Economics 134 L9. Climate Change III. Risk, Uncertainty, and Irreversibility

Will Rafey

UCLA

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Climate change

Why study climate change?

1. One of the greatest challenges of our time
2. Raises new and interesting economic issues
    1. ~~balancing energy use with decarbonization (L7)~~
    2. ~~discounting and long-run environmental policy (L8)~~
    3. risk, uncertainty, and irreversibility (today)
    4. international negotiation and cooperation (L10)

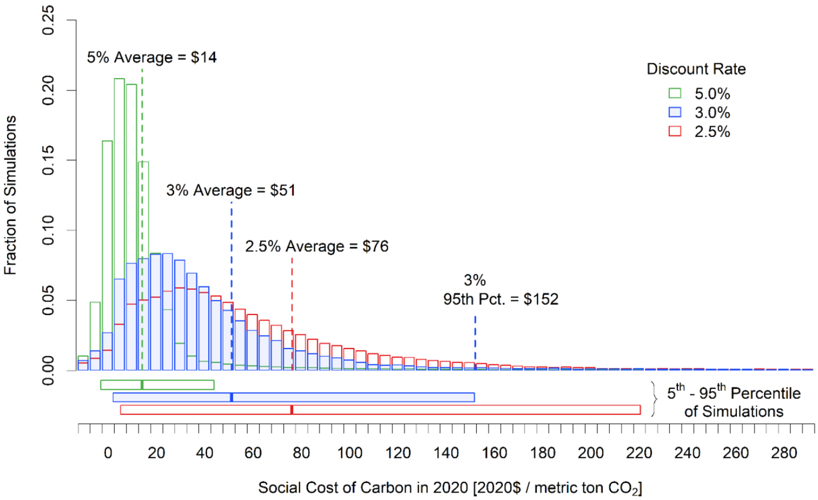
Uncertainty in environmental economics

General sources of uncertainty:

1. Difficult to determine the true benefits from environmental protection
2. Difficult to predict with certainty the effectiveness of a particular policy
   - highly nonlinear environmental damages
3. Hard to determine current and future costs of a policy
   - people, firms respond; innovation is uncertain

Uncertainty in Obama's social cost of carbon

Figure ES-1: Frequency Distribution of SC-CO₂ Estimates for 2020[6]



Source. Interagency Working Group on Social Cost of Greenhouse Gases, United States Government, "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990," February 2021.

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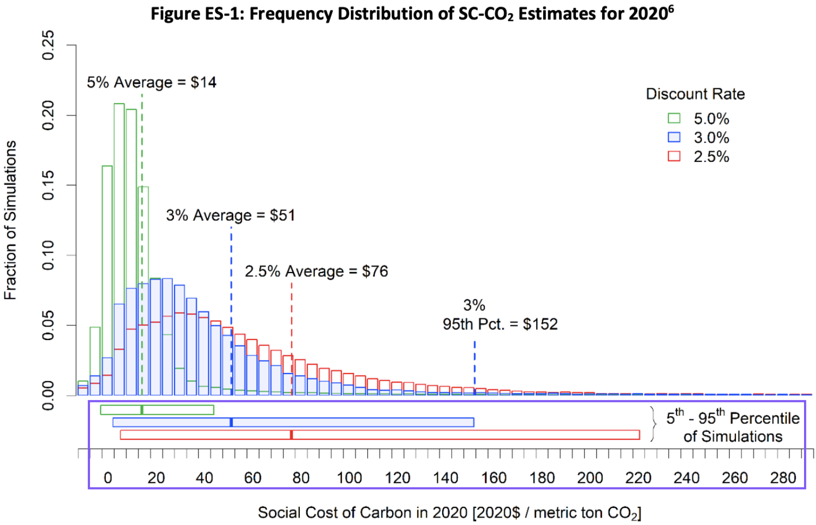

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Sources of uncertainty in future climate change

Natural science:

- equilibrium climate sensitivity
- sea level rise

Economic forecasts:

- population, technological, economic growth
- economic damages; extent, cost of adaptation

We will be more formal about these issues soon.

Recap of expected utility

General approach to decision-making under uncertainty.

Suppose that we can draw a rabbit from the hat, that the rabbit can be of quality $s \in \{1, 2, \dots, S\}$, and that we obtain utility

$$u(s)$$

from a rabbit of type s.

Let the probability of each s be given by $p(s)$, with $\sum_s p(s) = 1$.

Definition (Expected utility)

The expected utility of drawing from the hat is

$$\mathbb{E}[u] = \sum_s p(s)u(s).$$

Discussion

Useful tool for analyzing decisions under uncertainty

$\hookrightarrow$ undertake a project if and only if $\mathbb{E}[u] \geq 0$.

Need to know

- $\{1, 2, \ldots, S\}$, the set of possible states of the world
- $u(s)$, the benefit from each state
- $p(s)$, the probability of each state

Risk aversion

Suppose that c is consumption and utility is

$$u(c) = \overline{u} + \frac{c^{1-\theta}}{1-\theta}$$

where $\theta > 0$ is the absolute value of the **elasticity of marginal utility**.

Why is this a nice utility function? Seems strange.

Here's why. Marginal utility is given by

$$u'(c) = \frac{1-\theta}{1-\theta} c^{-\theta} = \boxed{c^{-\theta}}$$

As c rises, marginal utility falls, by

$$u''(c) = -\theta c^{-\theta-1}.$$

So, the **elasticity** of marginal utility is $u''(c)\frac{c}{u'(c)} = -\theta$.

Risk aversion, cont'd

Let $u(c) = \overline{u} + \frac{c^{1-\theta}}{1-\theta}$.

Also suppose that

- $\overline{u} = 2$
- $\theta = 2$

so that $u(c) = 2 - 1/c$.

Suppose that c is random, and that

$$c = \begin{cases} 1 & \text{with probability } \frac{1}{2} \\ 3 & \text{with probability } \frac{1}{2}. \end{cases}$$

Then the expected value of c is

$$\mathbb{E}[c] = \frac{1}{2} \cdot 1 + \frac{1}{2} \cdot 3 = 2.$$

Measured in utility terms, $u(\mathbb{E}[c]) = u(2) = 2 - \frac{1}{2} = \frac{3}{2}$.

Risk aversion, cont'd

Alternatively, the **expected utility** of the random c is

$$\begin{aligned}\mathbb{E}[u(c)] &= \sum_c p(c)u(c) \\ &= \frac{1}{2}\cdot u(1) + \frac{1}{2}\cdot u(3) \\ &= 2 + \frac{1}{2}(-1) + \frac{1}{2}\left(-\frac{1}{3}\right)\end{aligned}$$

which is $2 - \frac{1}{2} - \frac{1}{6} = \frac{4}{3}$.

And, $\frac{4}{3} < \frac{3}{2}$. Expected utility is **less** than the utility from obtaining $\mathbb{E}[c]$ with certainty.

This preference, that $\mathbb{E}[u(c)] < u(\mathbb{E}[c])$, is known as **risk aversion** (and is a general property of any concave utility function).

Implications for environmental protection

Suppose that we can protect a forest and obtain a “profit” of $c = 2$.

Otherwise, we can destroy the forest, and obtain profits

$$c = \begin{cases} \frac{1}{2} & \text{with probability } \frac{1}{2} \\ 4 & \text{with probability } \frac{1}{2} \end{cases}$$

because the timber obtained from the forest might be sold at a low or high price.

The expected profit from destroying the forest is

$$\mathbb{E}[c|\text{destroy}] = \frac{1}{2} \cdot \frac{1}{2} + \frac{1}{2} \cdot 4 = 2 + \frac{1}{4} = \frac{9}{4}$$

which exceeds the profit from protection.

If we were just maximizing expected profits, then it is optimal to **destroy** the forest.

Forest example, cont'd

However, suppose that we are instead maximizing expected utility, with the utility function $u(c) = \overline{u} + \frac{c^{1-\theta}}{1-\theta}$, with $\overline{u} = \theta = 2$ as before.

If we are comparing $u(2)$ with $u(9/4)$, we still destroy. ✓

However, we if we have to make the decision **before** we learn about the price of timber, then the expected utility from destroying the forest is

$$\mathbb{E}[u(c)|\text{destroy}] = 2 - \frac{1}{2} \cdot \frac{1}{1/2} - \frac{1}{2} \cdot \frac{1}{4} = 2 - 1 - \frac{1}{8}$$

or $\frac{7}{8}$, whereas the utility from conservation is

$$u(2) = 2 - \frac{1}{2} = \frac{3}{2}$$

and so our conclusion is reversed: the uncertainty over timber prices makes it optimal to **conserve** the forest. ✓

Discussion

Uncertainty can play a crucial role in decisionmaking

Depends on

- the utility function (level of risk aversion)
- the **source** of uncertainty

Note that there could be uncertainty over the costs of environmental protection (e.g., the timber price from forgone sales) or uncertainty over the benefits.

$\hookrightarrow$ whether uncertainty implies “more” or “less” environmental protection depends on the specific case

Estimating the expected social cost of carbon

Typical approach is to try to define a state space S and probabilities $p(s)$.

Example: US Environmental Protection Agency (September 2022), EPA External Review Draft of Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances, EPA-HQ-OAR-2021-0317

Study two types of uncertainty:

1. parametric uncertainty—
   - equilibrium climate sensitivity
   - productivity growth
   - population growth
2. model uncertainty—which IAM to use

Method: run various models under different parametric assumptions; show the distribution of outcomes

Example: uncertainty in climate physics

Equilibrium climate sensitivity, η, measures how much the Earth's surface will warm after a doubling of carbon dioxide:

$$\Delta T = \eta \cdot \frac{\Delta CO_2}{420 \text{ ppm } CO_2}$$

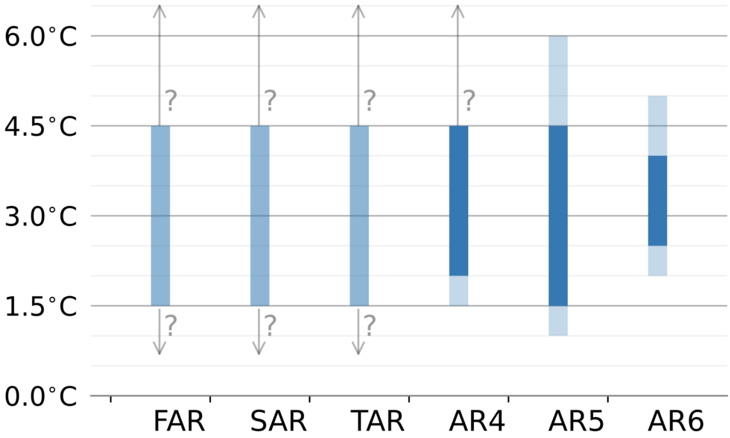
Higher sensitivity $\implies$ greater warming from a given increase in carbon

Difficult to determine because of feedback loops ("equilibrium"):

- melting of sunlight-reflecting ice (albedo) $\uparrow$
- higher evaporation increasing water vapor $\uparrow$
- cooling effect of clouds $\downarrow$
- changes in carbon sunk in the ocean $\downarrow\uparrow$

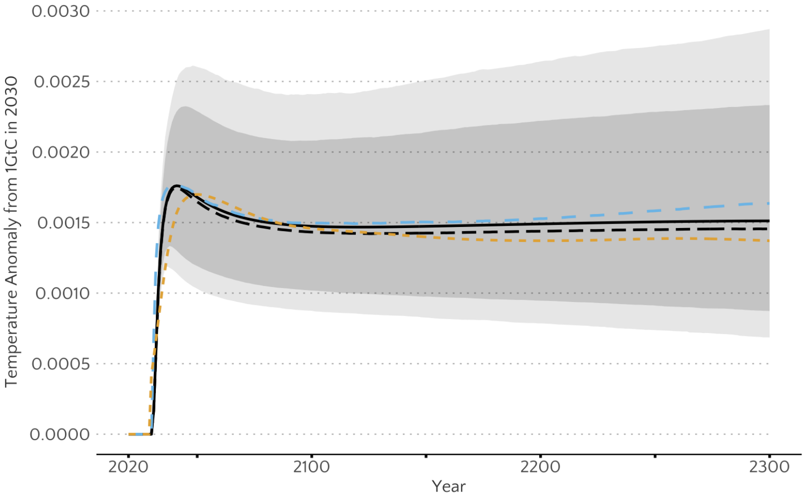
Vertical temperature gradient ("lapse rate") (Mount Rysy, Poland, May 2019)

Uncertainty in climate sensitivity



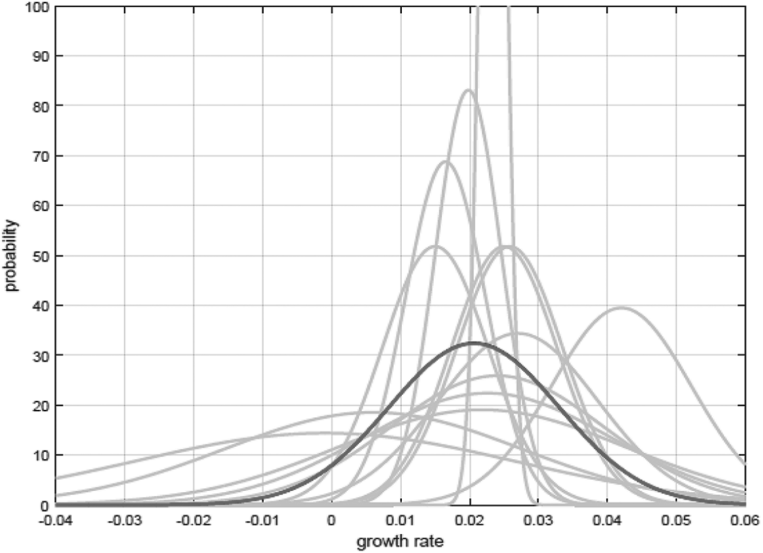
Source. Historical estimates of climate sensitivity η from the IPCC, 1990–2021 (FAR–AR6).

Uncertainty in climate sensitivity



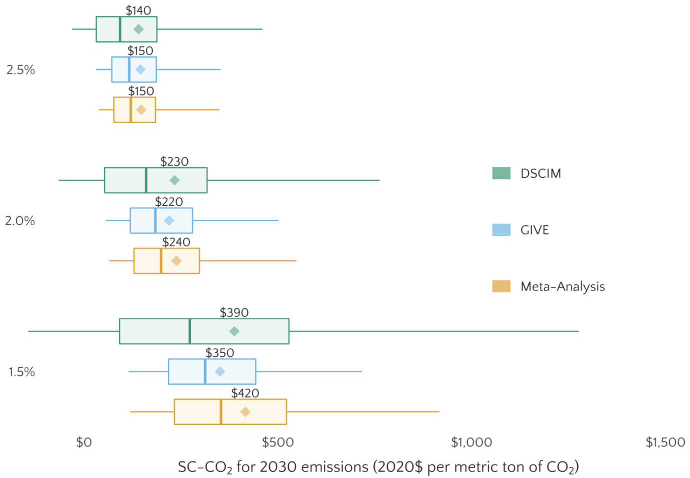
Mean (**solid**) and median (dashed); 5th to 95th (**dark shade**); 1st to 99th (light shade) percentile ranges; colors are different models. **Source**. EPA 2022, "EPA External Review Draft of Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances," September. Figure 2.2.3.

Example: uncertainty over future productivity, g



Results

Social Cost of Carbon for 2030



Boxes span the inner quartile range (25th to 75th percentiles), whiskers extend to the 5th (left) and the 95th (right) percentiles. The vertical lines inside of the boxes mark the median of each distribution, and the points inside of the boxes and dollar estimates on top of the boxes mark the simple mean (average).

Results

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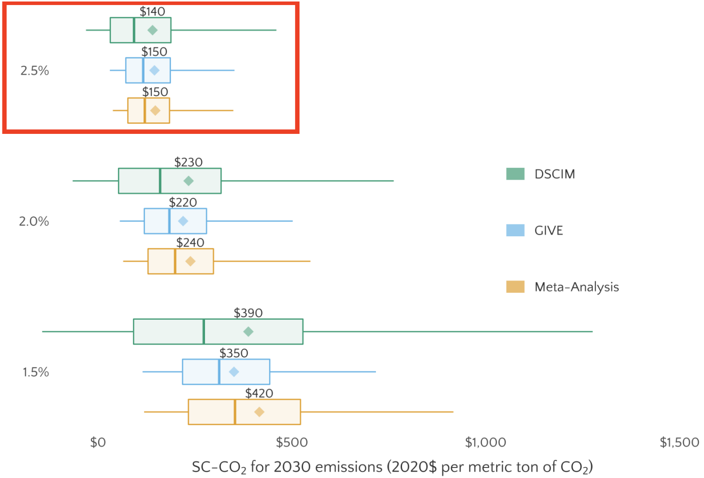

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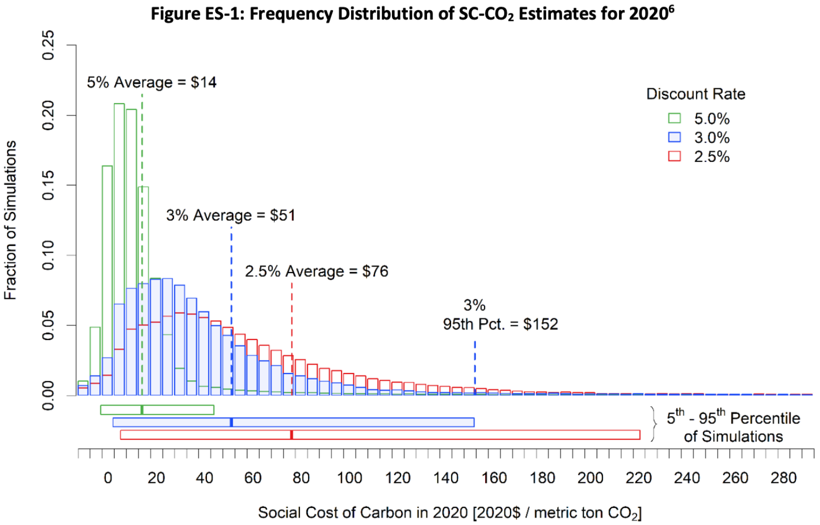
Uncertainty in Obama's social cost of carbon

Obama / Interagency Working Group approach:

- climate sensitivity: assume $\eta \in [0, 10]$
- assume the median $\eta = 3^\circ$C
- also assume $\eta \in [2, 4.5^\circ\text{C}]$ with probability $2/3$
- consider various socioeconomic scenarios
- three models (DICE, PAGE, FUND), weighted equally

Uncertainty in Obama's social cost of carbon



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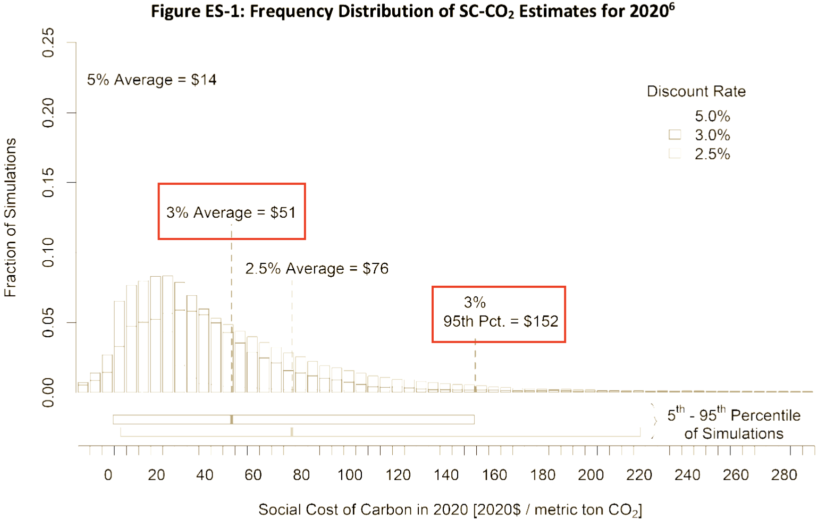
Where does this leave us?



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Irreversibility

Often our intuition about uncertainty is related to dynamics. Related but **distinct**.

Suppose that there are two periods: today and tomorrow.

- The forest can be destroyed today to obtain 2 units of utility.
- Tomorrow, we learn either that the forest was very valuable (say, 3) or valueless (say, 0).
- Today, we know that the probability is $1/10$ that the forest is very valuable.

The expected net benefit of destroying the forest today, for discount rate $r > 0$, is

$$2 - \frac{1}{10} \cdot \frac{3}{1+r} > 0$$

so we **should** destroy the forest if we are comparing expected benefits with costs.

Irreversibility, cont'd

However, suppose that we can **delay** our decision until tomorrow.

If we know we will destroy the forest no matter what, then we would still want to destroy today, because

$$2 > \frac{2}{1+r}.$$

However, if the forest is very valuable, we would rather not destroy it. So, the expected value today of delaying the decision until tomorrow is

$$\frac{1}{1+r}\left[\frac{9}{10}\cdot 2 + \frac{1}{10}\cdot 3\right] = \frac{2.1}{1+r}$$

so if $r < 0.05$, we would like to delay the decision until tomorrow.

Bottom line: delaying an irreversible decision can create a positive **option value**

$\hookrightarrow$ whether delay is optimal here depends on r and the probability of a mistake, $\frac{1}{10}$

Discussion

Irreversibility interacts in complicated ways with uncertainty

- if we had perfect foresight, irreversibility would be irrelevant!

Environmental economics often raises such concerns:

1. Environmental damage often partly or totally irreversible
   - e.g., atmospheric carbon concentrations; ecosystem destruction
   - uncertain environmental damages from irreversible choices can create a **positive** option value of protecting the environment now
   - prefer to wait for uncertainty to resolve ("**precautionary principle**")
2. Environmental protection can entail fixed costs
   - e.g., install new technology
   - technological uncertainty can create a **negative** option value
   - prefer to wait to see if technology improves

In either case, just comparing the expected benefits with expected costs gives a misleading answer: need to account for the **option value**.

Catastrophic events

Let's return to our prior model, where

$$u(c) = \overline{u} + \frac{c^{1-\theta}}{1-\theta}$$

with $\overline{u} = \theta = 2$.

Suppose that we can act now to prevent climate change for some cost. If we **do not** act, then our consumption will be either

$$c = \begin{cases} \frac{1}{10} & \text{with probability } 0.1 \\ 1 & \text{with probability } 0.9, \end{cases}$$

because there is a small chance of catastrophe. Then expected consumption is

$$\mathbb{E}[c] = 0.9 + 0.01 = 0.91,$$

which would give utility of $u(\mathbb{E}[c]) = 2 - 1/.91 \approx 0.901$.

Catastrophic events, cont'd

However, the expected utility from not acting on climate change is

$$\mathbb{E}[u(c)] = 2 - 0.1 \cdot \left(\frac{1}{1/10}\right) - 0.9 \cdot 1 = 2 - 1.9 = 0.1$$

which is **much lower** than 0.901.

More generally: if consumption under the catastrophic scenario falls to some $\underline{c}$, then utility in that scenario becomes very negative, since $\lim_{c \to 0} u(c) = -\infty$.

Expected utility becomes unbounded unless the probability of catastrophe diminishes at least as rapidly as utility falls.

So, with extreme events, the probability of a catastrophic scenario can **determine** the expected utility from action on climate change

- "everything" in the cost-benefit analysis depends on $\underline{c}$ and its probability p

Tipping points

Various nightmare scenarios due to climate change, not outside the realm of possibility:

- sudden collapse of the Greenland and West Antarctic ice sheets
- weakening or reversal of the thermohaline circulation
- cascade of positive feedbacks (albedo, carbon sinks, permafrost)
- new, extreme weather patterns

Tipping points and economic analysis

Basic problem: if we don't know $p(s)$ for these s, we can't calculate $\mathbb{E}[u]$.

Marty Weitzman (2007):

> *The overarching problem is that* **we lack a commonly accepted usable economic framework** *for dealing with these kinds of thick-tailed extreme disasters, whose probability distributions are inherently difficult to estimate (p. 723)*

Similar argument made by Bob Pindyck at MIT (2013):

> *IAMs tell us* **nothing** *about the likelihood and nature of catastrophic outcomes, but it is just such outcomes that matter most for climate change policy. Probably the best we can do at this point is come up with plausible estimates for probabilities and possible impacts of catastrophic outcomes.*

Climate change policy as catastrophe insurance?

Implications for policy:

> *The basic issue here is that spending money to slow global warming should perhaps not be conceptualized primarily as being about consumption smoothing as much as being about* **how much insurance to buy** *to offset the small change of a ruinous catastrophe that is difficult to compensate by ordinary savings. (Weitzman, 2007, p. 703)*

Next time

- Problem set 2 posted on Gradescope; due next Thursday, 6 Nov, by 5pm
- Next Monday, we will talk about international equity and political economy