Technology R&D as Greenhouse Insurance

Erin Baker  
*University of Massachusetts, Amherst*

Leon Clarke  
*Joint Global Change Research Institute*

John Weyant  
*Stanford University*
Uncertainty and Emissions Control

- 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
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

\[ Q = f(\tau, \varepsilon) \]

Abatement Cost Curve

\[ C = f(\mu) \]

\( \varepsilon = \) emissions

\( \tau = \) “standard” inputs

\( \mu = \) emission reductions
Many ways in which R&D might alter technology
What is Increasing Risk?

► “Risk” – “uncertainty” – “Mean-preserving-spread”
  - NOT A CHANGE IN THE MEAN!

► Many ways to create a mean-preserving spread.

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

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

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

The abatement cost curve pivots downward.
Two R&D Programs:
(2) Emissions Reduction

Production Function

\[ Q = f(\tau, \varepsilon) \]

Abatement Cost Curve

\[ C = f(\mu) \]

The abatement cost curve pivots to the right
R&D impacts convexity of cost curve / production function

Flatter $\Rightarrow$ R&D increases in risk

More convex $\Rightarrow$ R&D decreases in risk
### 2 Types of increasing risk

#### Increasing Probability

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<th>med</th>
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Increasing Probability

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

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Increasing Damage
Results – Increasing Probability

Optimal R&D vs. Probability of high damage

- Green line: Cost Reduction
- Blue line: Emissions Reduction

Billions of US$ vs. Probability of high damage
Results – Increasing Damages

- Optimal R&D
- Billions of US$

Graphs showing the relationship between % GDP Loss and Optimal R&D, and Billions of US$ with Emissions Reduction and Cost Reduction.
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

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

\[ E_t = (1 - \mu_t) \sigma A_t K_t^\gamma L_t^{1 - \gamma} \]