *Key Elements of Robust Decision Making*

- Consider large ensembles (hundreds to millions) of scenarios
- Seek robust, not optimal strategies
  - Types of robustness include:
    - Trade optimal performance for less sensitivity to assumptions
    - Keeping options open
    - Reduce number of poorly defined risks
- Achieve robustness with adaptivity
- Design analysis for interactive exploration of a multiplicity of plausible futures

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# *Abrupt Climate Change May Make Optimal Climate Policies Particularly Sensitive to Assumptions*

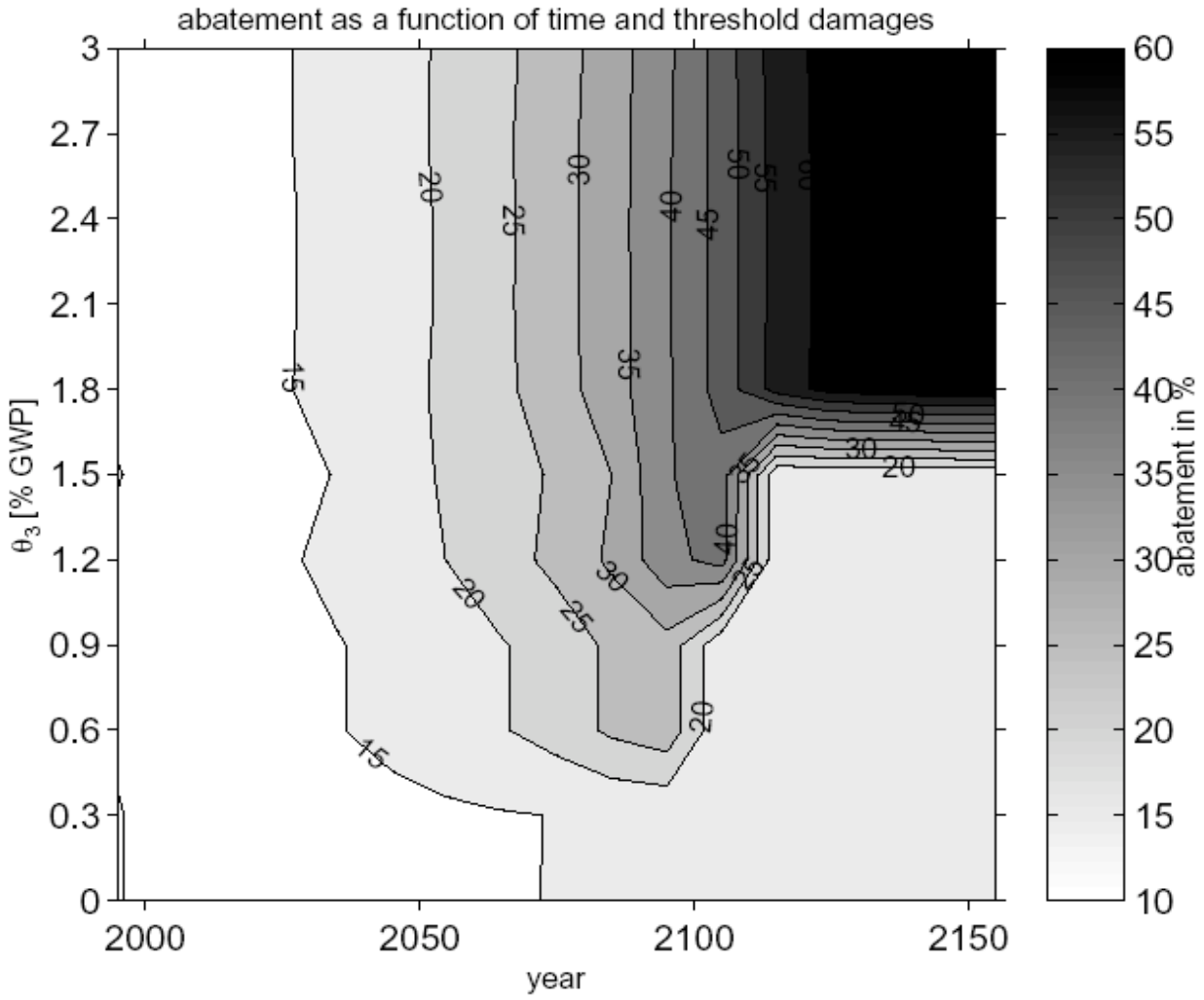
- **Calculate utility of abatement paths (2005-2300) using Nordhaus' DICE integrated assessment model with simple threshold model of abrupt change**

$$Y(t) = Y'(t)[1 - \theta_3] \text{ if } Conc(t') \geq Conc_{Thres} \text{ for any } t' < t$$

- **Find global optimum abatement path using SRES evolutionary solver**

- **Examine "level sets" of solutions**
  - **A level set is all the solutions whose objective functions are close to that of the optimum**

# *Abrupt Change Can Induce Non-Linear Behavior in Optimal Abatement Policies*

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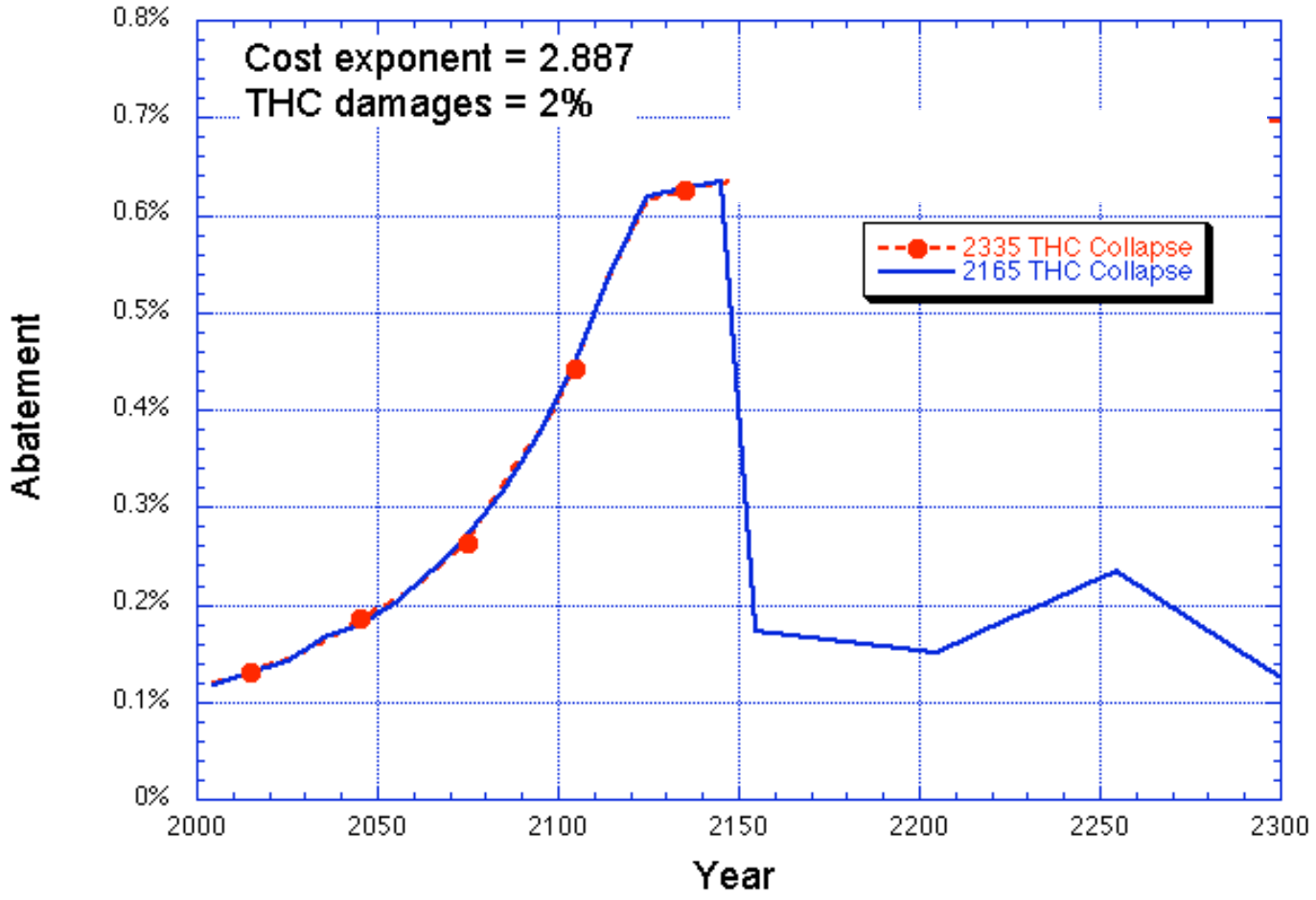
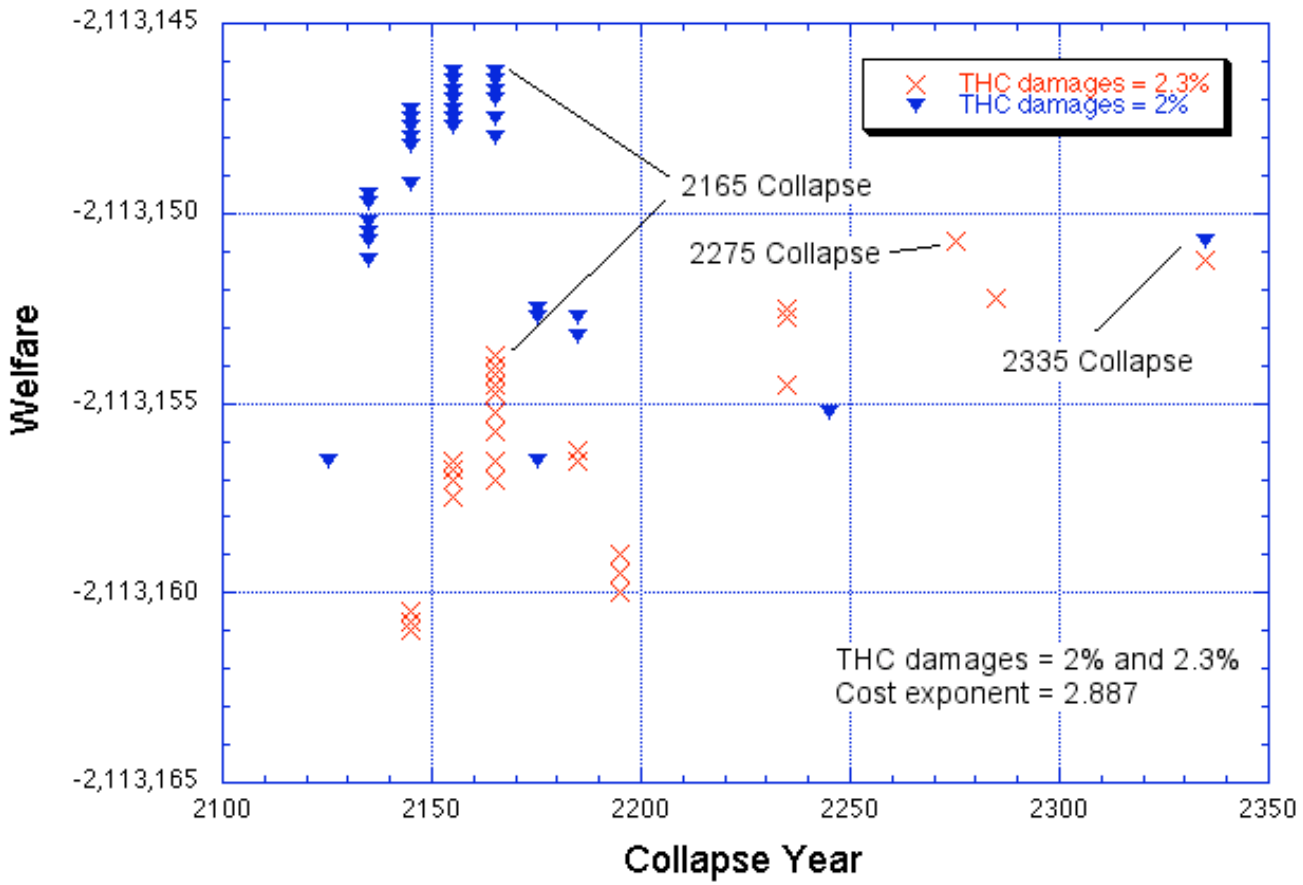
***Source: Keller (2003)***

# *Optimal Path for One Set of Assumptions*



# *Level Sets Suggest These Solutions Come From One of Two Local Optima*

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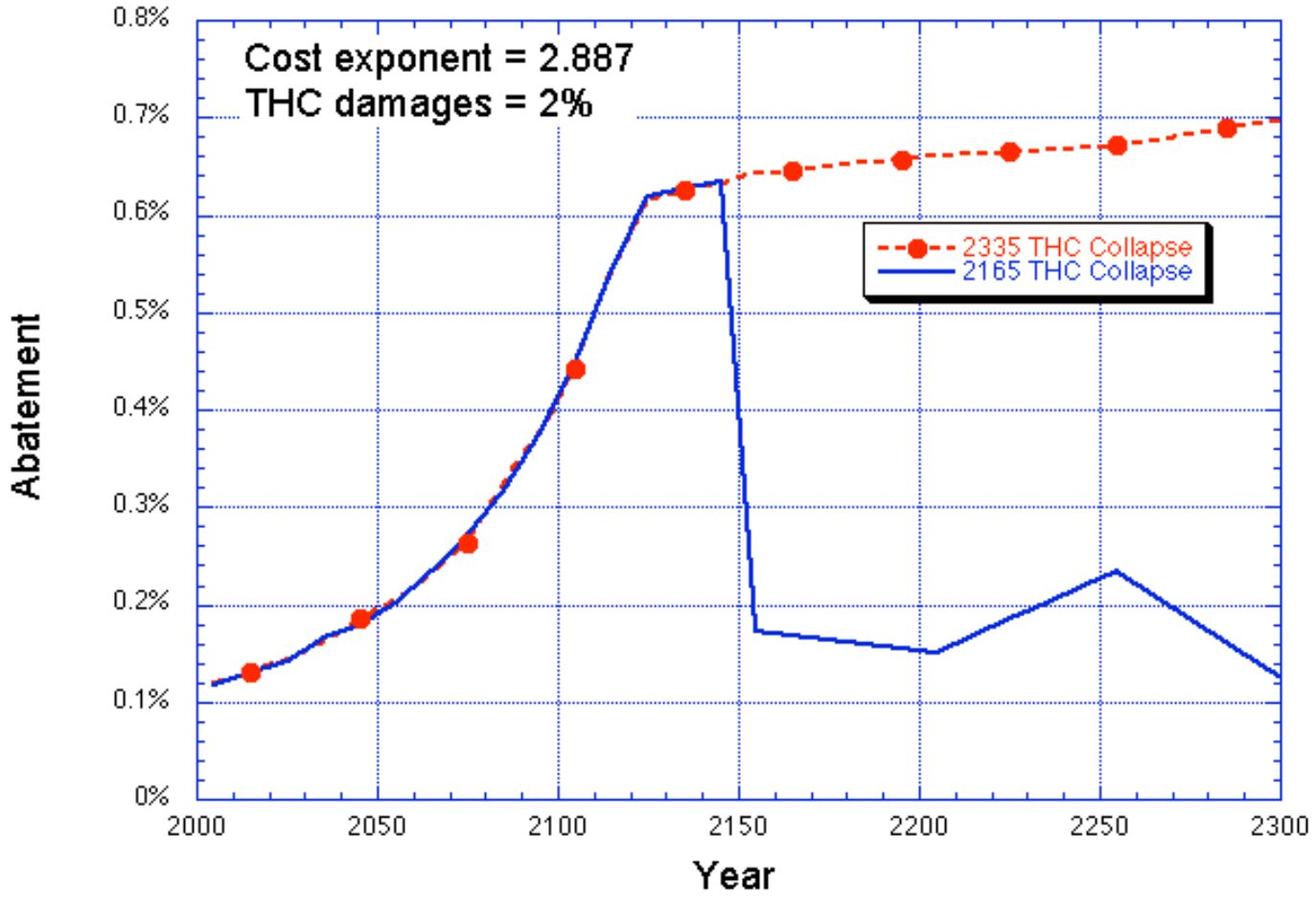
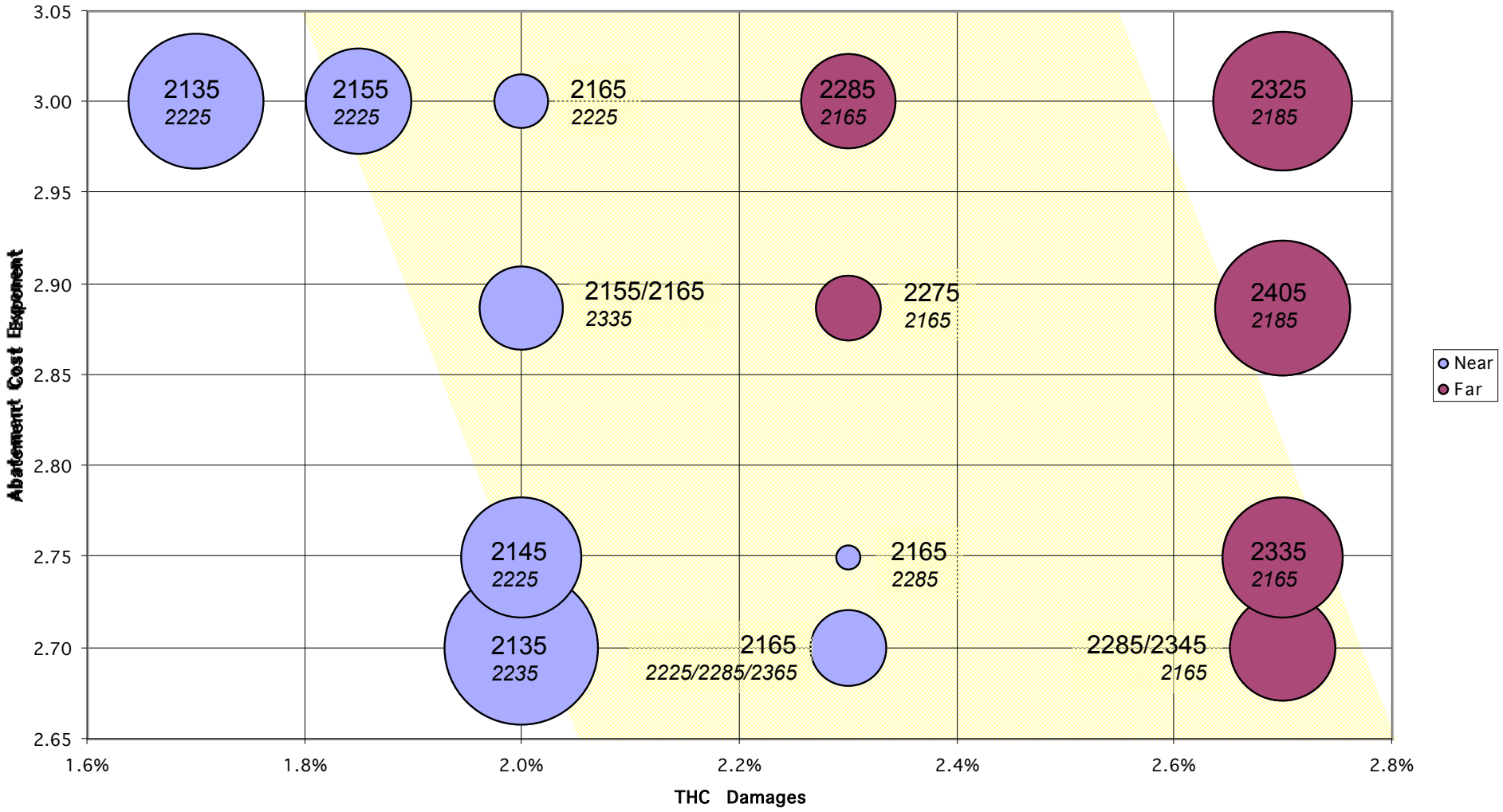
# *Two Paths with Nearly Equal Performance*



# *Regions of Parameter Space Where Optimal Policies Can Be Very Sensitive to Assumptions*

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# *Simple Example Explores Implications of Uncertain Thresholds for Abrupt Change*

**Example: What near-term actions will help ensure strong economic growth and a healthy environment over the course of the 21st century?**

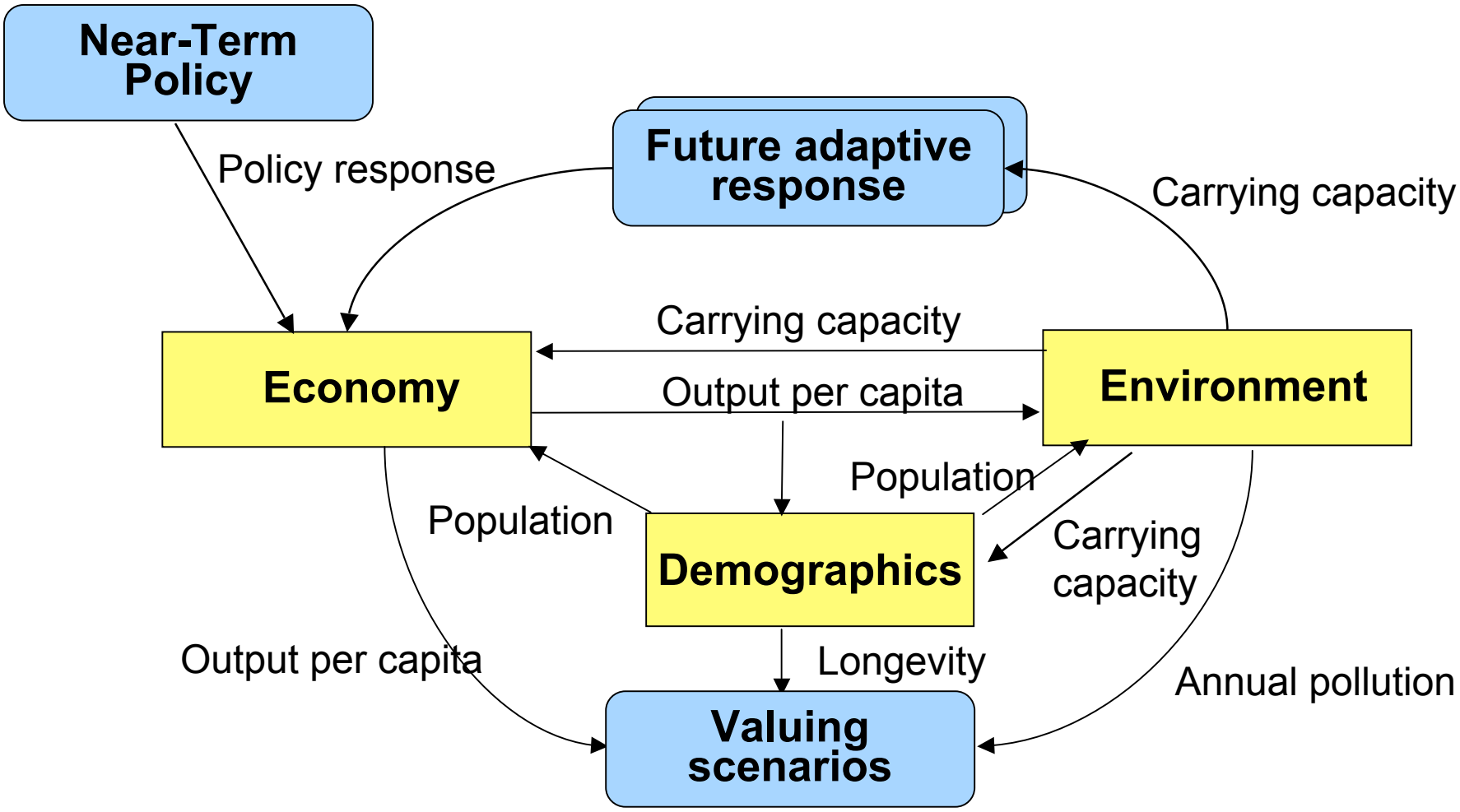
Used "Toy" systems-dynamics model with

- Emissions threshold which triggers rapid decline in environmental "carrying capacity"
- 41 input parameters representing uncertainties about
  - future economic, demographic, and environmental trends
  - values and capabilities of future decisionmakers
- Near-term strategies affect "decoupling" rate



Lempert, Popper, and Bankes, 2003: Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis, RAND, MR-1626-CR

# *Scenario Generator Links Near-Term Actions to Outcomes*

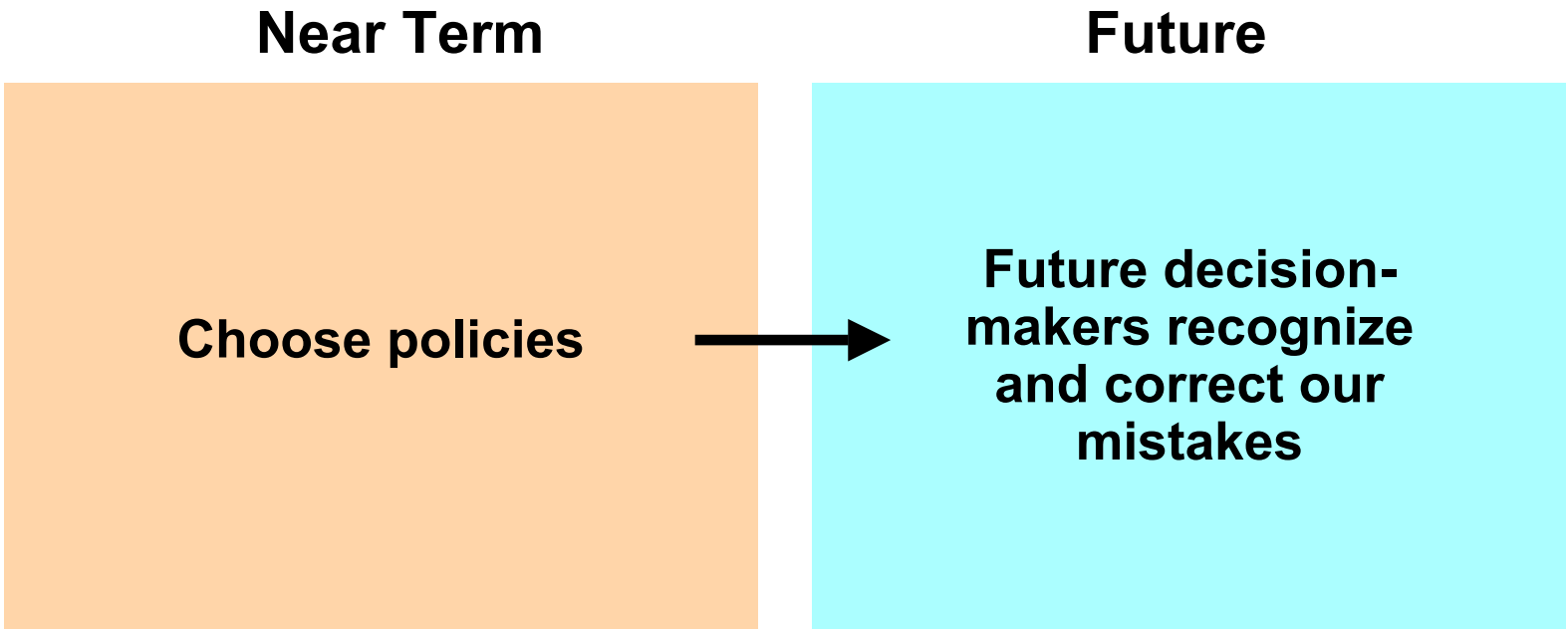




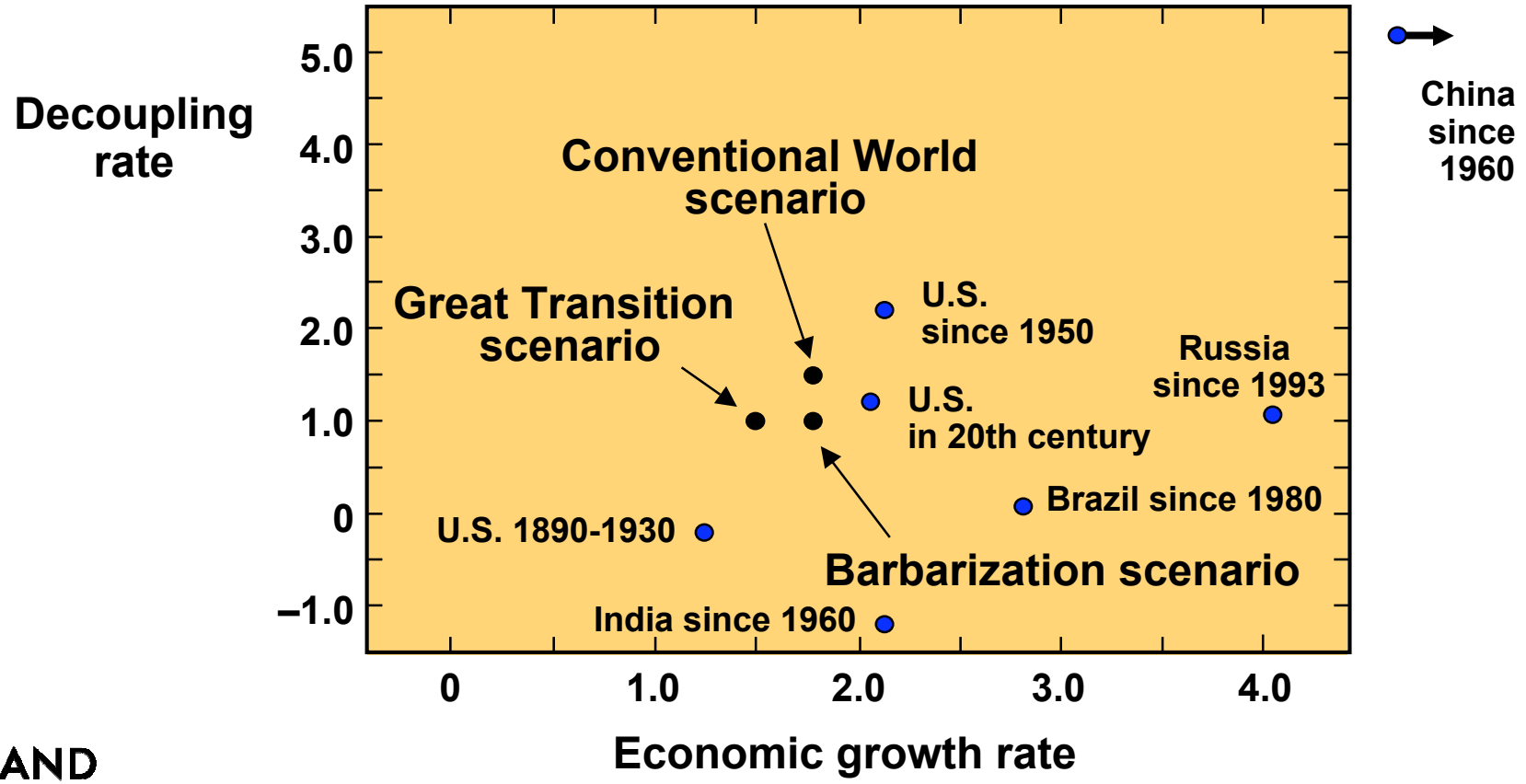

Two regions: OECD and other

# *Compare "Fixed" Near-Term Strategies Across Scenarios*

**Assume near-term policy continues until changed by future generations**



# *Strategies Must Address a Wide Range of Plausible Futures*

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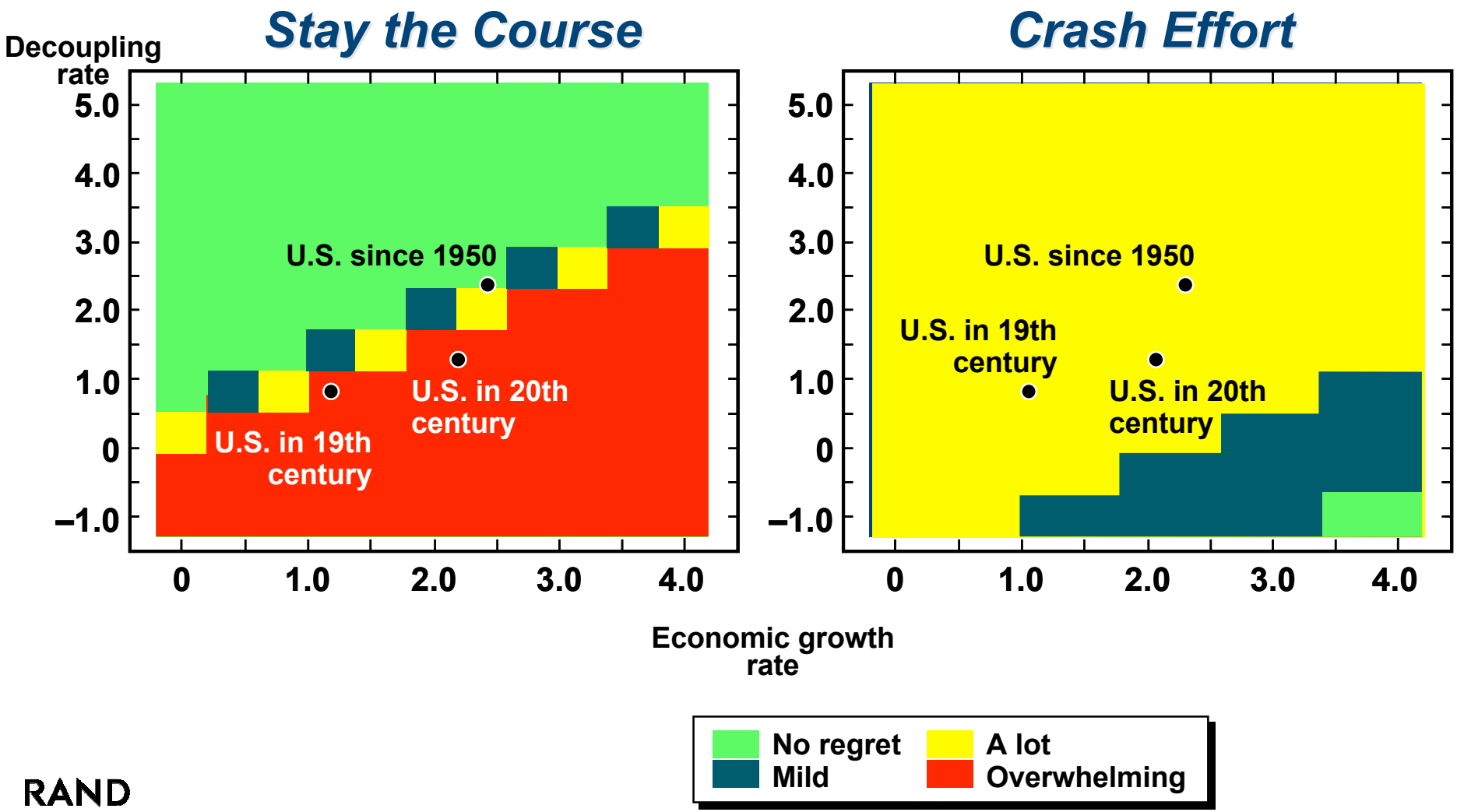
# Exploration Demonstrates No "Fixed" Strategy Is Robust

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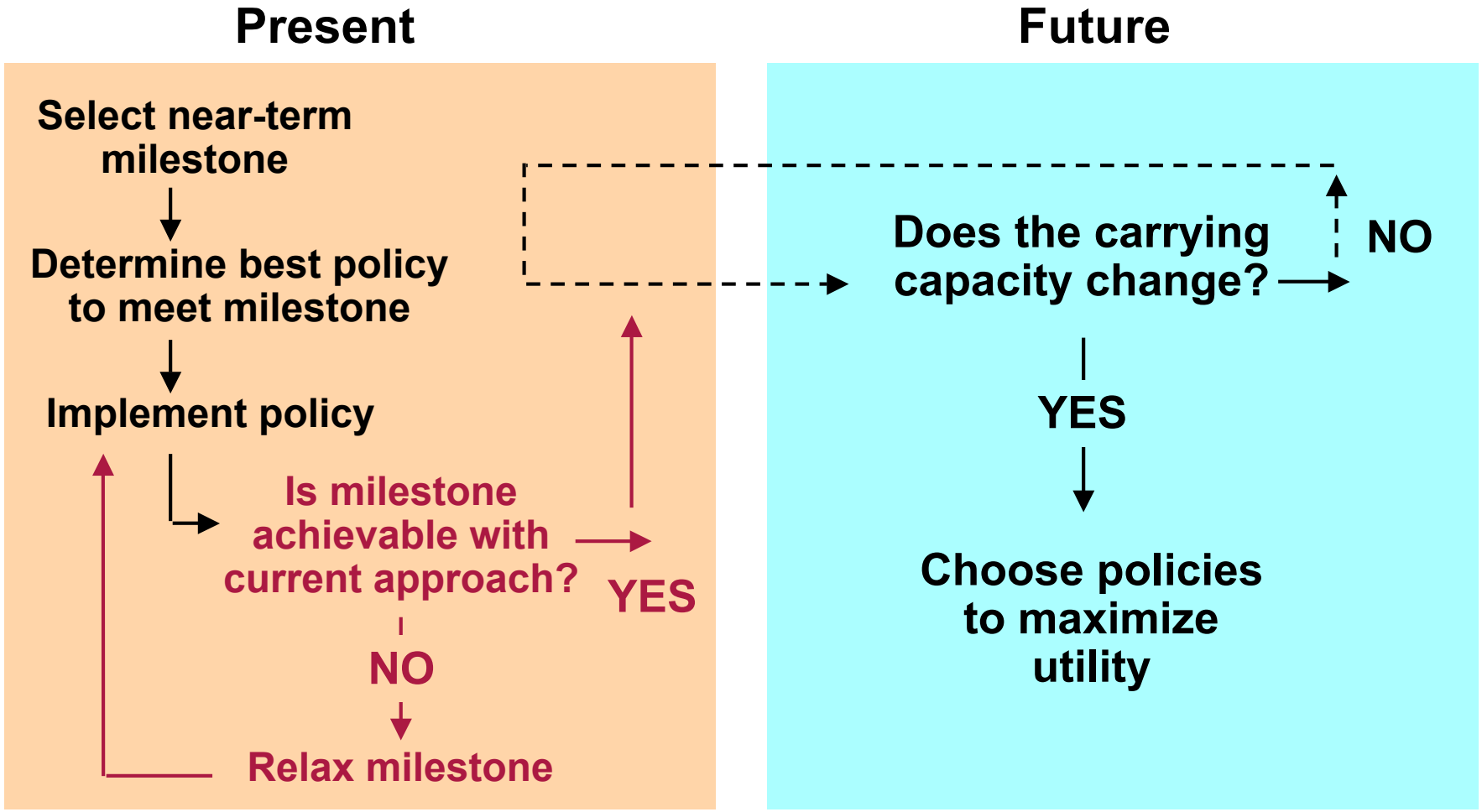
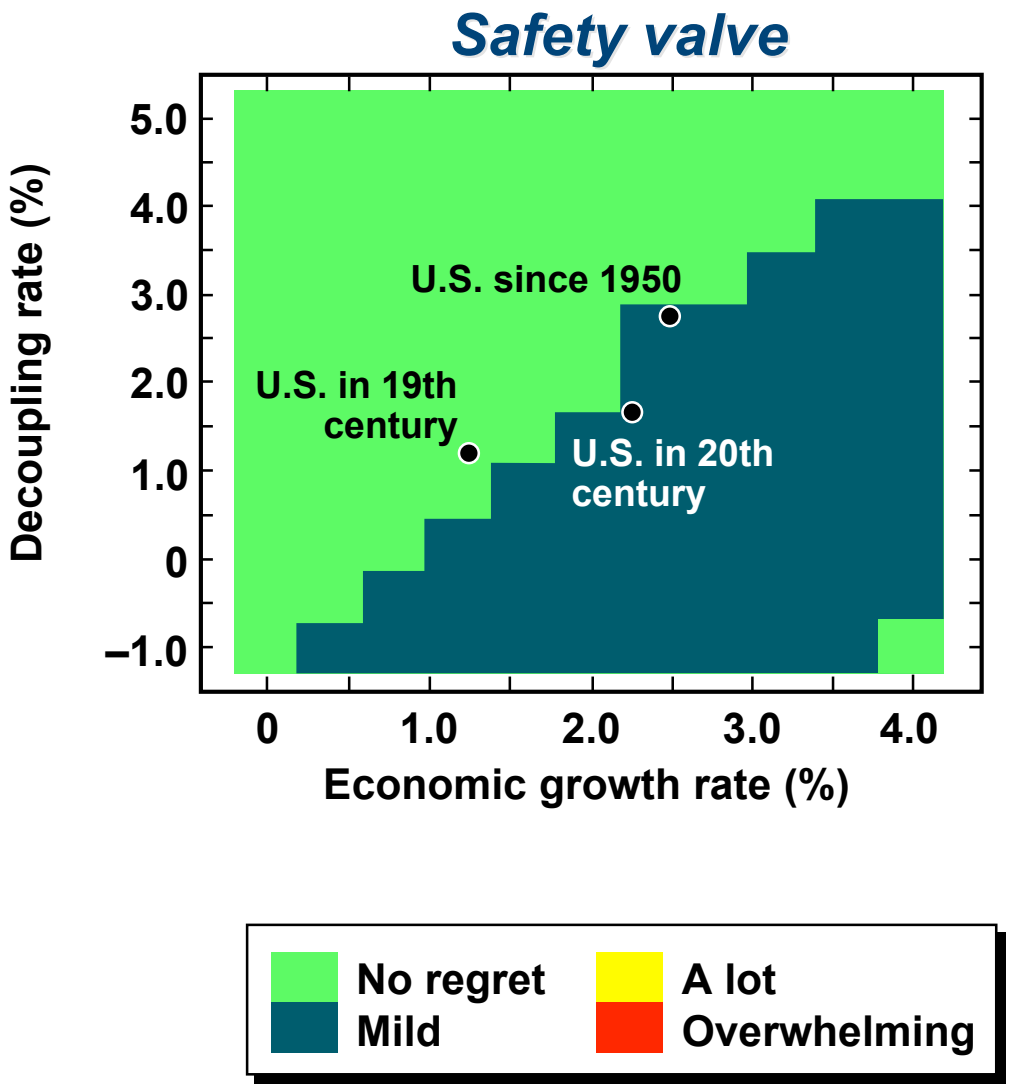
# *Start with a Milestone, but Evaluate Progress Early and Modify Milestone If Necessary (Safety Valve)*



# "Safety Valve" Strategy Appears Highly Robust

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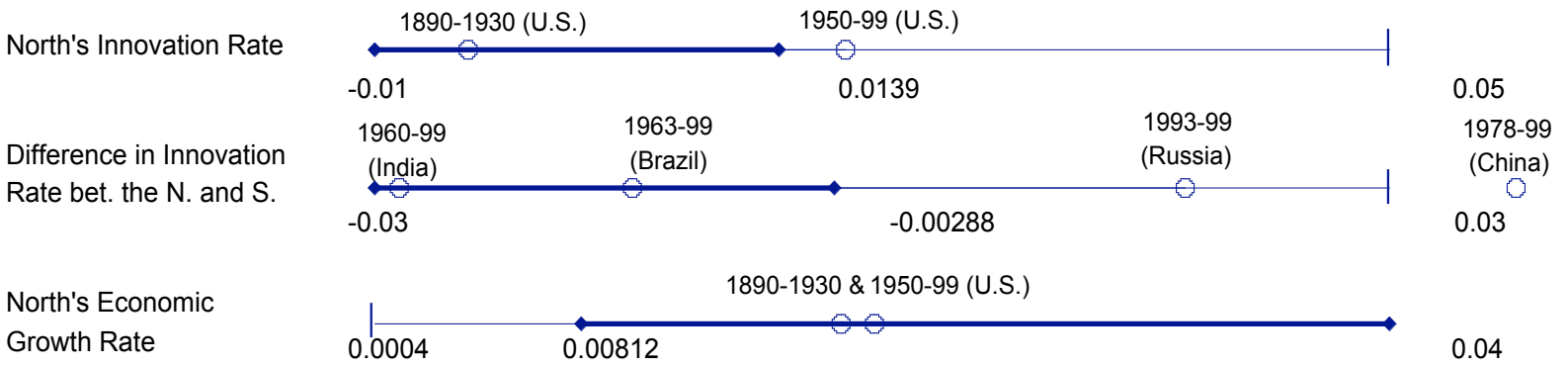
# *What Uncertainties Are Most Important?*

- Key question – where does candidate robust strategy fail?
- Initial scan suggests most robust strategy is “Safety Valve” with stringent near-term emissions intensity milestones & cost thresholds
- “Data-mining” method identifies low-dimensional, easy-to-interpret region of input parameter space where strategy performs poorly
- Decisionmakers should focus attention on this “Low Global Decoupling” scenario

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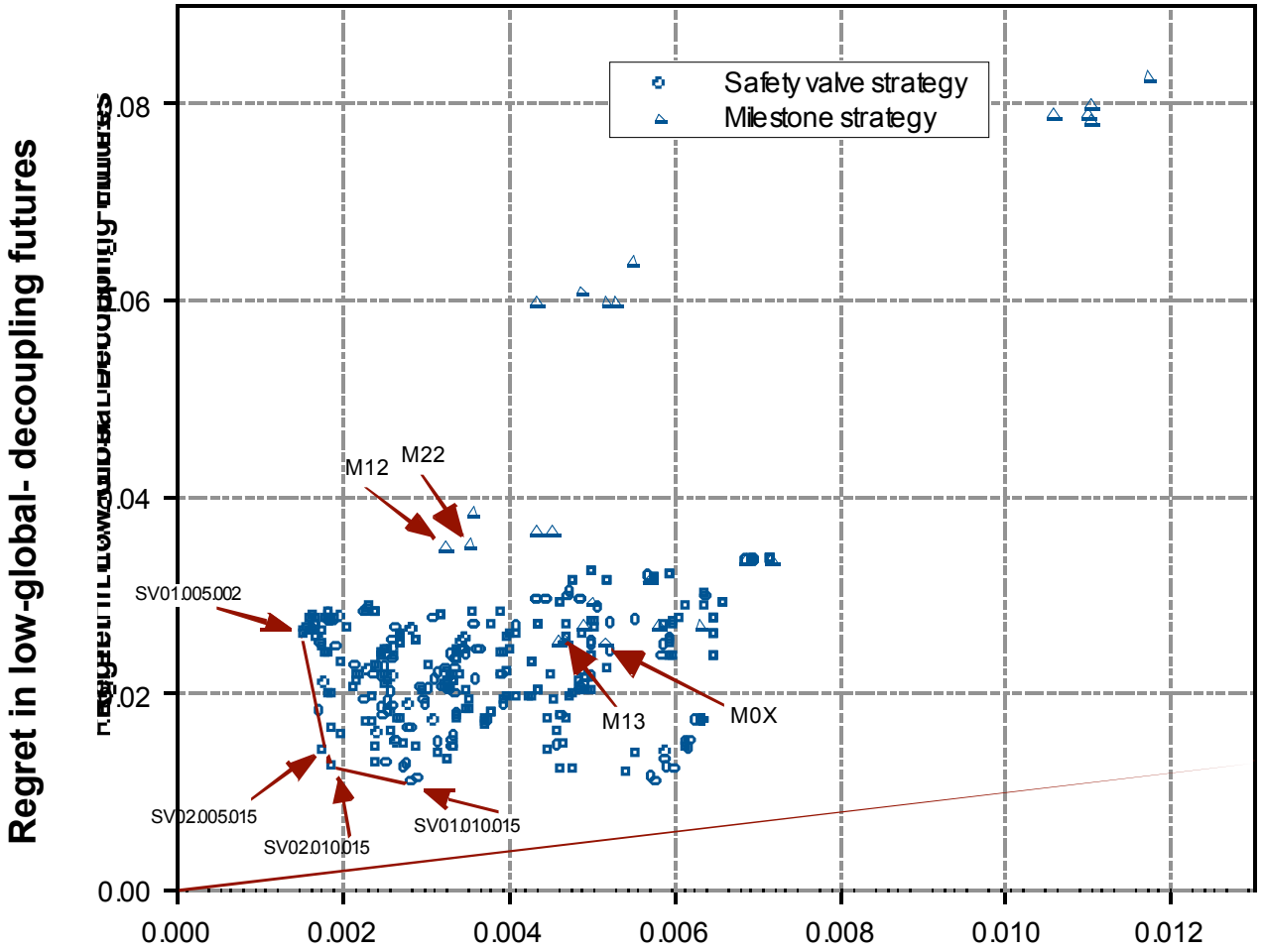
# *What are Best Strategies to Hedge Against These Vulnerabilities?*

**Assessment of strategies over two computer-generated scenarios**

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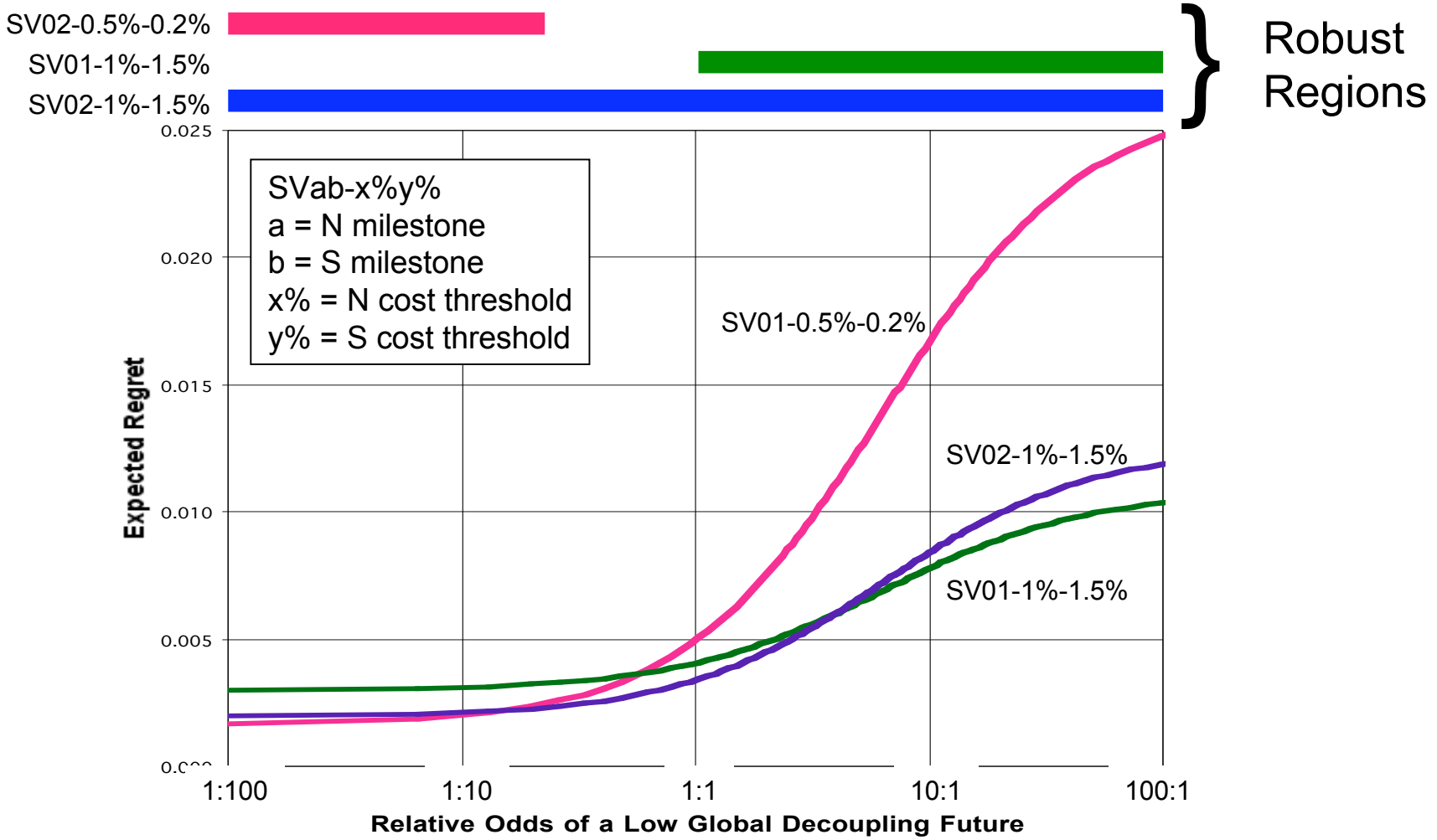
# *Analysis Suggests Design of Robust Adaptive Strategy*

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# *Note Robust Strategy Does Not Depend on Level of Threshold for Abrupt Change*

- **Model assumes future decision makers have (an uncertain) ability to detect and respond to changes in carrying capacity**

- **Robust near-term strategy sufficiently slows pollution growth so future decision makers can respond successfully to changes they detect**
  - **Position of threshold relatively unimportant to such strategies**
  - **Capabilities of future decision makers relatively more important**

***Results for climate policy may be different***

# *Addressing Surprise*

- **Results based on exploration over model parameters (and some structural uncertainty).**

  ***But what if we are examining the wrong model?***

- **We challenged group of experts to suggest plausible "surprises" which would cause the candidate strategy to fail**

- **Exploration over the results of these new models suggested robust strategy still performed well**

# *Summary*

- **Decision framework of robust strategies can help assess alternative policies even when there are large uncertainties in our understanding of the underlying physical and other relevant systems.**
  - **Key idea: design policy strategy whose good performance is relatively insensitive to key uncertainties and then characterize residual vulnerabilities**

- **The most important scientific information for the design of robust strategies may be different than the most important information for the advance of science**
  - **Range of outcomes, thresholds, prediction vs. detection, value of information, etc.**

- **Robust decision and other appropriate decision frameworks may help communicate deeply uncertain scientific information to policy makers**