CLIMATE CHANGE ENERGY TECHNOLOGY POLICY UNDER UNCERTAINTY

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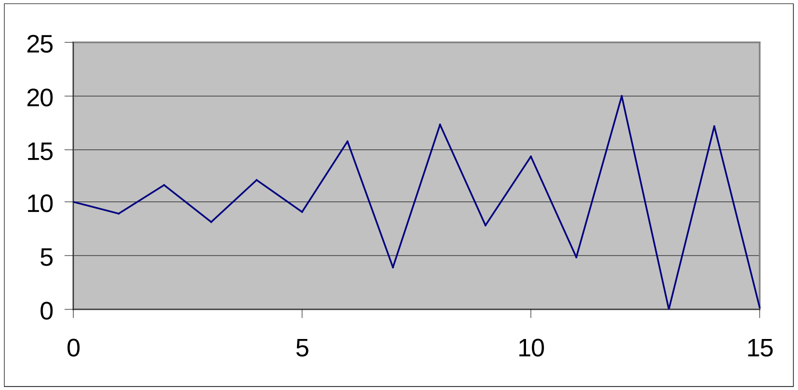
European Summer School on Uncertainty, Innovation, and Climate Change

Lecture II

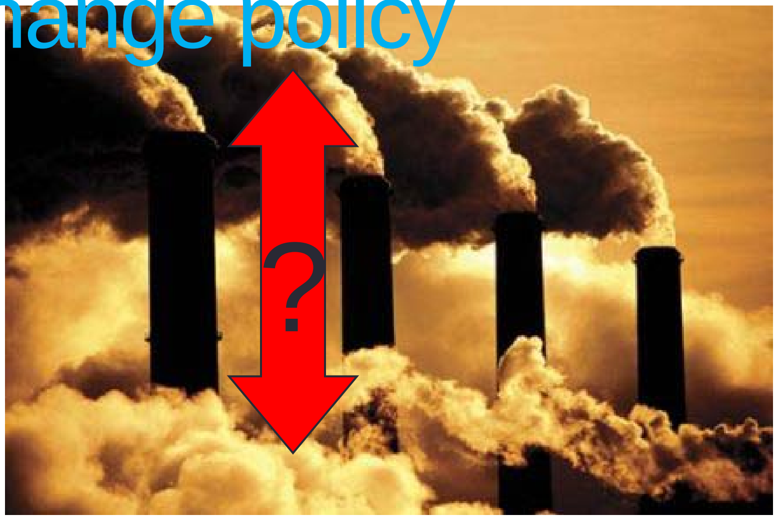
Objectives

- Overview of expert elicitations
- Apply elicitations to a government R&D portfolio problem

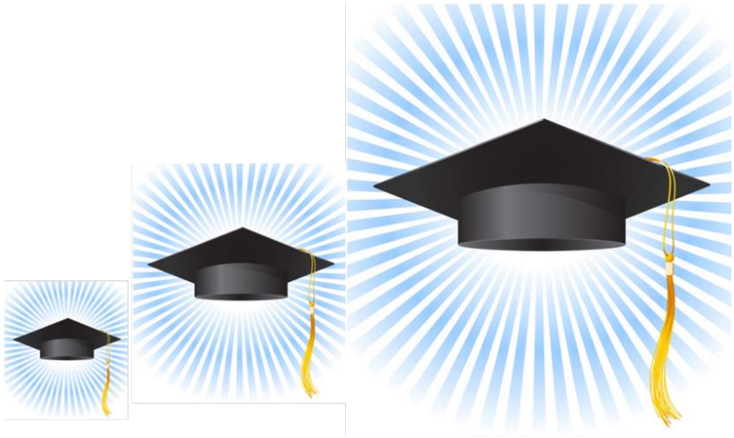
Uncertainty and Learning has ambiguous impacts on optimal climate change policy



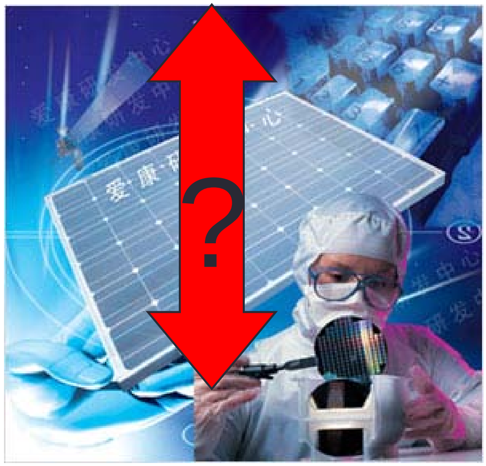
Increasing risk in climate damages or technology



Optimal emissions can increase or decrease



An increase in the amount we expect to learn



Optimal R&D can increase or decrease

Why use elicitations for technical change?

Why use elicitations for technical change?

- Past data can give general insights (speed of average technical change), but *cannot differentiate between specific technologies*, or tell us if a breakthrough is coming
  - *"To the extent that probability of achieving success depends on breakthroughs, what has happened with other technologies will not offer much to differentiate paths that are particularly promising."*

Why not use elicitations?

Why not use elicitations? Biases and Huerisitcs

20 Questions

- About how many answers were a surprise? Either below 1^{st} percentile or above 99^{th}?

Results of 20 questions

- Number of answers that were in the 1st or 99th percentile: xx
  - Percentage:
- Number of answers that we would expect: 8
  - Percentage: 2%

1.	Population of Cuba, 1965	7,631,000
2.	1975 imports of Italy ($ million)	43,626
3.	Airline distance in statute miles from San Francisco to Moscow	5855
4.	Fraction of group favoring abolition of "victimless" crime laws	35.7%
5.	The closing Dow Jones Industrials average for May 26, 1969	946.9
6.	The number of pages in the Wall Street Journal of May 27, 1969	36
7.	Birthday of Soccer player Pele (day/month/year)	23/10/1940
8.	Fraction of group considering themselves a member of a religion	32.14%
9.	American battle deaths in Revolutionary War	4435
10.	Number of labor strikes in US during WW II (Pearl Harbor - VJ Day)	14371
11.	Height of Hoover Dam (feet)	726
12.	Fraction of group that has served in the Armed Forces	14.29%
13.	Length of Broadway run of "Oklahoma" (days)	2246
14.	Gross tonnage of liner "United States"	52072
15.	U.S. whiskey production (legal) in 1965 (thousands of gallons)	117930
16.	Fraction of group that has ridden a motorcycle (solo)	35.71%
17.	Length of Danube River (miles)	1770
18.	Popular votes cast for Eisenhower in 1956 (millions)	35.6
19.	Worldwide airplane accident deaths on scheduled flights during 1960	307
20.	Fraction of group willing to accept (–$50, $100) gamble	57.14%

Estimate the number of rooms in the MGM Grand in Las Vegas

- Write down your median estimate

Anchoring

- “The MGM Grand has more than 50 rooms”
  - Average estimate:

- The MGM Grand has fewer than 5000 rooms”
  - Average estimate:

Biases and Heuristics

- Over confidence
  - Experts think they more than they do.
- Anchor and Adjust
  - You start with the 50th percentile – what you think the answer is; and then you adjust to get the extremes.
  - People almost always adjust too little.
  - Best to start with the extremes, rather than the median.

Biases and Heuristics

- Over confidence
- Anchor and Adjust
- Representativeness
  - Base rate
  - Reversion to the mean.
- Availability
  - Judging a probability by how easy it is to think up similar situations
  - Airplane accidents versus car accidents
  - Terrorist attacks versus cholesterol
- Motivational bias
  - Salesman may forecast a poor sales environment.
  - Weather forecasters would rather over estimate chance of rain

Responses to Heuristics and Biases

- Practice
- Awareness of heuristics and biases
- Assessment Techniques
  - Using thought experiments.
  - Ask for high and low estimates first, and then median.
  - Ask questions in multiple ways. Induce contradictions. Have experts re-think.
- Decompose the problem into smaller problems.
- Ask multiple experts and average answers.
- Mathematically adjust
- Do skill testing on the experts and weigh the most skillful highest.

When should you use elicitations?

Elicitation approaches

- Ask for high, low, and median (95th, 5th, 50th percentile)

  "What is the lowest energy penalty you can envision for absorption/solvent technologies in 2025 under these conditions? We are looking for a value that is sufficiently low that you think there is perhaps only 1 chance in 20 that the actual energy penalty will turn out to be lower."

- Ask for probability of certain pre-determined values.

  "What is the probability that a precombustion capture technology (e.g., sorption enhanced WGS, pressure swing adsorption, hydrate formation) will be developed that can be incorporated into a standard IGCC plant, with a parasitic energy loss of 10% or less?"

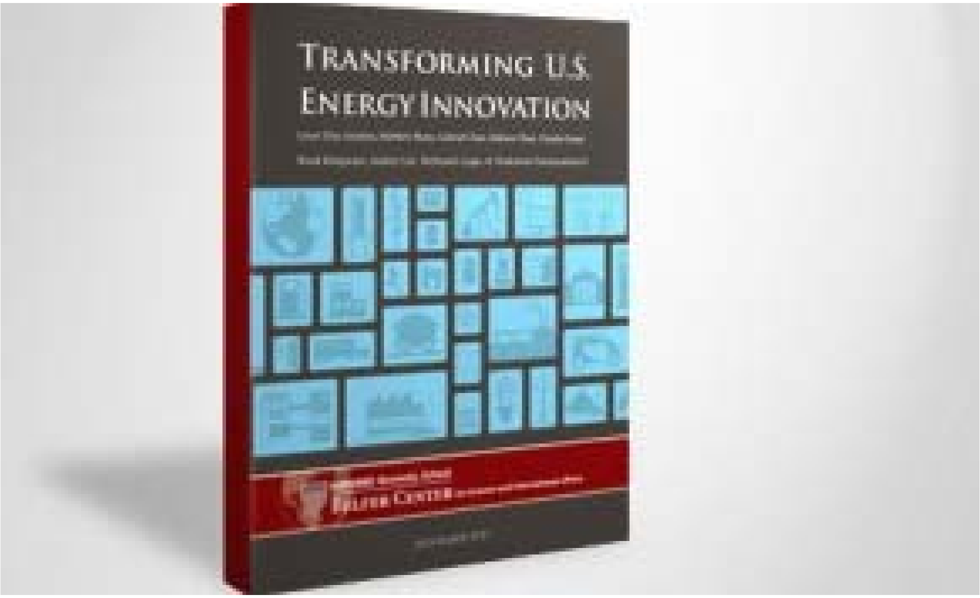
- Everything must be defined to pass "the clarity test"
  - The above questions were conditional on policy/R&D scenarios

IMPLEMENTING ELICITATION DATA

How to implement elicitation data

- Transforming US Energy Innovation by Diaz Anadon et al
- **A multi-model approach by Baker et al**
- TEaM Project
- Modeling Uncertainty Project by Nordhaus et al

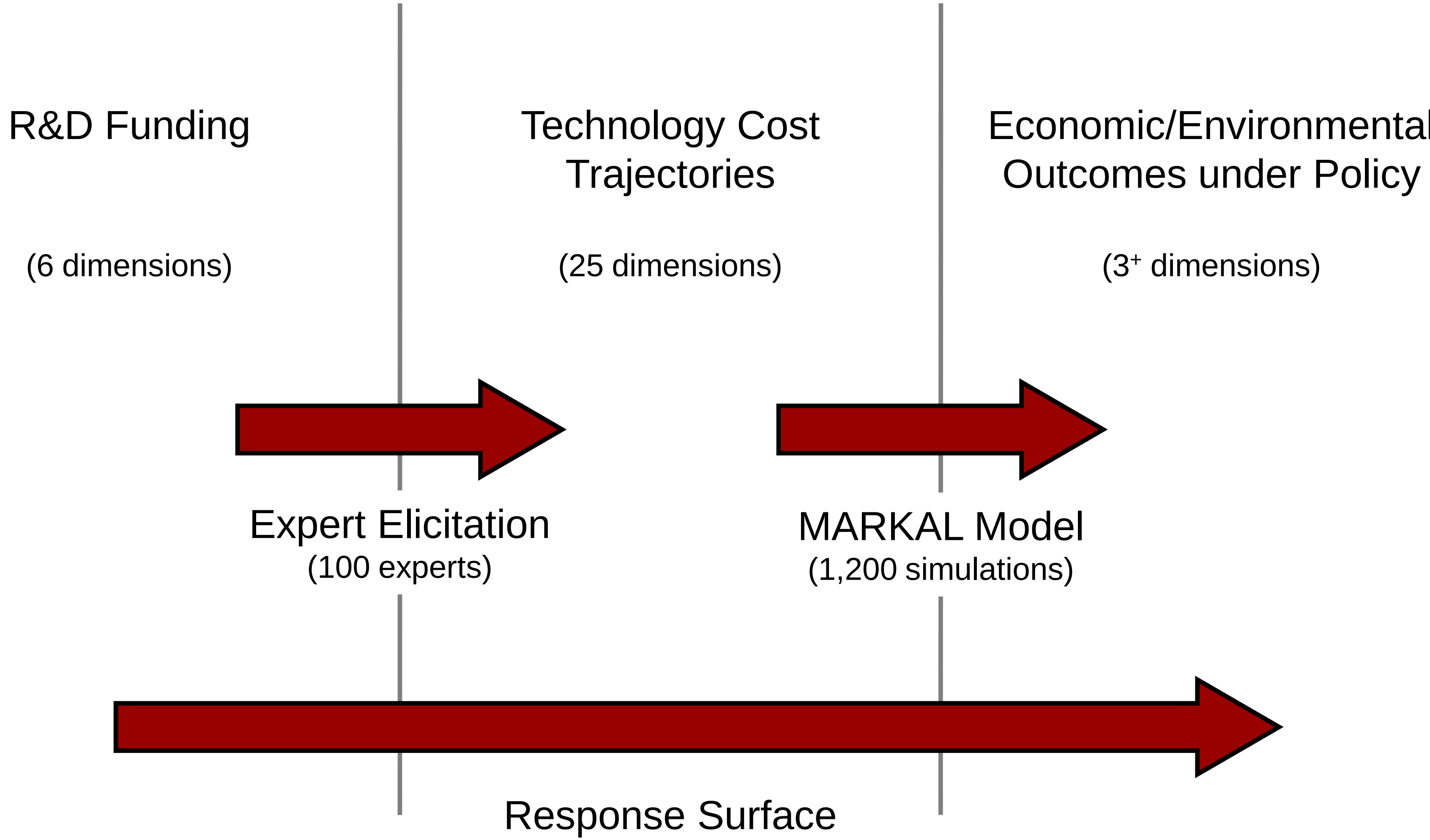
Transforming U.S. Energy Innovation (Nov. 2011)



Authors: Laura Diaz Anadon (Project Director), Matthew Bun (Co-PI), Gabriel Chan, Melissa Chan, Charles Jones, Ruud Kempener, Audrey Lee, Nathaniel Logar, Venkatesh Narayanamurti (Co-PI)

Available at: http://belfercenter.ksg.harvard.edu/publication/21528

Overview of Harvard approach



Response Surface

Process:

- for a given R&D level, calculate the conditional cost distribution (“the target distribution”) and use importance sampling to calculate the expectation of output metrics under the target distribution, $\mathbf{E}_{\text{cost}}\left[\text{output} \mid \text{R\&D}\right]$
- fit a high-dimensional polynomial to the expectations over a grid of R&D values

Results:

- polynomial coefficients that describe a surface of economic/ environmental outcomes as a function of an R&D vector

Post-Processing:

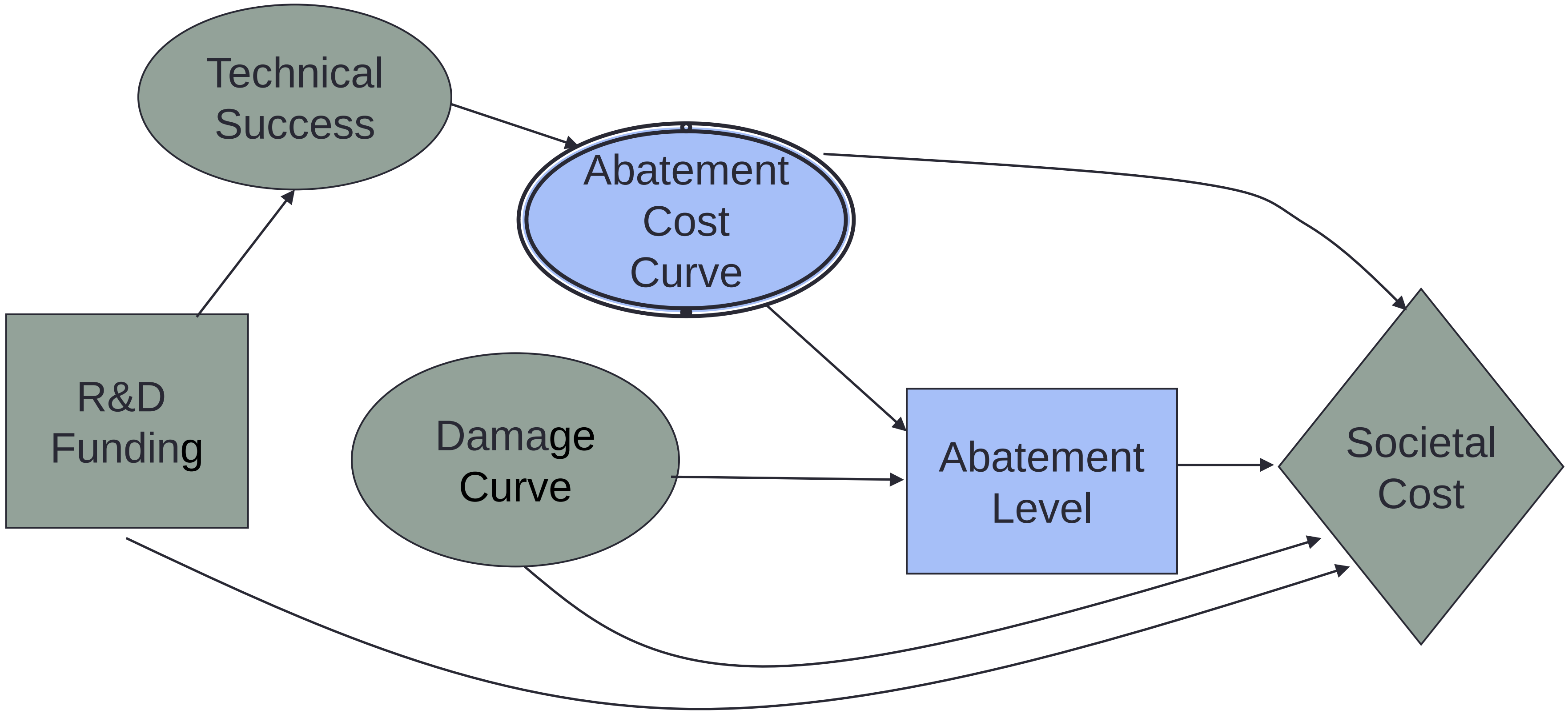
- Constrained optimization over the surface using a decision criteria (e.g. minimum expected carbon price)

The Elicitation and Modeling Project (TEaM)

- Aggregate elicitations from multiple teams
- Derive “covering distributions”
- Run points through multiple models (GCAM, MARKAL, WITCH)
- Post-process to get probability distributions
- Implement in simple decision problems

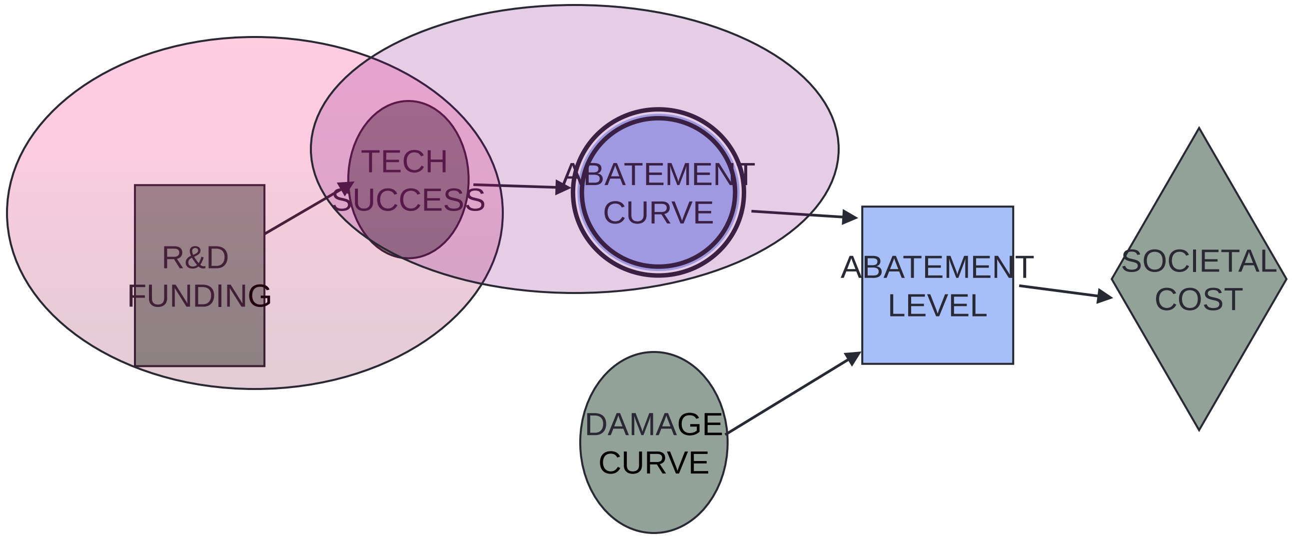
EXAMPLE: ENERGY TECHNOLOGY R&D

Paradigm: Act – Learn – Act

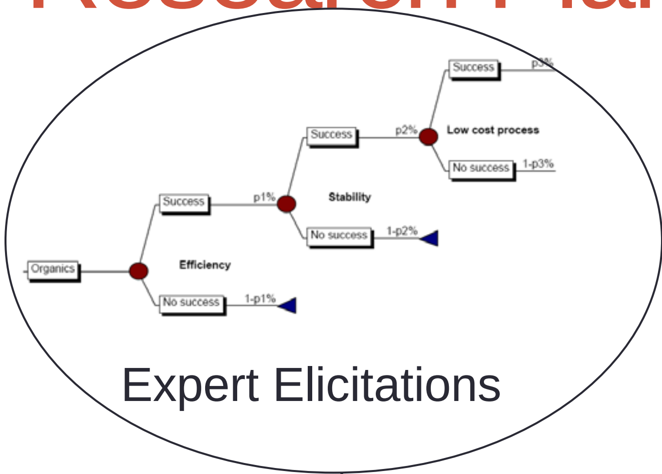


What is needed?

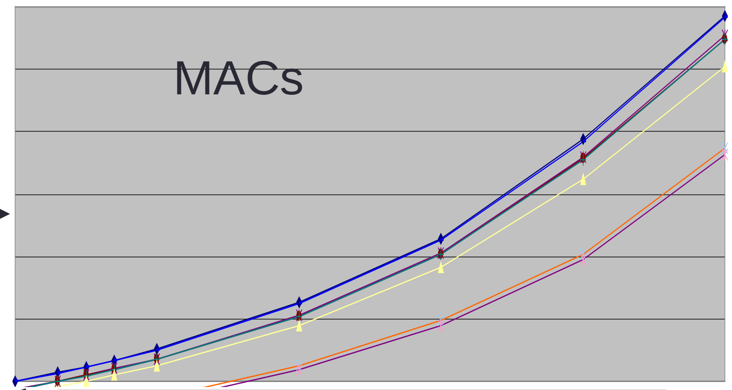
- What is the probability distribution over different outcomes of technical change?
- How will different technologies impact the MAC, if successful?



Research Plan

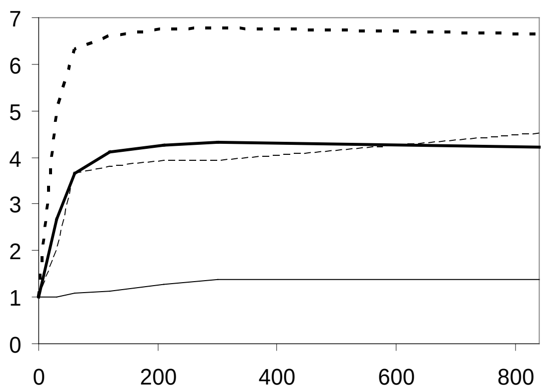


definitions of success



MiniCAM calculations of impact on MAC

probabilities

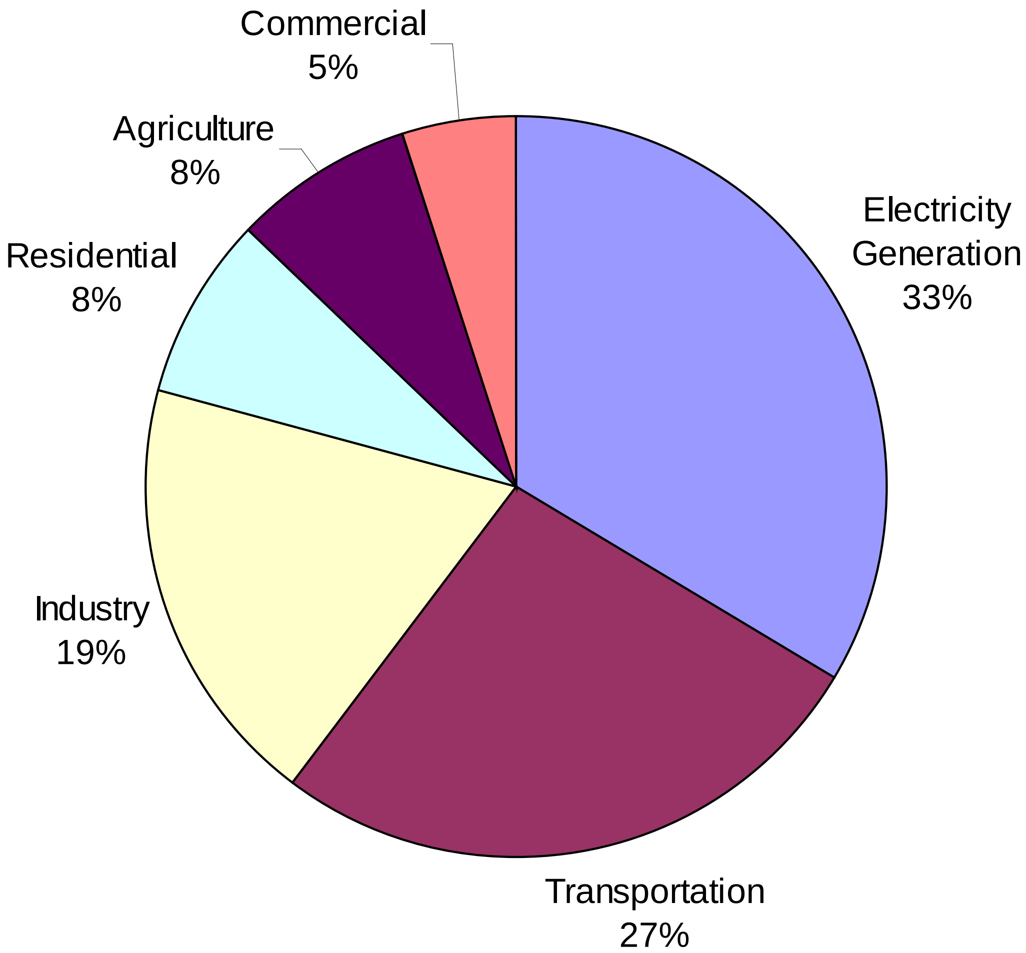


Random Returns to R&D

- Collect Expert Assessments of Potential R&D Projects
- Determine Impact on MAC, using MiniCAM
- Develop portable representations of the probabilistic impact of technical change.

Baker, Chon, & Keisler (2007)

US Greenhouse Gas Emissions Allocated to Economic Sector : April 2002



Assessments: Identify More Specific Technical Directions within Broad Categories

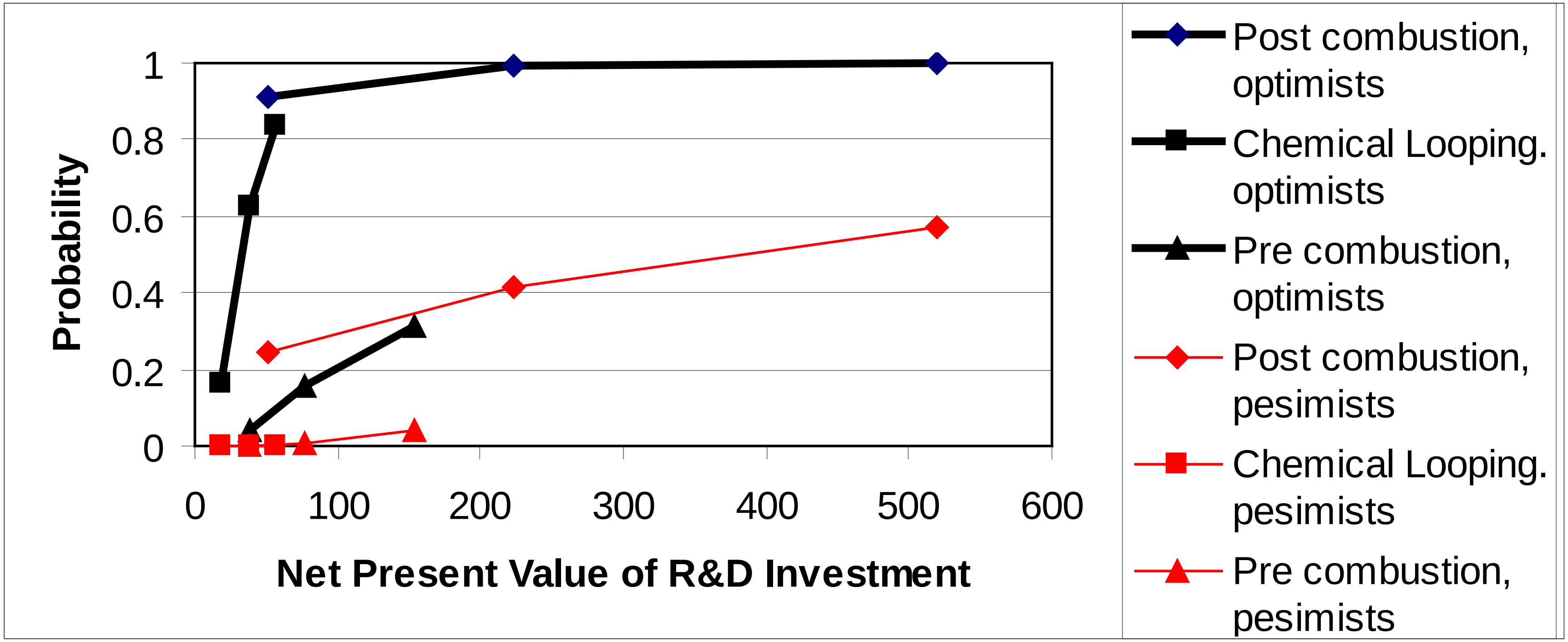
Advanced Solar PVs
Carbon Capture and Storage & Combustion
Nuclear Fission
Bio-electricity
Wind and Solar Grid Integration
Biofuels
Batteries

CCS:
Pre-Combustion
Chemical Looping
Post-combustion

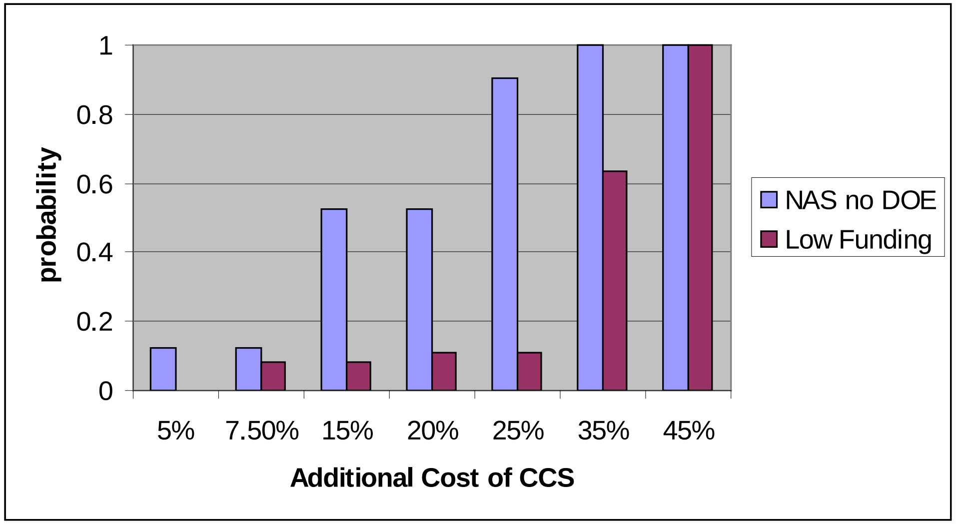
Technology Endpoints

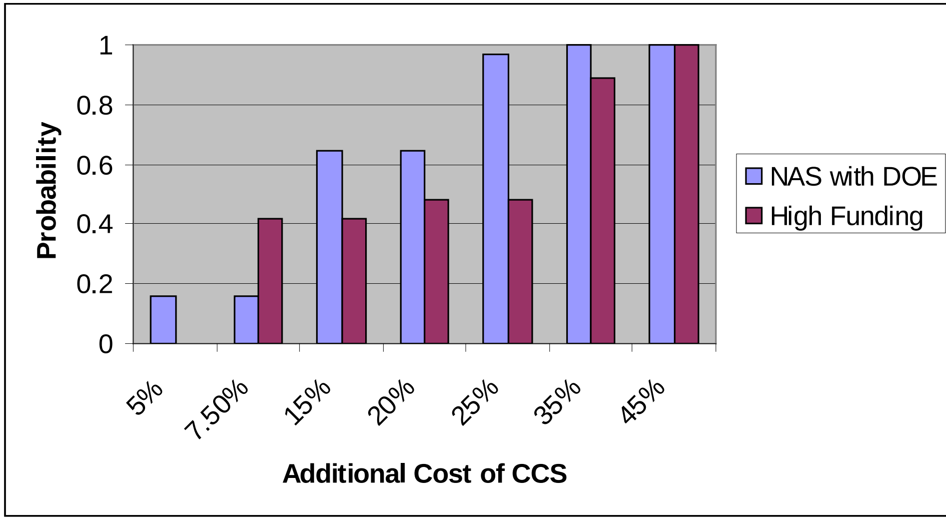
Technology	Definition of success	Energy Requirement	Non-energy cost	Capture Rate
Pre-combustion	parasitic energy loss ≤10%; incremental capital cost for IGCC ≤10%.	2.0 MJ/kgC	2.4 cents/kgC	90% (98%)
Chemical Looping	Operation at 1200 degrees K; cost of energy of 0.05cents/kWh	0.66 MJ/kgC	0.83 ents/kgC	90%
Post-combustion	availability of 90%; derating of 30%; cost per ton of CO2 avoided of $25; - on at least 50% of available coal	4.7 MJ/kgC	3.0 cents/kgC	90%

Probability of success: CCS



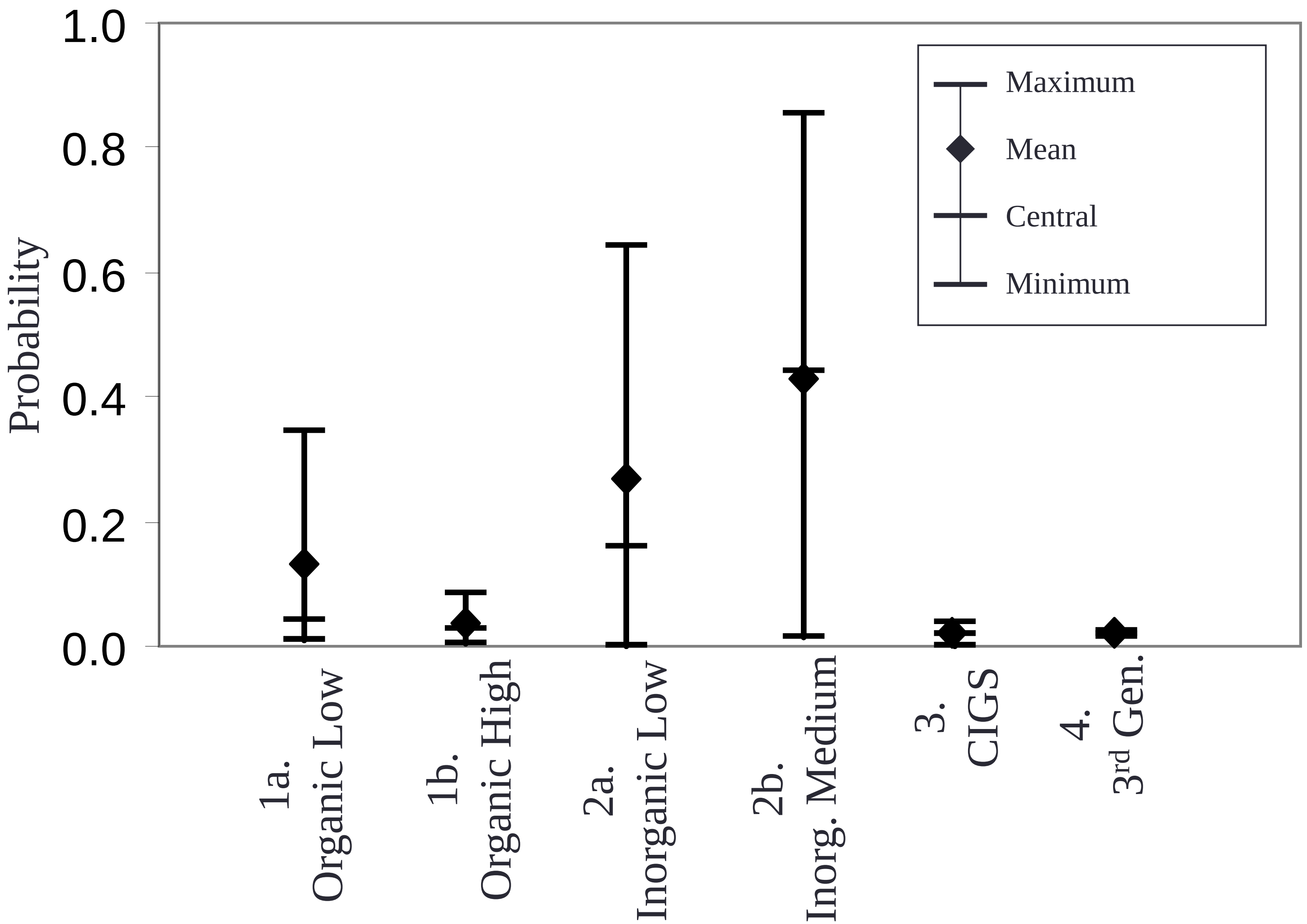
National Academy Study



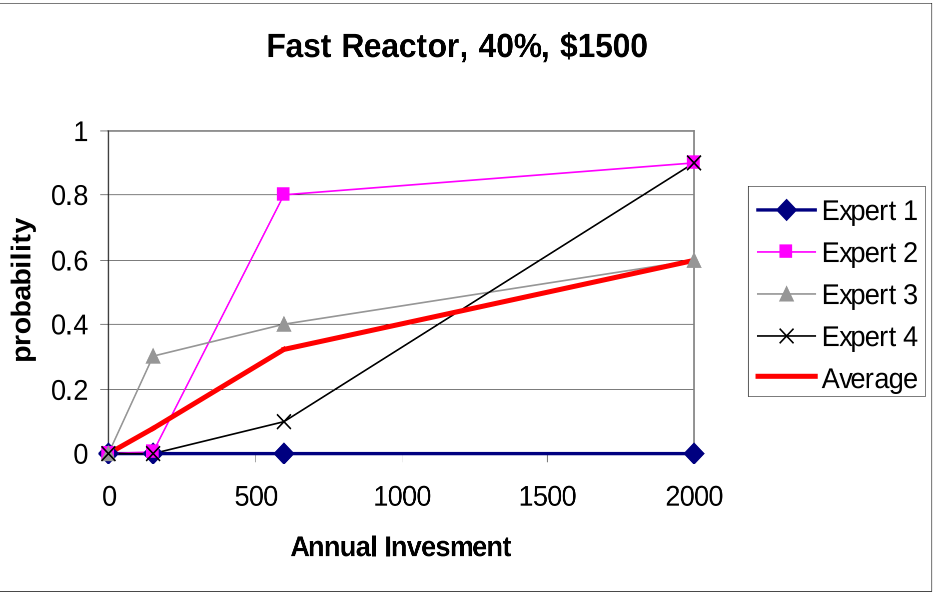


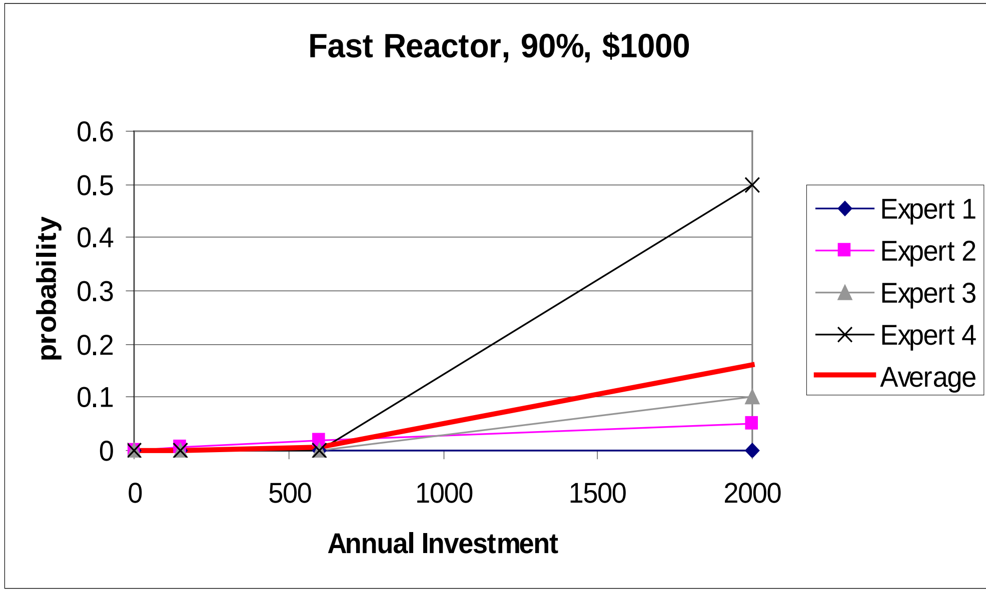
The probability that CCS will be viable ranged from 66% to 77% in the NAS

Probability of success: Solar PV

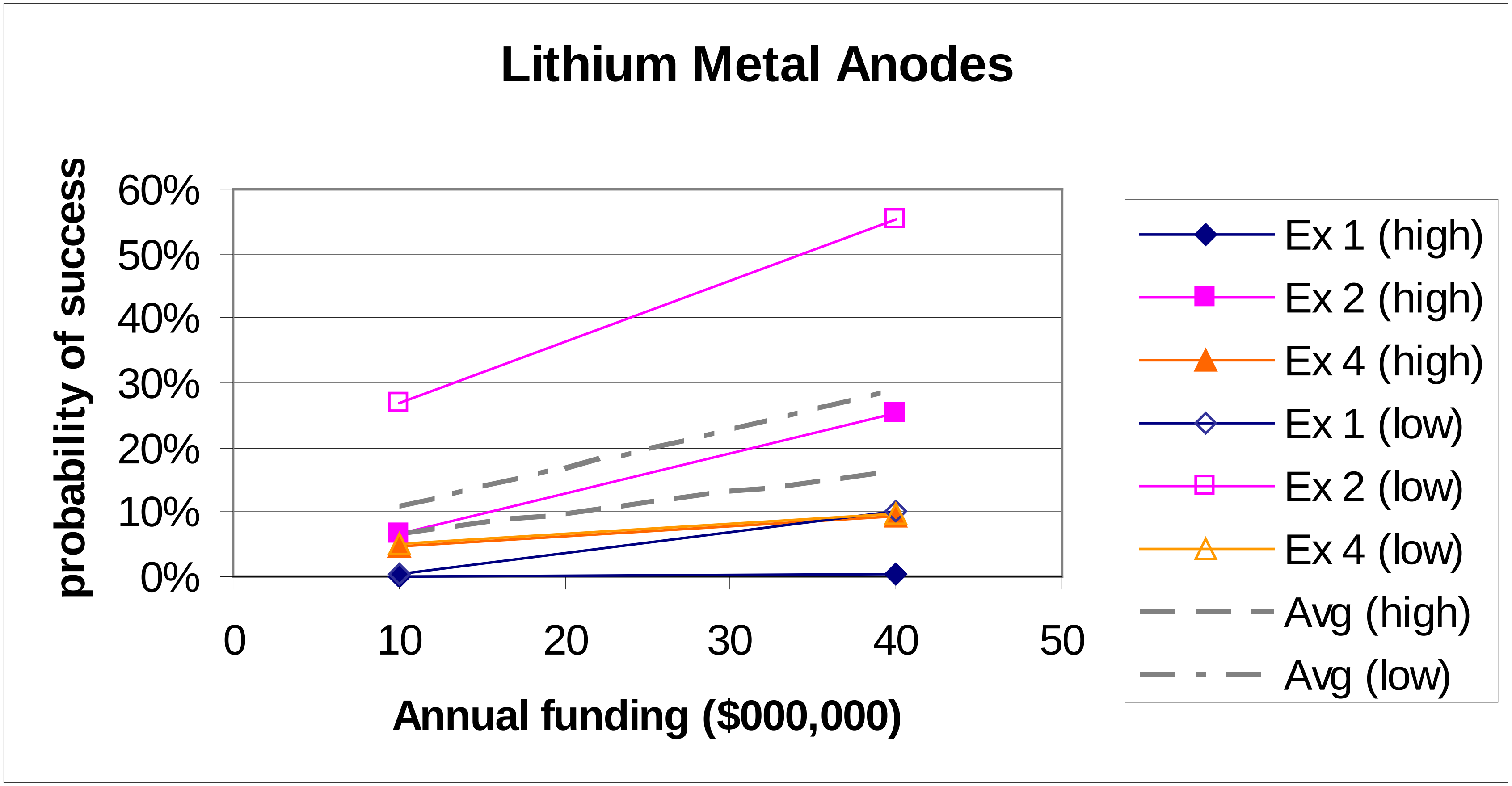


Probabilities of success: Nuclear Fast Reactor

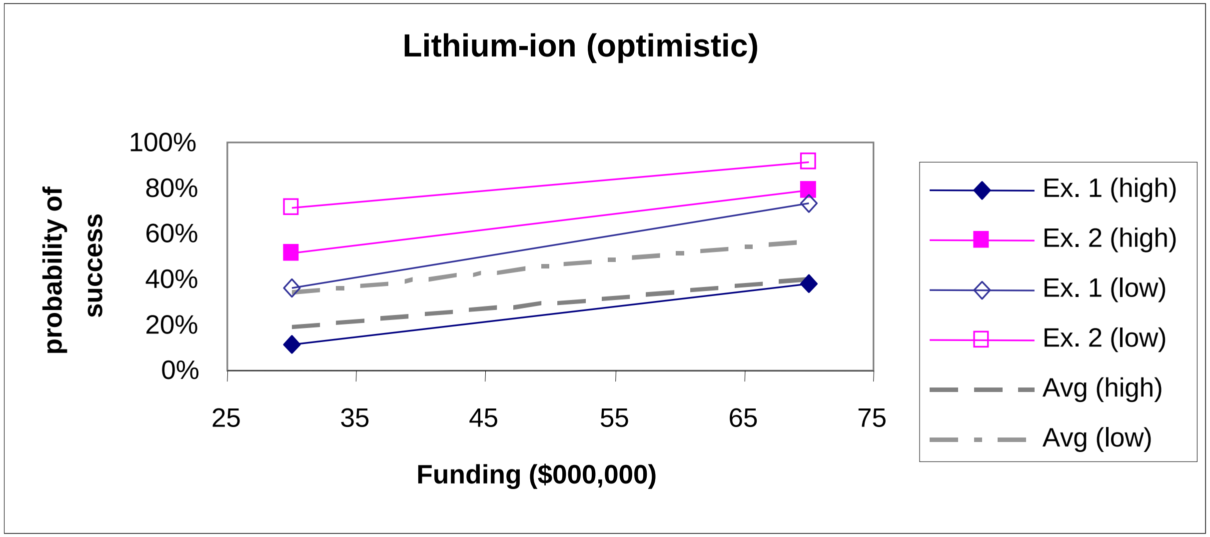


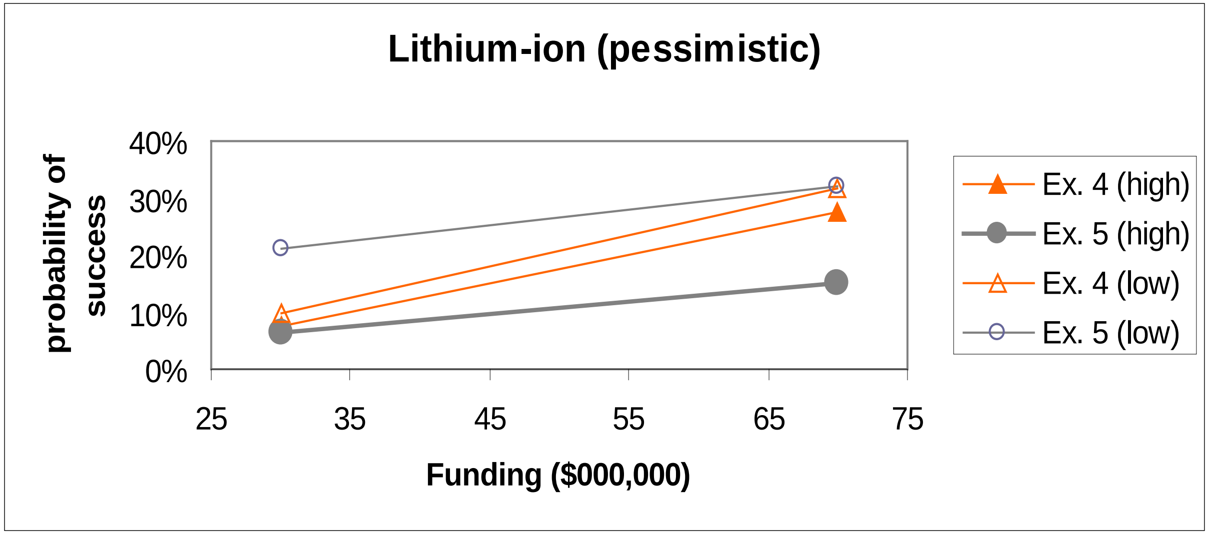


Probabilities of success: batteries with Li metal anodes (for EV or PHEV)



Probabilities of success: batteries with Li-ion (for PHEV)

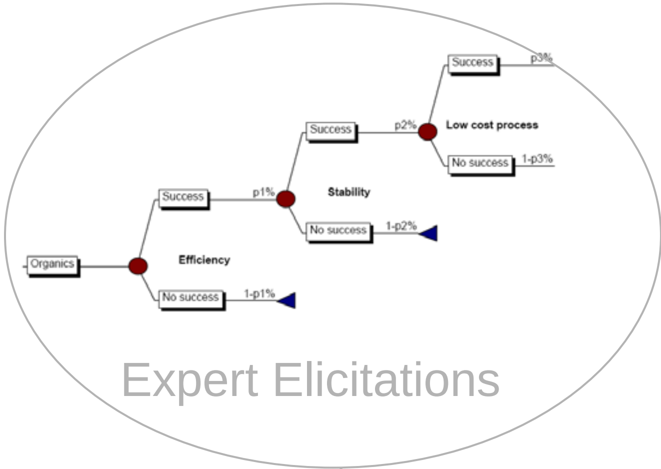




Conclusions

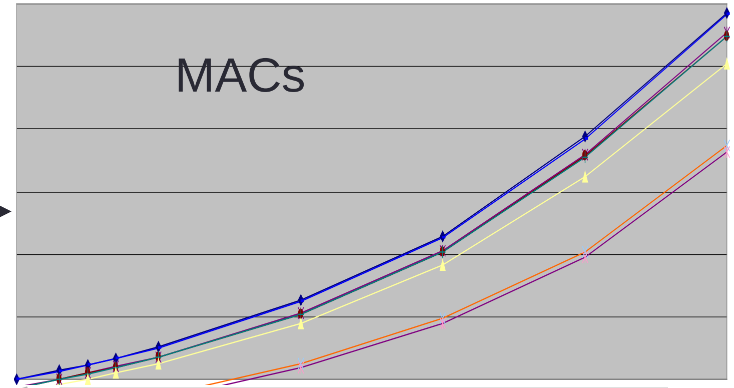
- Other than nuclear, experts gave us relatively small budgets.
- We found considerable disagreement among experts
  - Optimists versus pessimists
  - Disagreement over cost targets
  - Fundamental technological disagreement
- The average expert is often close to the median expert

Research Plan



Expert Elicitations

definitions of success



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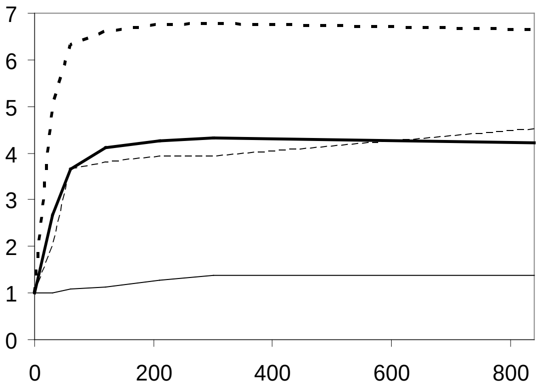

Random Returns to R&D

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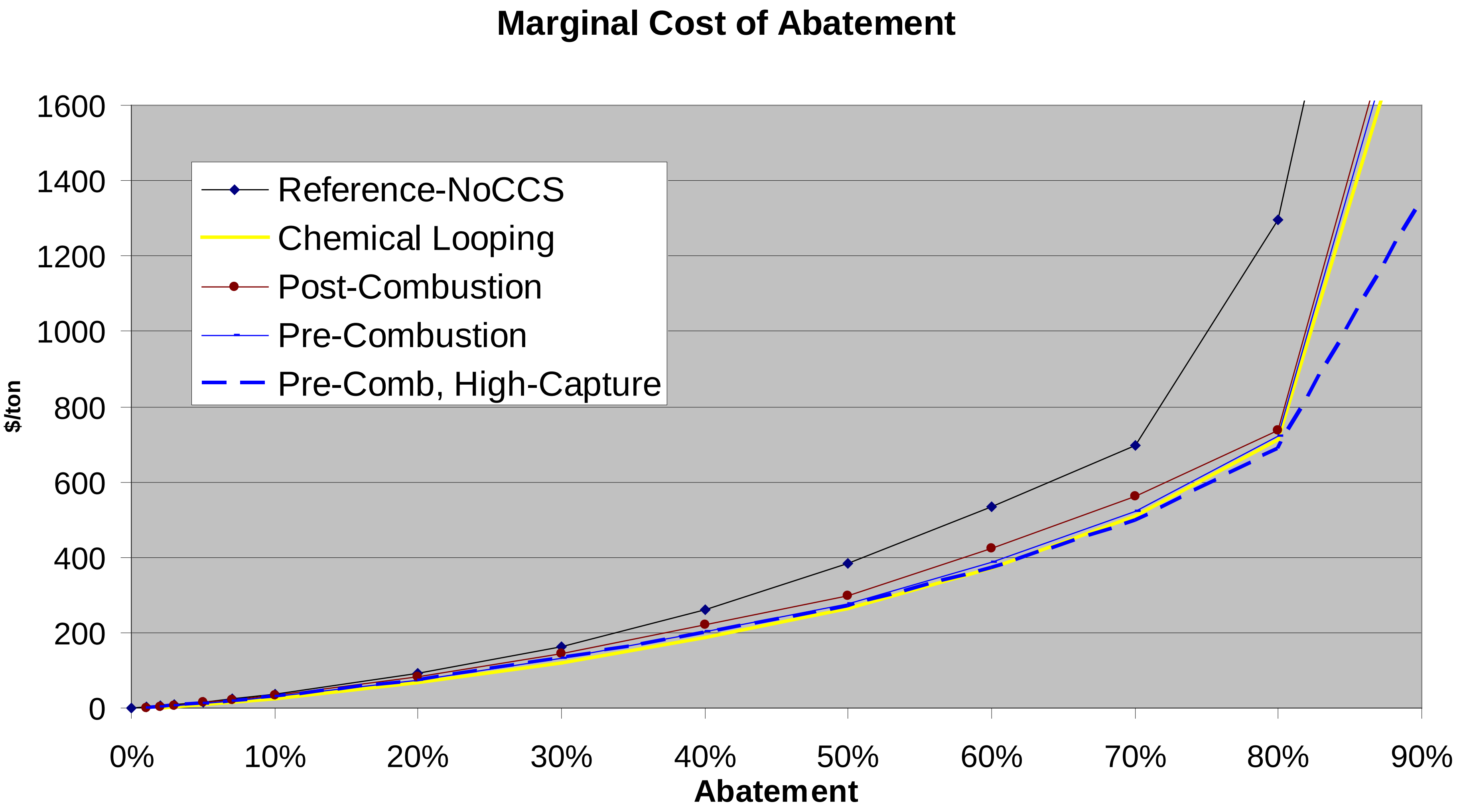
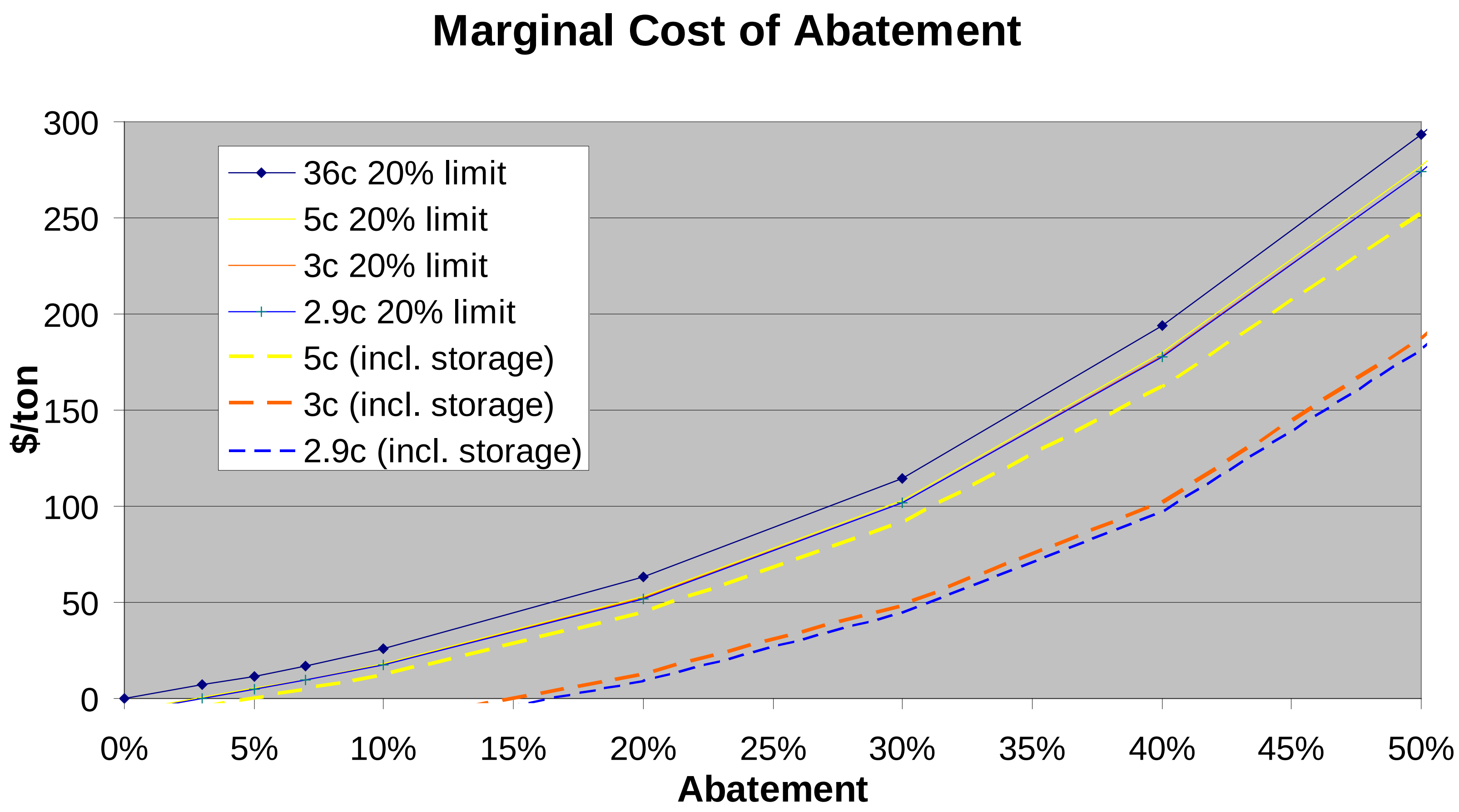
CCS

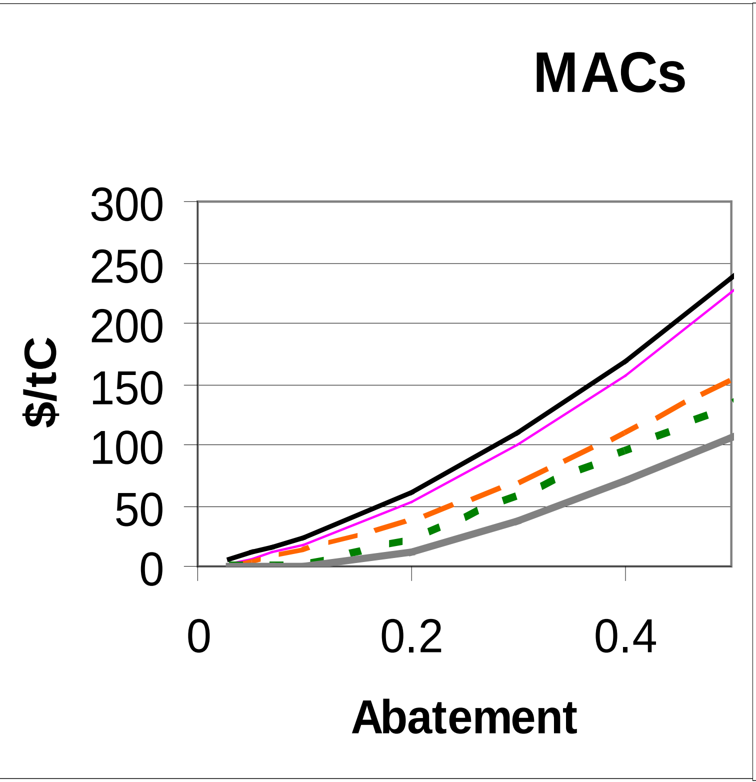


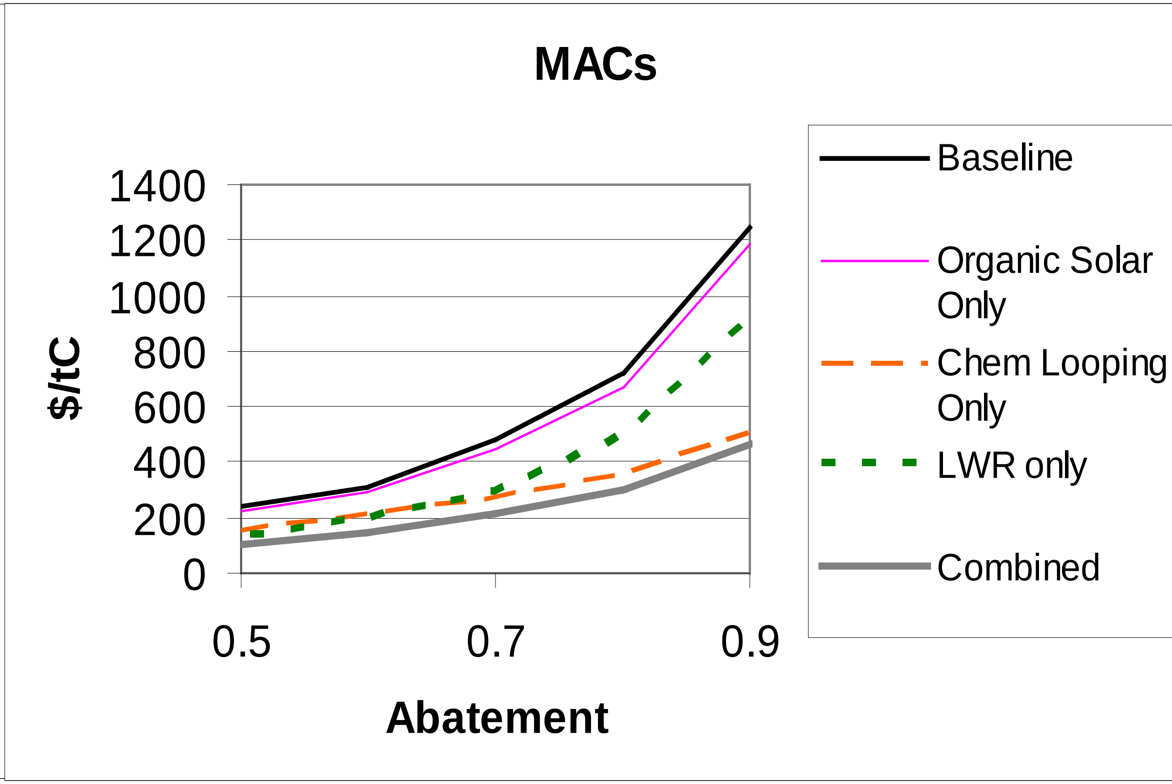
Marginal Cost of Abatement
Reference-NoCCS
Chemical Looping
Post-Combustion
Pre-Combustion
Pre-Comb, High-Capture
$/ton
1600
1400
1200
1000
800
600
400
200
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
Abatement

Solar with and without free storage



Impact of technology on the MAC: solar, CCS, Nuclear

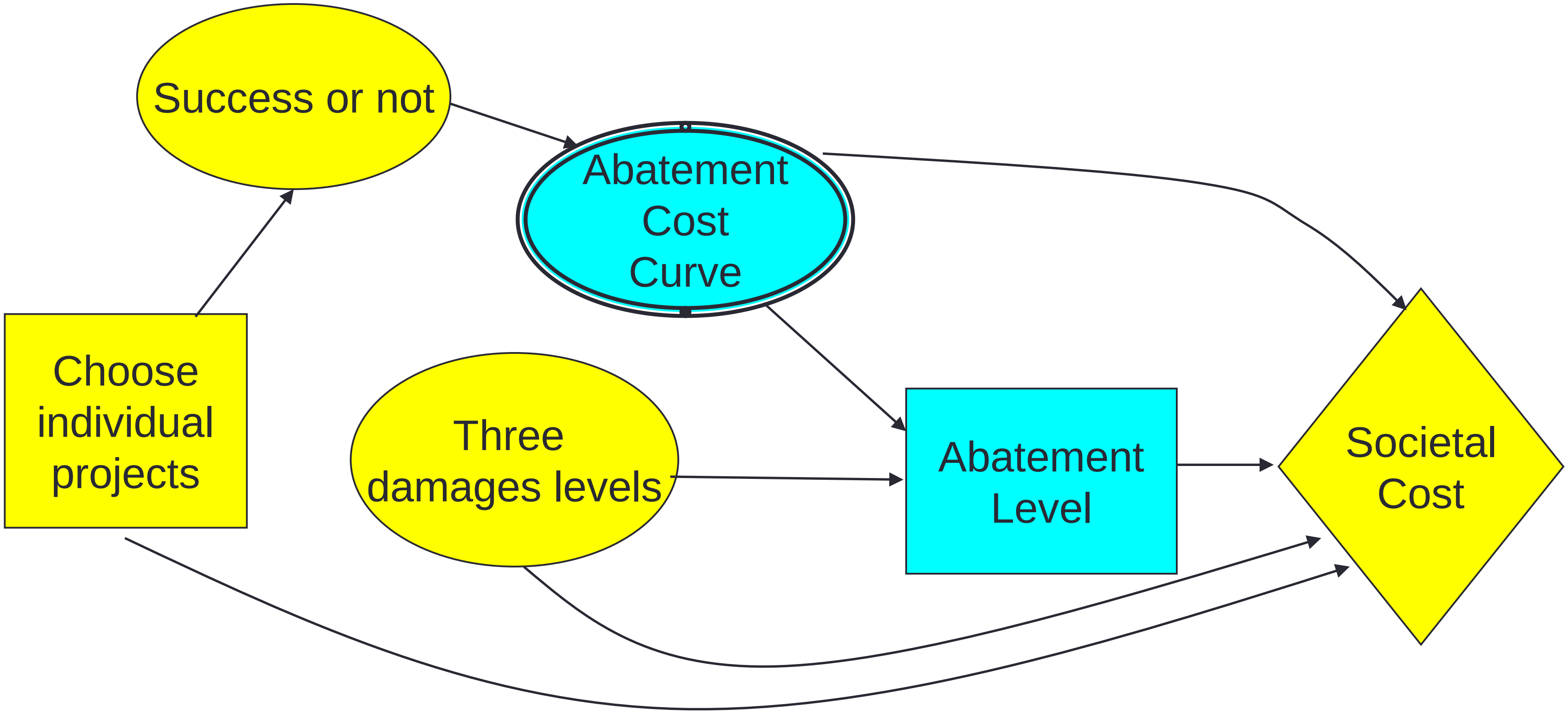




R&D PORTFOLIOS

Part I

Mixed Integer Non-linear Stochastic Program



Challenges

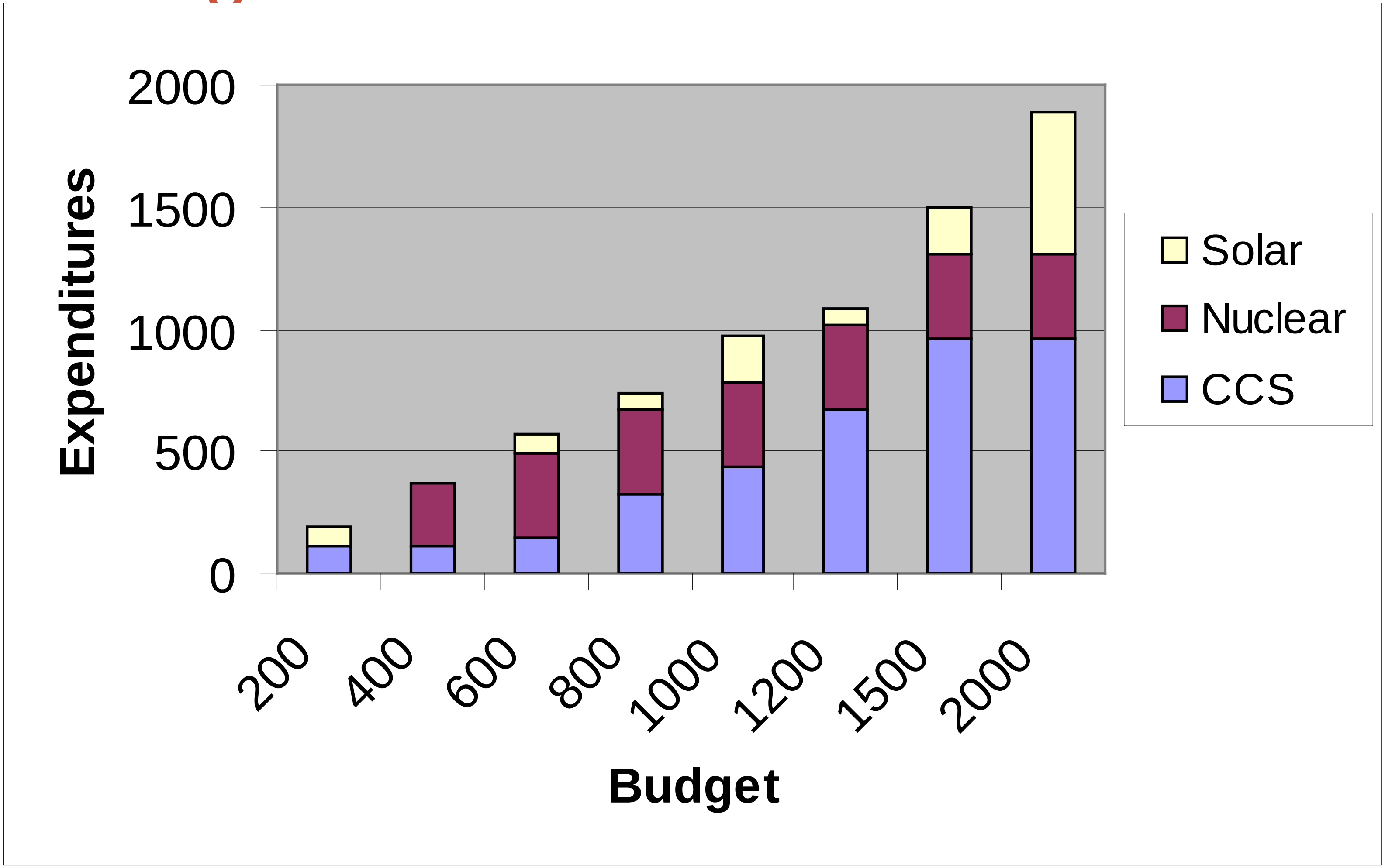
- Dynamic Programming versus Stochastic Programming
  - Constraints
  - Curse of dimensionality
- The probability of success is a function of decision variable, investment.
  - We re-formulated the problem so that the probabilities are fixed and only the outcome depends on investment.
- Non-linear, non-convex second stage problem.
  - We re-formulated the problem to avoid non-convexity
- Curse of dimensionality
  - Use a sampling process

Different Representations of Risk

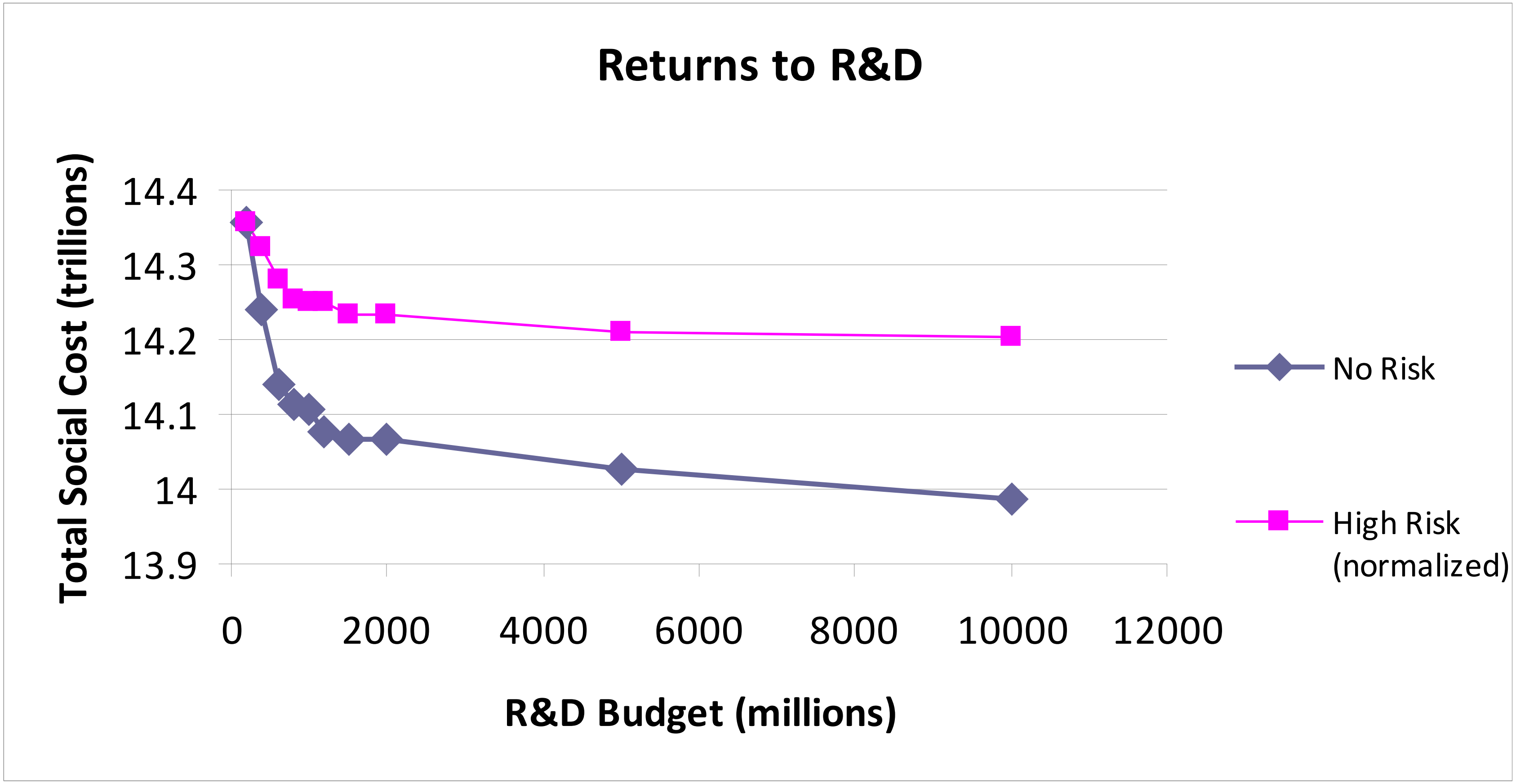
Zhigh	1	3	14
Pl	0	2/3	13/14
Ph	1	1/3	1/14
Abatement if Z high	46%	80%	100%

Z low is 0; optimal abatement is 0%

The optimal portfolio did not change with damage risk.



Expected Total Social Cost



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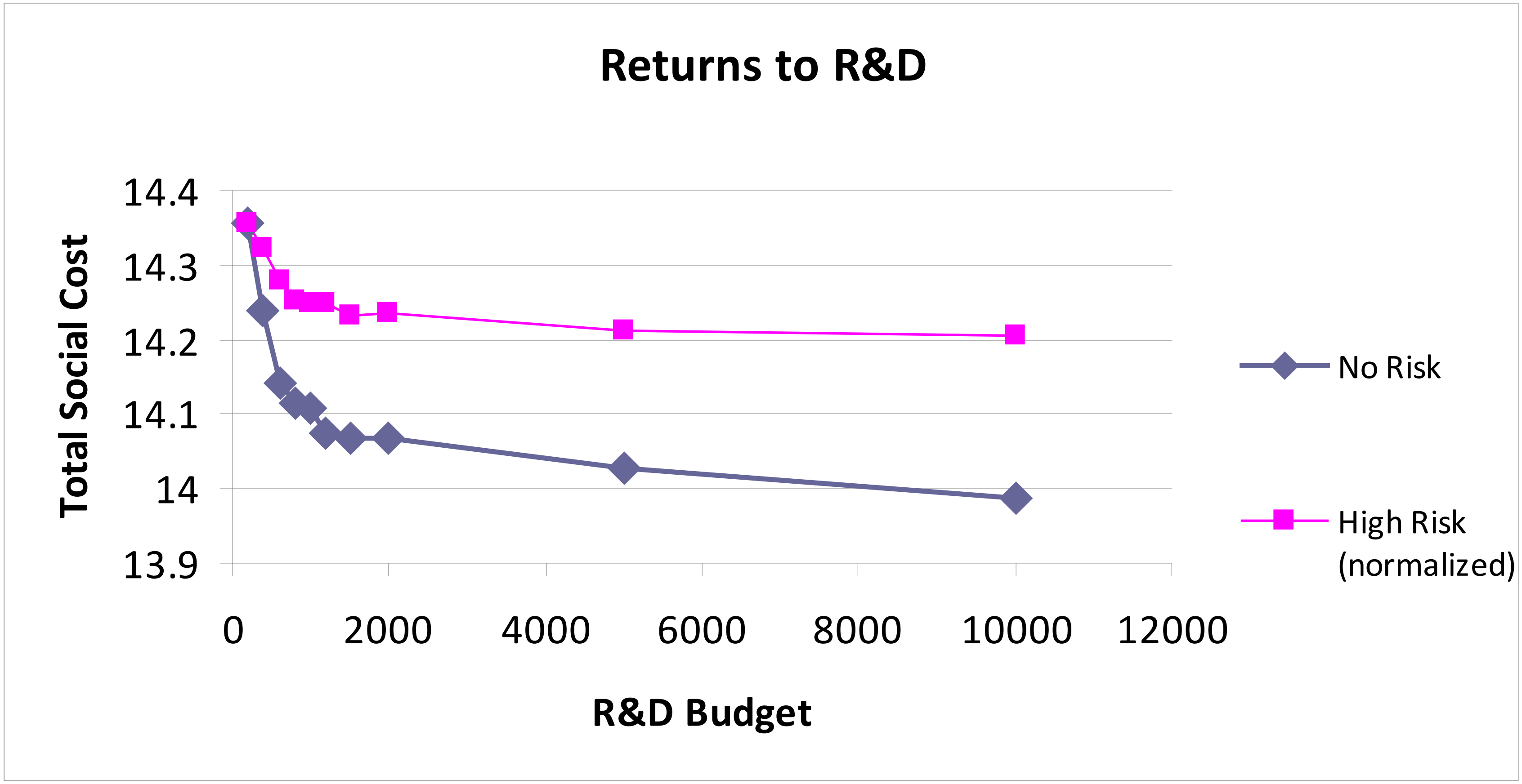
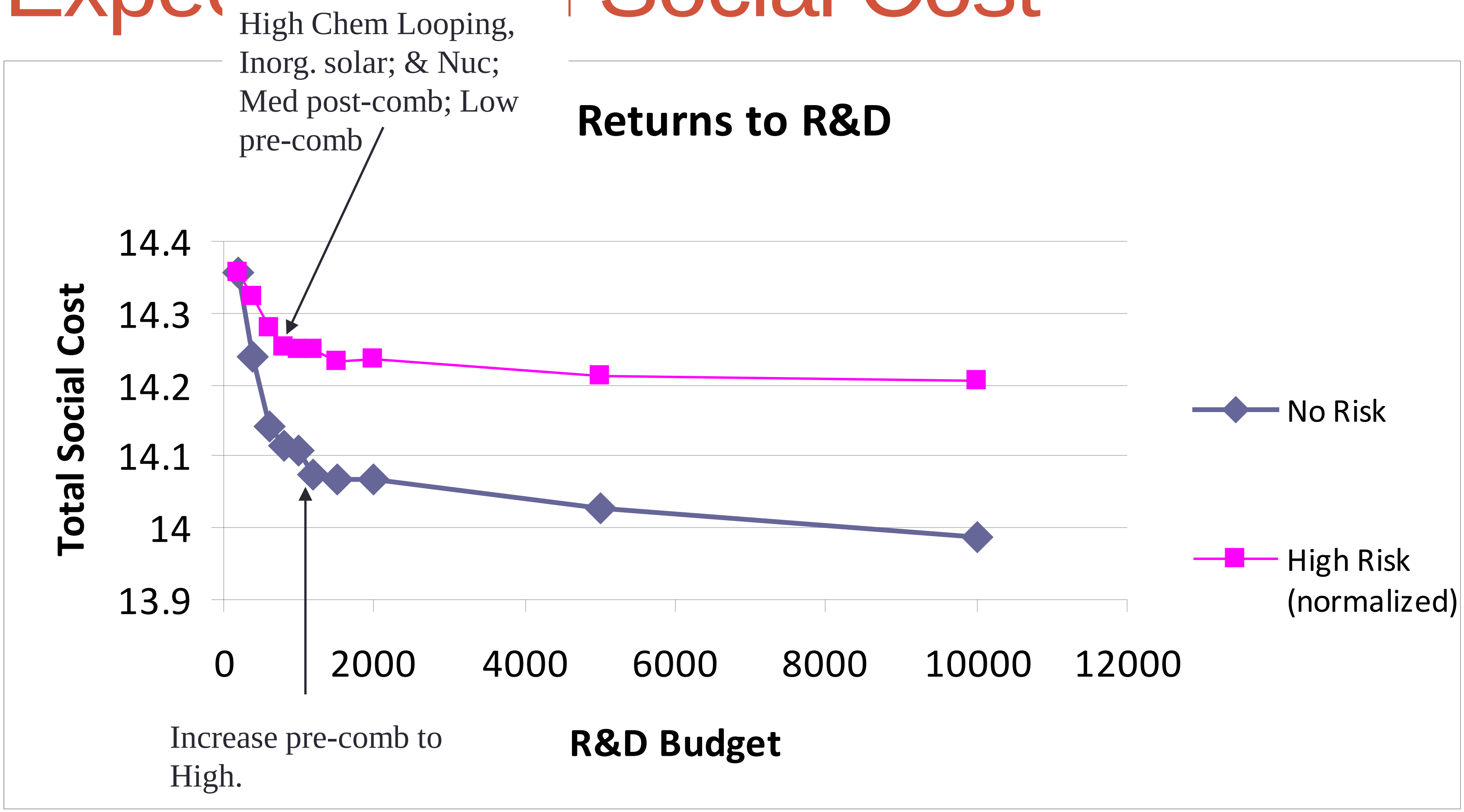


In no- risk case, expected abatement cost *INCREASES* with R&D. The benefits are on the environmental side.

In the high-risk case, the expected damages aren't effected by R&D. All benefits are in cost reduction.

Expected Total Social Cost



R&D PORTFOLIOS

Part II

Dynamic Detailed IAM with R&D

- Based on well-known DICE model
  - 25 10-yr periods
  - Add R&D and uncertainty
- Two-stage stochastic nonlinear programming problem
  - Uncertainty in technologies and damages resolved after 50 years

Technical change, represented by α, pivots and shifts the MAC

pivot shift

$$c\left(\mu_t,\vec{\alpha}\right)=\left(1-.08\alpha_1-0.92\alpha_2\right)c\left(\mu_t\right)-\left(0.02-0.06\alpha_1-0.14\alpha_2\right)c\left(0.5\right)\mu_t$$

Damages depend on temp τ, and have a random shift parameter, π

$$D\left(\tau\right)=1+\tilde{\pi}\tau^2$$

Unadjusted output is reduced by the cost of abatement and by damages

$$y_t=\frac{1-c\left(\mu_t,\vec{\alpha}\right)}{D\left(\tau_t,\tilde{\pi}\right)}y_t{}^g$$

Output is divided between consumption, investment in capital, and R&D for the first 5 period.

$$y_t=c_t+I_t+\kappa\gamma_t$$

Symbol	Definition
c()	cost of abatement
D()	Damages from climate change
μ	abatement, as a fraction
α	parameter representing technical change
τ	temperature change
π	random damage parameter
y, y^g	output, adjusted and unadjusted
c	consumption
I	investment in capital
κ	opportunity cost of R&D
γ	R&D investment cost

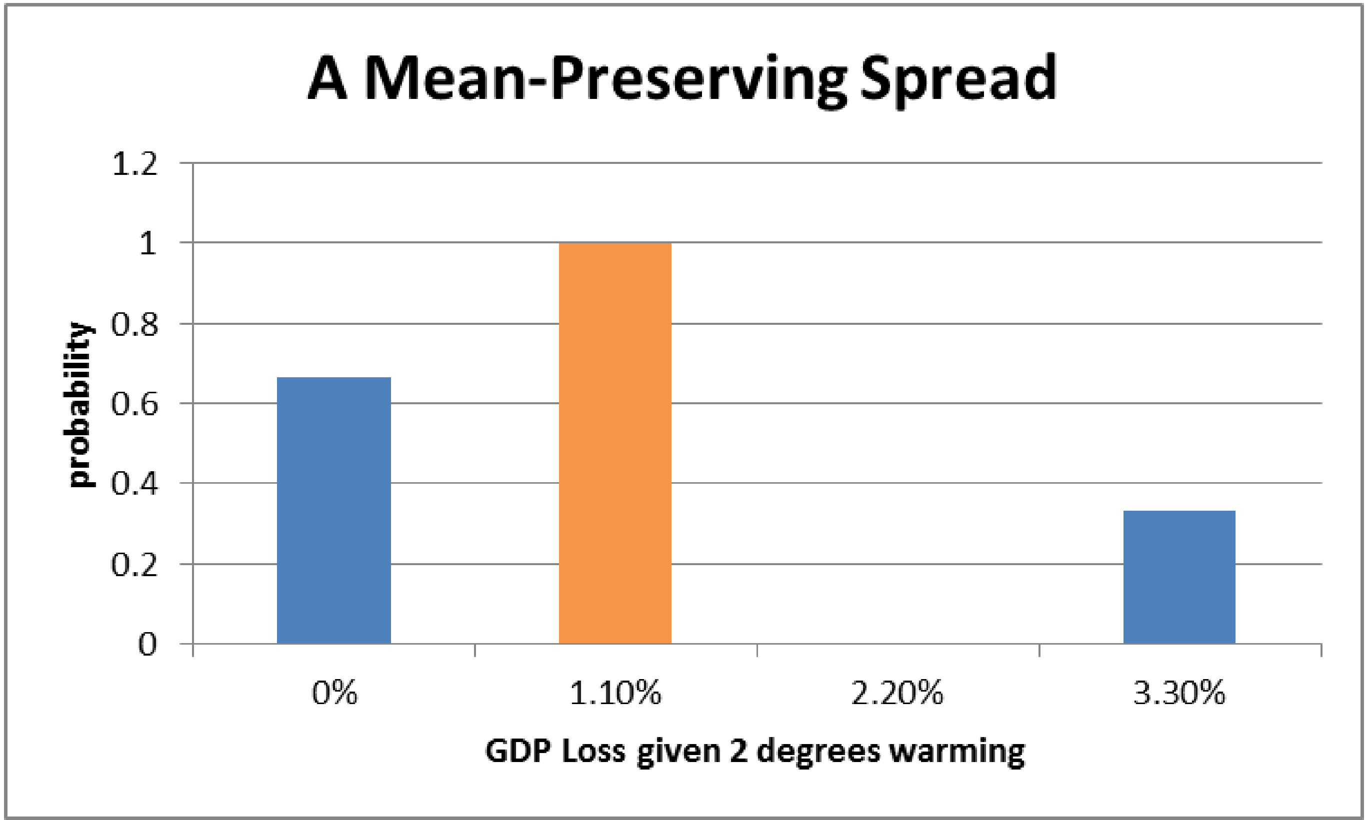
Experiments

Focus on comparing different policy environments

Policy	Abatement	Key characterisitcs
Baseline no-controls	0	
DICE Optimal	optimal	
Stern	optimal	Abatement chosen under low interest rate
Stern Fixed	optimal	Abatement and R&D chosen under low interest rate
Gore	Lower bound between 0.25 - 0.95	Limited participation
Kyoto Strong	fixed for 150 years	Limited participation
2 degrees	optimal	Upper bound on temperature

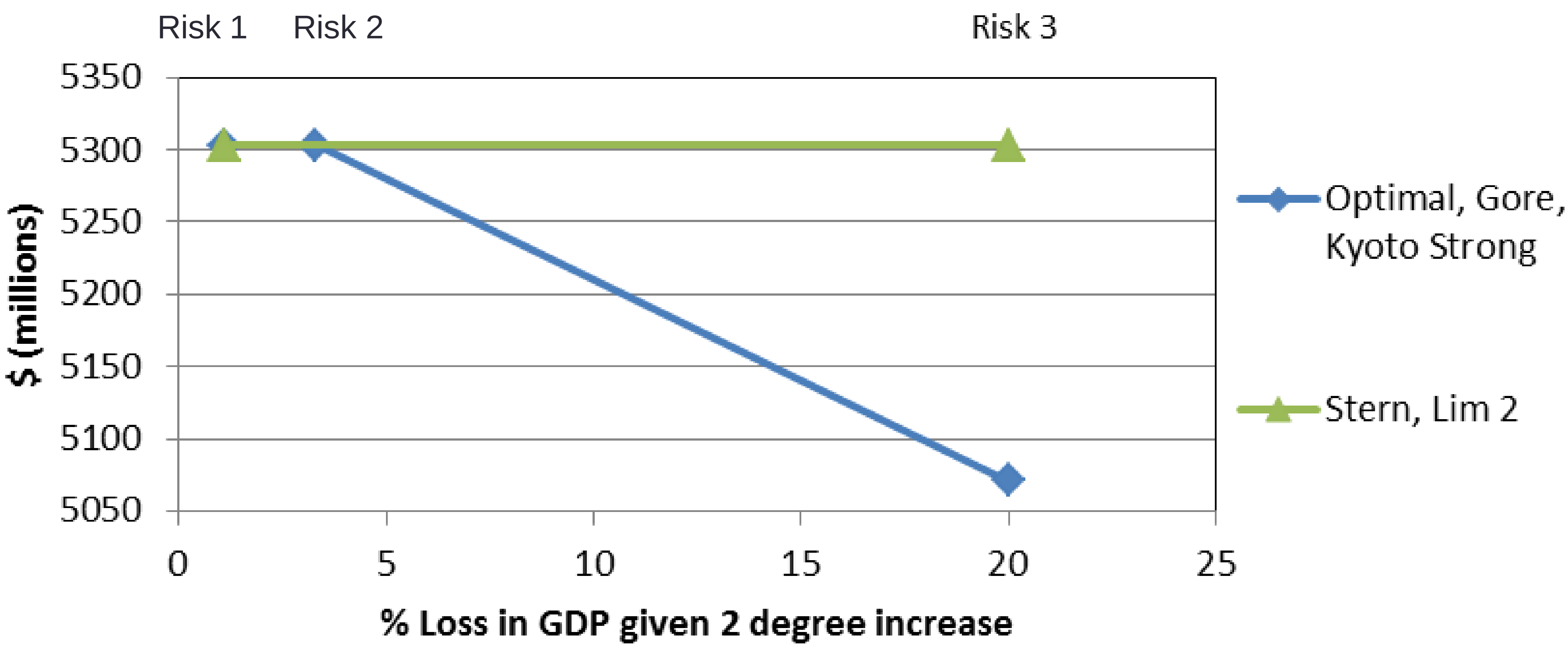
Different representations of climate risk

	No risk (1)	Medium risk (2)		High risk (3)		Very high risk (4)		Intermediate (5)		
Probability	1.000	0.667	0.333	0.945	0.055	0.973	0.028	0.309	0.673	0.018
GDP Loss	1.1%	0.0%	3.3%	0.0%	20.0%	0.0%	40.0%	0.0%	1.1%	20.0%
π	0.003	0.000	0.009	0.000	0.063	0.000	0.167	0.000	0.003	0.063



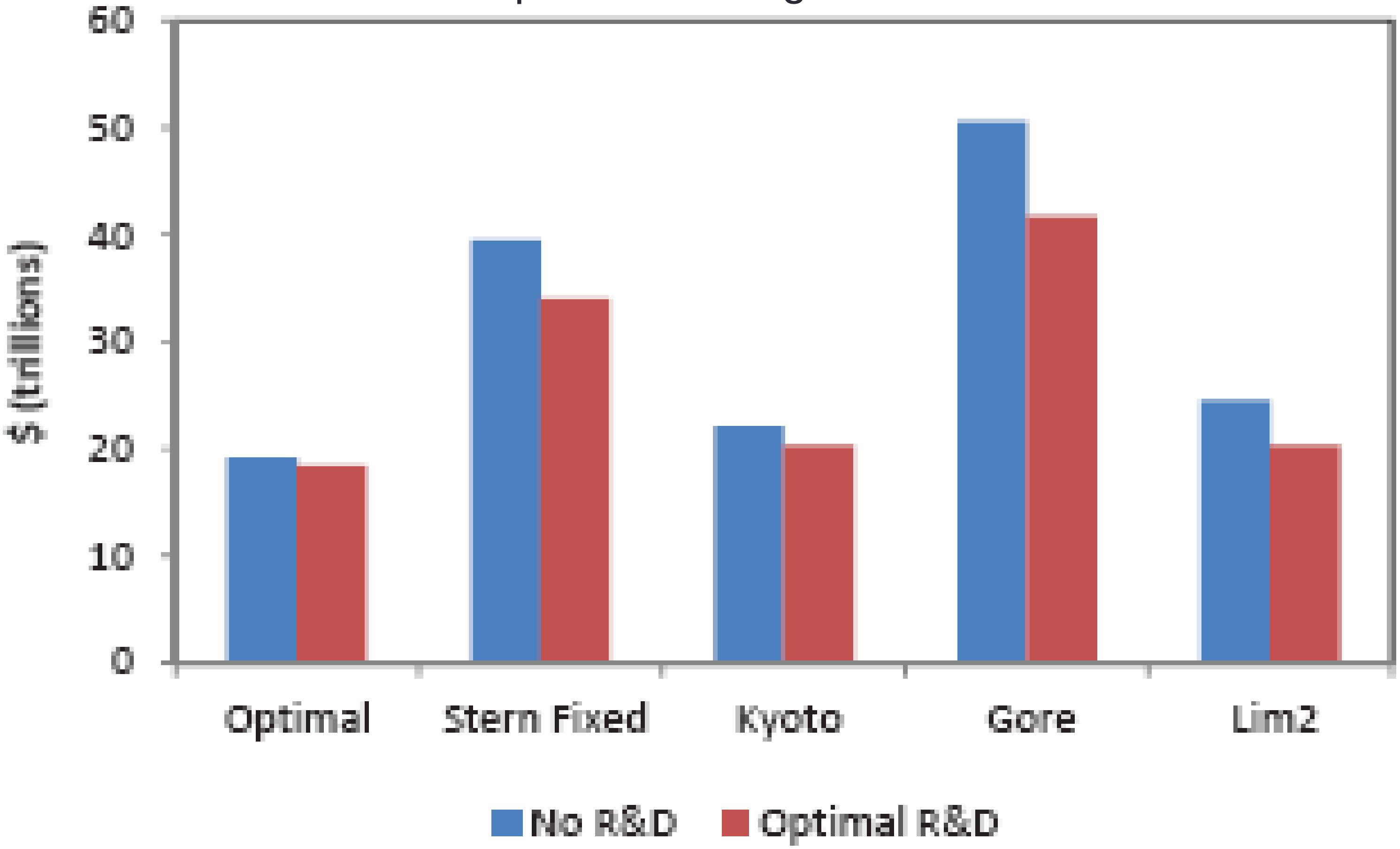
RESULTS

Optimal R&D Investment is robust

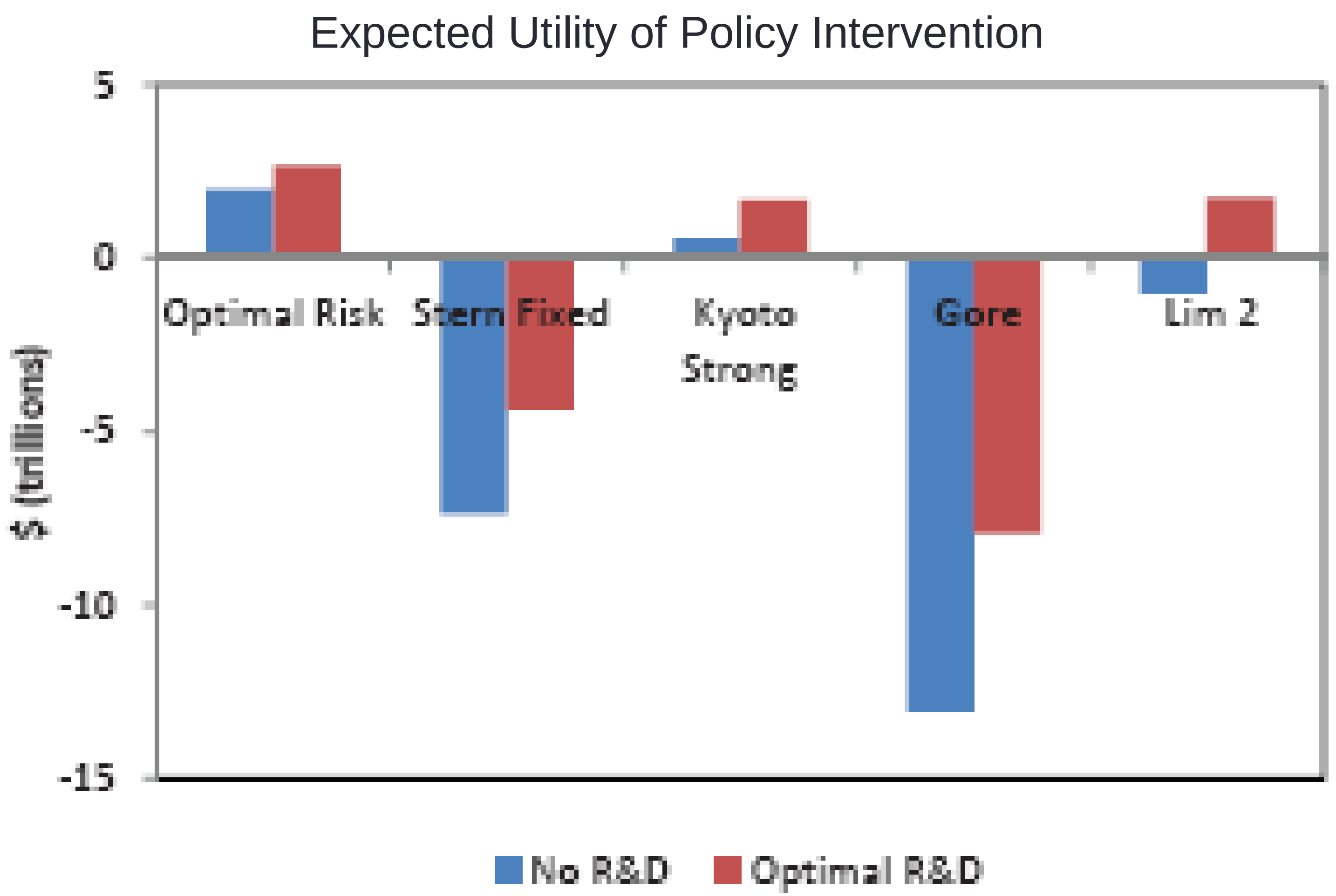


R&D has larger impact in "2nd best" policy environments

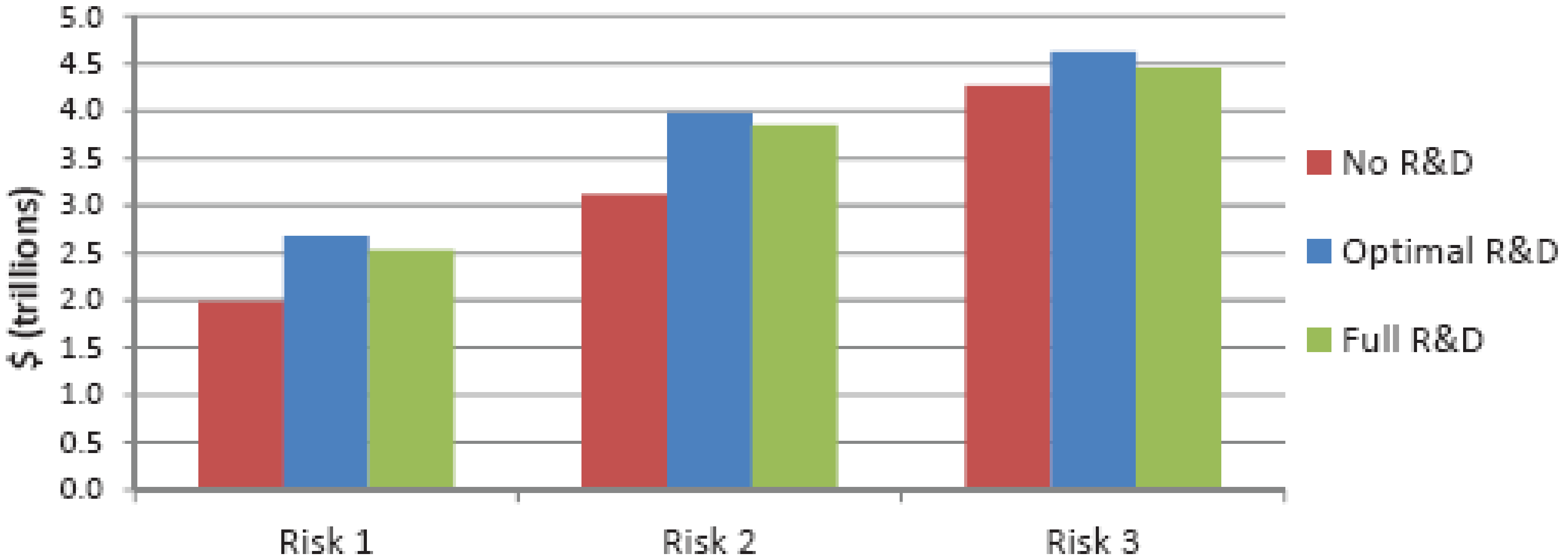
Expected Damages + Abatement Costs



R&D might save a Kyoto-type agreement

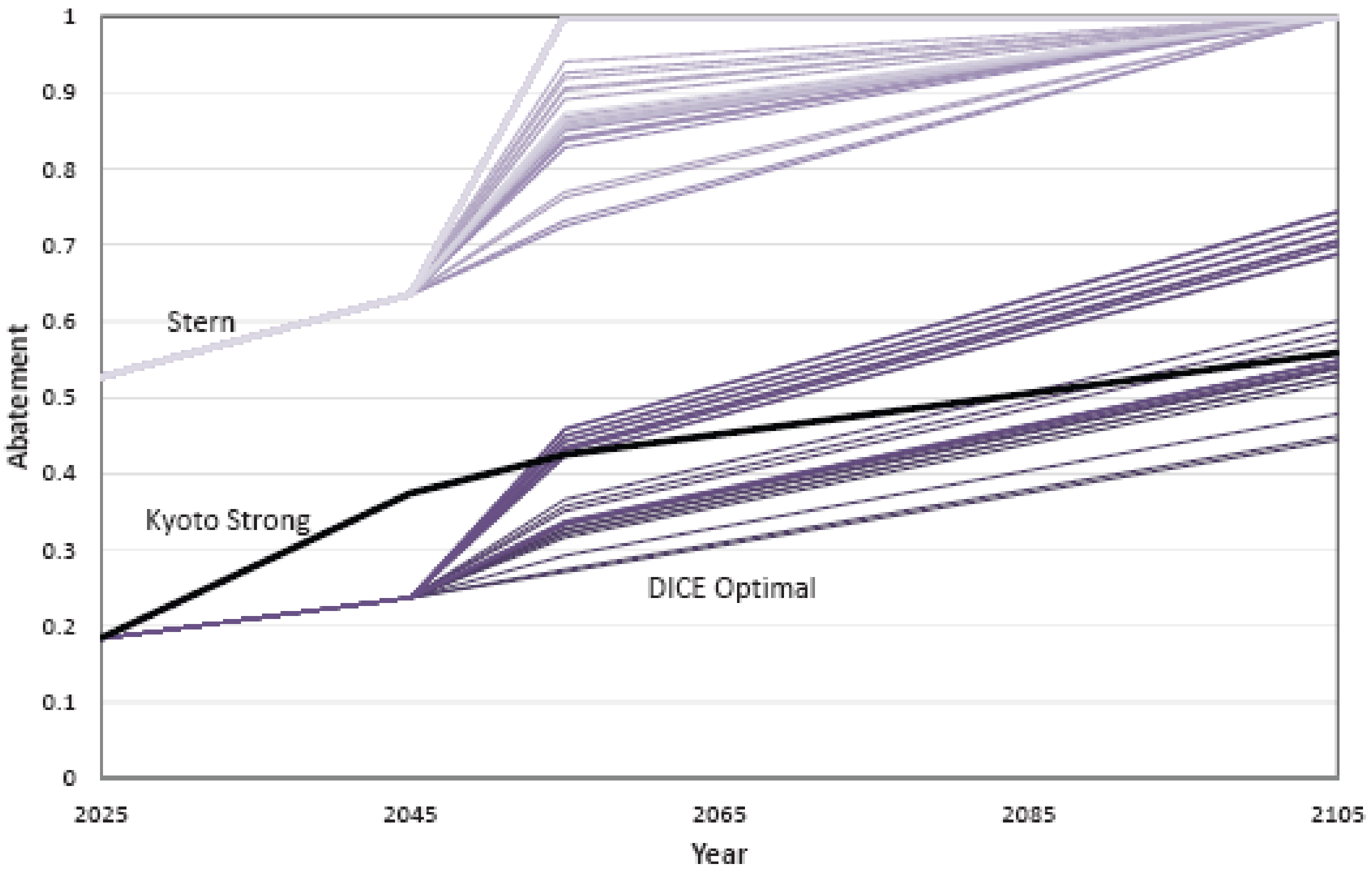


Under-investment and over-investment have an asymmetric impact



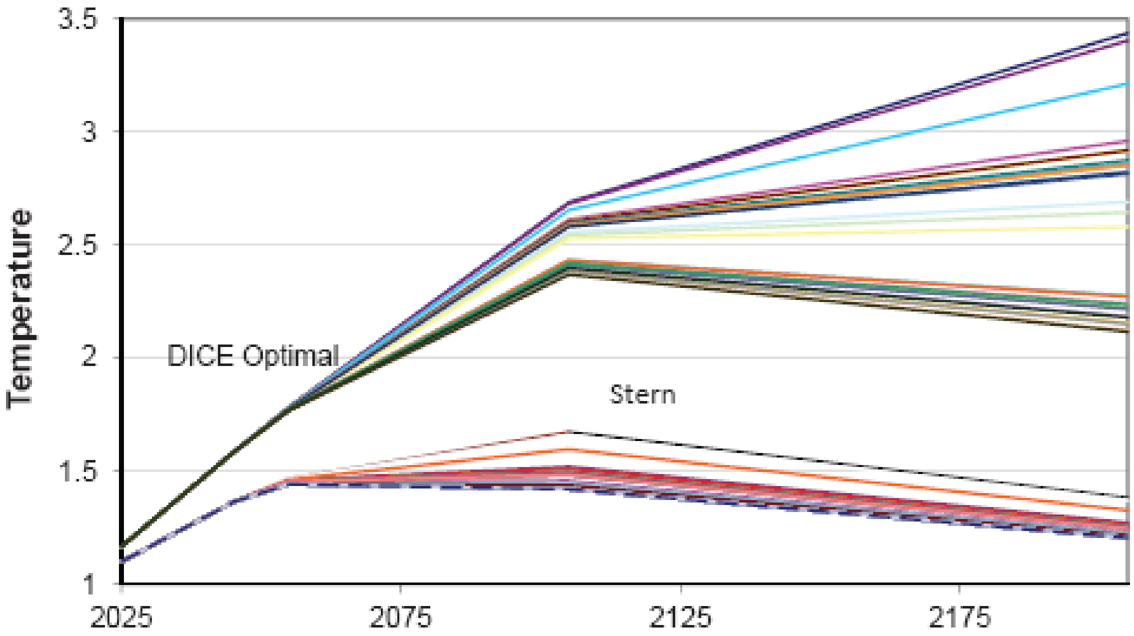
Expected Utility of Optimal Policy under different risk cases and different R&D investments

Abatement path depends on technology (and damages).

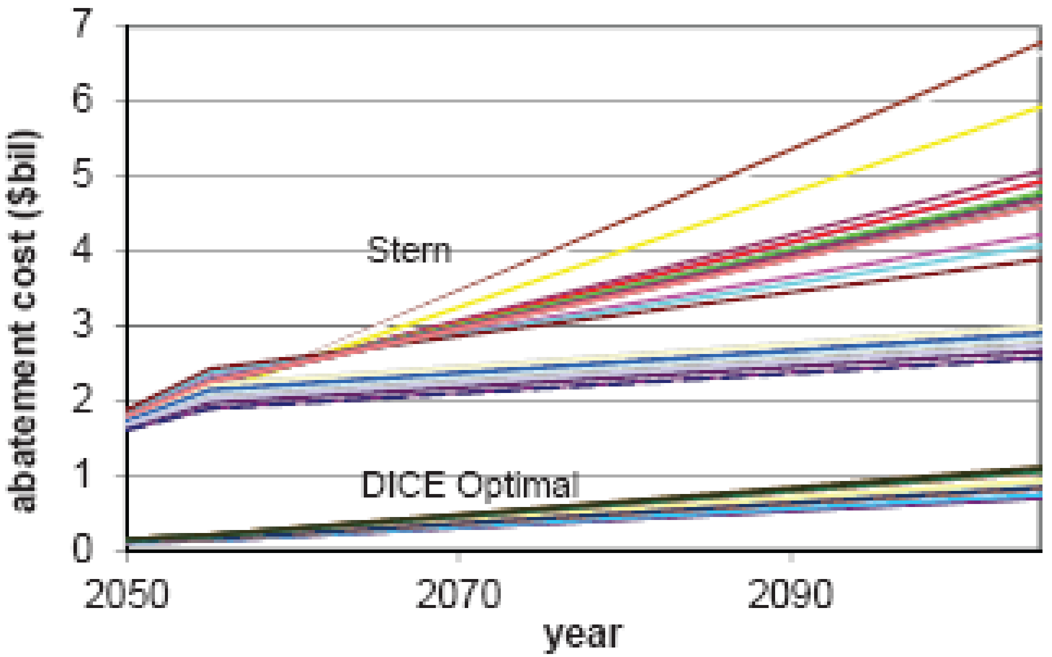


R&D has different impacts in the different policy environments

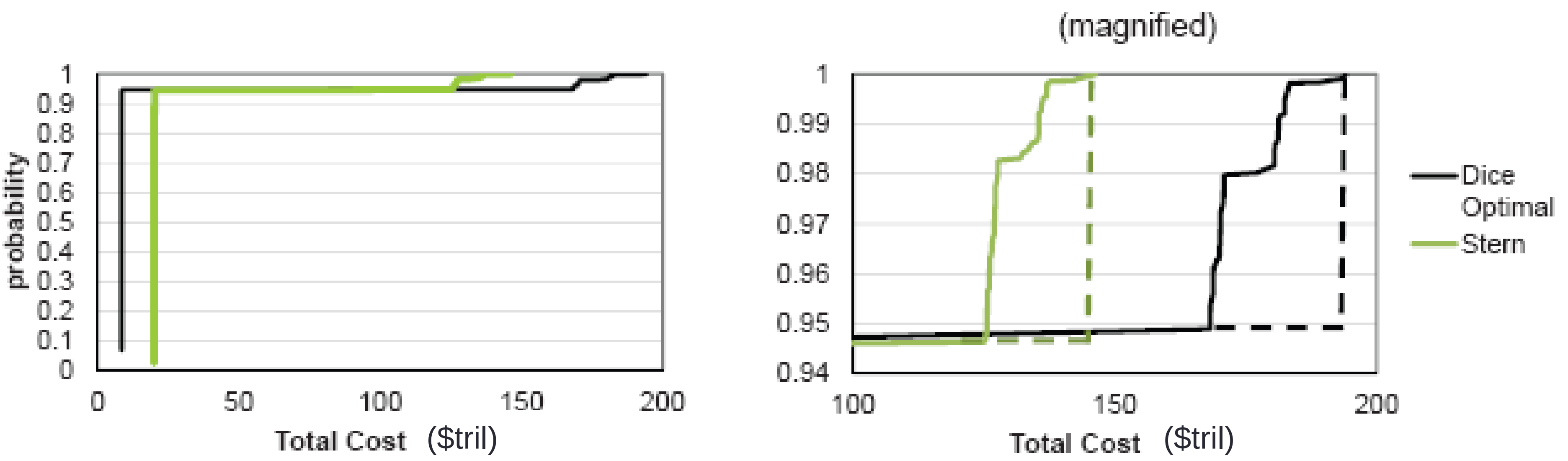
Temperature Paths



Abatement Cost Paths



Total costs depend on technology, damages, and policy



Policy Implications

- Optimal R&D investment is fairly robust to risk, policy, opportunity costs.
  - Under-investment appears more costly and risky than over investment
- R&D has more value in “2^{nd} best” policy environments.
  - Kyoto Strong and 2 degrees go from negative or flat to positive
- The role of R&D is different in different policy environments and risk cases
  - If abatement is high, it mostly effects costs
  - If abatement is low, it mostly effects environmental variables.
- The Stern policy can be seen as response to risk aversion.
  - R&D can be seen as in investment in risk reduction.