A New Decision Science for Complex Systems: A Decade of Enabling Tools

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with Steven Popper, David Groves, Jordan Fischbach, and Nidhi Kalra

Systems Analysis 2015 Conference
IIASA
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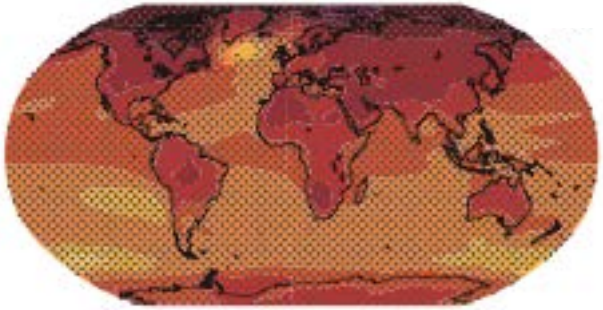
How Can Systems Analysis Best Support Solutions to Really Hard Problems?

Water Resources

Energy



Climate change

Defense

Coastal Protection

Economic policy

These Challenge All Offer Examples of "Wicked Problems"

Characteristics of "wicked" problems include:

- Not well bounded,
- Framed differently by various groups and individuals,
- Large to existential scientific uncertainties,
- Non-linear dynamics, and
- Not well understood until after the formulation of a solution

People often:

- Are overconfident
- Take actions inconsistent with their longer-term interests
- Avoid acknowledging tradeoffs
- Employ decision making heuristics inappropriate for their situation

Kahneman (2011)

Our world displays heterogeneity and deep uncertainty, that is:

- Diversity of priorities, goals, and values
- Irreducible uncertainty regarding consequences of our actions

Sen (2009)

People often judge information and potential policy responses by their perceived consistency with ethical values and group identify

These "bugs" in human judgment suggest decision support tools are useful

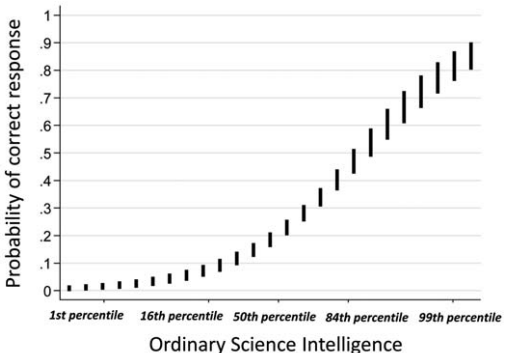
These features of the world suggest that decision tools designed for simple problems can fail for "wicked ones"

Climate-Related Decisions Don't Always Suffer From a Lack of Information

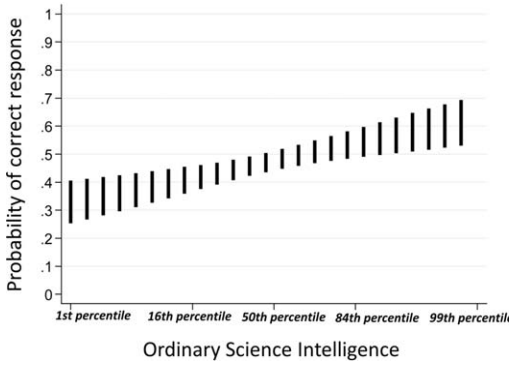
Public understanding of science as function of "scientific intelligence"

What gas makes up the majority of Earth's atmosphere?

[Hydrogen, Nitrogen, Carbon Dioxide, Oxygen]



There is "solid evidence" of recent global warming due "mostly" to human activity such as burning fossil fuels



Kahan, D.M., *Climate-Science Communcation and the Measurement Problem.* Advances in Political Psychology, 2015. 36

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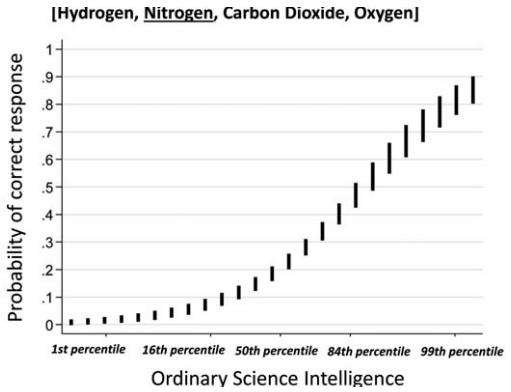

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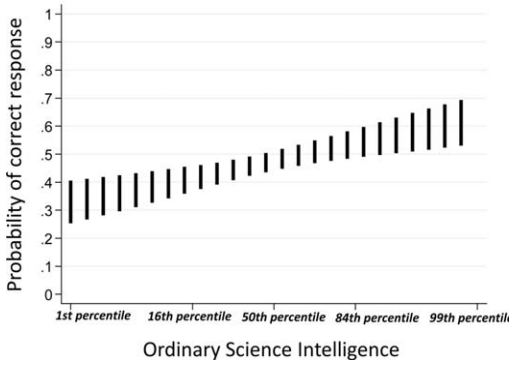
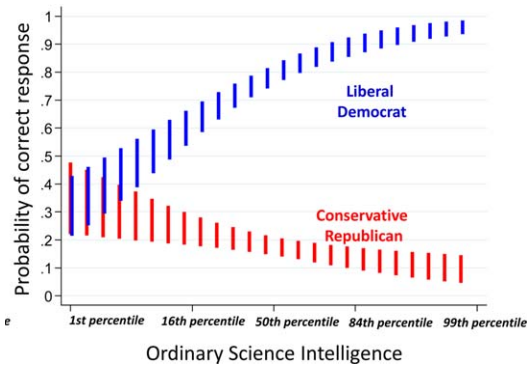
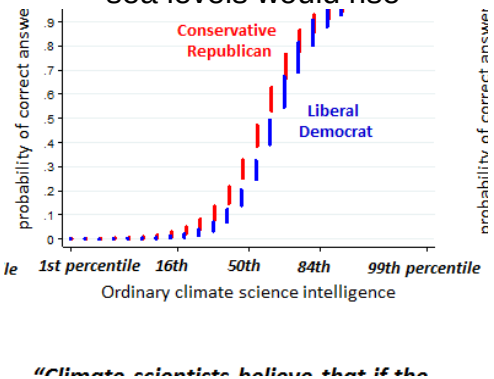




Climate scientists believe that if the North Pole icecap melted as a result of human-caused global warming, global sea levels would rise



Kahan, D.M., *Climate-Science Communication and the Measurement Problem.* Advances in Political Psychology, 2015. 36

Increased Understanding of Decision Support Processes Allows More Effective Use of Models

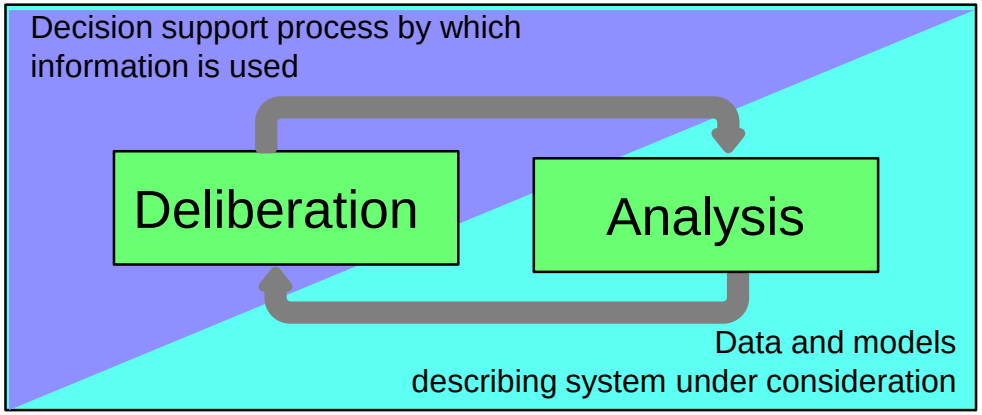
Decision support:

- Represents organized efforts to produce, disseminate, and facilitate the use of data and information to improve decisions
- Includes as key elements:
  - Recognition that decision processes are at least as important as decision products
  - Co-production of knowledge between users and producers
  - Institutional stability (important for building understanding and trust)
  - Design for learning

NRC (2009)

For example, “deliberation with analysis” process appropriate when preferences evolve during interactions with other people and analytics

Participants in decision define objectives, options, and other parameters



Participants work with experts to generate and interpret decision-relevant information

New analytic capabilities enable use of models in new ways

- We can increasingly use models as exploratory, rather than consolidative…

- Exploratory models:
  - Map assumptions onto consequences, without privileging any one set of assumptions
  - Support inductive reasoning

- Consolidative models:
  - Gather all relevant knowledge into a single package which, once validated, can be used as a surrogate for the real world
  - Support deductive reasoning

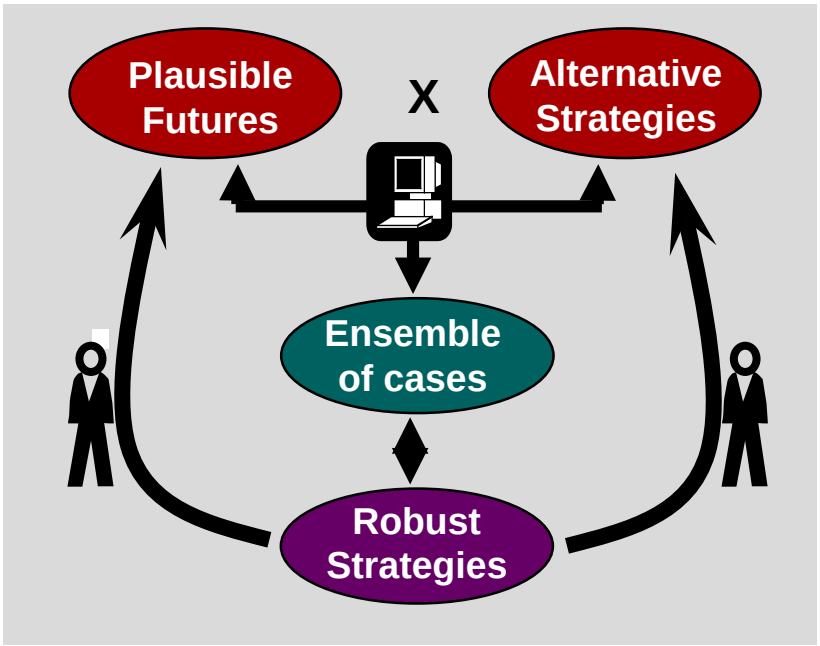
- Using new analytic capabilities such as:
  - Inexpensive, fast computing
  - Interactive visualizations
  - Classification (scenario discovery) algorithms
  - Multi-objective (robust) optimization

Bankes (1993)

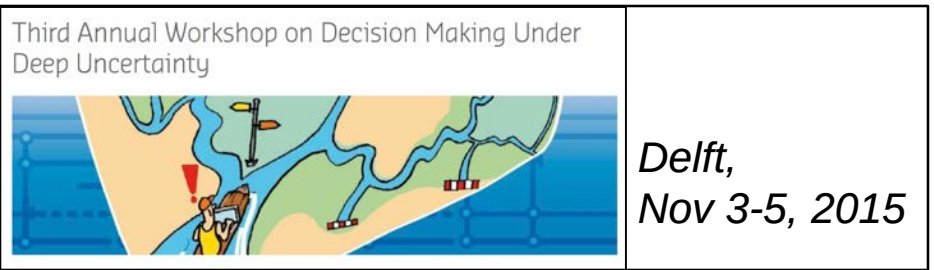
Key Principles for Decision Support Under Conditions of Deep Uncertainty

- Consider a **multiplicity** of plausible futures
- Seek **robust**, rather than optimal, strategies
- Seek robustness with **adaptive** strategies that evolve over time in response to new information
- Use computer to **facilitate discourse** among humans, not to dictate conclusions

Seek to combine human and machine capabilities,
To provide a "prosthesis for the imagination"



Lempert, Popper, Bankes (2003)

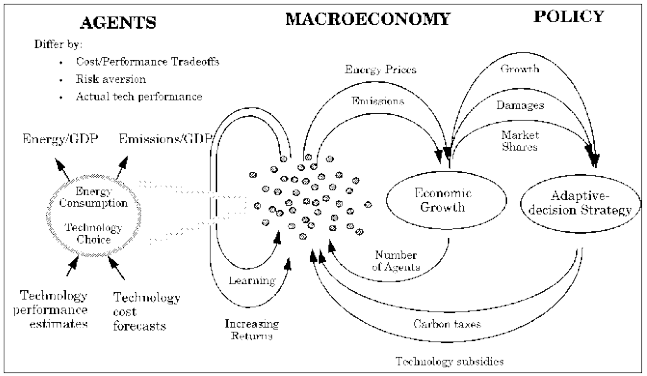


Outline

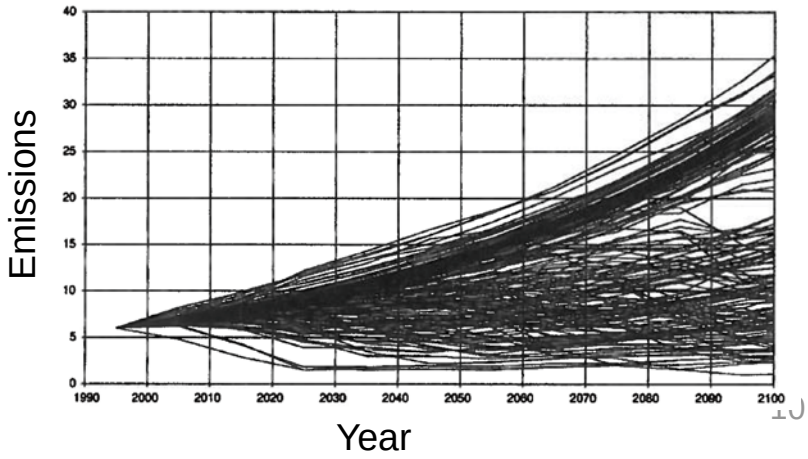
- **Initial explorations**
  - **Carrots and sticks for low carbon technology (2000)**
- **New tools**
  - **Terrorism risk insurance (2007)**
- **Current state of the art**
  - **Colorado basin management (2012)**
  - **Policy persistence (2015)**
- **Next Steps**

In 2000, Applied Exploratory Modeling to Simple Agent-Based Model of Technology Diffusion

- Policy question: What mix of policies (price instruments and focused subsidies) best promotes low carbon technologies?
  - Heterogeneity of agents and potential broad social benefits generated by early adopters seem important to this question
  - ABM can represent these attributes



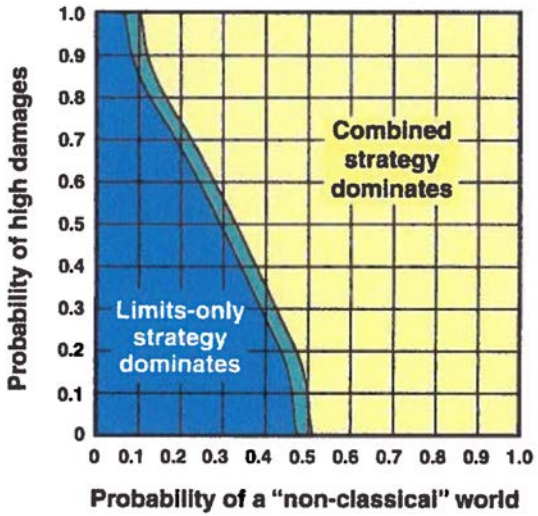
- Generated a large ensemble of models runs
  - All runs consistent historical record
  - But nonetheless follow diverse paths into the future



Robalino and Lempert (2000). "Carrots and Sticks for New Technology" Integrated Assessment 1(1): 1-19.

Can Generate Policy Relevant Arguments from Such Exploratory Models

1. Consider two strategies:
   - Price instruments only
   - Price instruments combined with technology subsidies
2. Stress test over ensemble of futures (six dimensions of uncertainty)
3. Identify low dimensional combinations of uncertainties most important in affecting choice between strategies, which are:
   - Size of climate impacts
   - Size of social benefits of early adoption not captured by early adopters
4. Run search looking for counter examples while writing paper



Offered as template for means to generate policy-relevant results with exploratory models

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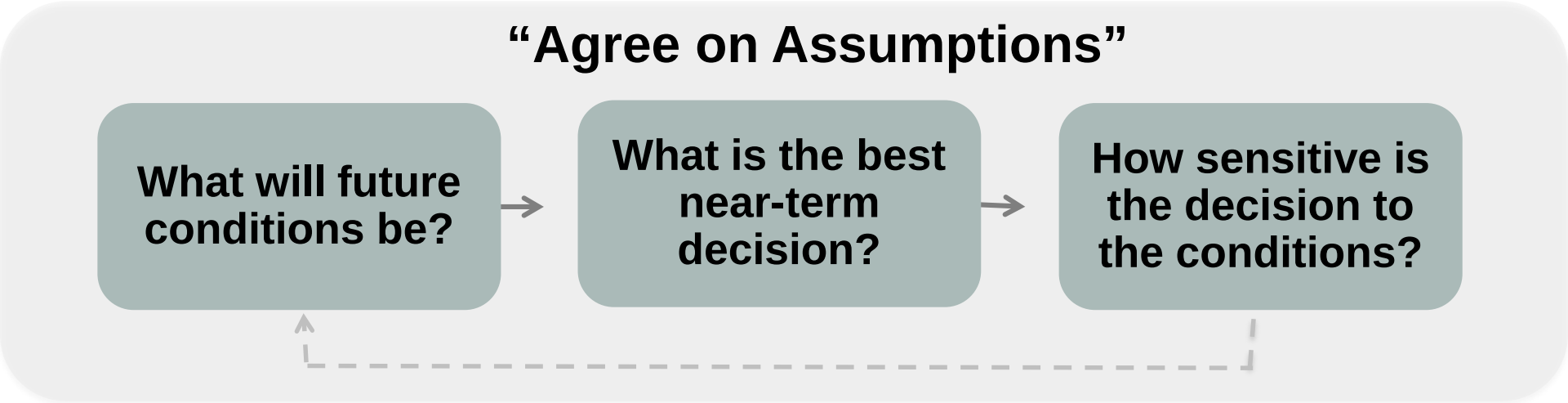
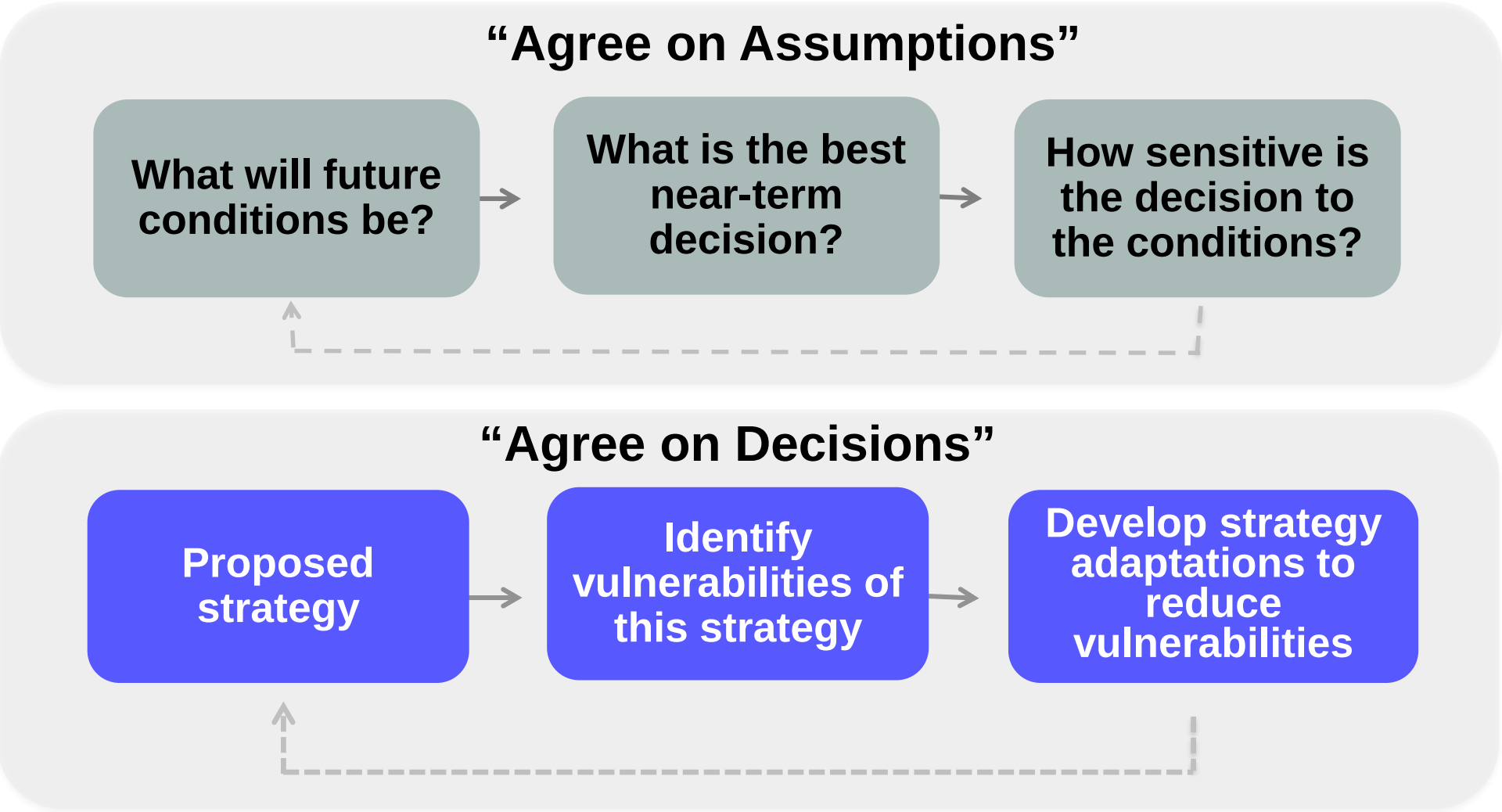
Traditional Risk Management Methods Work Well When Uncertainty is Limited



But under conditions of deep uncertainty:

- Uncertainties are often underestimated
- Competing analyses can contribute to gridlock
- Misplaced concreteness can blind decisionmakers to surprise

Under Deeply Uncertain Conditions, Often Useful To Run the Analysis "Backwards"



Kalra, N., S. Hallegatte, R. Lempert, C. Brown, A. Fozzard, S. Gill and A. Shah (2014). Agreeing on Robust Decisions: A New Process fo Decision Making Under Deep Uncertainty. WPS-6906, World Bank.

Backwards Analysis Often Focuses on Supporting Decision Structuring Tasks

	Decision Structuring Tasks	Choice Tasks
Forward analysis	Framing often an input to the analysis	Strong focus on defining and identifying rational choice
Backwards analysis	Framing is an output of the analysis	Choice left to decision makers

Thanks to Casey Helgeson, LSE

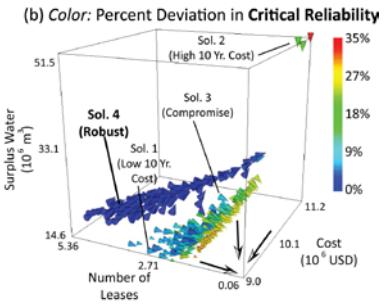
Decision structuring tasks include defining the problem in a way that opens it up to thoughtful consideration, defining the objectives to be achieved, and assembling a menu of options that might achieve those objectives.

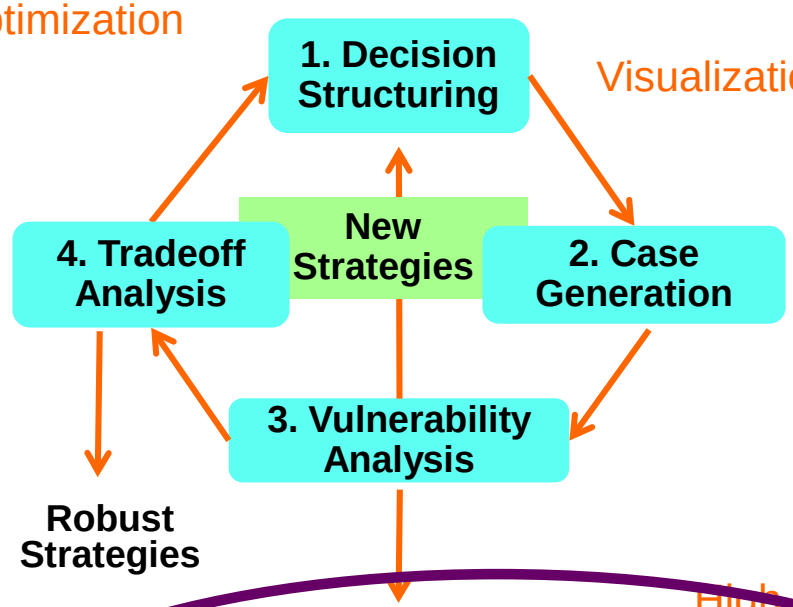
Choice tasks that include selecting the best decision among a menu of available options given estimates of their consequences.

Emerging Computational Tools Faciliate This Type of Decision Support

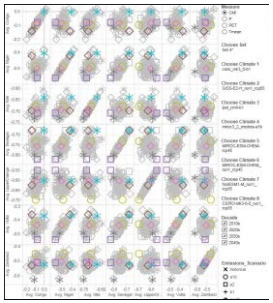
Robust Decision Making (RDM), a "backwards' analysis, is an iterative, quantitative decision support methodology often used to facilitate deliberation with analysis

Multi-objective (robust) optimization

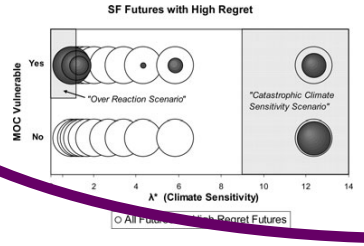




Visualization



High performance computation

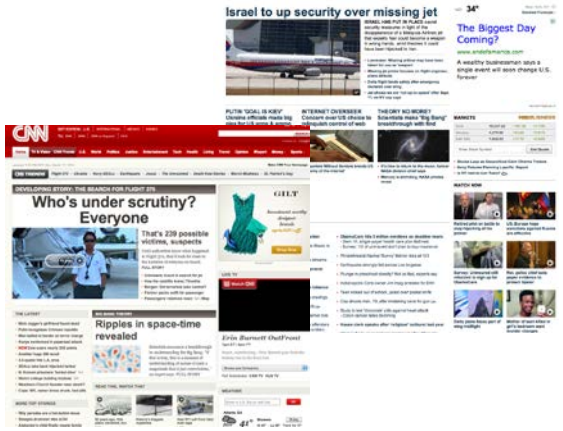


Analytic methods to suggest scenarios

- Scenario discovery
- Scenario diversity

Scenarios Address Cognitive Barriers That Complicate Effective Decisions Under Uncertainty

Over-confidence



Uncertainty absorption

Strategic use of uncertainty

Schoemaker (1993)

But Scenarios Can Prove Ineffective in Decision Support Processes

Ambiguity and Bias

Illusion of Communication

Relevance and Context

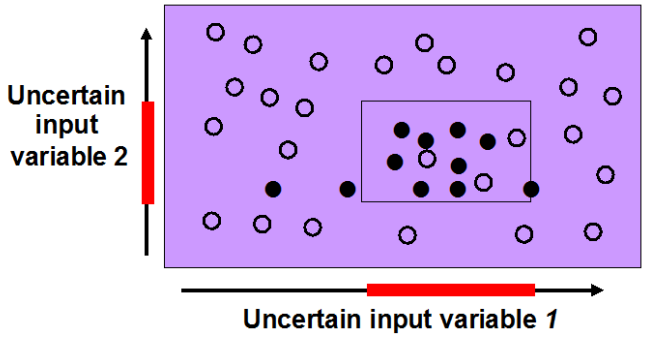
Surprise

Lempert (2013)

With Scenario Discovery, Policy-Relevant Scenarios Emerge From Analysis

1. Generate large, multi-dimensional database of simulation model runs

2. Use classification algorithms to find interpretable (low dimensional) clusters of policy-relevant cases



Maximize coverage, density, and interpretability

Density

Coverage

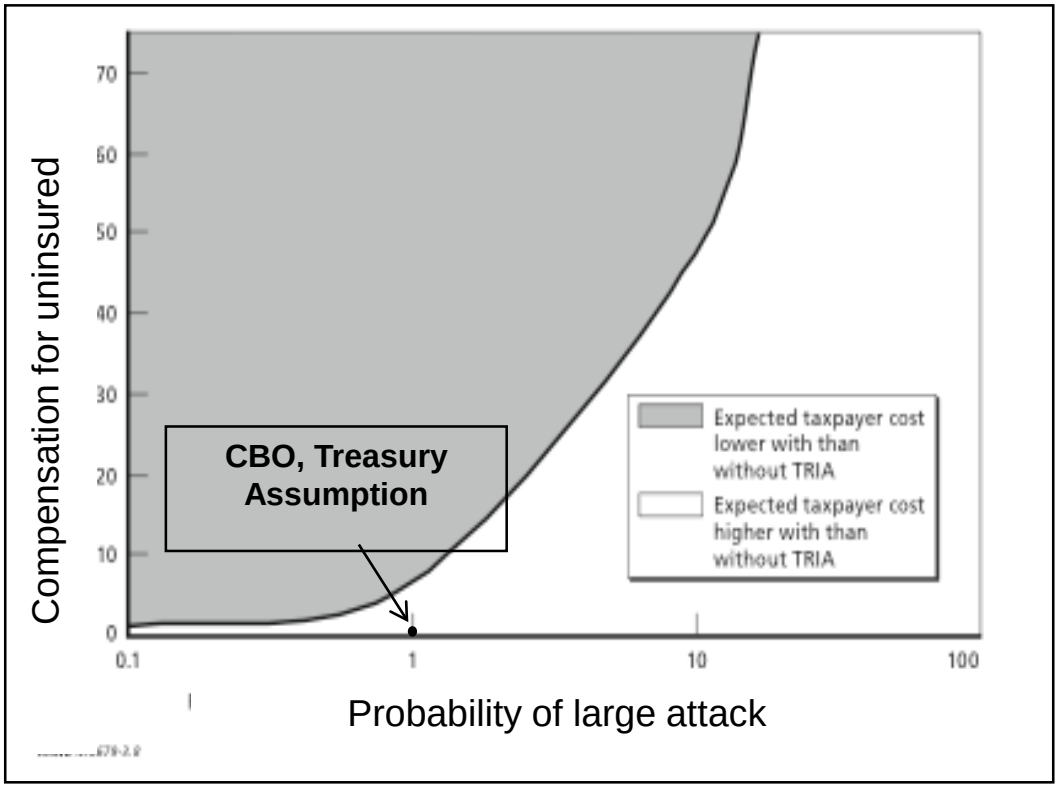
3. Resulting scenarios often provide effective decision support

See IQ SCENE workshop (http://www.wholesem.ac.uk/iq-scene/iq-scene) and forthcoming special issue of Environmental Modeling and Software

For Example, This Approach Proved Useful in RAND Study of Terrorism Insurance

In 2007, US Congress debated re-authorizing U.S. Terrorism Risk Insurance Act (TRIA). RAND study and its scenarios:

- Cited on floor of US Senate by a proponent
- Called "insidious" by opponents
- Usefully informed Congressional debate



Scenario discovery identified these parameters as most important among over a dozen uncertain model parameters

Note that this scenario:

- Remains consistent with official US Government forecasts, but suggests why other answers are (more than) possible
- Mixes uncertainty regarding states of the world with uncertainty regarding probabilities
- Mixes external and internal drivers

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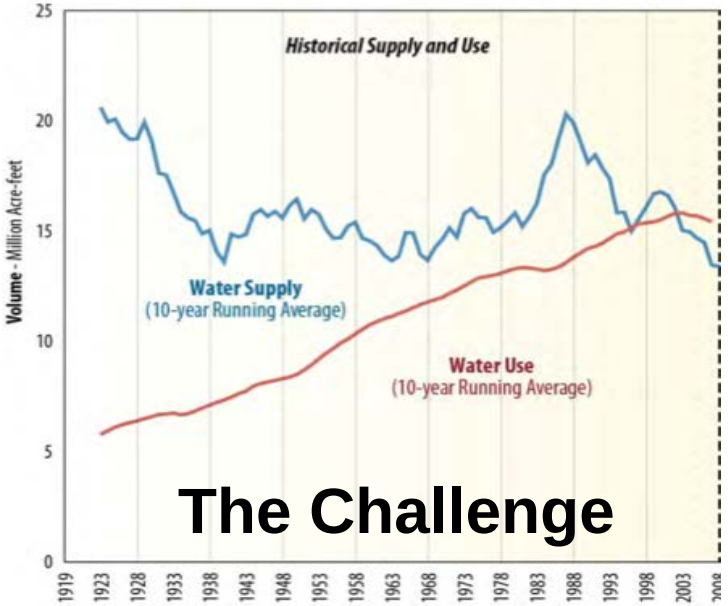
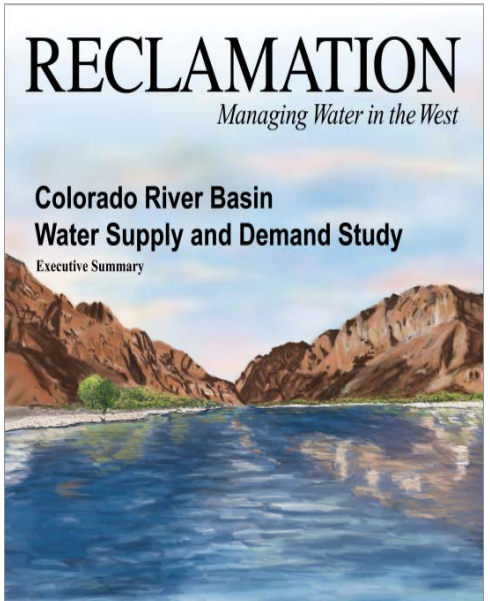
Used Robust Decision Making to Facilitate Management of Colorado Basin

In collaboration with seven states and other users, Bureau of Reclamation:

- Assessed future water supply and demand imbalances over the next 50 years
- Developed and evaluated opportunities for resolving imbalances



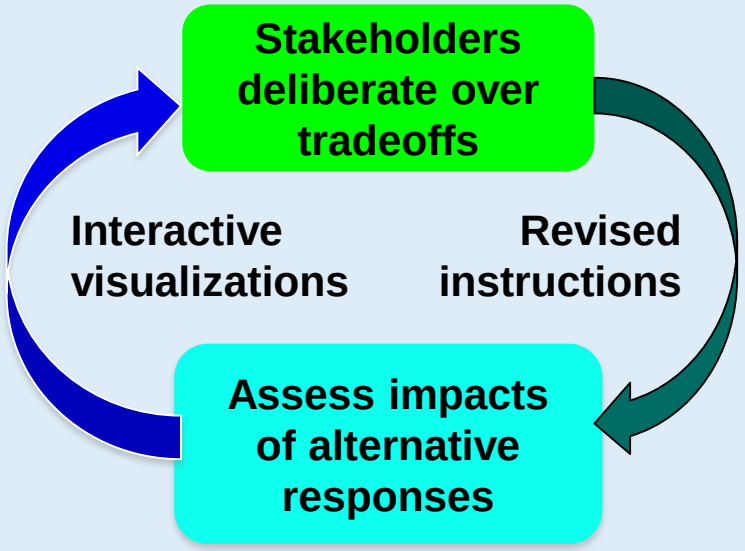
The Study



Embed Analytics in "Deliberation with Analysis" Process of Stakeholder Engagements

Deliberation with analysis

Dozens of workshops with many stakeholders over two years



Planning Tool and Risk Assessment Model

Analysis:

- Stress test strategies over 24,000 alternative paths into the future
- Identifies scenarios that illuminate vulnerabilities of strategies
- Suggests portfolios of response options robust over a wide range of futures.

Groves, Fischbach, Bloom, Knopman and Keefe (2013). RAND RR242

Analysis Employs Complicated (But Not Complex) Systems Models

Strategies
- Current management plan
- Adaptive response strategies
  - Hundreds of distinct options
  - Organized as act, monitor, respond adaptive strategies

Uncertainties (24,000 futures)

Climate projections (1,000)
- Recent historic
- Paleo records
- Model projections
- Paleo-adjusted model projections

Several demand projections

Behavior of future decision makers

Large scale hydrological simulation model:
RiverWare™ (CADSWES)

Outcomes
- 26 measures of environmental, economic, water supply, energy, and recreational performance

Analysis Illuminated Vulnerabilities of Plans and Helped Identify Responses

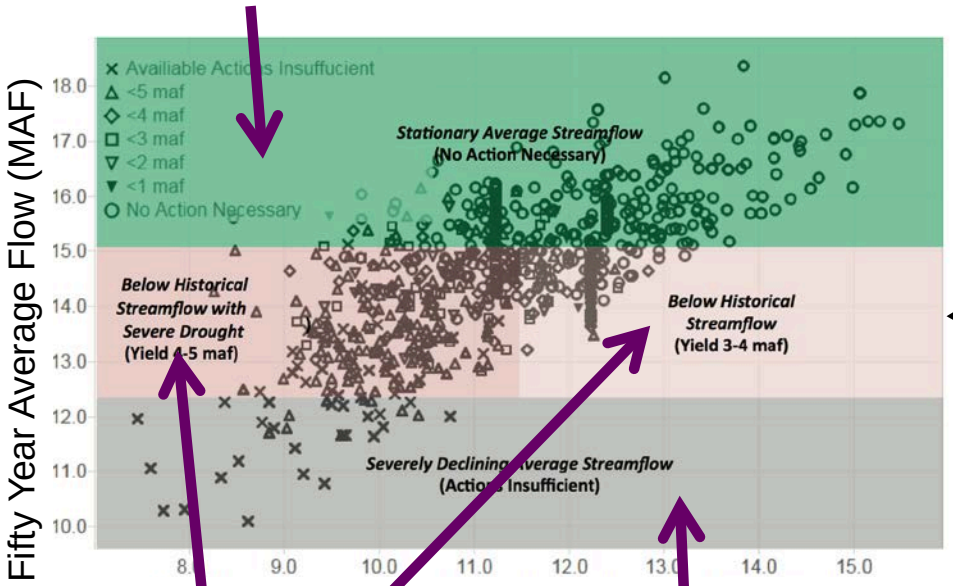
Key drivers of vulnerability for current river management plan are both climate-related:

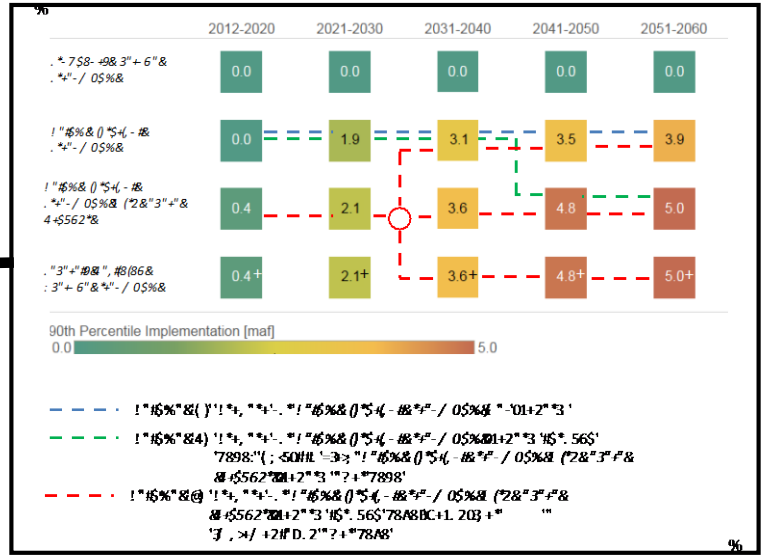
- Fifty year average river flow
- Driest eight year period

Analysis suggests rule-based adaptive strategies, which include:

- **Near-term actions**
- **Trends to monitor**
- **Contingency actions**

Business as Usual





Two Adaptive

Transformative

Bloom (2014)

Haasnoot, M., J. H. Kwakkel, W. E. Walker and J. ter Maat (2013). Global Environmental Change 23(2): 485-498.

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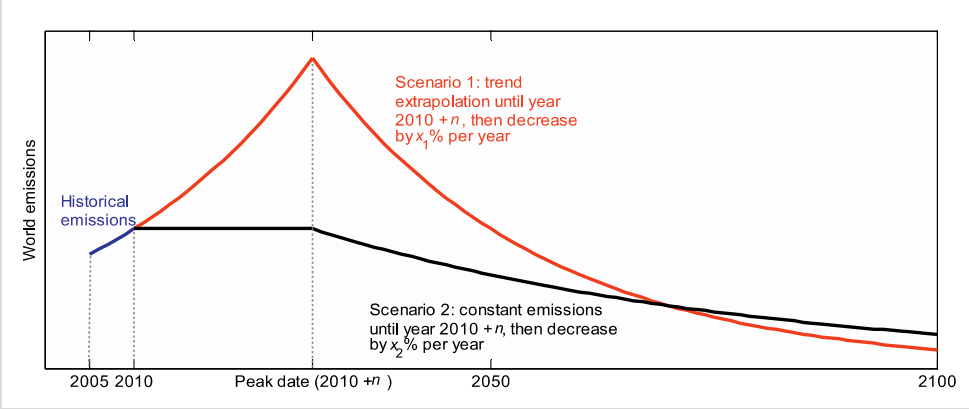
Significant Gap Between Climate Action and Aspiration

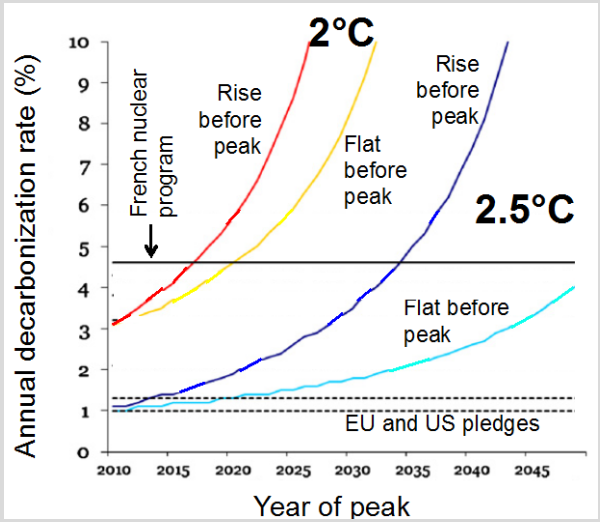
- **Historically fast decarbonization rate needed to reach policy goal of not more than 2° C warming**
  - **Few current policies seem consistent with such a rate**

Imagine emissions peak in n years



Guivarch & Hallegatte (2012) "2C or not 2C?"
Global Environmental Change

How fast do emissions need to fall after the peak?



In addition, many analyses focus on policies (e.g. long-term targets or emission reduction paths) not under the control of any current policy makers

Some Policy Makers Appear to Understand These Challenges

Pres. Obama on Paris Talks in recent Rolling Stone interview:

"I'm less concerned about the precise…country targets [because] a percent here or a percent there…is not going to be a deal-breaker….

"There will be a momentum…People, I think, will be not as fearful of the consequences or as cynical about what can be achieved. Hope builds on itself. Success breeds success."

Can we say anything more systematic about "momentum"?

Why Do Some Reforms Persist Over Decades While Others Do Not?

- **Occasionally forces align and policy makers have a window of opportunity to make a large policy change**
- **Sometimes these changes persist over time -- sometimes they don't**

Persist

- **Social security**
- **Voting rights**
- **Airline deregulation**

Don't Persist

- **Tax reform**

Patashnik (2003) "After the public interest prevails: The political sustainability of policy reform", Governance.

Reforms that Persist Often Create Constituencies that Support Them

Persist

- **Social security** ✓
- **Voting rights** ✓
- **Airline deregulation** ✓

Retirees

New voters

Airlines with operations well-suited to deregulated environment

Don't Persist

- **Tax reform**

X

How might this mechanism help in the design of greenhouse gas emissions policies?

Isley, Lempert, Popper, and Vardavas (2015). "The effect of near-term policy choices on long-term greenhouse gas transformation pathways." Global Environmental Change 34: 147-158.

Simulation Tracks Co-Evolution of Technology and Political-Economy

Draws on several literatures:

- Political science literature of policy persistence (Patashnik 2003)
- Economic/game theoretic literature describing how competition among firms and government shapes policy outcomes (Grossman and Helpman 1994)
- Agent-based, evolutionary economic formalisms (Dosi et. al. 2006; Gerst et. al. 2013) that related industry structure to firms' technology investments

•Exploratory modeling analysis compares how near-term choices about policy architecture affect long term decarbonization rates

	Tax	Cap & Trade
Price only	Plain tax	Auctioned permits
Exclude incumbents	Grandfathering	Free permits
Transfer $ from hi to lo emitters	Long term carbon rights	Allocate some permits by market share

Nine policies X 6,000 futures
(50 repetitions/future)

↓

2.7 million runs (~90GB of data)

↓

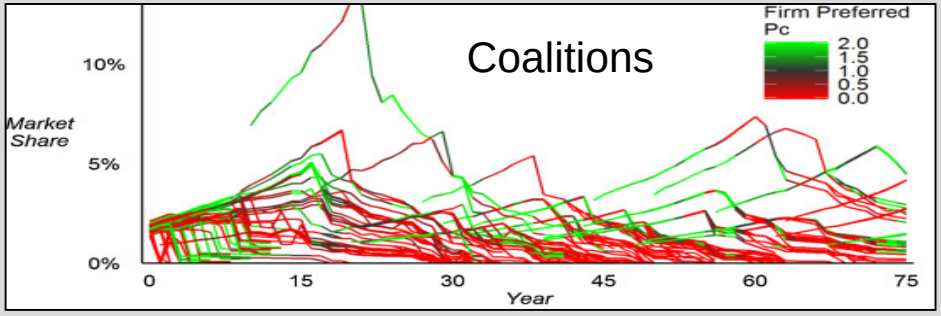
Search database for key drivers of policy impact

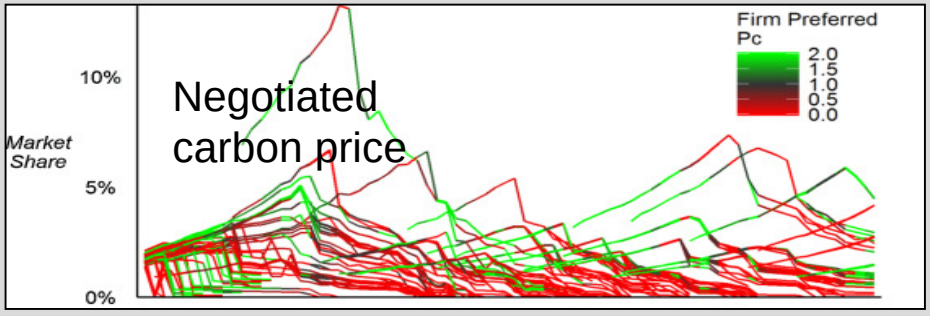
In Some Conditions, Near-Term Choices Have Large Effect on Long-Term Outcome

Looking over all runs, we find that:

- Excluding incumbents from carbon price makes little difference
- Revenue transfers can make large difference (~ 1% point in decarbonization rate over decades) in some cases
- Key drivers of futures where near-term policy choice makes a difference include:
  - Low elasticity of demand
  - Intermediate potential for R&D to generate improvements in carbon intensity
  - Various combinations of government preferences
- Government agency that administers carbon price may also be important near-term policy choice

For one run:





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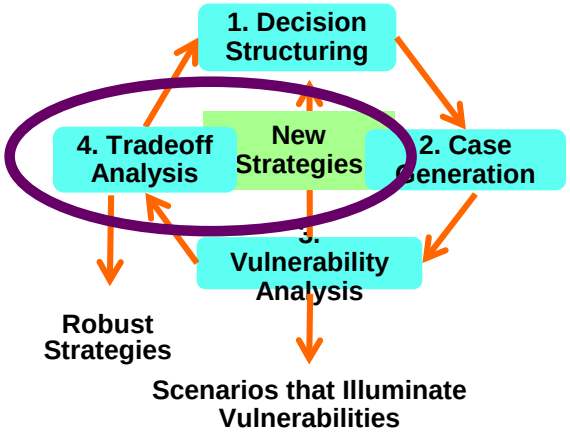
Multi-Objective Robust Optimization Tools Are Also Crucial and Available



Tools for finding pareto "satisficing" surfaces for wicked problems using complex models now sufficiently capable to use in deliberative policy environments

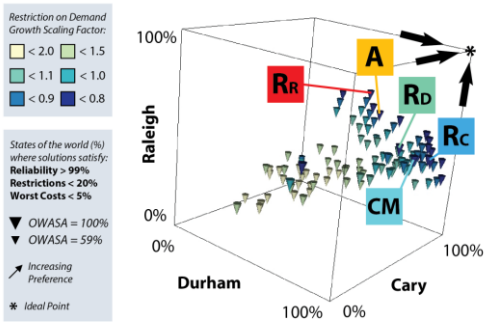
- Louisiana Coastal Master Plan
- Dutch Adaptive Delta Plan
- Colorado Basin

Structured Decision Making helps generate and evaluate adaptive strategies in situations with multiple participants and interests, conflicting information, and uncertainty

Display multi-objective tradeoffs

Objective	Attribute	Direction	Units	Commercial	Sprd at the Pain 1	Sprd at the Pain 3
Conservation	% meeting Rec Plan Objective 1	H	%	82%	72%	79%
Conservation	No of returns in 2016-2019 (ave)	H	# 000	47.7	16.8	28.7
Conservation	Probability of extinction	L	%	0.0%	3.4%	0.4%
Conservation	% Enhanced fish 2010	L	%	56%	26%	37%
Conservation	% Enhanced ave fish 2016-2019	L	%	45%	32%	45%
Costs	Total Costs	L	$Yr Ave $00	$ 588	$ 171	$ 328
Catch	Traditional Commercial	H	# 000	5,877	3,088	3,878
Catch	Available Comm TAC Above Vedder	H	# 000	131	2,920	2,130
Jobs	Total FTEs	H	# FTEs	4.10	1.60	2.50

Gregory (2014) Using Structured Decision Making Approaches to Clarify Environmental Management Choices



In North Carolina, such methods helped neighboring water agencies develop coordinated plans robust against inter-related

- Reliability shocks
- Financial shocks

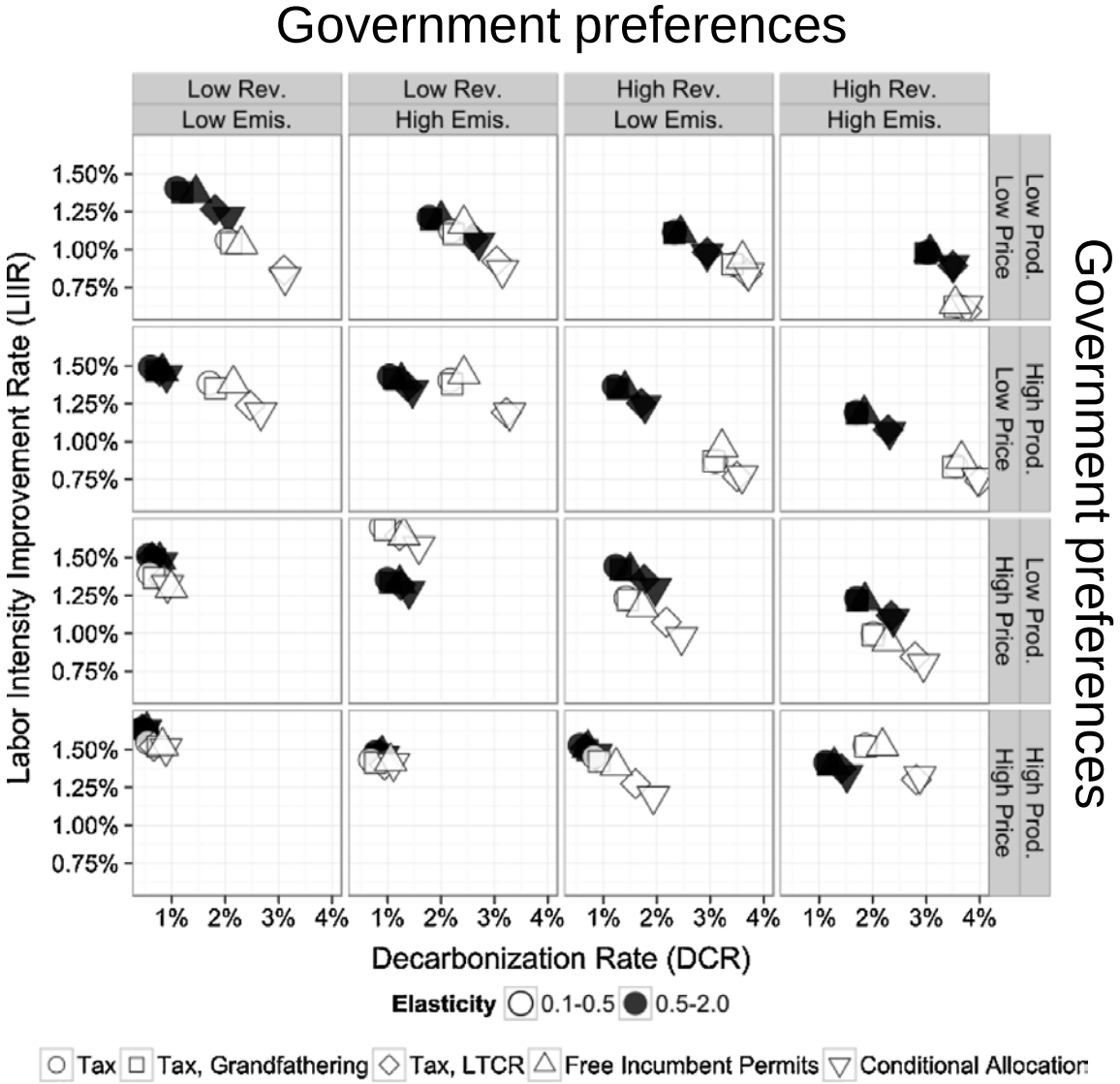
Herman, Zeff, Reed, & Characklis (2014), Beyond optimality: Multistakeholder robustness tradeoffs for regional water portfolio planning under deep uncertainty, *Water Resources Research*, *50*

Summary

- Fortunately, systems analysis can prove useful for wicked problems
  - But we need to be more attentive about how models are used (rather than the models themselves) in decision support processes
- New computational tools can now more fully enable:
  - Using complex simulations as exploratory models
  - Deliberation with analysis processes with parties to decisions
- These approaches will likely be even more important as we grapple with
  - Transformative policies
  - The role of institutions in our models and policy instruments

Thank you!

In Some Conditions, Near-Term Choices Have Large Effect on Long-Term Outcome



Find that:

- Elasticity of demand and government preferences are key drivers of policy outcomes

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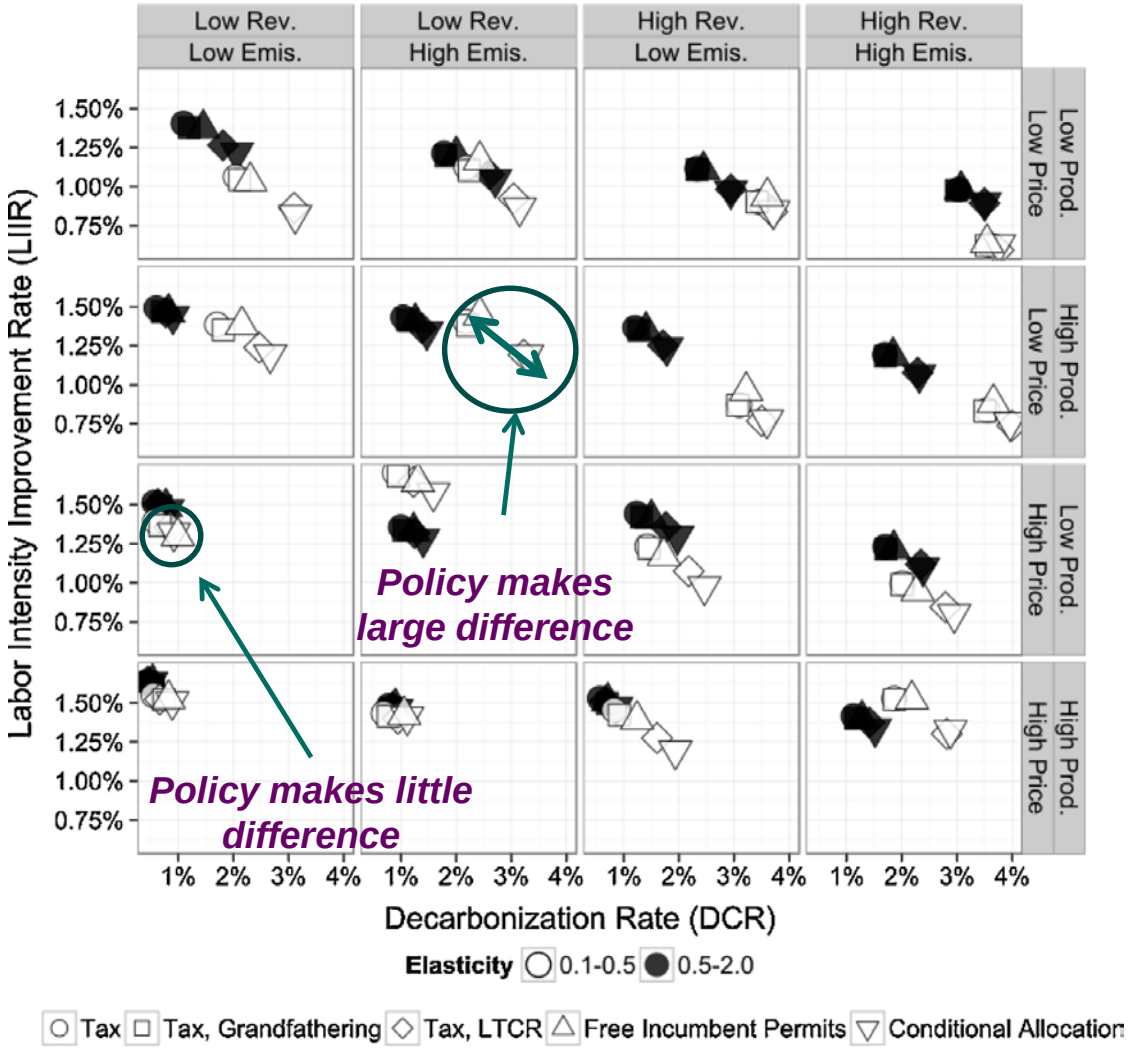

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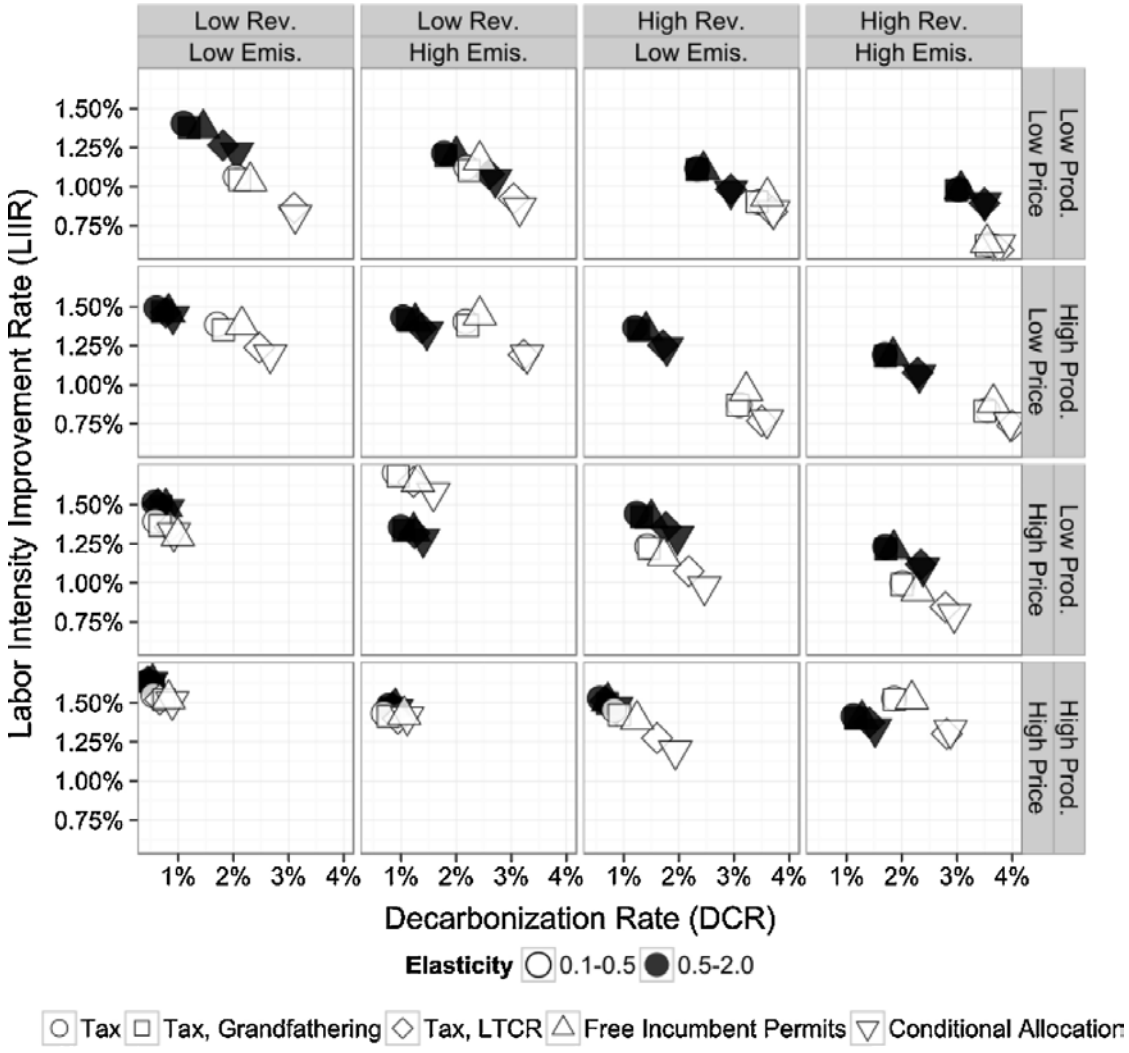

Find that:

- Elasticity of demand and government preferences are key drivers of policy outcomes
- Excluding incumbents make little difference
- Revenue transfers can make large difference

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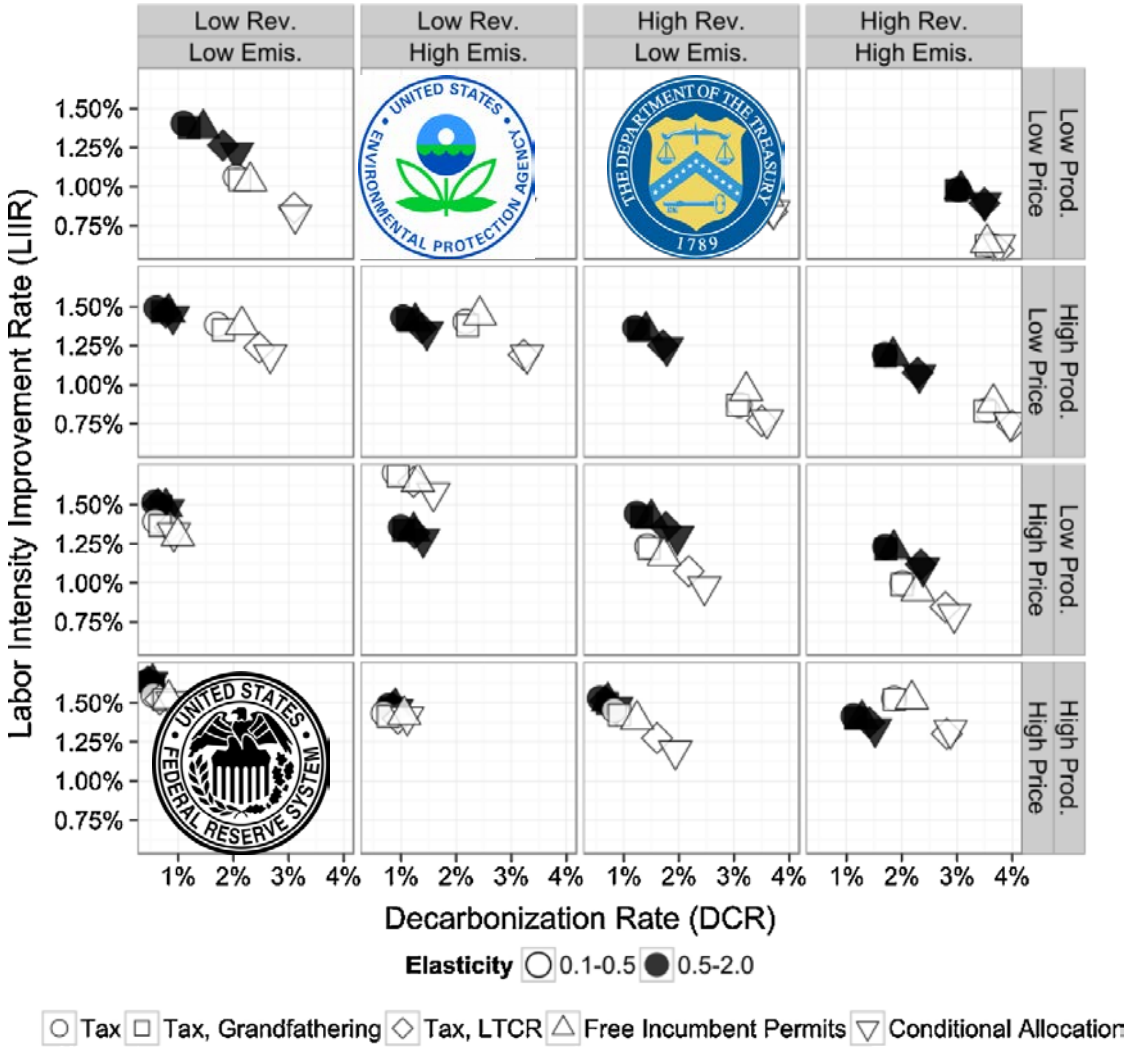


Find that:

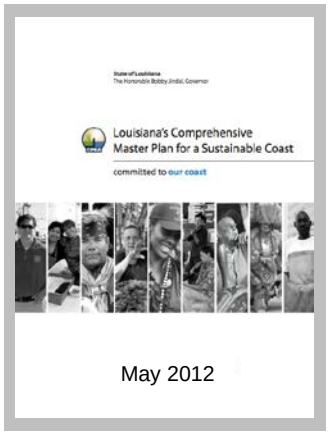
- Elasticity of demand and government preferences are key drivers of policy outcomes
- Excluding incumbents make little difference
- Revenue transfers can make large difference
- Institution that administers carbon price may also be important*

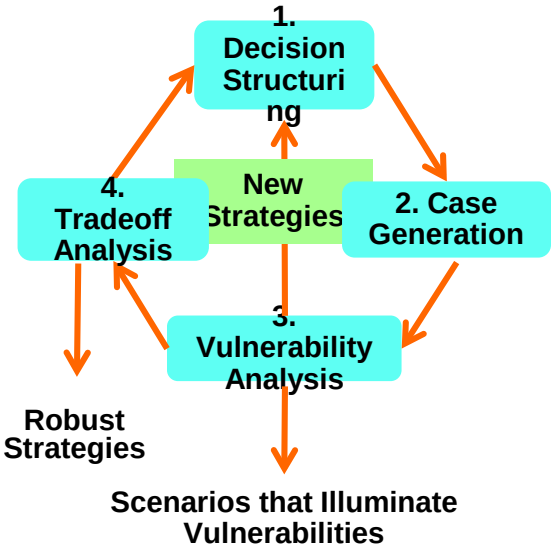
* *Though this pushes menu-auction model past intended range of applicability*

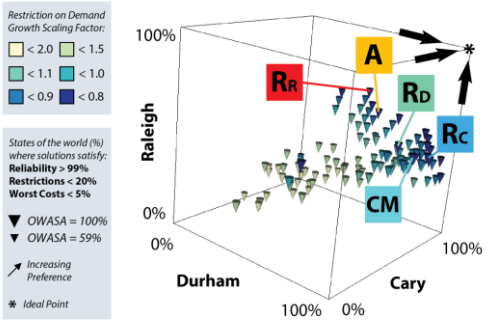
Multi-Objective Robust Decision Tools Can Usefully Facilitate Development of New and Complex Strategies

Methods and models for multi-objective robust decision making can now facilitate decision processes in some policy areas

- Louisiana Coastal Master Plan
- Dutch Adaptive Delta Plan







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