Uncertainty, Ignorance and Solar Geoengineering

Richard J. Zeckhauser
richard_zeckhauser@harvard.edu
hks.harvard.edu/fs/rzeckhau/

In collaboration with:
Gernot Wagner
gwagner@fas.harvard.edu
gwagner.com

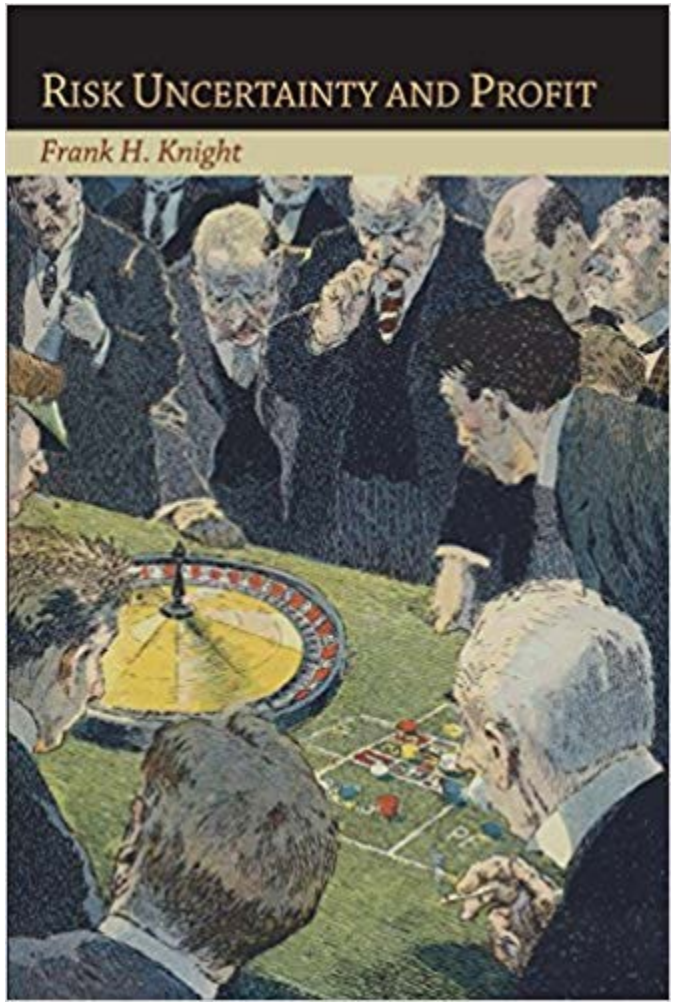
Question 6—Stavins to RJZ

"SG is both a hedge against uncertain but potentially catastrophic risks of (or, alternatively, damages from) climate change – and has its own associated risks, known and unknown.

"How can we better understand these uncertainties and incorporate them into useful decision-making processes?"

Risk, uncertainty, and ignorance

A gambler's perspective



Risk: probabilities of states of the world known

- Rolling a 7 with one roll of two dice

Uncertainty: probabilities of states of the world unknown

- The chance that Ted Cruz will be re-elected

Ignorance: Identity of important states of the world is unknown and likely unknowable

- Arab Spring, gas explosions in Massachusetts, magic illusion

Source: Zeckhauser, R. 2006. "Investing in the unknown and unknowable." *Capitalism and Society*, 1: 1–39, Article 5.


PENN & TELLER:
FOOL US

A medical thought experiment

Another kind of risk-risk tradeoff scenario

Spouse has bad case of cancer

Should she try to get a bone marrow transplant?

Alternative: high-dose chemotherapy

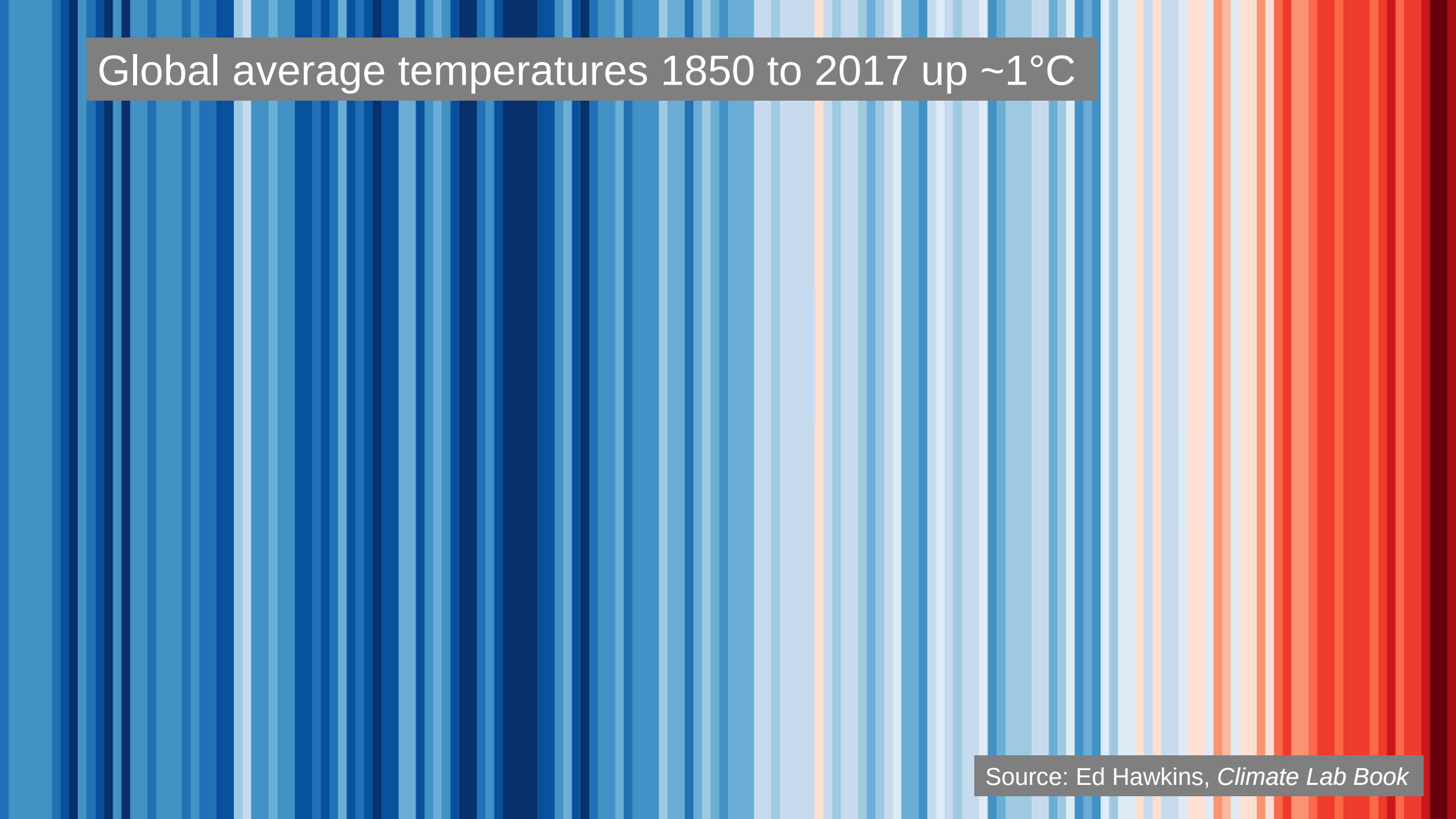
Her doctors: “We discourage bone marrow transplants. They have a 4% treatment mortality.”

You ask: “What is the gain in long-run survival probability?”

Doctors: “Our best guess would be 10%; maybe higher. Of course, it could be lower.”

Sally Zeckhauser is alive and well 23 years later.

Errors of omission and commission should be weighted equally


Global average temperatures 1850 to 2017 up ~1°C
Source: Ed Hawkins, *Climate Lab Book*

Uncertainty and climate change

The case of equilibrium climate sensitivity

CO_2 concentrations increase by ~2ppm/year

They have already passed 410ppm, >50% above 280ppm preindustrial

At +2ppm/yr, they will pass 560ppm, 2x preindustrial CO_2, in 75 years

We are “likely” (66%) in a world where 2xCO_2 causes 1.5-4.5°C of warming

So much for averages…

And there’s a not-so-small (17%?!) chance of 2xCO_2 leading to >>4.5°C warming

Ignorance: Future Consequences of Climate Change?

Migration as a consequence of climatic extremes

Societal reactions to mass migration

Uncertainty and solar geoengineering

A thought experiment

Adding aerosols to the stratosphere acts to offset warming almost linearly

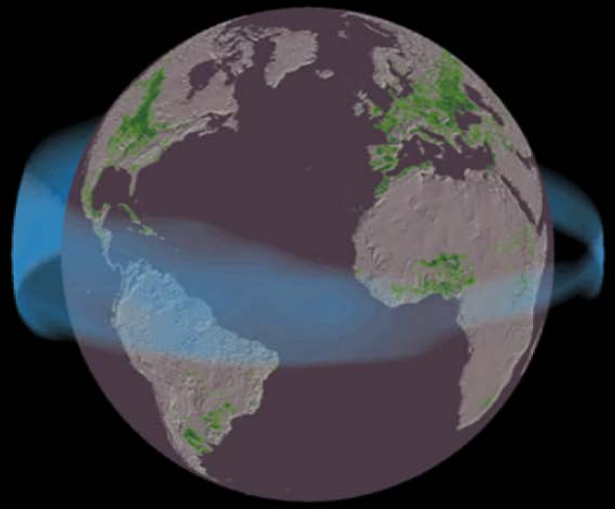
100,000 tons of SO_2 reduces global average temperatures ~0.1°C

200,000t SO_2 reduce T by ~0.2°C, …

But what if there's a small (10%?) chance of SO_2 deployment leading to a planetary catastrophe?

How does SG uncertainty compare with climate uncertainty?


Climate change consequences
Solar geoengineering side effects



What’s the head-spinning, presently unknowable SG consequence?

What's the low-probability, high-consequence way SG could go wrong?

Prior: SG good for crop yields due to lower temps

2018 *Nature* cover identifies negative effect due to diffuse sunlight from Pinatubo

But *Nature* study is wrong, too; e.g. misses CO_2 fertilization effect!

How much of what SG will produce is known, not *yet* known, or simply unknowable?

Source: likely BCA to Proctor et al 2018 *Nature* cover, by Kate Ricke, David Keith, others.

Important major potential downsides of SG possibly unknown

If it stumps Penn & Teller, what hope is there for the rest of us?

There are lots of ways to do levitation.

Penn & Teller assessed and dismissed each possible explanation.

They confessed ignorance.

Can we proceed to experiment with SG, even recognizing our ignorance?

That an experiment has unknowable consequences is not a TRUMP card.

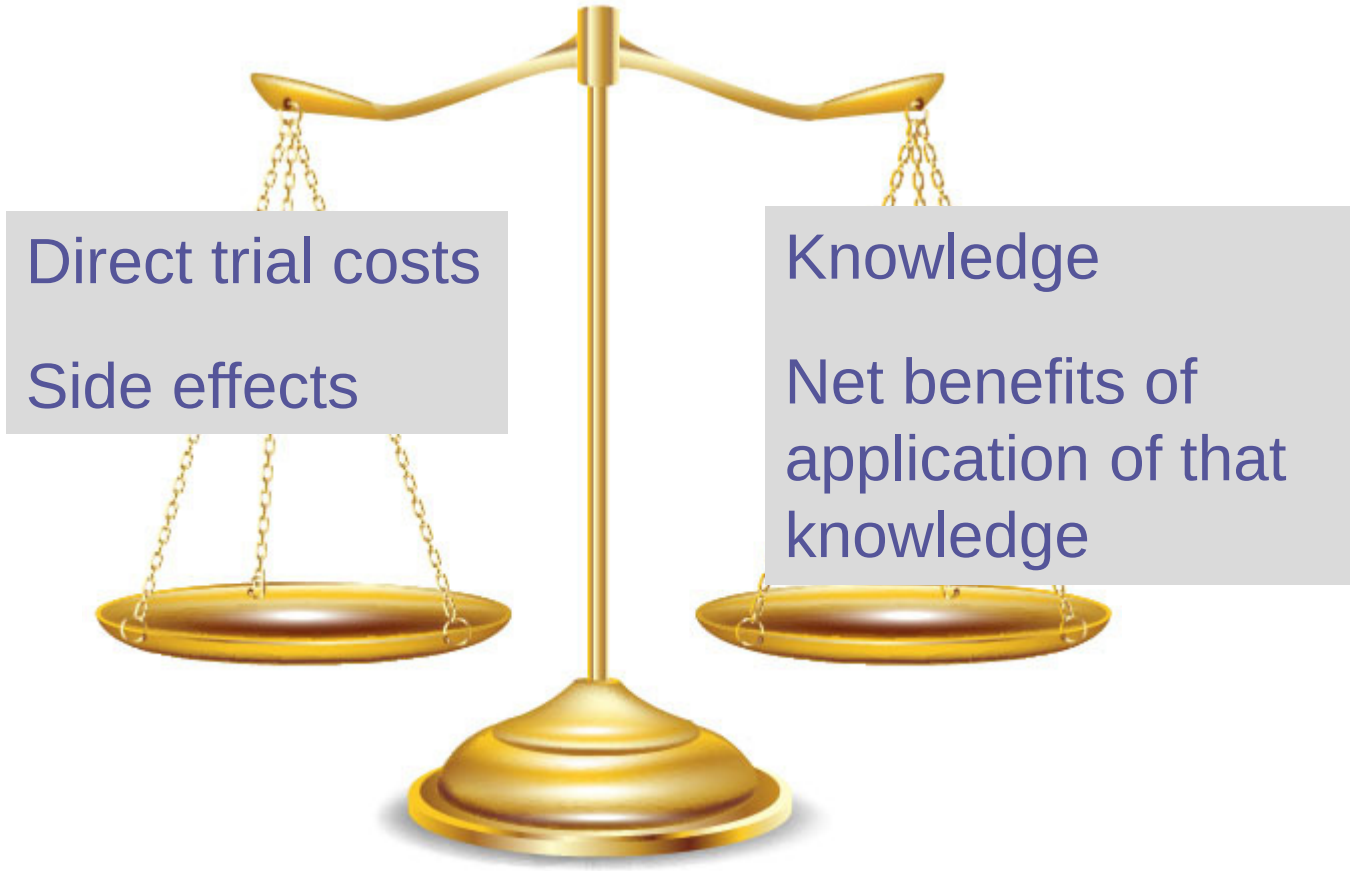
It does not automatically say STOP.

Errors of omission and commission should be weighted equally

SG is like many technologies

We can learn a great deal about it through scientific investigation

However, a “trial run” may be more informative than even intense scientific investigation



Model addressing SG ignorance

Fuller model under development (possibly joint with Chris Avery)—includes ignorance about climate damages

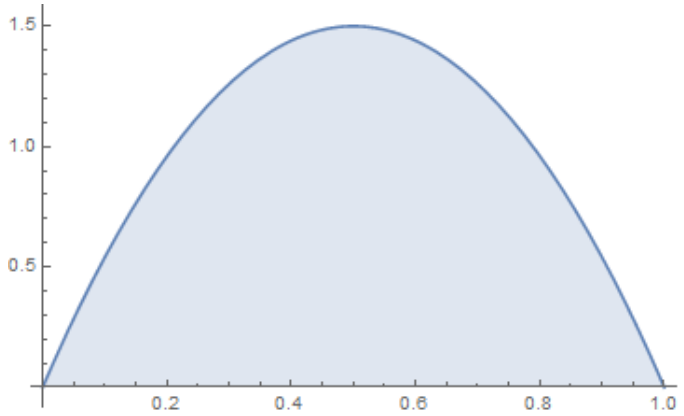
- 2 periods: one experimental, one implementation
- SG is “fast, cheap, and imperfect”
  - — “Fast”: Feedback within a period
  - — “Cheap”: Zero direct costs
  - — “Imperfect”: Potentially large SG damages (SGD), following β-function
- Learning within a period is incomplete, via altering β-function parameters
- SG measured in form of Mt sulfur/year. Sulfate sensitivity ξ in $\frac{W}{m^2}/\frac{Tg\ S}{yr}$
- SG modifies “realized temperature” ($RT_t = T_t - \xi\ SG$)
- Quadratic climate damages: $D_t = A\ RT_t^2\ Y_t$
- Objective to minimize expected damages $E[D_1 + SGD_1 + \delta(RT_2 + SGD_2)]$
- Current simplifying assumptions, relaxed in future work:
  - — No mitigation
  - — No climate damage uncertainty
  - — No risk aversion

Learning about SG damages

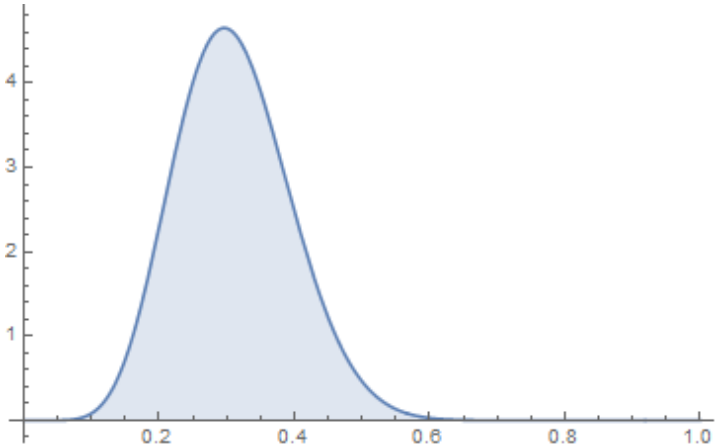
SG damages assumed to follow β-function

- Assume SG damages = $a\ b\ s^k$, with b = BetaDistribution(α, β)
- Learning represented by changing α and β.
- Objective: (1) Pick s_1; (2) Pick s_2 contingent on first-period outcome to minimize expected damages $E[D_1 + SGD_1 + \delta(RT_2 + SGD_2)]$
- E.g.: $a = .001$, $k = \frac{3}{2}$

Period 1: $\alpha = 2$, $\beta = 2$



Period 2: $\alpha = 9$, $\beta = 20$



Summary of results

Version 0.1

- Greater SG risk, lower s_1
- Greater assumed knowledge, lower s_1
- Longer s_2 period, greater s_1
- s_2 grows with GNP in period 2
- Results intuitive
- Value of exercise: getting thinking straight about value of testing (“Optimal tasting©”)

Next model steps:

- Incorporate learning about climate damages
- Incorporate mitigation expenditures
- Add risk aversion
- HARD: Realistic uncertainty parameter values

Concluding thoughts

- The greater are the uncertainties about SG damages, the more appealing, on an expected value basis, is SG

The reason:

- Significant positive correlation between SG uncertainty and climate change uncertainty

And:

- Climate change uncertainty dramatically more consequential