R&D Decision Frameworks: Integrating elicitation data, IAMs, and decision insights

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Uncertainty in climate change modeling and policy

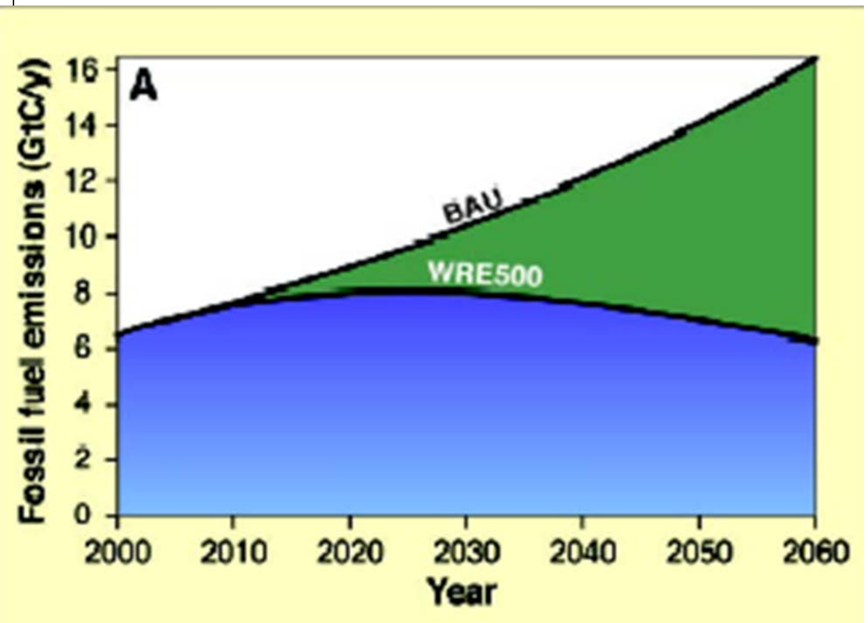
ADVANCE Workshop

Milan, 13th May 2014

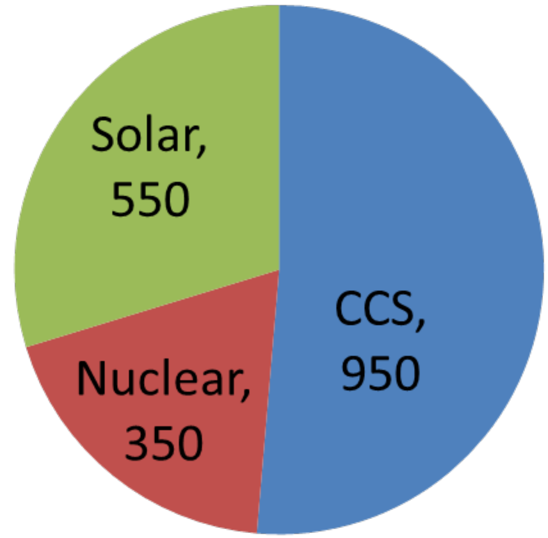
Advanced Model Development and Validation for the Improved Analysis of Costs and Impacts of Mitigation Policies

The research leading to these results has received funding from the European Union's Seventh Framework Programme [FP7/2007-2013] under grant agreement n° 308329

What to do about climate change?



What is the optimal path for a carbon tax and/or an emissions path?



What is the optimal portfolio of technology policies?

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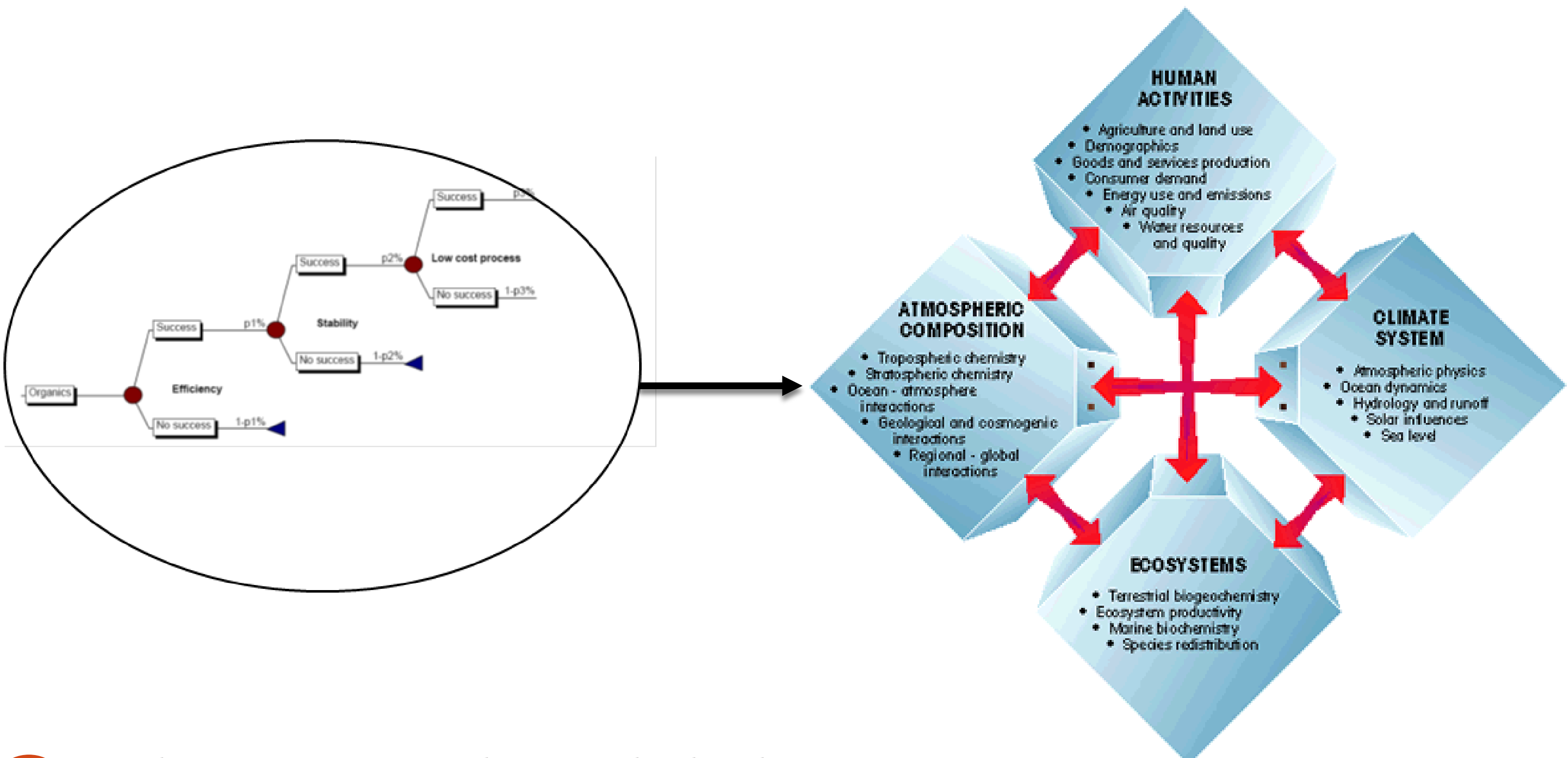
Integrating Expert Judgments and IAMs to inform energy technology policy



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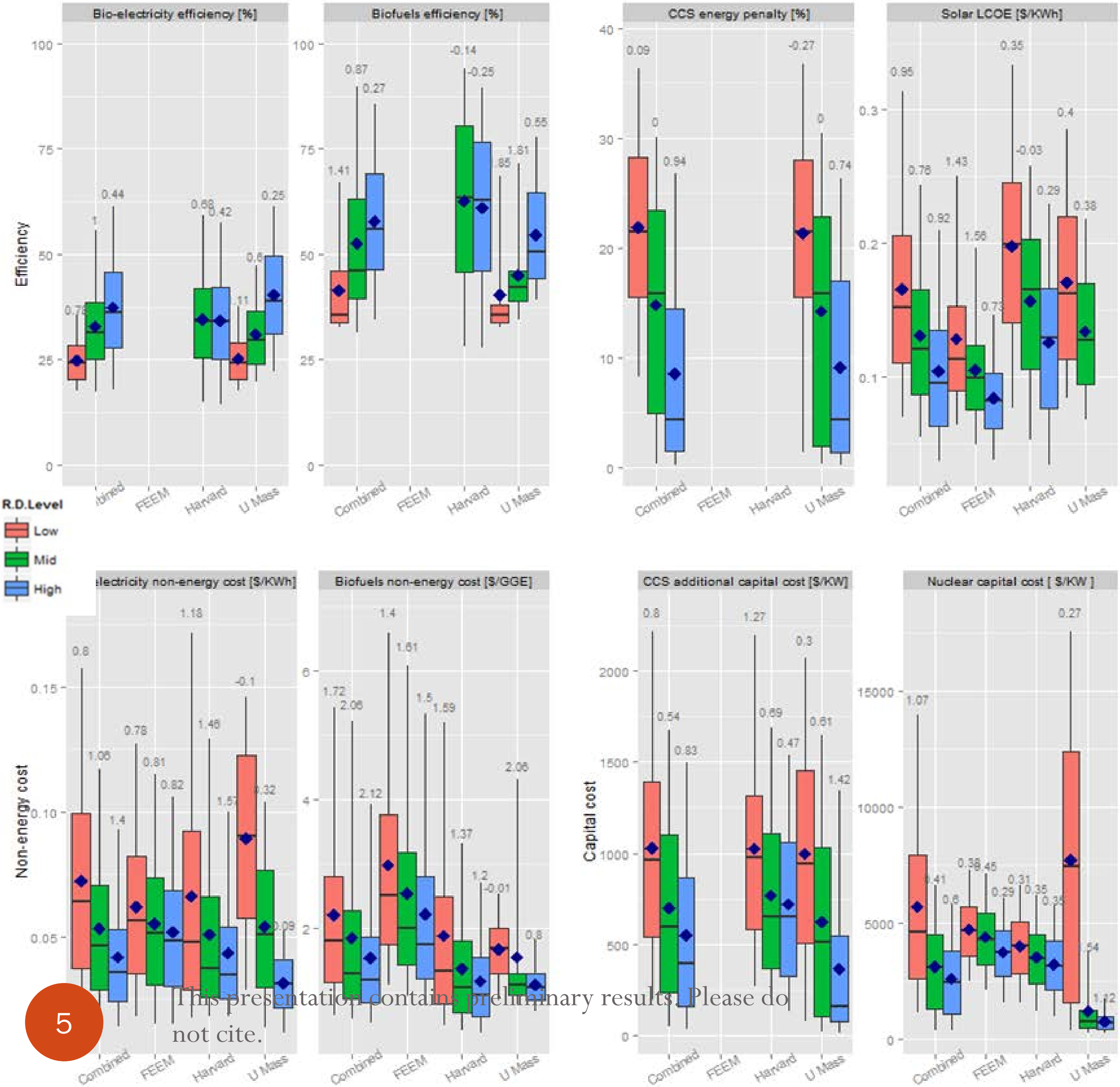
Outline

- Introduce the TEaM Data
- Discuss Decsion Frameworks
- Focus on 1-stage and 2-stage DMUU
  - R&D portfolio models
  - Importance sampling
  - Results

Harmonized TEaM Results



UMass	Low	Mid	High
Solar	25	140	NA
Nuclear	40	480	1980
CCS	13	48	108
Biofuels	13	201	838
Bio electricity	15	50	150
Harvard			
Solar	143	409.1	4091
Nuclear	466	1883	18833
CCS	701	2250	22500
Biofuels	214	585	5850
Bio electricity	214	585	5850
FEEM			
Solar	163	244	326
Nuclear	942	1883	18833
CCS	NA	NA	NA
Bio fuels	160	240	320
Bio electricity	161	242	322
Funding Levels $M/yr			

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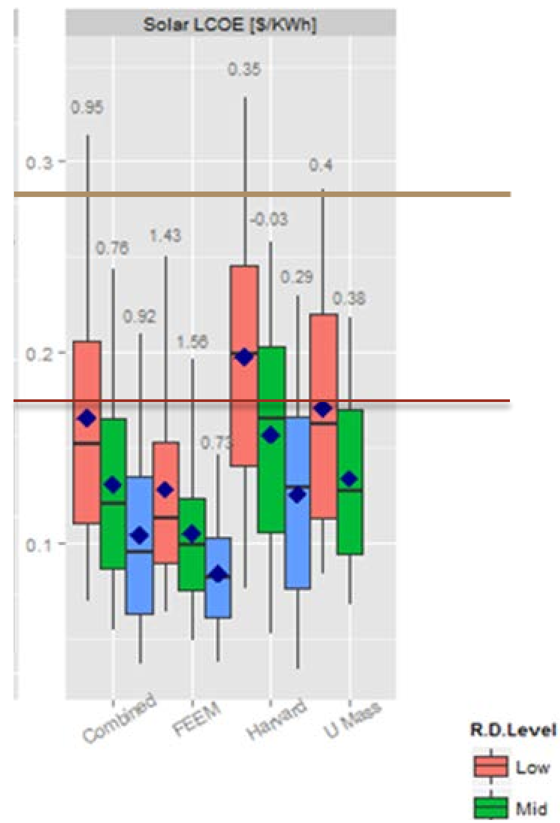
The Solar LCOE was harmonized using a capacity factor of 12%

Reference	Module cost 2050 ($/Wp)	Module cost 2025 ($/Wp)	Module cost 2014 ($/Wp)	BOS ($/Wp)	lifetime	LCOE TEaM
China			0.75	0.73	20	$0.17
China			0.75	1.67	20	$0.28
UMass, medium	0.35	0.51		0.73	30	$0.13
UMass, aggressive	0.17	0.25		0.35	15	$0.08



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Returns to R&D

$$R_{L-M} = \frac{m_L - m_M}{m_L}$$

Combined	FEEM	Harvard	UMass
CCS	Solar	CCS	Nuclear
Nuclear	Bio-fuels	Bio-electricity	CCS
Solar	Nuclear	Solar	Bio-electrici
Bio-electricity	Bio-electricity	Biofuels	Biofuels
Bio-fuels		Nuclear	Solar

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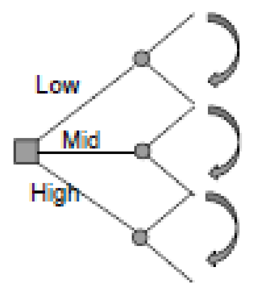
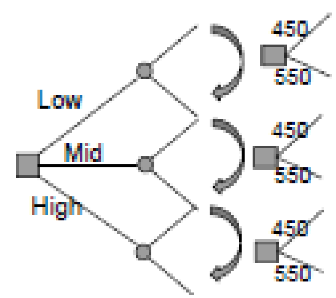
Some conceptual frameworks

- Sensitivity Analysis
  - How does outcome X change if parameter Y changes?
- Uncertainty Analysis
  - What is the probability distribution of outcome X
    - (For a given decision D)
  - Which uncertain parameters most influence the uncertainty in X
- Decision Under Uncertainty
  - One-stage: What is best decision now?

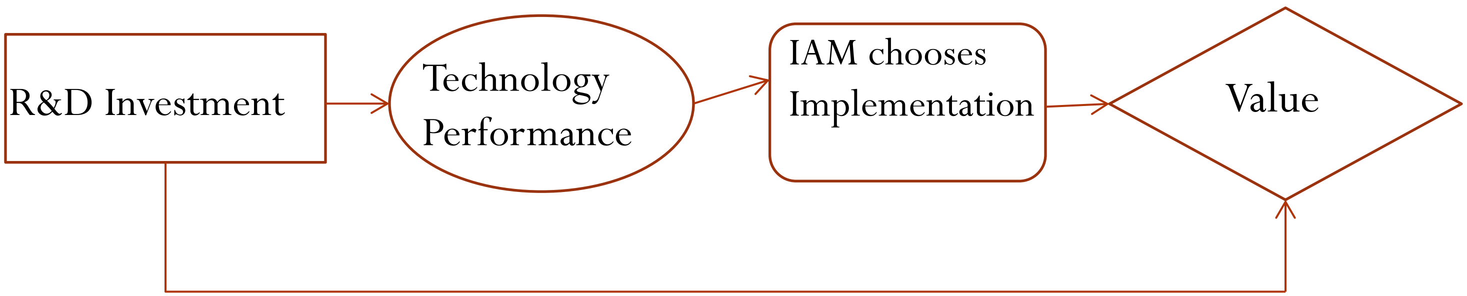


  - Two-stage: What decision D_1 is best now if
    - We are uncertain about some parameters, and
    - We will get new information later, and
    - We can make another decision(s) D_2

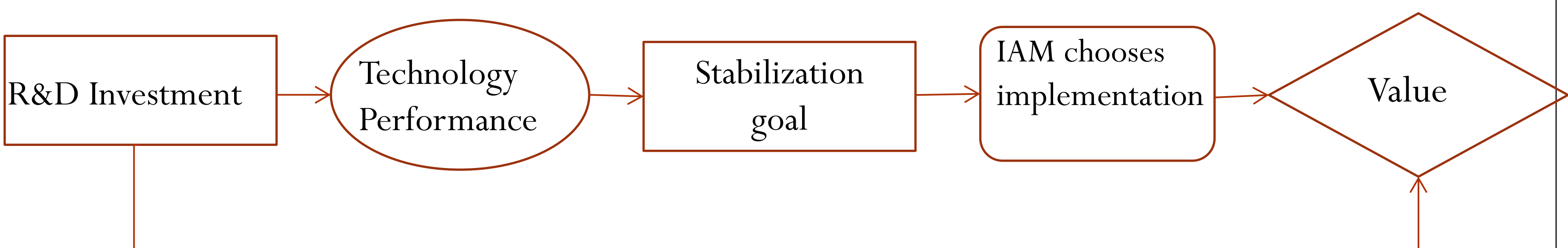


Decision Frameworks: Example

One-stage (given a stabilization goal)**:**



Two-stage:



The models

One stage: $$\min_I \left\{ E_I \left[\widetilde{TAC}_s + \widetilde{D}_s \right] + \beta F_I \right\}$$ For s= 450, 550, unc

Two stage: $$\min_I \left\{ E_I \left[\min_s \left(\widetilde{TAC}_s + \widetilde{D}_s \right) \right] + \beta F_I \right\}$$

TACs = total abatement cost for stabilization s

Ds = climate damages for stabilization s: $D_S = \sum_t \delta^t \pi T_{t,S}^2 G_t$

$I=(I_1,..,I_5)$

$$F_I = \sum_j I_j$$

Delta – discount factor

Pi – damage multiplier

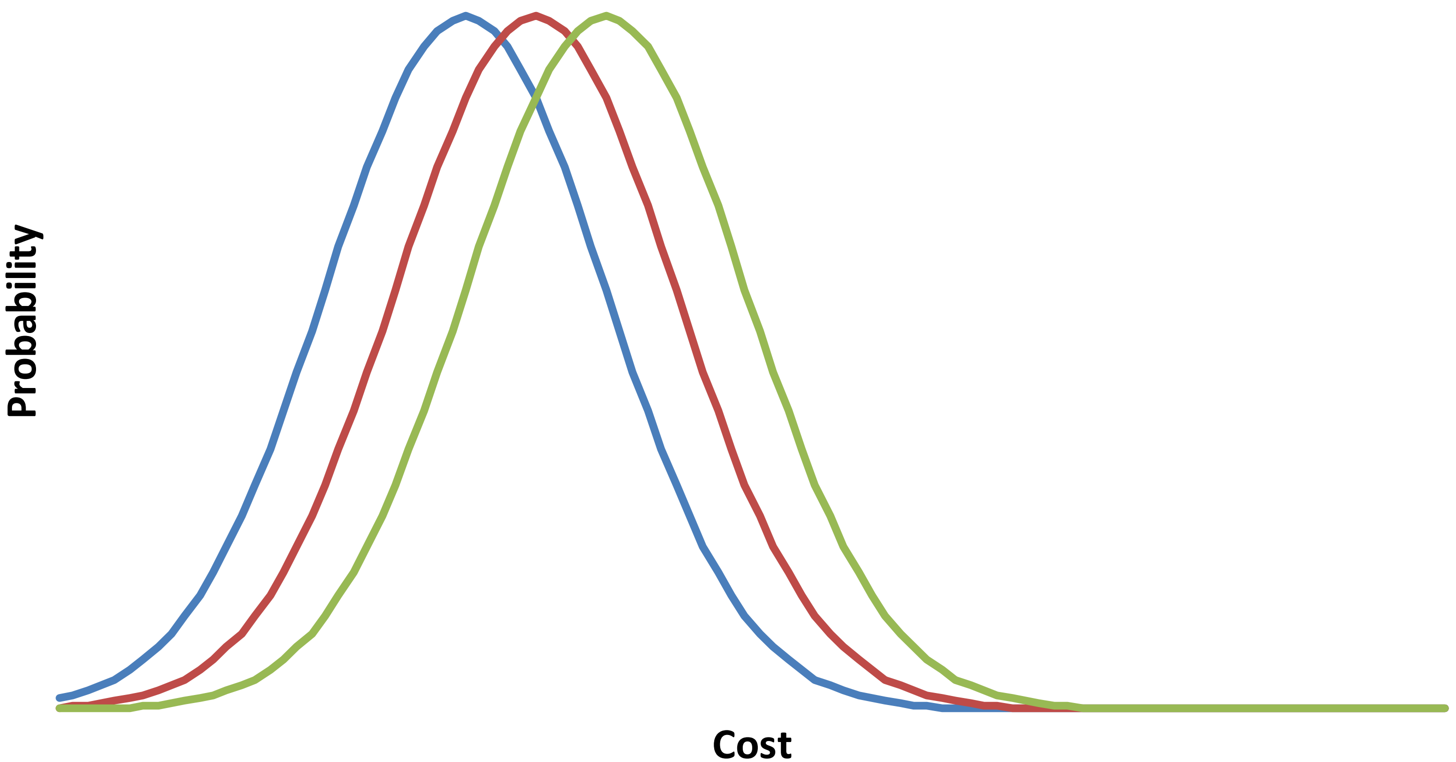
T global mean temp

G GDP

β = opportunity cost

Covering Distributions with Importance Sampling

Nominal (elicited) distributions $q_{ij}(x_i)$



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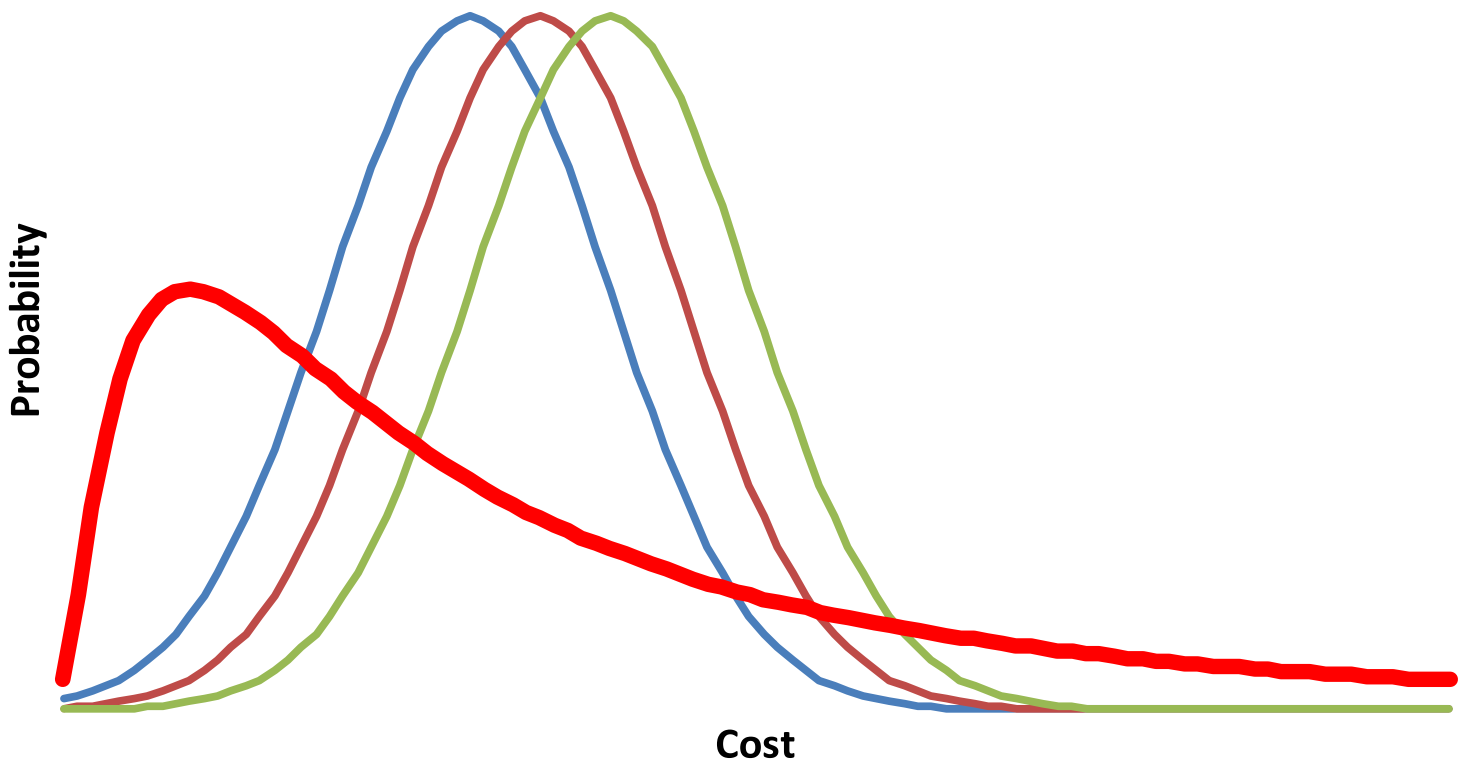
Covering Distributions with Importance Sampling

Nominal (elicited) distributions $q_{ij}(x_i)$

Covering (importance) distribution $p_{i(x_i)}$ chosen to span the range of nominal distributions and sample from the area of interest.



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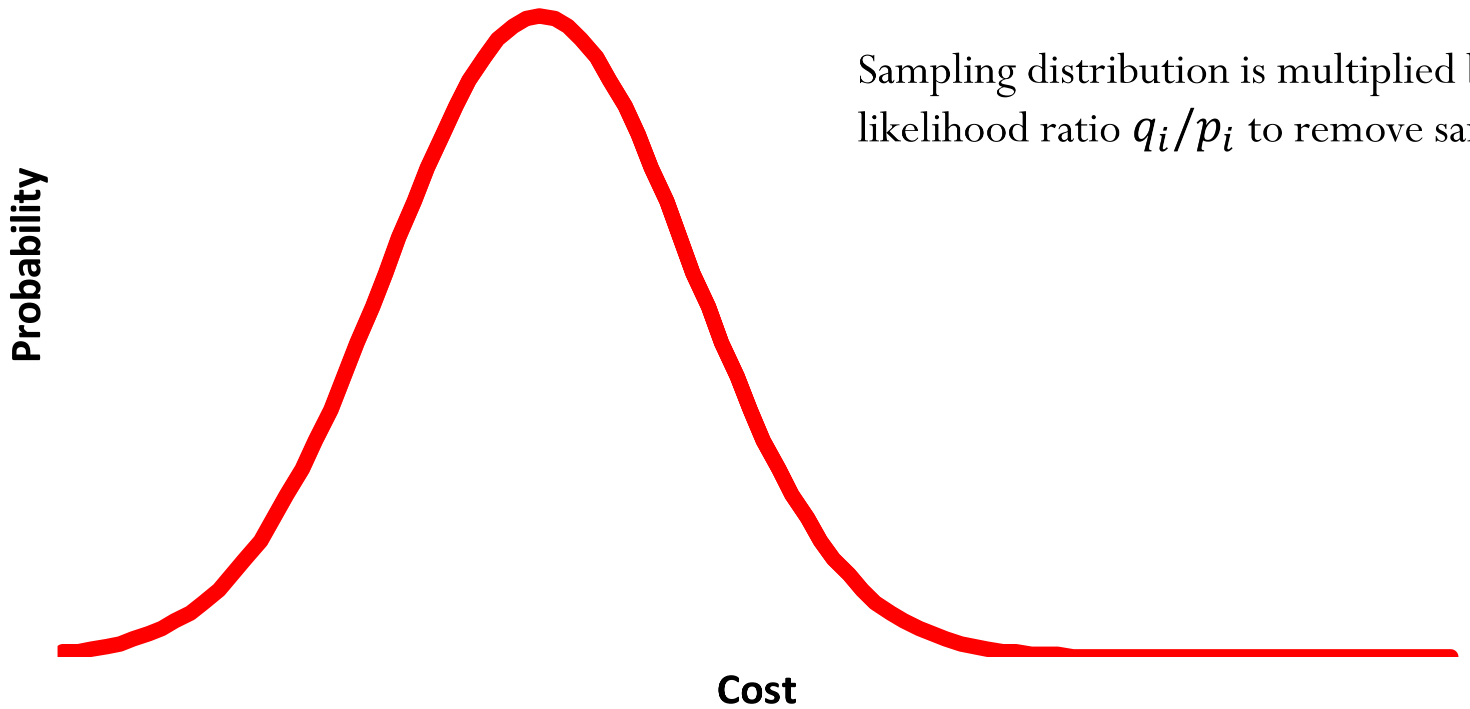

Sampling distribution is multiplied by the likelihood ratio q_i/p_i to remove sampling bias.

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Implementing uncertainty: Importance Sampling

Covering distributions							
Quantities	**1**	**2**	**3**	**4**	**5**	**6**	
Solar LCOE	0.250164328	0.22849298	0.364588	0.03362	0.080216	0.126532	0.065
Nuclear capital cost	2515.199486	900.3193306	5616.354	597.7449	339.7441	886.1703	2137
Biofuels non-energy cost	2.131165676	1.565583097	0.265261	4.932704	3.48862	5.781956	7.088
Biofuels efficiency	46.46690905	27.75857482	24.41591	51.3686	30.17639	29.26475	74.6
Bio-electricity non-energy cost	0.04029036	0.025817958	0.034113	0.169694	9.96E-03	0.069278	0.023
Bio-electricity efficiency	14.18800969	26.0226515	41.79696	7.340489	27.60165	14.59448	83.75
CCS additional capital cost	2728.175502	1275.022402	408.7799	1693.235	3228.776	590.0318	2179
CCS energy penalty	6.28121852	24.61319645	7.333404	42.2095	25.36598	25.81081	8.813

Covering distribution generated using pi

Elicited distribution is qi

Reweight the sampled points using $\frac{q_i}{p_i}$

Funding levels

- Combined funding averages three teams.
- Harvard can only invest in both biofuels and bioelectricity
- Assumed that bio investment is divided evenly for calculation of combined funding.

UMass	Low	Mid	High
Solar	25	140	NA
Nuclear	40	480	1980
CCS	12.75	48	108
Biofuels	12.5	201	838
Bio electricity	15	50	150
Harvard*			
Solar	143	409	4091
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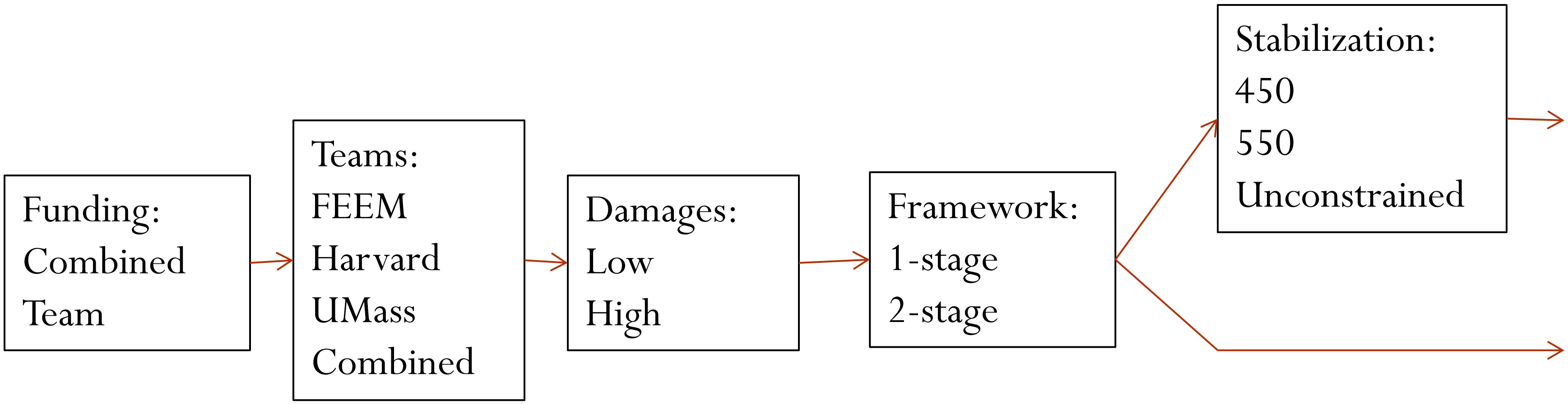
CCS	701	2250	22500
Biofuels**	214	585	5850
Bio electricity**	214	585	5850
FEEM			
Solar	171	257	342
Nuclear*	753	1514	15140
CCS	NA	NA	NA
Biofuels	168	252	336
Bioelectricity	169	254	338
Funding Levels $M/yr			

Experimental design



Damages	Parameter pi	Annual loss of GDP given 2 degree warming
Low	.0035	1.4%
High	.0170	6.8%

Results

1-stage model results are not very robust across teams or stabilizations

Stab\team	Harvard	FEEM	UMass	Combined
450	Bio	CCS	Nuc, CCS, bioF, bio-E(h)	bio-E,Nuc
Unconstr - hi	Solar, Bio	Solar, biofuel	Nuc	biofuel,Nuc
550-hi	Bio	bioE	Nuc, bio-E	bio-E
550-lo	Bio		Nuc	
Unconstr -lo	Bio		Nuc	

Most technologies come out low. Those shown come out medium, unless marked with (h)

Value of Technology in “no-policy” world

Stab\team	Harvard	FEEM	UMass	Combined
450	Bio	CCS	Nuc, CCS, bioF, bio-E(h)	bio-E,Nuc
Unconstr - hi	**Solar, Bio**	**Solar, biofuel**	**Nuc**	**biofuel, Nuc**
550-lo	Bio		Nuc	
Unconstr -lo	**Bio**		**Nuc**	

2-stage vs 1-stage

Stab\team	Harvard	FEEM	UMass	Combined
450	Bio	CCS	Nuc, CCS, bioF, bio-E(h)	bio-E,Nuc
550-hi	Bio	bioE	Nuc, bio-E	bio-E
Framework 2 –hi	Bio	bioE	Nuc, CCS, bioF, bio-E(h)	Nuc, **biofuels**, bioE

Stab\team	Harvard	FEEM	UMass	Combined
550-lo	Bio		Nuc	
Unconstr -lo	Bio		Nuc	
Framework 2 – lo	Bio		Nuc	

Conclusion

- Importance sampling is a promising method for combining large IAMs with expert elicitations
  - Importance sample needs to be chosen carefully, especially when there are many random variables being multiplied
- Results of portfolio optimization do not directly follow the results of data – the optimal investment depends on more than the technological outcome
- Energy technology R&D is valuable even in the absence of climate policy
- Some technologies may have an "option value" that cannot be easily identified in one-stage frameworks