HARVARD Kennedy School

BELFER CENTER
for Science and International Affairs

**ENERGY TECHNOLOGY INNOVATION POLICY**

August 1, 2012

Using Expert Assessments of Technical Uncertainties for R&D Portfolio Design: Strategies for U.S. Energy R&D Budget Allocation

Climate Change Impacts and Integrated Assessment Workshop
Snowmass, CO

Gabe Chan and Laura Diaz Anadon
Harvard Energy Technology Innovation Policy group
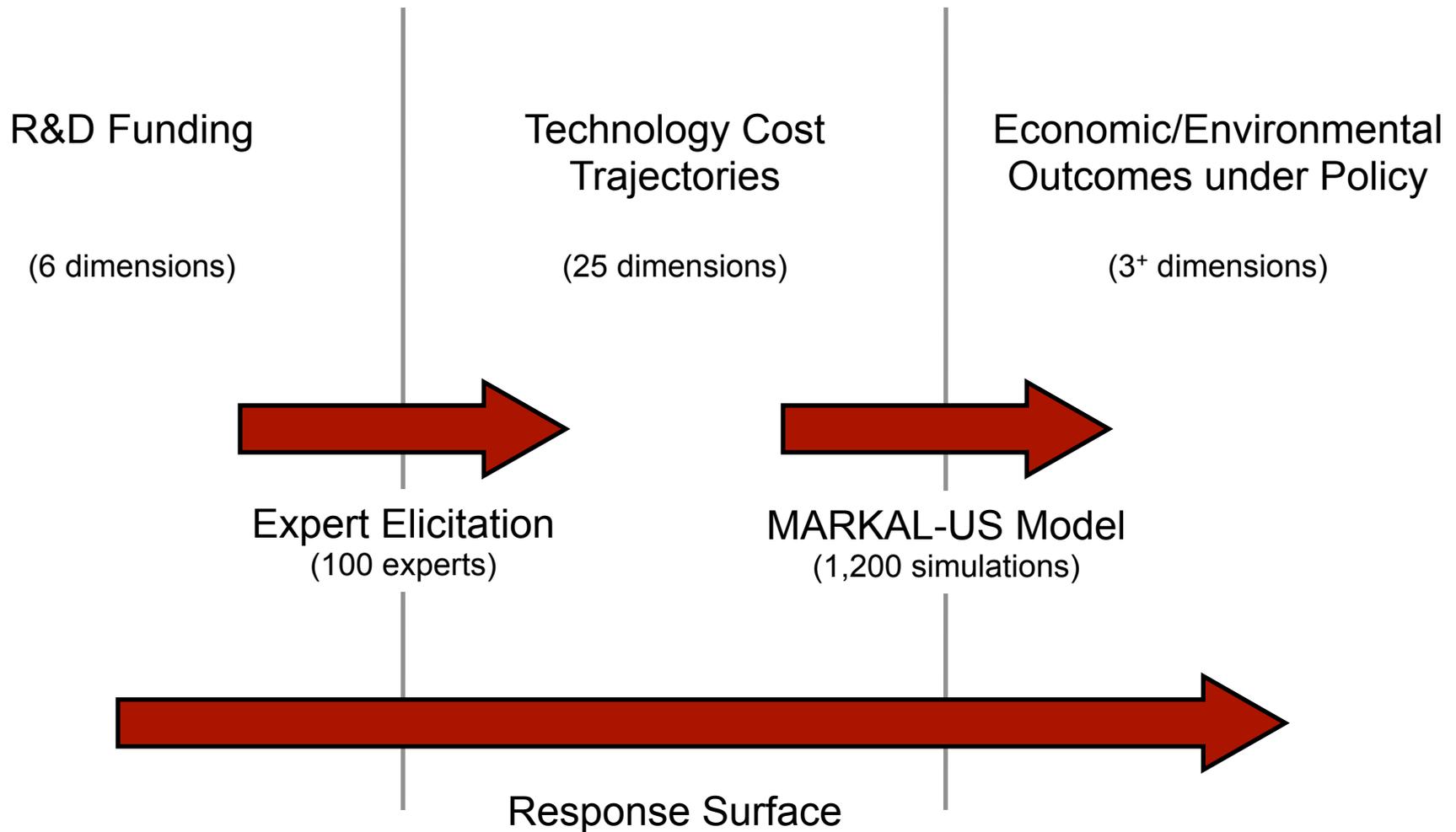Technology Elicitations and Modeling (TEaM) Project

Transforming U.S. Energy Innovation (Nov. 2011)
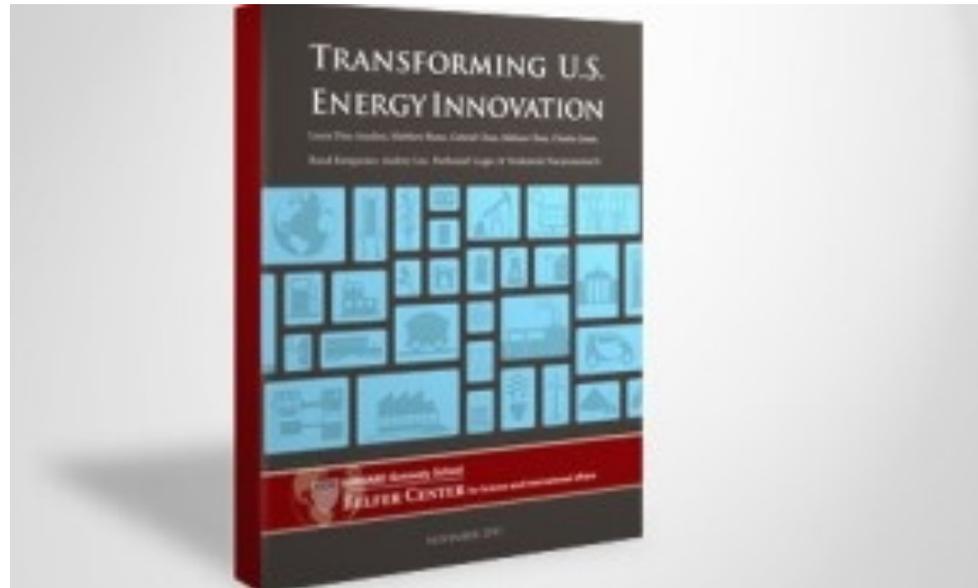
Authors: Laura Diaz Anadon (Project Director), Matthew Bun (Co-PI), Gabriel Chan, Melissa Chan, Charles Jones, Ruud Kempener, Audrey Lee, Nathaniel Logar, Venkatesh Narayanamurti (Co-PI)

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

Overview of our approach

R&D Funding

(6 dimensions)

Technology Cost Trajectories

(25 dimensions)

Economic/Environmental Outcomes under Policy

(3$^+$ dimensions)

Expert Elicitation
(100 experts)

MARKAL-US Model
(1,200 simulations)

Response Surface

Expert Elicitation and Distribution Fitting

Process:
- 100 experts in 7 technology areas (nuclear, energy storage, bioenergy, buildings, vehicles, fossil energy, PV) completed written or online expert elicitation surveys

Results:
- estimates of the 10th, 50th, and 90th percentiles of cost for 25 technologies in 2010 and in 2030 conditional on 4 levels of R&D funding
- inter-technology correlations between 2030 costs (estimated by experts in a pilot question and by our internal team)
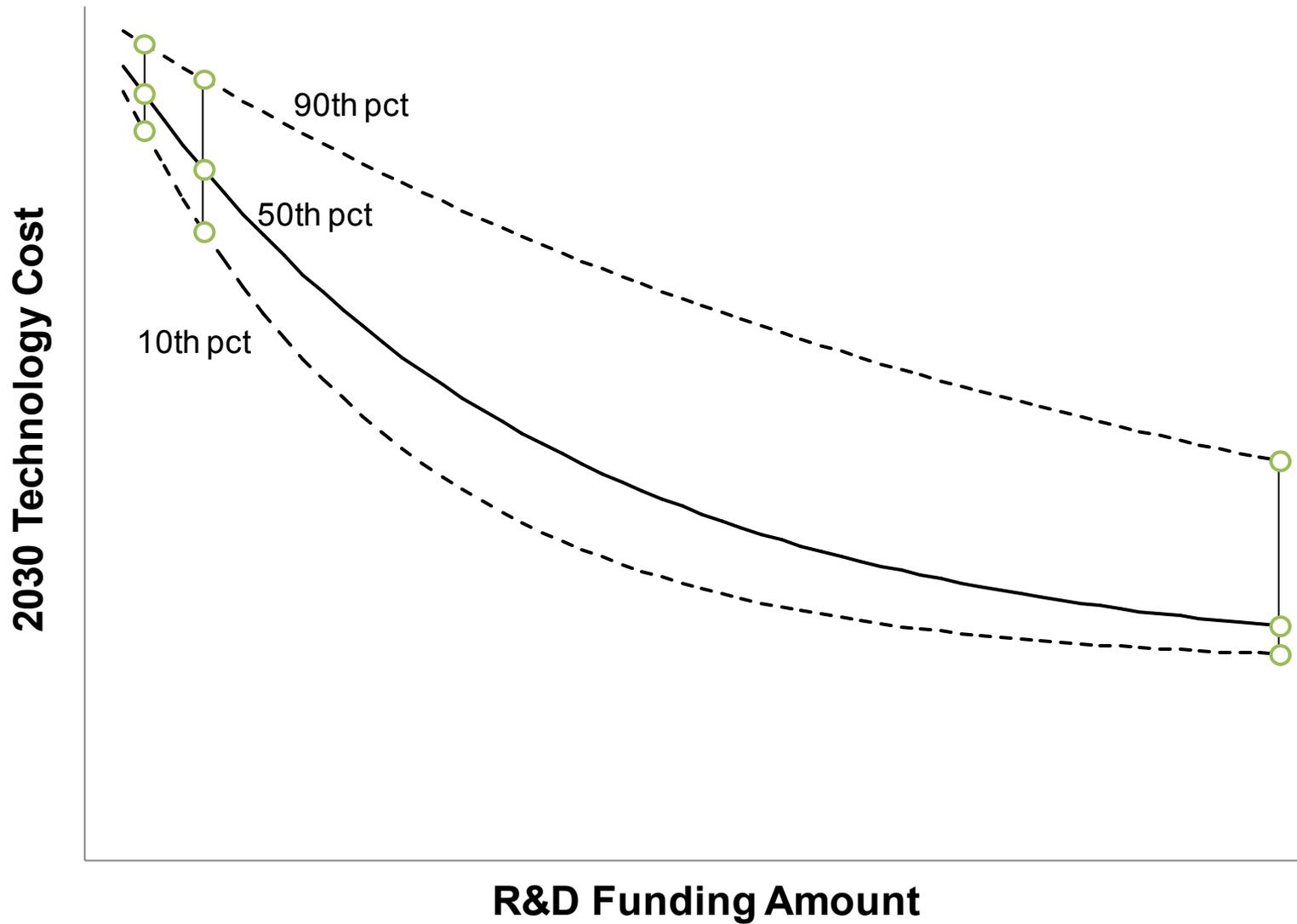
Post-Processing:
- interpolation of 2030 cost percentiles for feasible R&D range
- probability distribution fitting to the estimated percentiles
- interpolation/extrapolation of 2010-2050 technology costs (using conditional copula sampling)
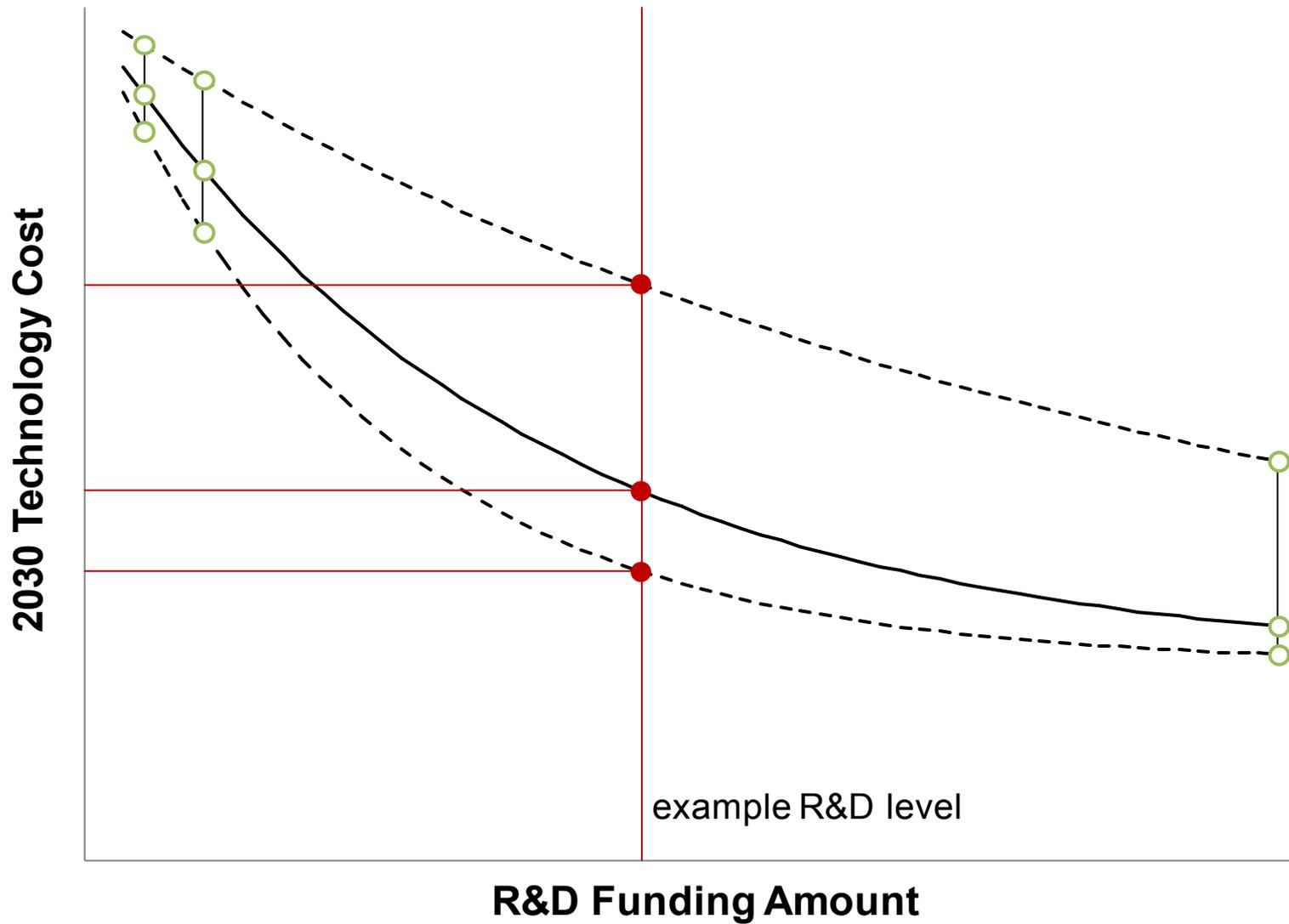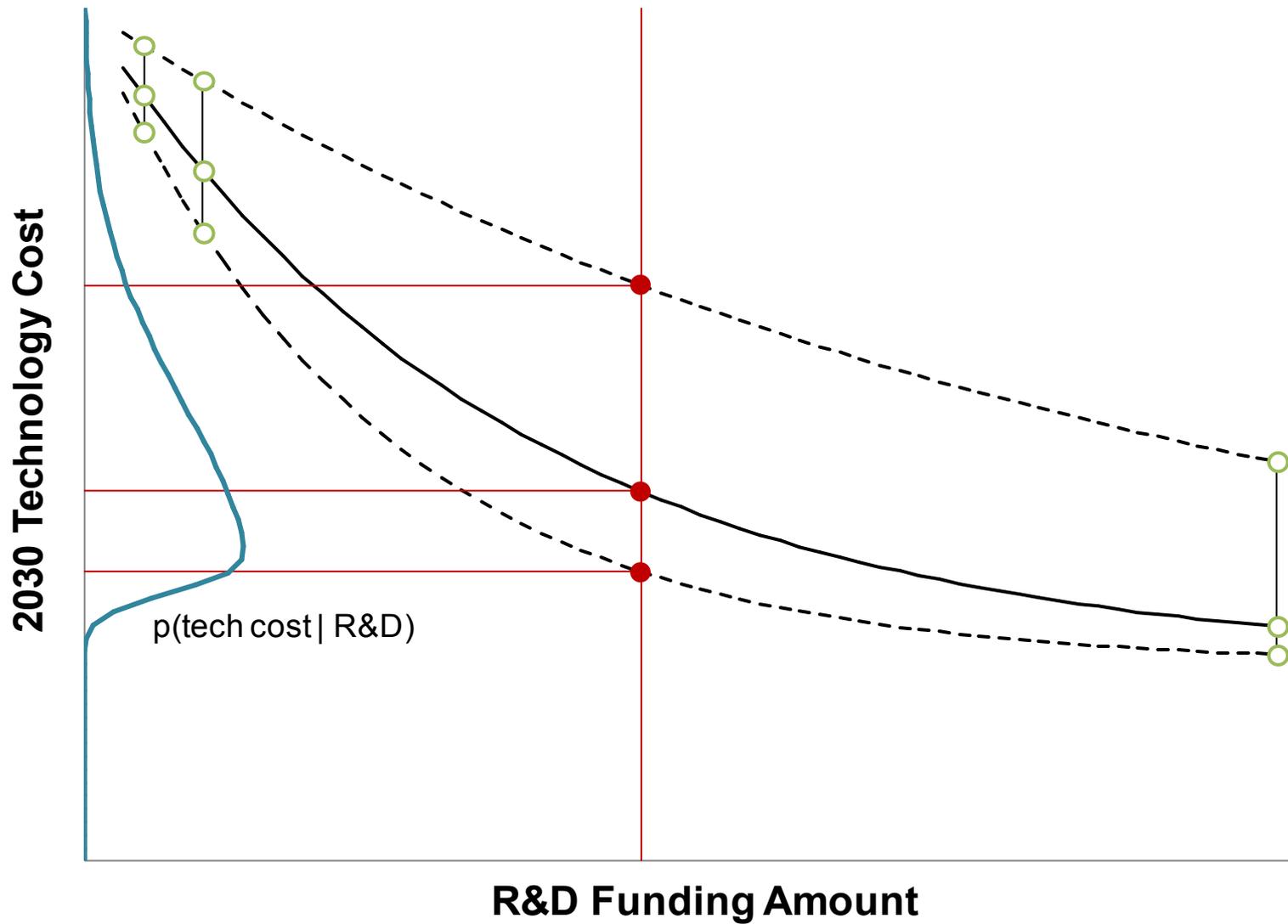
Expert Elicitation and Distribution Fitting

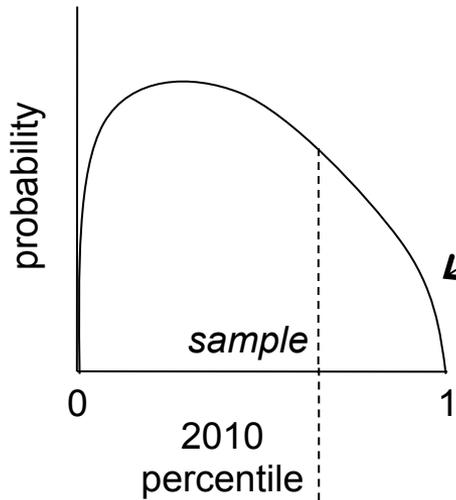**2030 Technology Cost**

90th pct

50th pct

10th pct

R&D Funding Amount
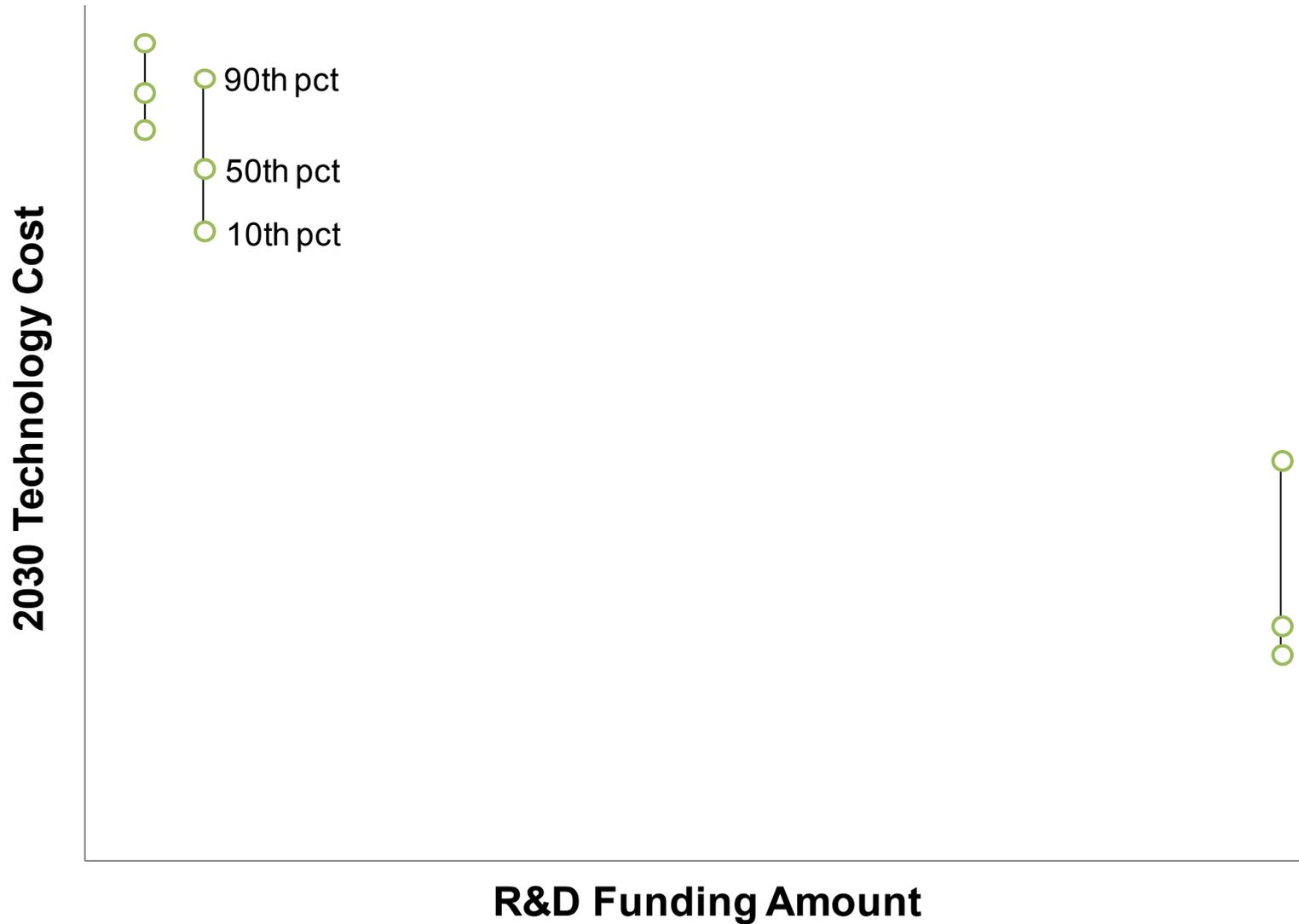
Expert Elicitation and Distribution Fitting

Expert Elicitation and Distribution Fitting

2030 Technology Cost

R&D Funding Amount

example R&D level

Expert Elicitation and Distribution Fitting

conditional copula

probability

0   1

2010 percentile

sample

Gaussian copula (ρ = 0.5)

2030 percentile

1

0

0   2010   1

2010 percentile

2030 elicited distribution

cumulative probability

1

0

sample

2030 cost

2010 elicited distribution

cumulative probability

1

0

2010 cost
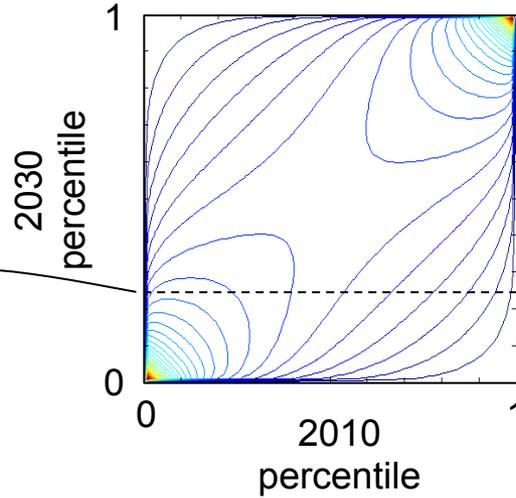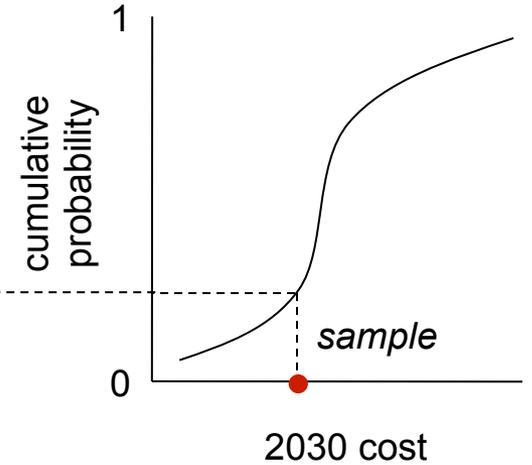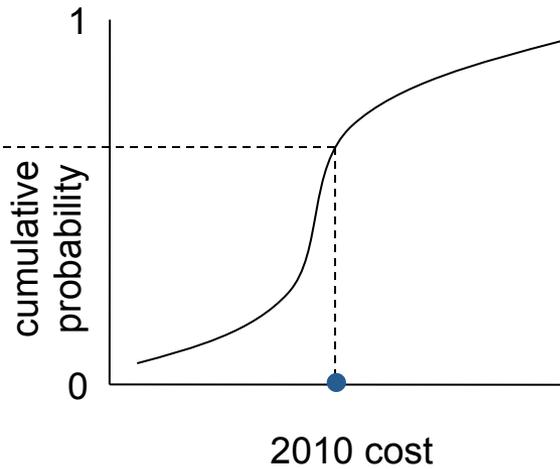
interpolated / extrapolated costs

cost

year
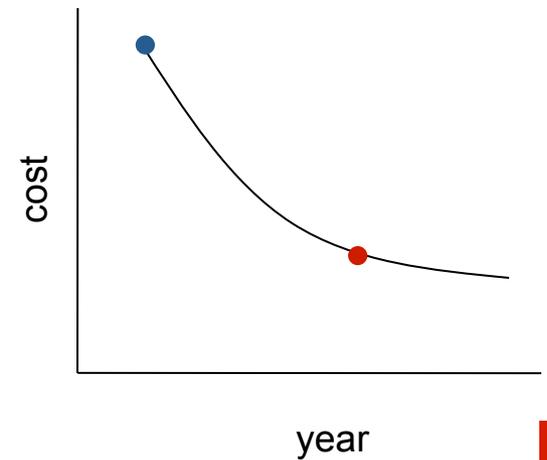
The MARKAL Model and Environmental Policies

Process:
- sample vectors of R&D over feasible ranges
- sample technology costs conditional on R&D with multi-dimensional conditional copula sampling
- run MARKAL on cost samples under 3 policy scenarios: BAU, 50% CO_2 reduction by 2030, 83% CO_2 reduction by 2030

Results:
- 1,200 runs of MARKAL for each policy scenario, each with a set of environmental/economic output metrics (e.g. CO_2 price, CO_2 emissions, total system cost)

Post-Processing:
- re-run the cost sampler 100,000 times and fit a kernel density approximation ("the sampling distribution")

Response Surface

Process:
- for a given vector of R&D levels, calculate the conditional cost distribution ("the target distribution") and use importance sampling to calculate the expectation of output metrics under the target distribution, $\int f(\text{cost}) p(\text{cost}|\text{R\&D}) d\,\text{cost}$
- create 10,000 Latin Hypercube samples over the feasible R&D space, calculate importance sampling expectations, and fit a high-dimensional polynomial (first-order interactions & quadratic terms) to these expectations

Results:
- polynomial coefficients that describe a surface of an economic/environmental outcome as a function of a 6 dimensional R&D vector

# Decision Analytic Framework

Setup:
- one decision maker
- uncertainty propagation
    1. a single decision maker sets R&D levels
    2. technology cost uncertainty is resolved
   3. the economy and environment are resolved

Optimization:
- we used a deterministic optimization routine to optimize the response surface under an aggregate budget constraint
- optimization criterion is to minimize the double expectation of outcome variables (over expected outcome uncertainty and cost uncertainty)
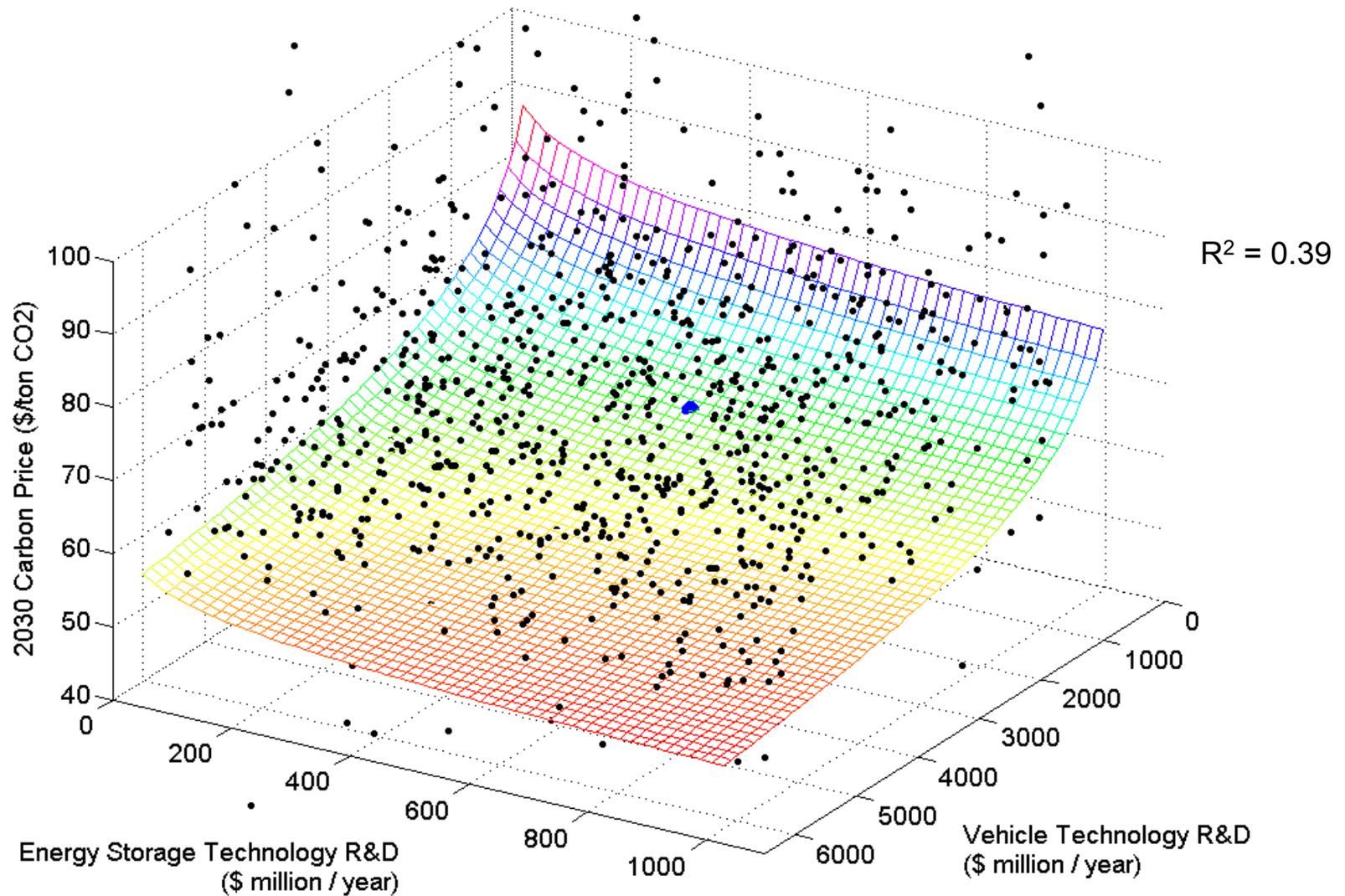- more sophisticated optimization techniques may work better
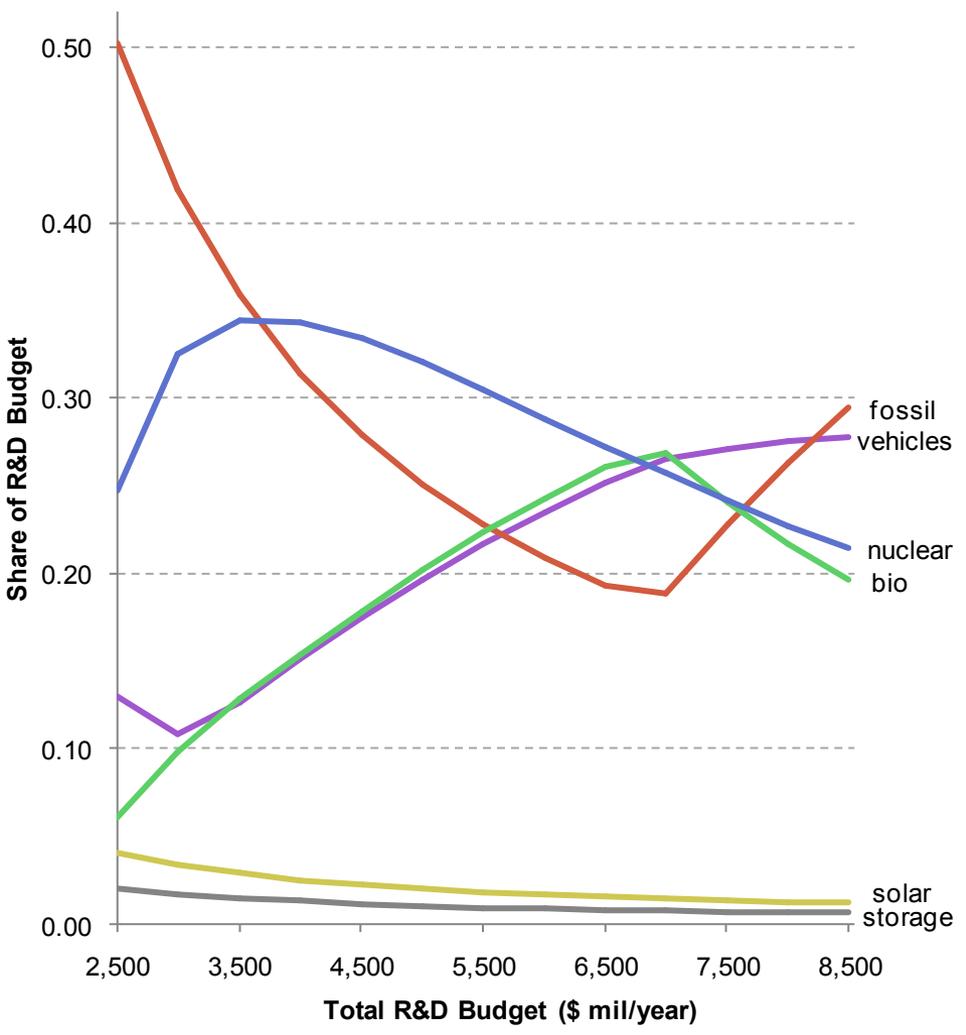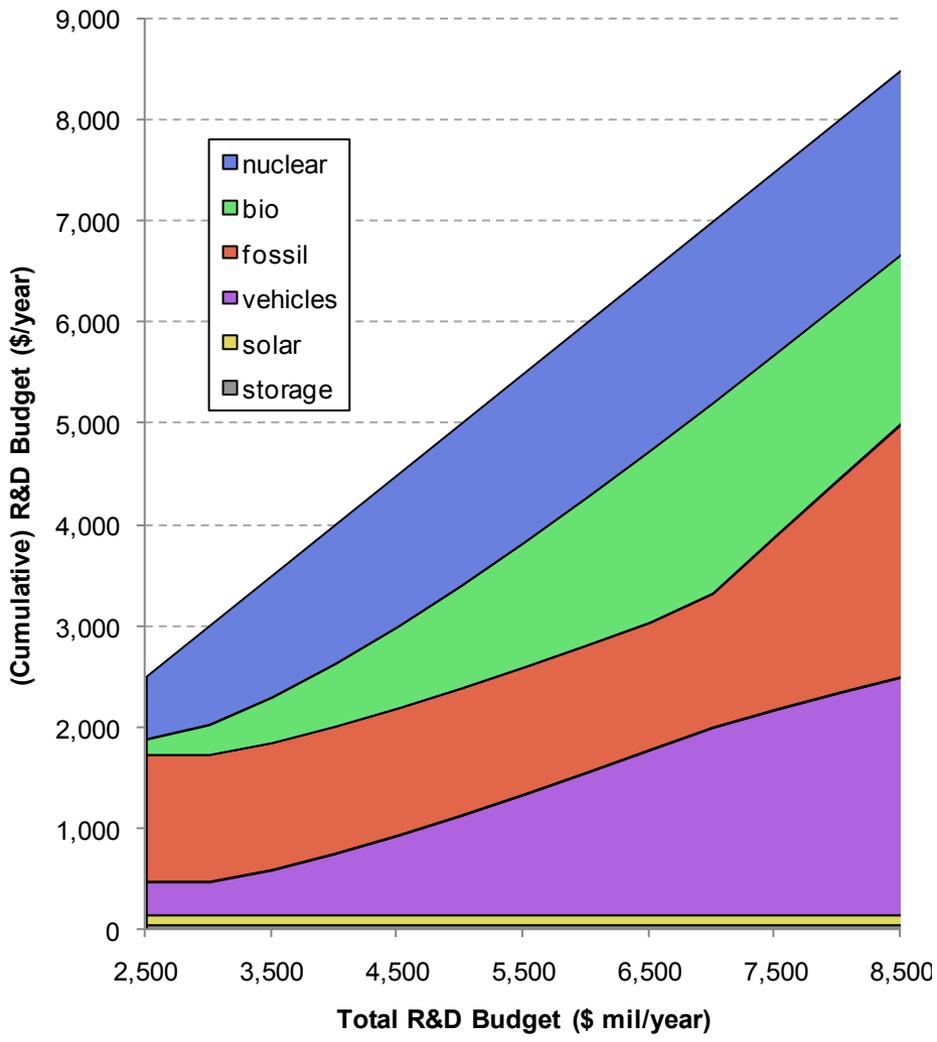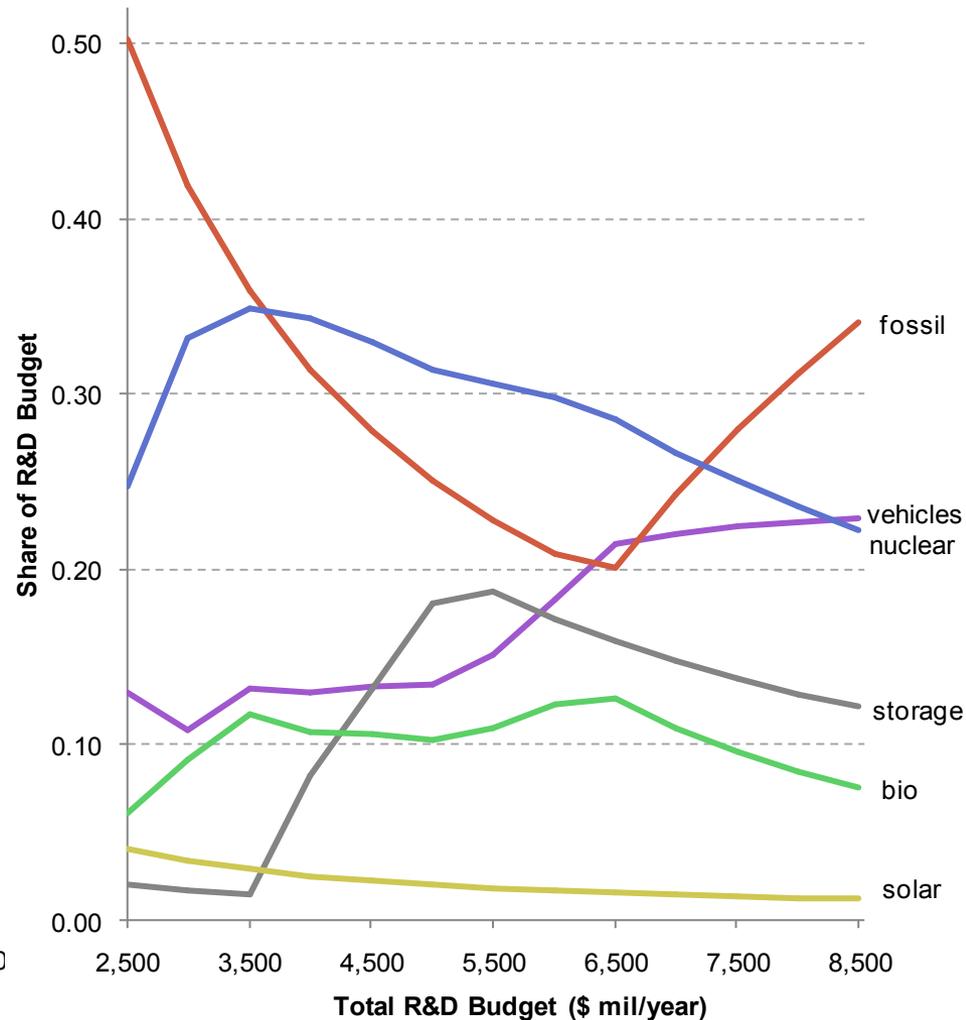
1-Dimensional Marginal Response Surfaces
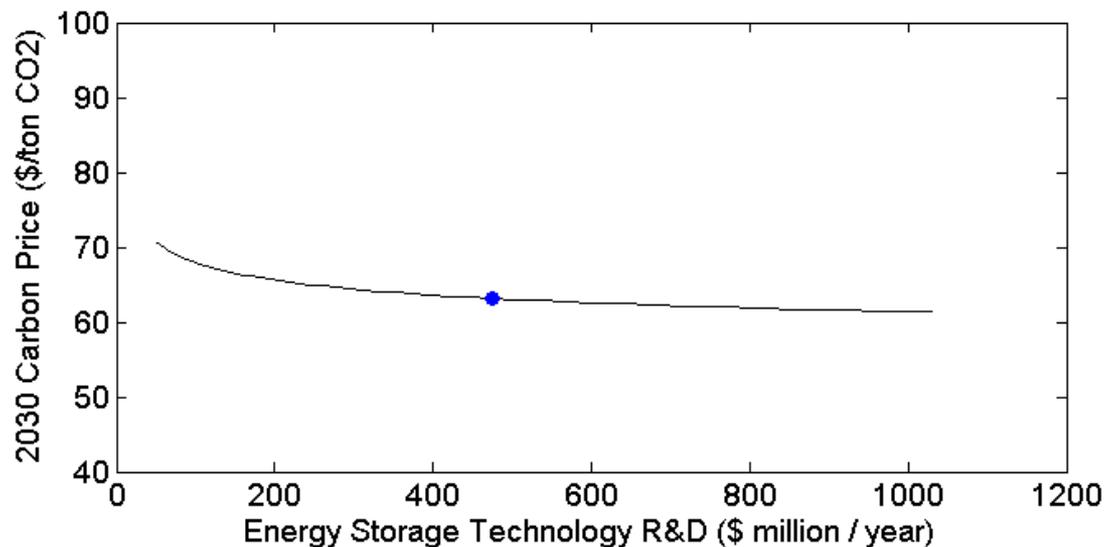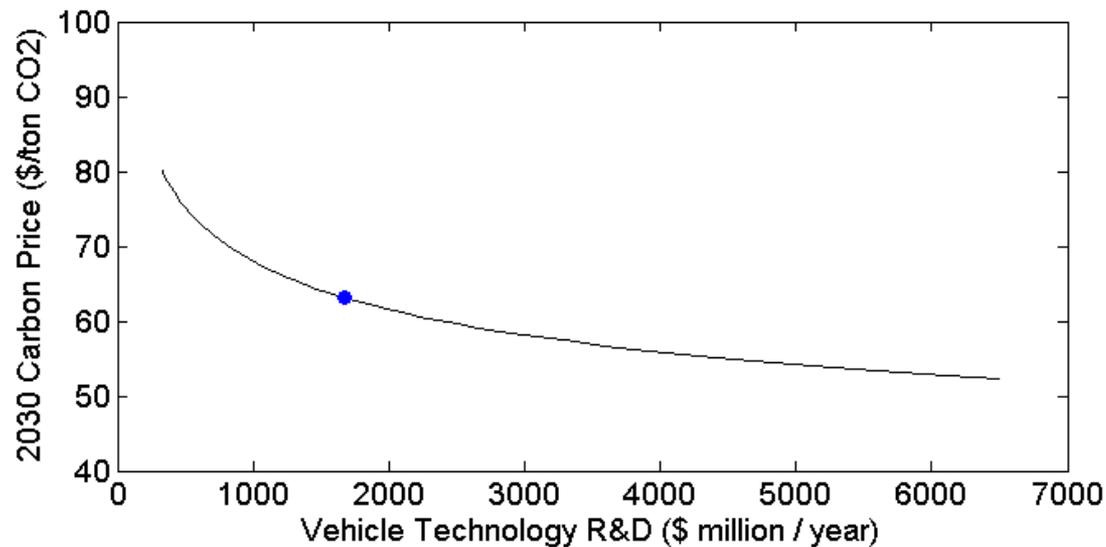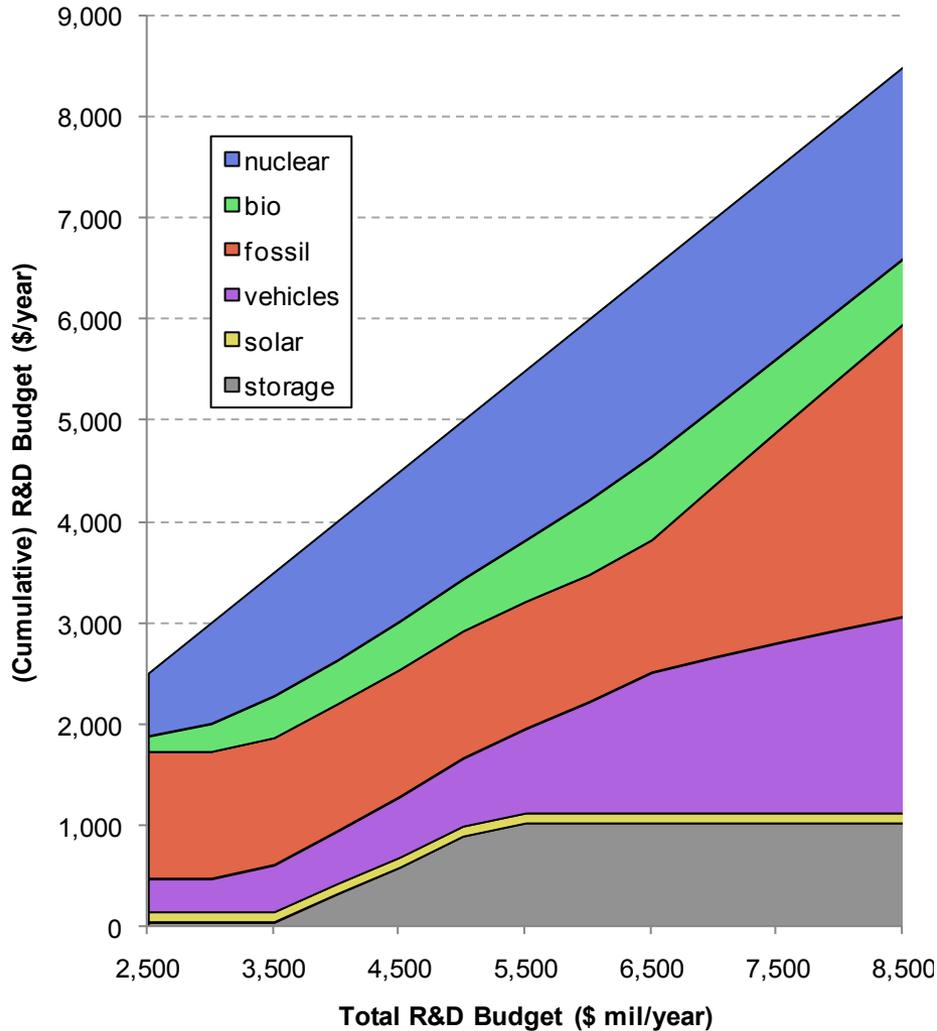
2-Dimensional Marginal Response Surface
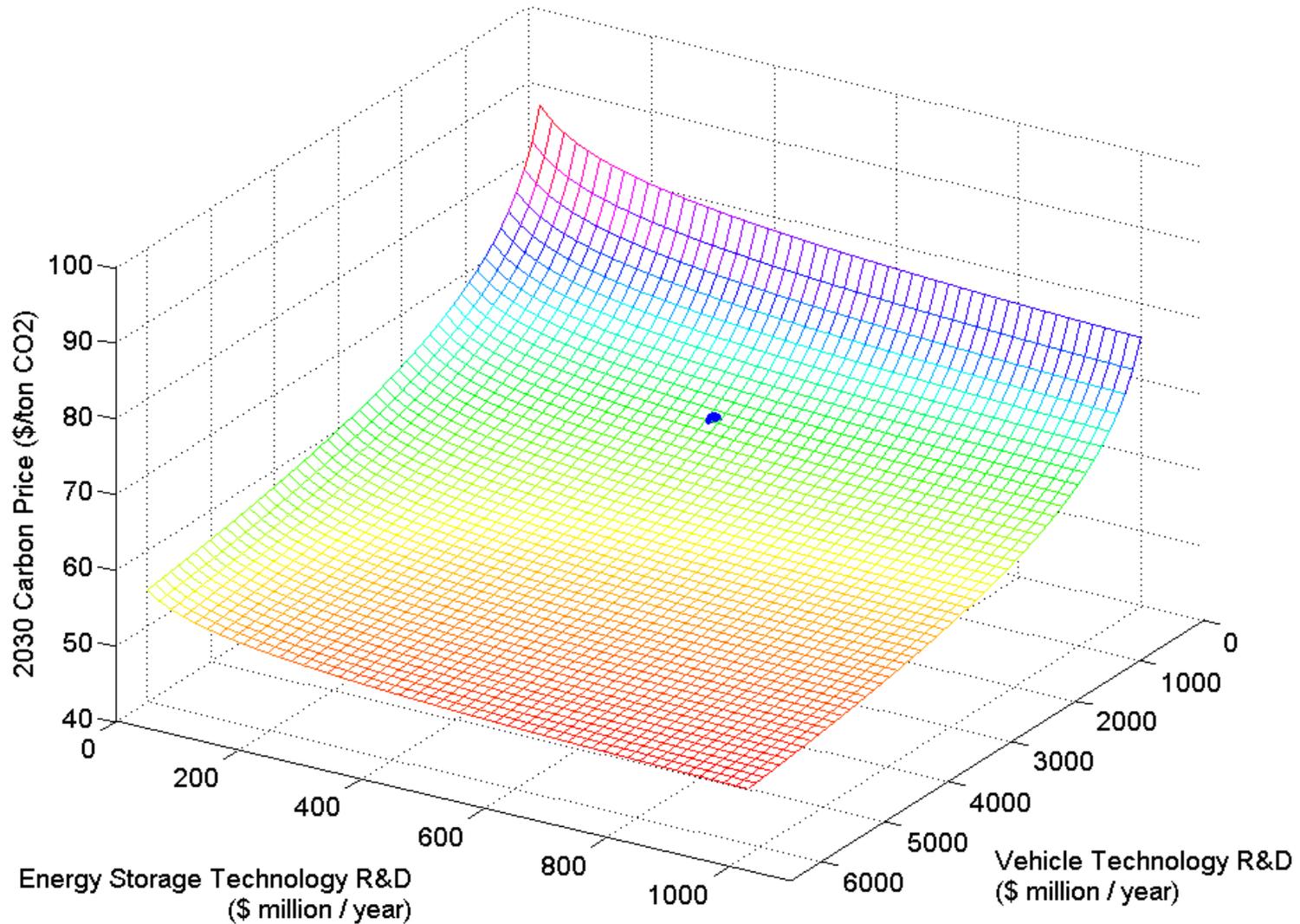
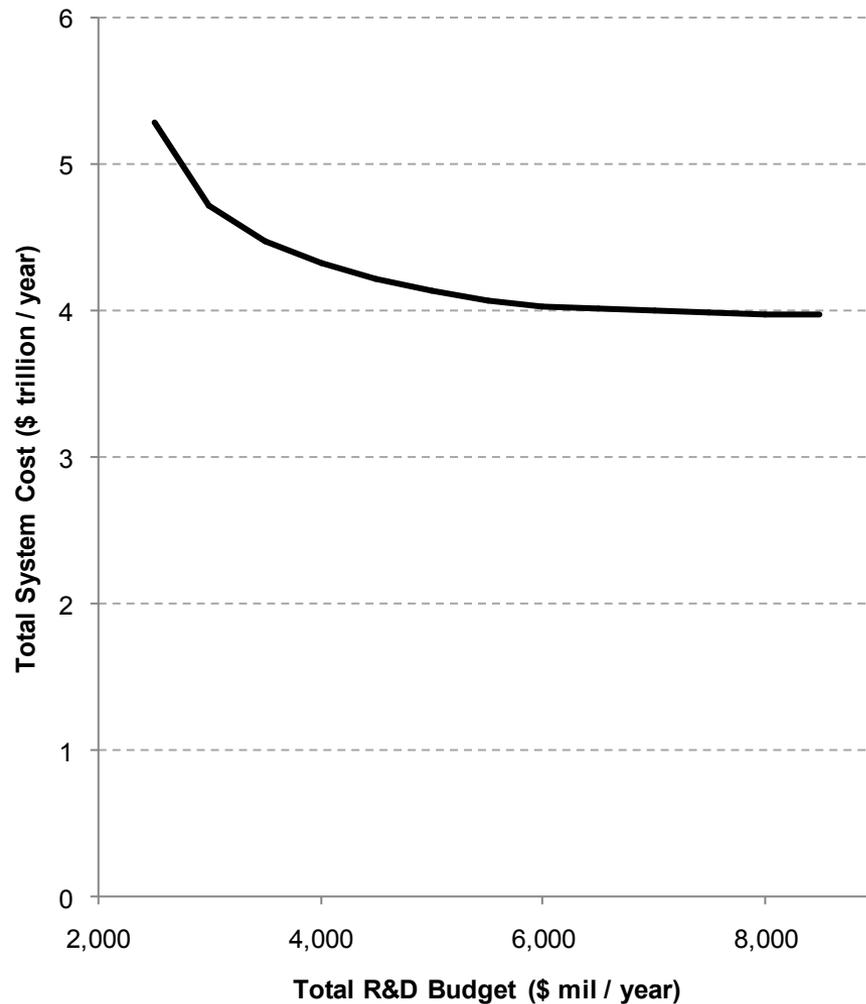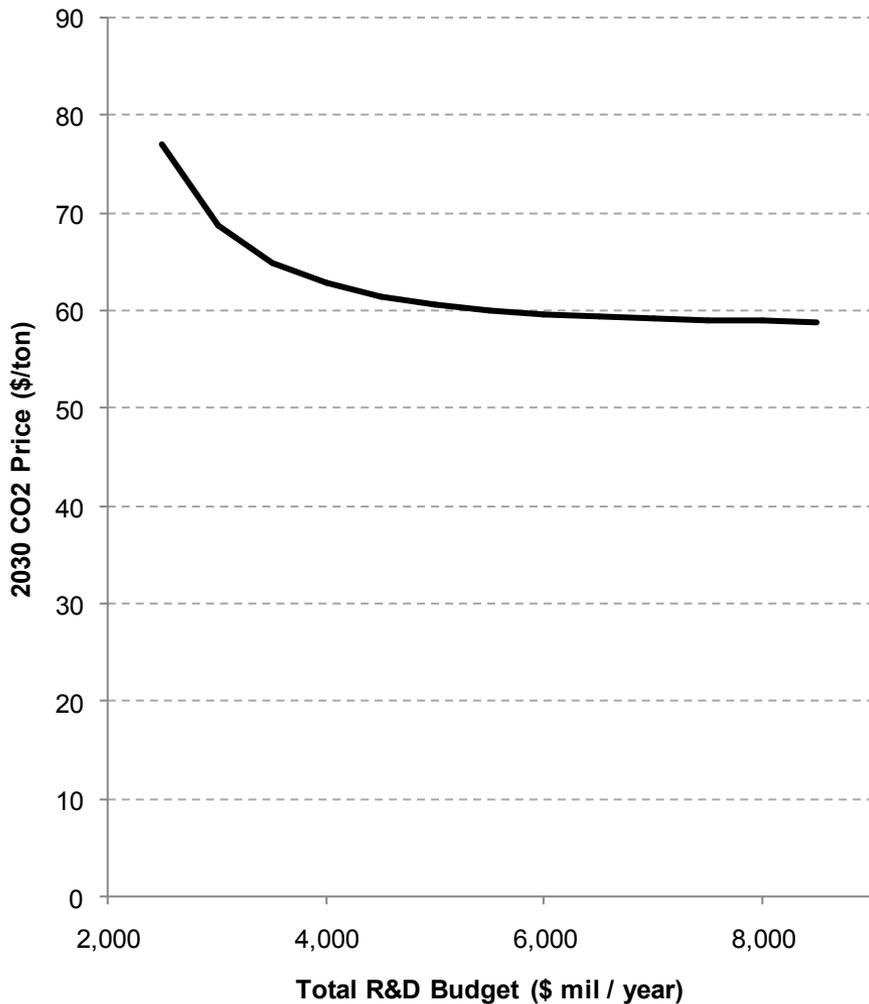# 2-Dimensional Marginal Response Surface

R&D Budget Allocations to Minimize 2030 CO_2 Price under 50% CO_2 Reduction Policy

R&D Budget Allocations to Minimize 2030 Total System Cost under 50% CO_2 Reduction Policy
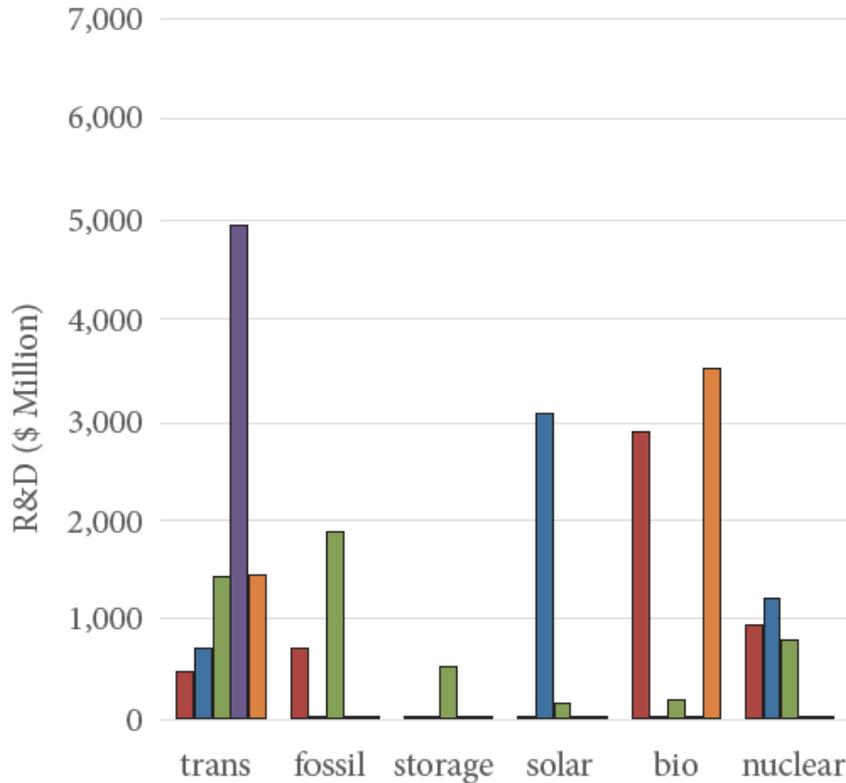
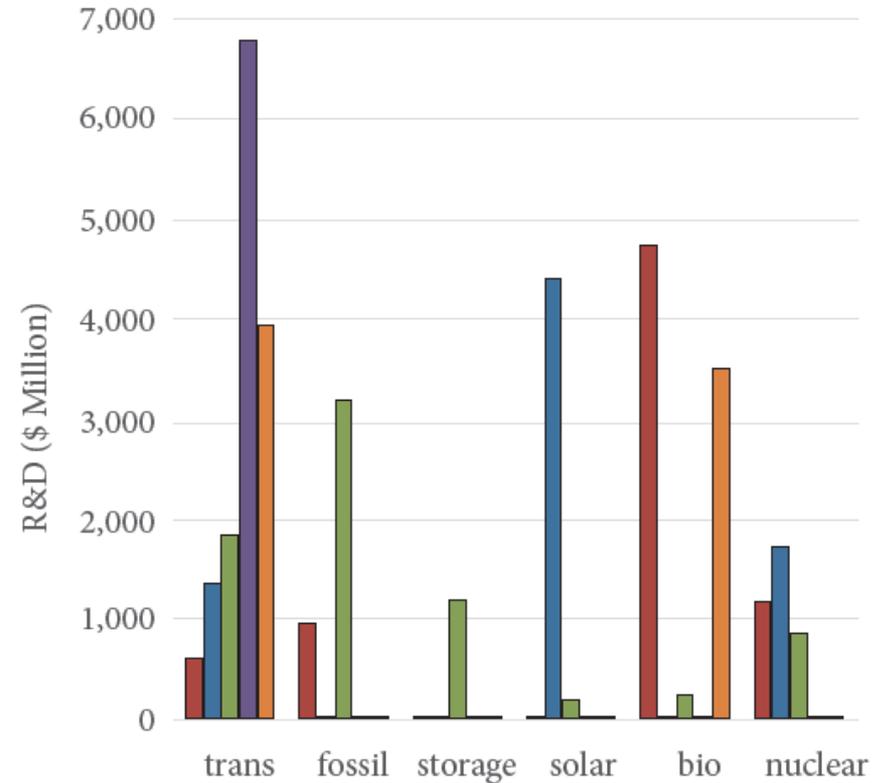# Minimum Output Value under 50% CO$_2$ Reduction Policy

Optimized R&D Budget Allocations under Different Policy Scenarios and Optimality Conditions

$5 bil R&D budget

$7.5 bil R&D budget

- No policy (CO_2 emissions)
- CES (CES credit price)
- 83% CO_2 cap (CO_2 credit price)
- No policy (consumer surplus)
- 83% CO_2 cap (consumer surplus)

Future Directions and Open Questions

Distribution fitting:
- Given the limited ability of experts to specify a probability distribution, the researcher has to exercise judgment to fully specify the distribution.
- Future directions: bounding estimators, alternative forms

R&D-cost functional form:
- Given the limited ability of experts to consider all possible R&D levels, the researcher has to exercise judgment to interpolate the relationship between R&D and future costs

Optimization design:
- There are multiple reasonable notions of optimality in this context due to outcome variable tradeoffs, risk, etc.
- Future directions: stochastic optimization and alternative optimality conditions (e.g. min probability of crossing a threshold, max probability of staying below a threshold)

Thanks
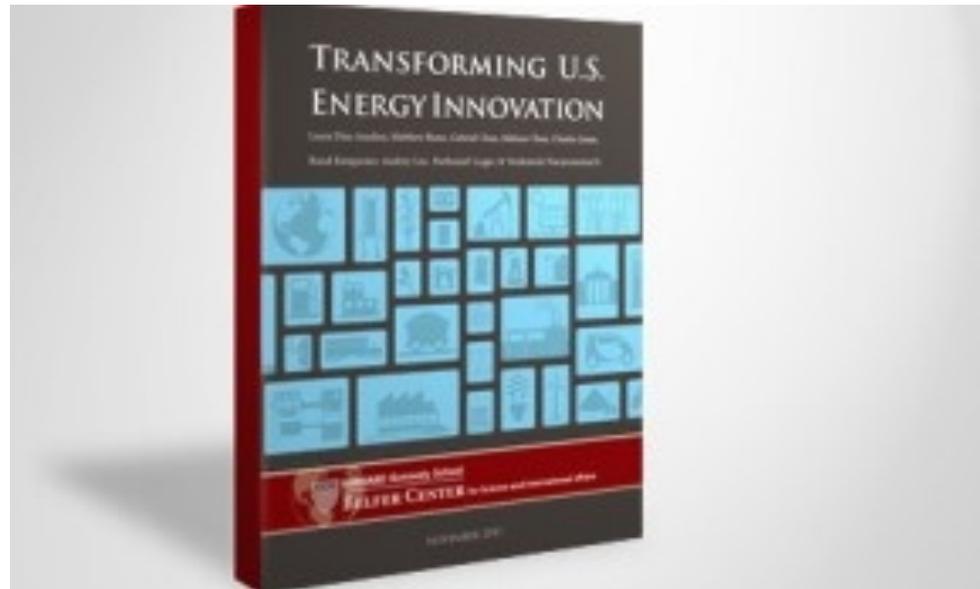
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Backup

Conditional Copula Sampling