Technology R&D as Greenhouse Insurance

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Uncertainty and Emissions Control

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- Uncertainty about how emissions today will cause damages tomorrow.
- But, we are learning more and more.
- Uncertainty, learning, and adaptation impact current decisions
- General conclusion: Uncertainty + Learning = less control of emissions.
  - Kolstad
  - Ulph & Ulph
  - Manne & Richels
  - Baker

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What about R&D?

- R&D planning is complicated by different programs
  - Solar PVs, windpower
  - Efficiency of coal-fired electricity
  - Gas turbines
  - Sequestration
- How does optimal R&D change with
  - Increasing risk and learning about climate damages
  - choice of R&D program

Overview

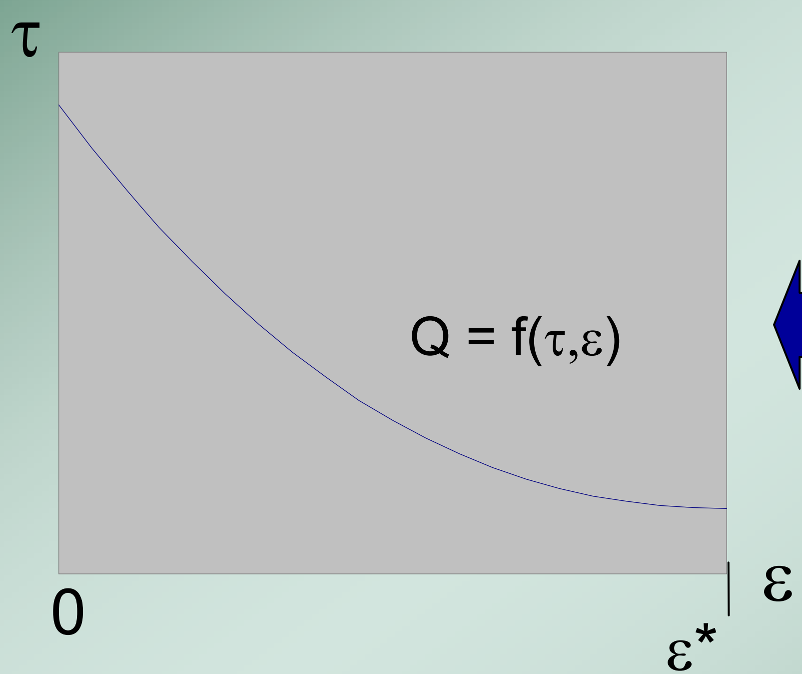
- Explore in a top-down framework the response of optimal R&D to increasing risk
- Theoretical results indicate that there is no single directionality:
  - How R&D is modeled matters, and
  - How increasing risk is modeled matters.
- Confirm this in a IAM.
- Along the way, discuss approaches for representing R&D effects in top-down models.

Agenda

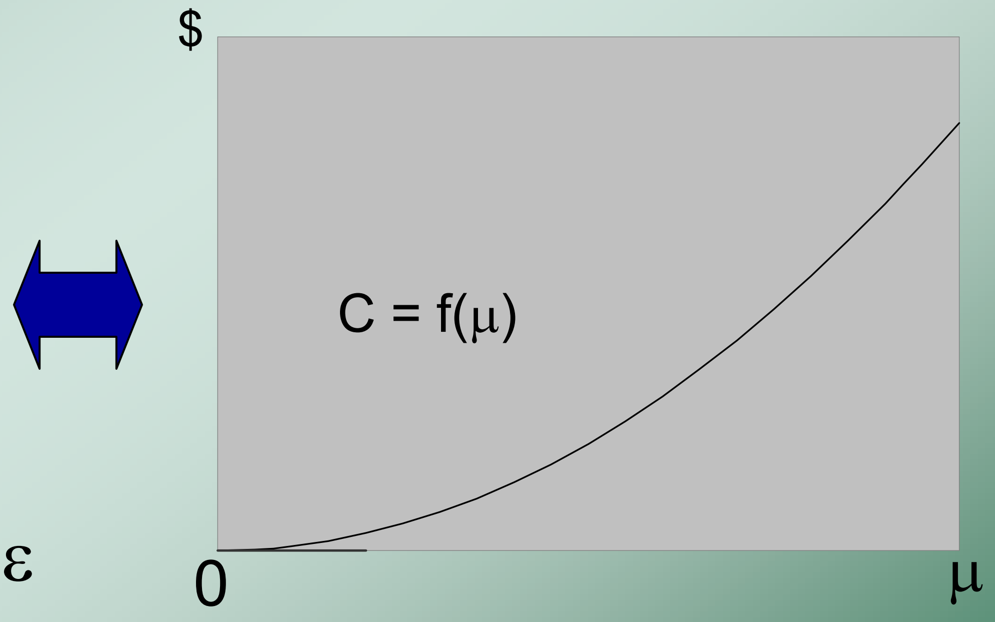
- ►Introduce Technological Change
- ►Introduce Increasing Risk
- ►Discuss Theoretical Model and Results
- ►Discuss Implementation in DICE
- ►Conclusions

How Might R&D Change Technology

Production Function



Abatement Cost Curve



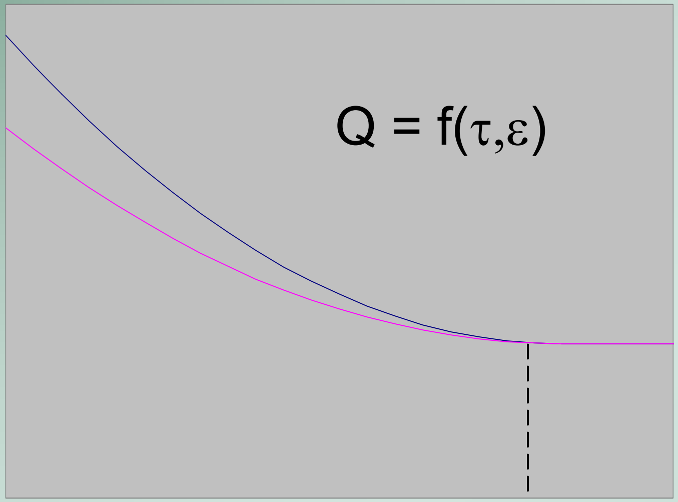
ε = emissions

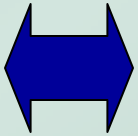
τ = “standard” inputs

μ = emission reductions

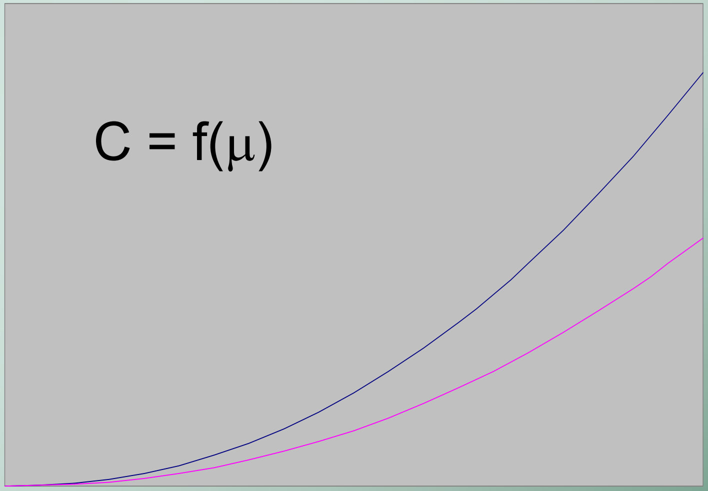
R&D and Technology: One Example

Production Function





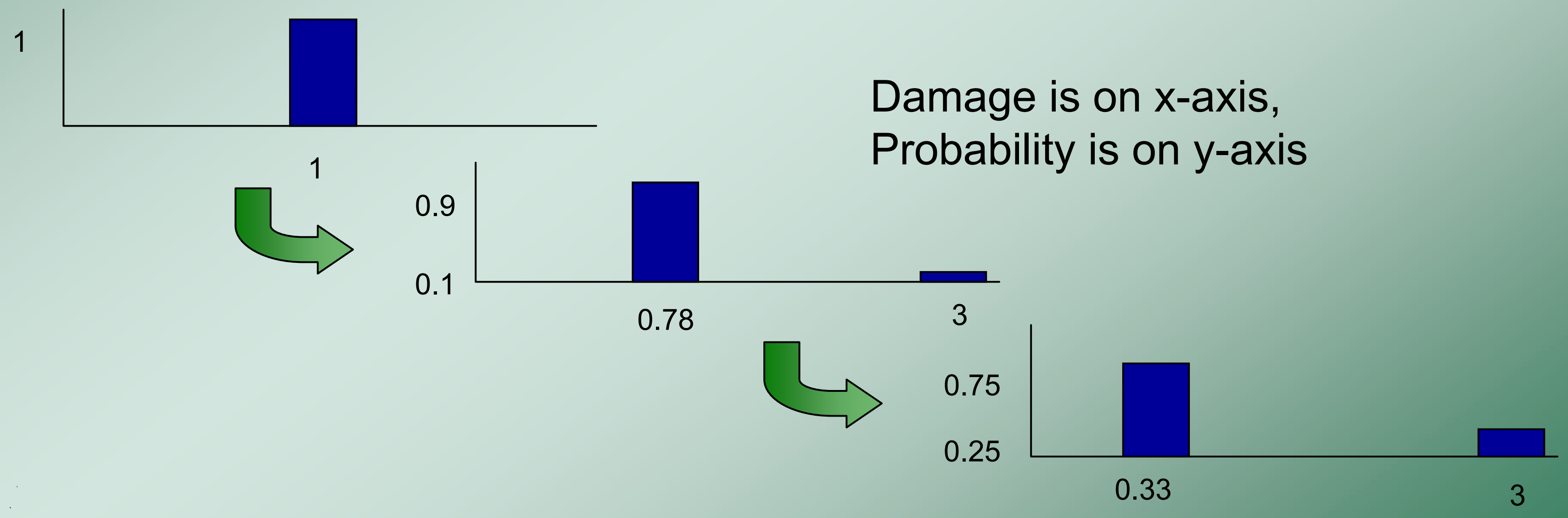
Abatement Cost Curve



Many ways in which R&D might alter technology

What is Increasing Risk?

- "Risk" – "uncertainty" – "Mean-preserving-spread"
  - See for example Rothschild & Stiglitz 1970,1971.
  - NOT A CHANGE IN THE MEAN!



Damage is on x-axis,
Probability is on y-axis

- Many ways to create a mean-preserving spread.

Theoretical Model

- ► Two period model
  - R&D investments in first period;
  - Abatement and improved technology in the second
- ► Initial uncertainty regarding the damages from climate change
  - Resolved at the start of the second period

Cost of R&D

Expected Costs of Abatement and Damages Assuming Optimal Abatement Behavior

$$\min_{\alpha} \quad \underbrace{g(\alpha)}_{\text{Cost of R\&D}} + \overbrace{E_z \min_{\mu} c(\mu,\alpha) + D(\mu,z)}^{\text{Expected Costs of Abatement and Damages Assuming Optimal Abatement Behavior}}$$

Theoretical Results

$$\min_{\alpha} g(\alpha) + E_z \min_{\mu} c(\mu, \alpha) + D(\mu, z)$$

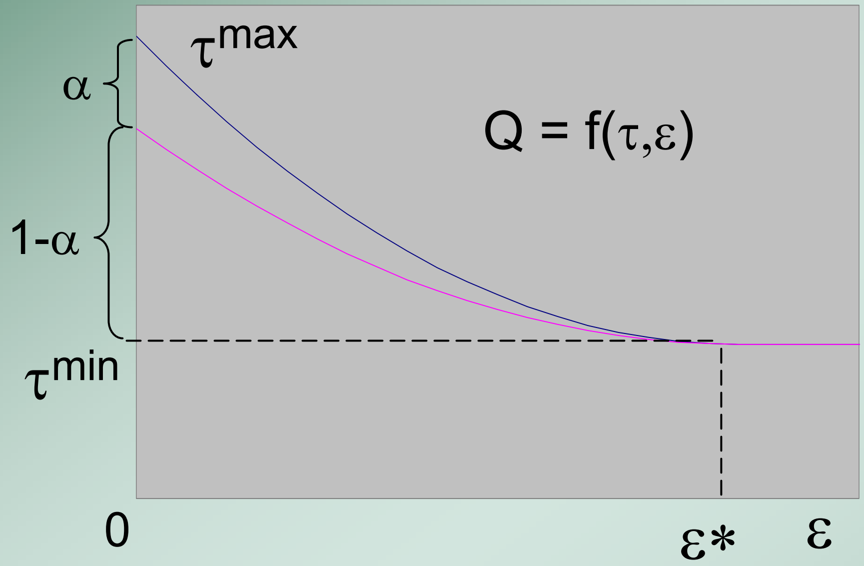
- Proposition: ***For every R&D program, optimal R&D decreases with some increases in risk***.
  - (Allowing for “Full abatement”)
- The converse is not true – some R&D programs will always decrease in risk.
- Individual R&D programs will react differently to an increase in risk.
- It is crucial to model the specific program.

Integrated Assessment Model

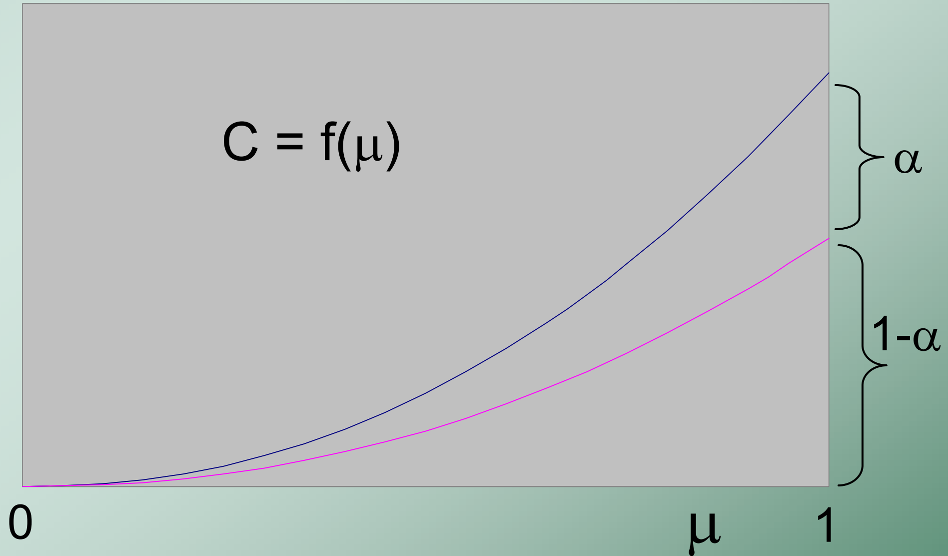
- William Nordhaus's DICE
- Optimal Growth + Climate Model
- Added uncertainty, using stochastic programming
- Added R&D as a decision variable
  - One time decision in 1st period before learning
  - Cost reduction implemented in 50 years, after learning.

Two R&D Programs: (1) Cost Reduction

Production Function



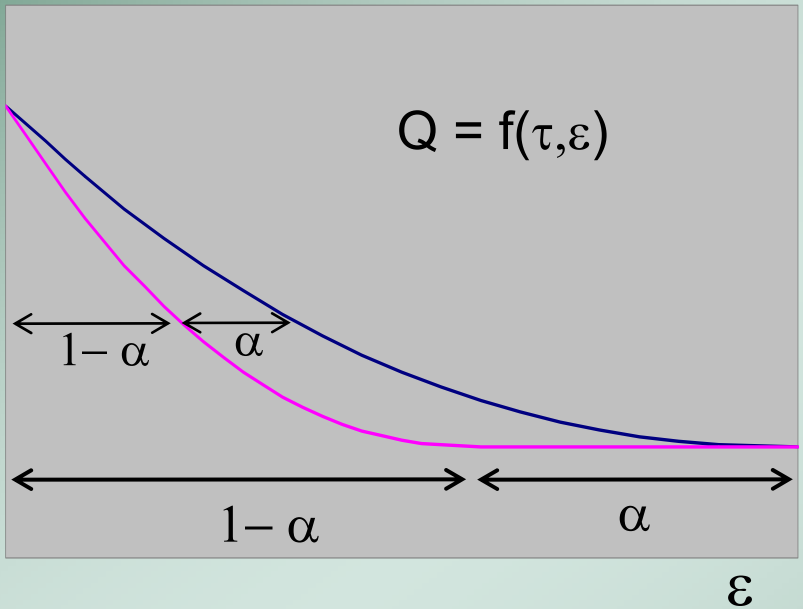
Abatement Cost Curve



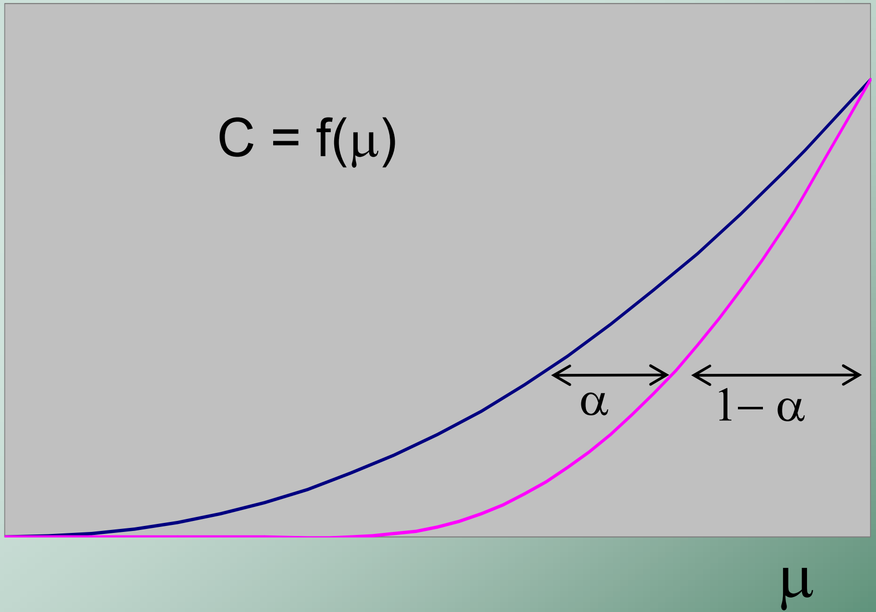
The abatement cost curve pivots downward

Two R&D Programs: (2) Emissions Reduction

Production Function

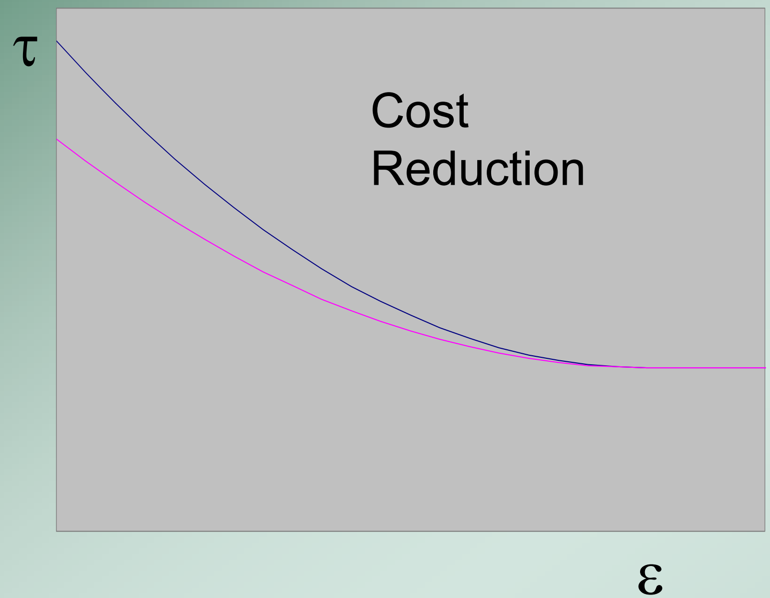


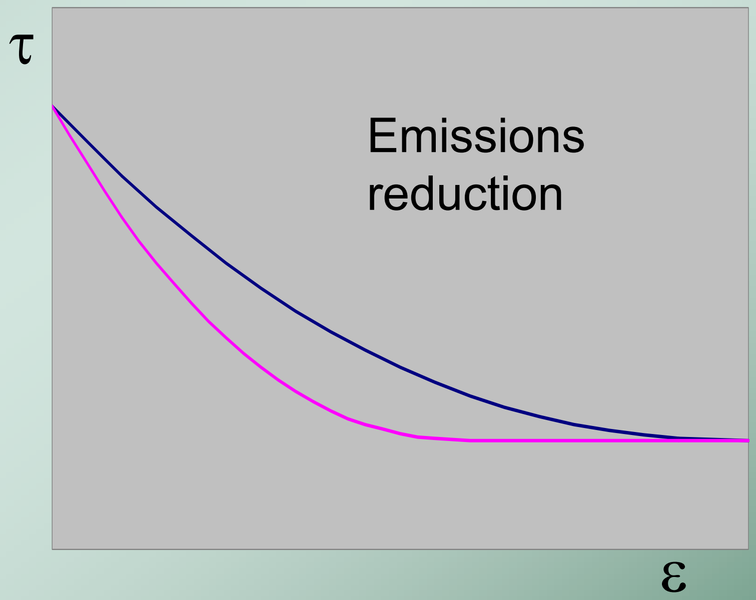
Abatement Cost Curve



The abatement cost curve pivots to the right

R&D impacts convexity of cost curve / production function





Flatter ⇒ R&D increases in risk

More convex ⇒ R&D decreases in risk

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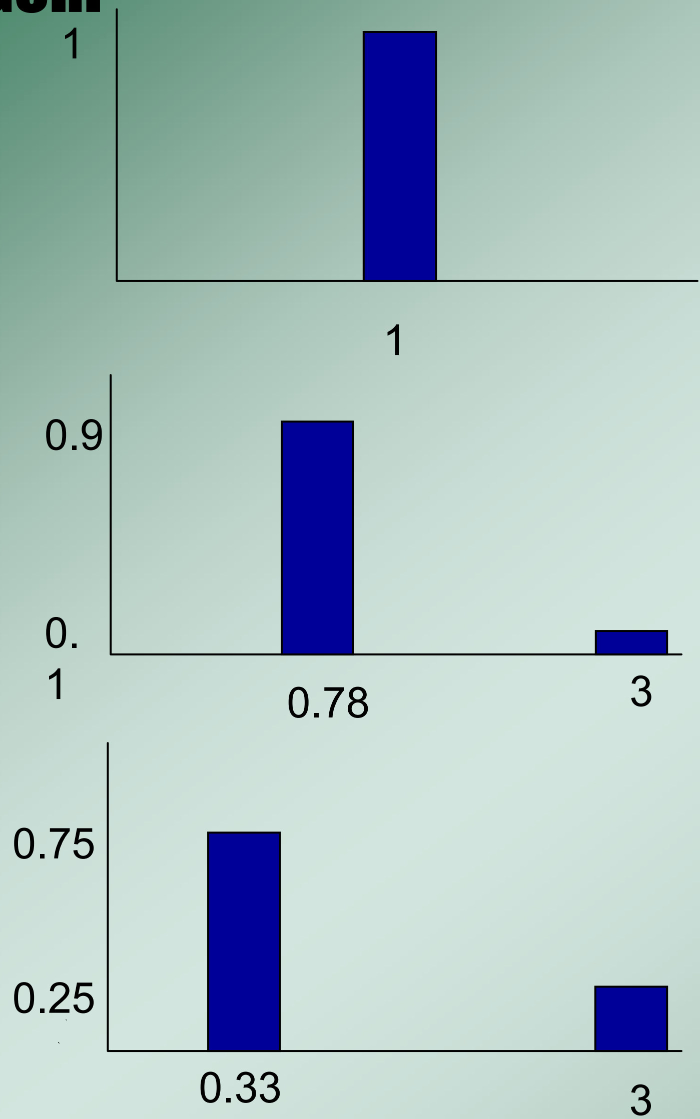
2 Types of increasing risk

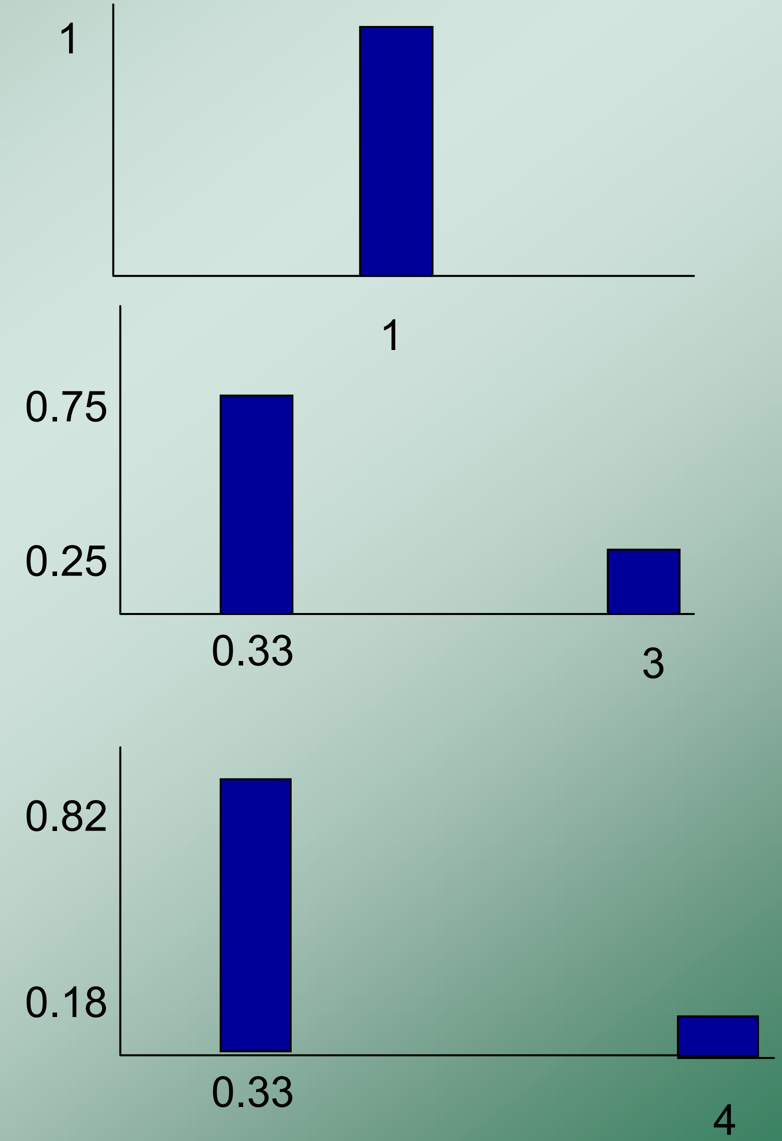
Increasing Probability	certain	low	med	high
Probability of high damage	0	.018	.050	.083
Value of high damage	-	.042	.042	.042
Value of low damage	.0035	.0028	.0015	0

Increasing Damage	certain	low	med	high
Probability of high damage	0	.018	.013	.0024
Value of high damage	-	.042	.057	.30
Value of low damage	.0035	.0028	.0028	0028

Increasing Probability

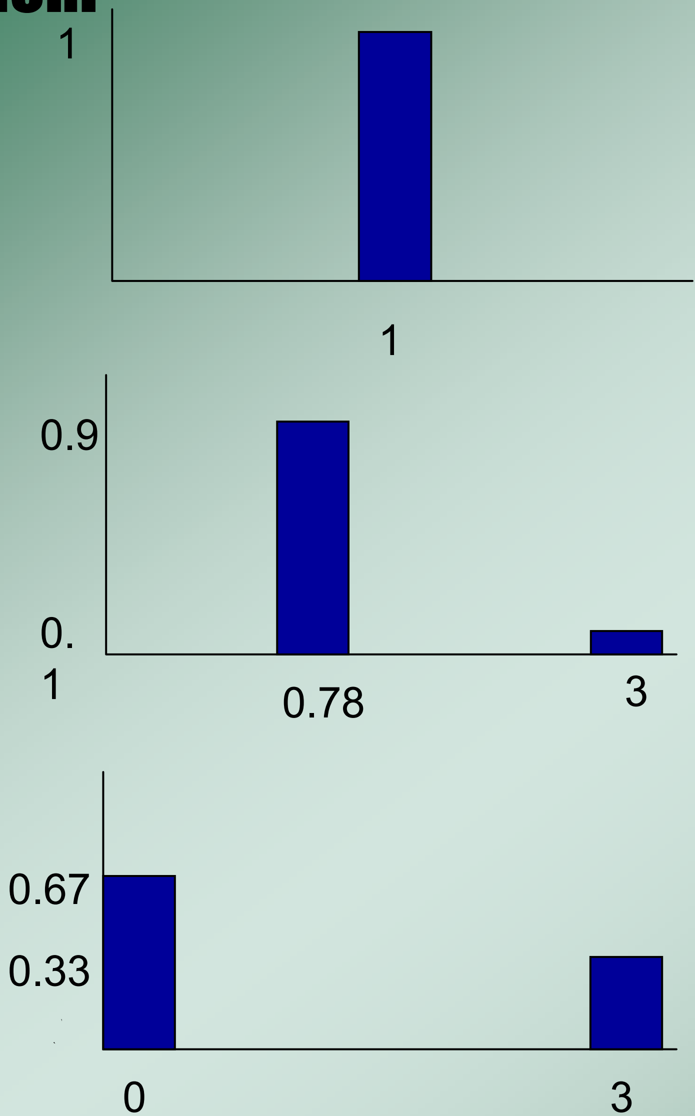


Increasing Damage

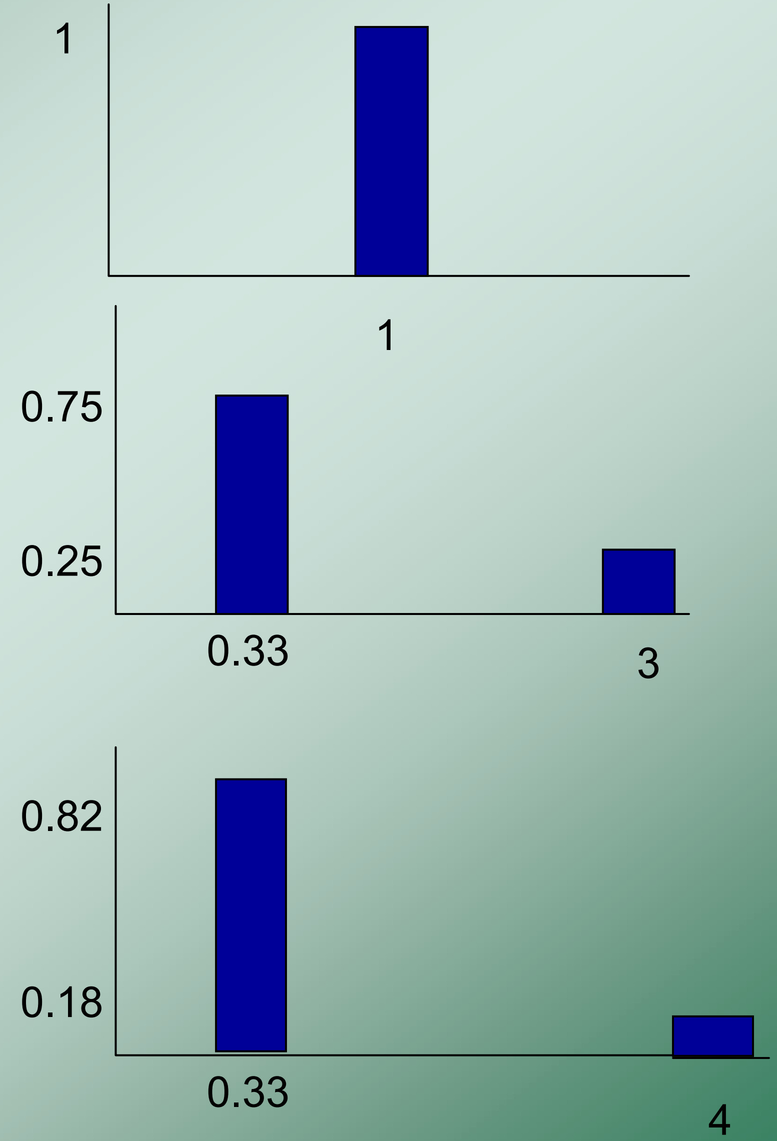


Damage is on x-axis, Probability is on y-axis

Increasing Probability

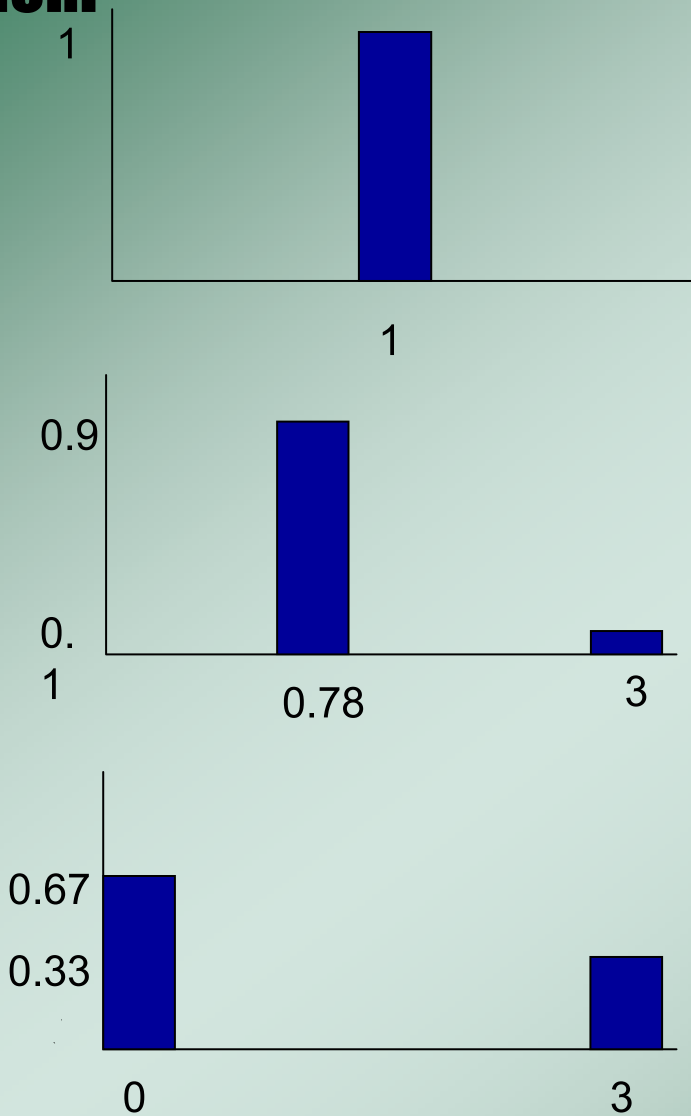


Increasing Damage

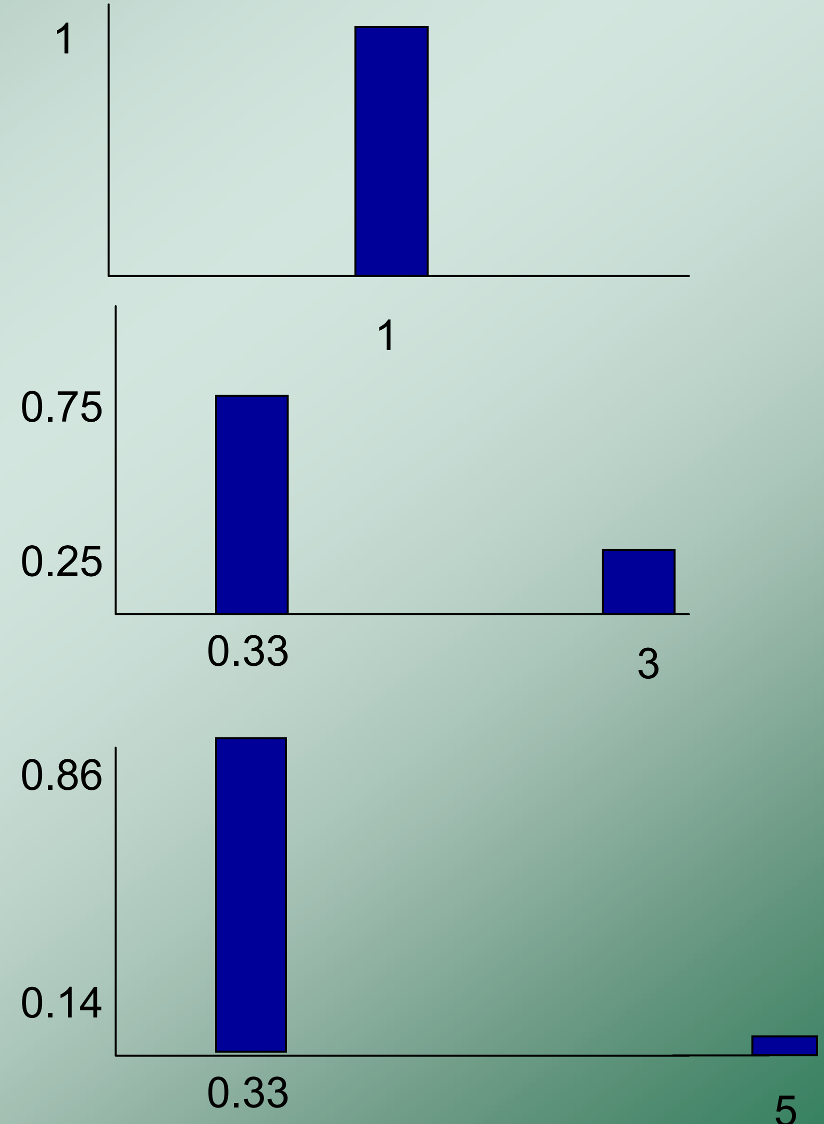


Damage is on x-axis, Probability is on y-axis

Increasing Probability

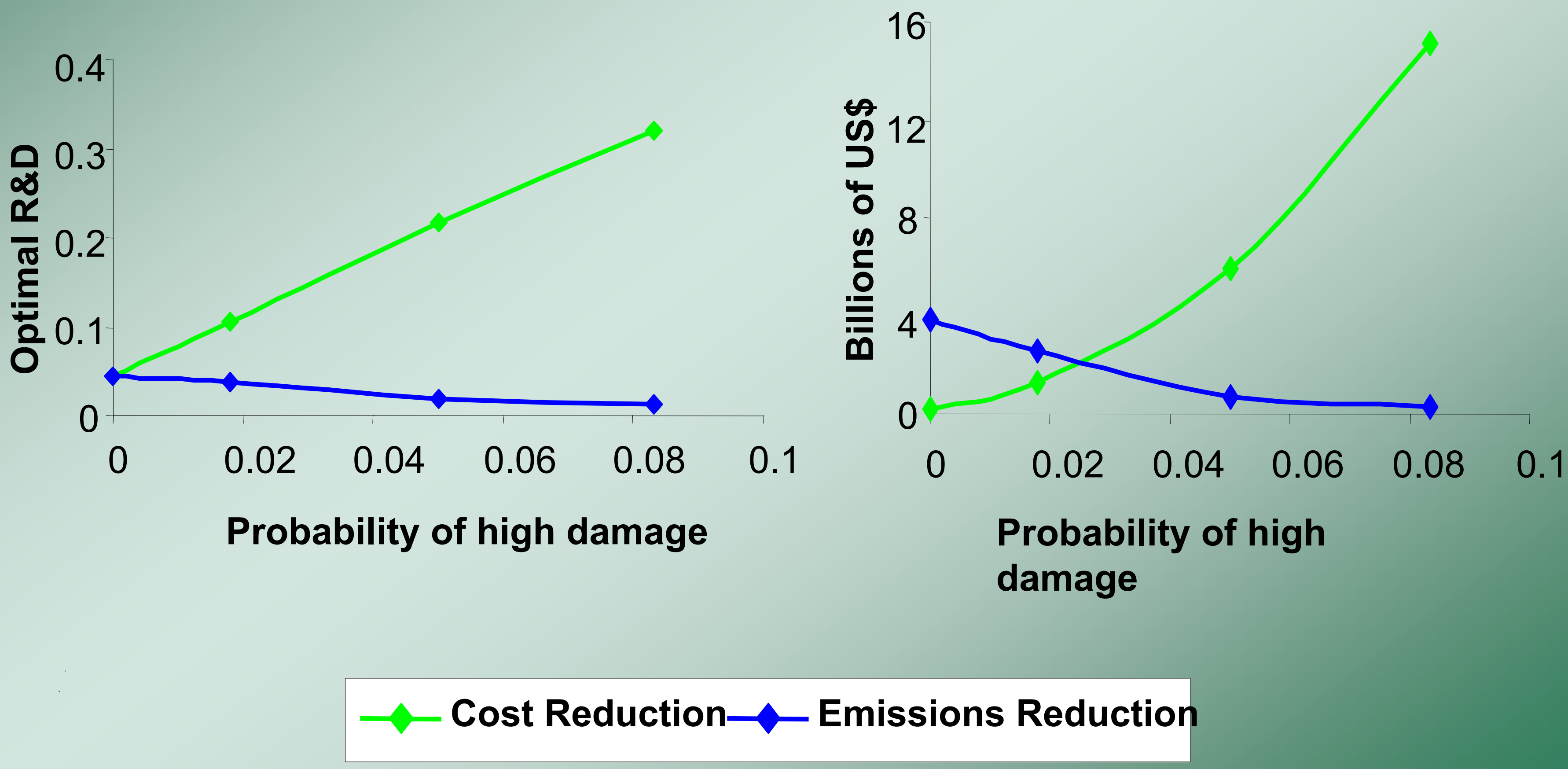


Increasing Damage

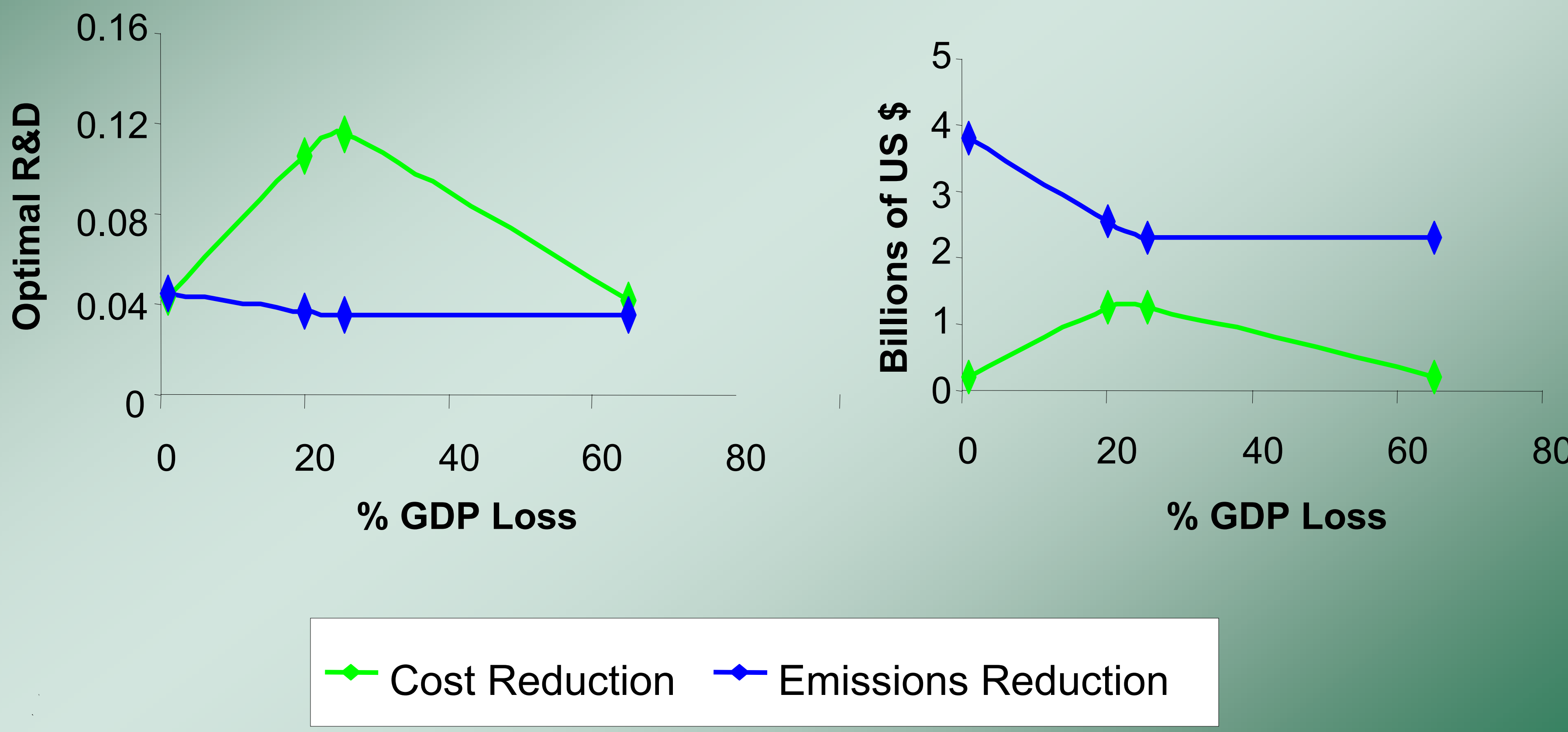


Damage is on x-axis, Probability is on y-axis

Results – Increasing Probability



Results – Increasing Damages



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Conclusions

- R&D can be a hedge against uncertainty.
- But, it depends on what kind of R&D.
  - R&D into reducing the cost of low carbon alternatives
- And what kind of risk.
  - Increasing the probability of needing very low carbon technologies, rather than considering higher levels of damages.

DICE equations

$$Q_t = \frac{1}{1+\theta_1 T + \theta_2 T^2}\left(1 - b_1 \mu_t^{\,b_2}\right) A_t K_t^{\,\gamma} L_t^{\,(1-\gamma)}$$

$$E_t = \left(1 - \mu_t\right) \sigma A_t K_t^{\gamma} L_t^{1-\gamma}$$