Climate change mitigation as catastrophic risk management

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Let’s go back to the *Stern Review*


£3.68 trillion
The price of failing to act on climate change
Landmark report reveals apocalyptic cost of global warming

Source: Observer newspaper, one day before publication of the Stern Review

Emissions path	Present value of total climate damage (% of global GDP)	Marginal damage cost of CO_2 (\$US/tCO2e)
Business as usual	11 [5, 20]	85
Stabilise greenhouse gases at 550ppm	1.1	30
Stabilise at 450ppm	0.6	25

What did the Stern Review's conclusions depend on?

The critics (δ=1.5%, η=2, no uncertainty: **0.6%**

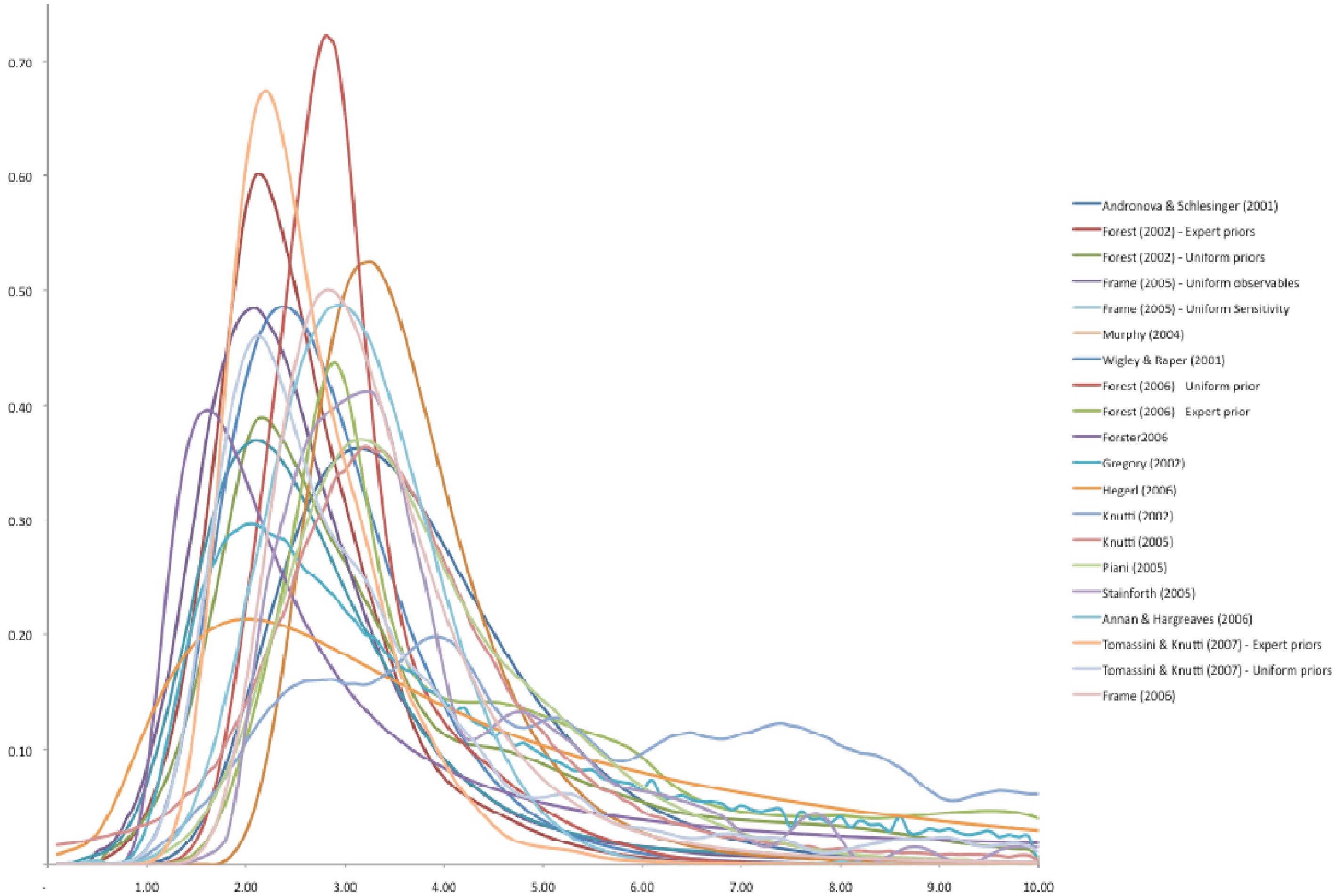
Change discount rate (δ=0.1%, η=1, no uncertainty): **3.5%**

Change uncertainty (δ=*1.5%*, η=2, expected-utility analysis): **1.1%**

Stern (δ=*0.1%*, η=1, expected-utility analysis): **10.9%**

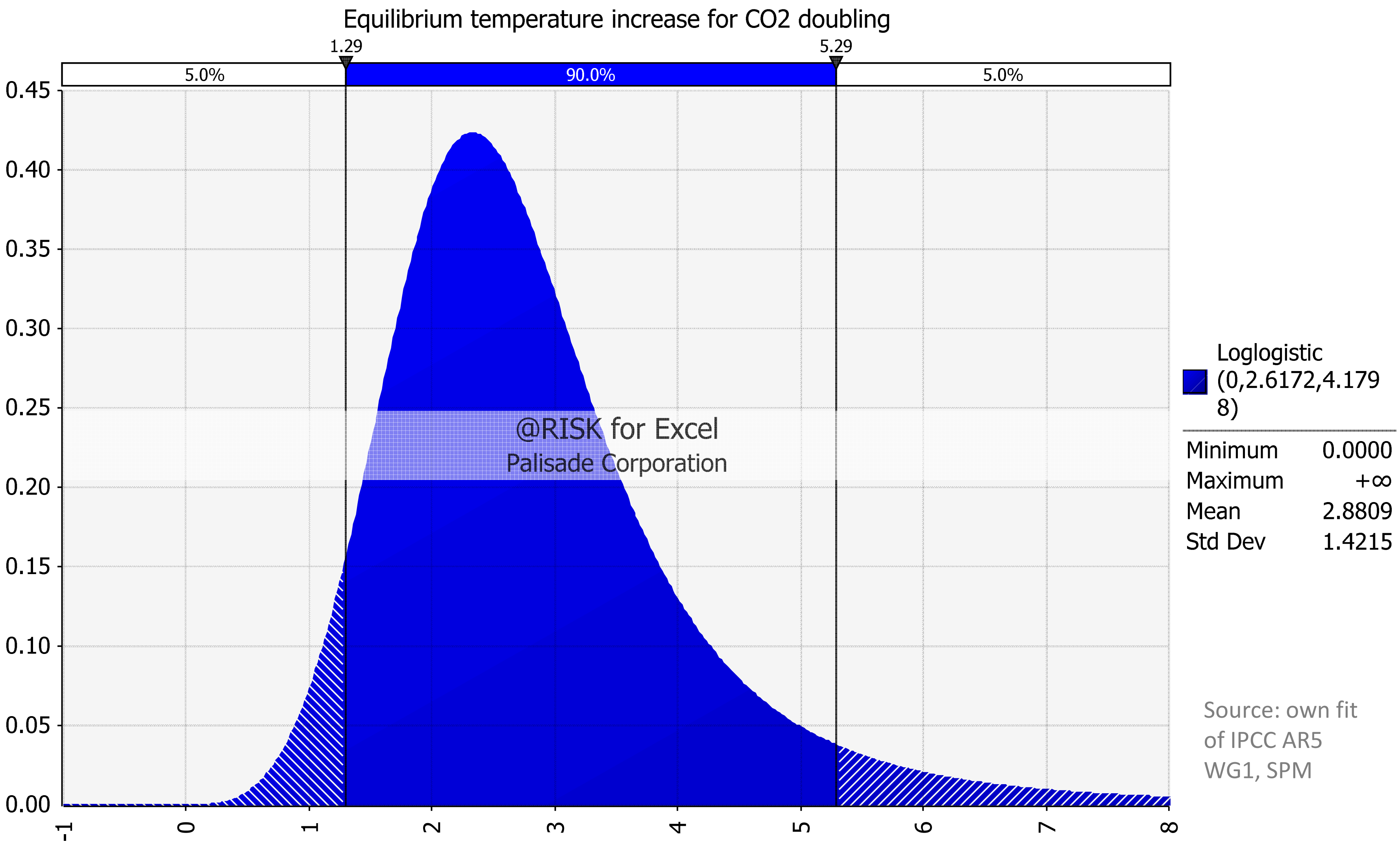
Source: Dietz et al. (2007) in *World Economics* **8(2)**

Martin Weitzman: Stern was right for the wrong reasons; fat tails are the right reason



Source: Malte Meinshausen

A very quick excursion: what does IPCC *AR5* say about climate sensitivity?



Source: own fit of IPCC AR5 WG1, SPM

Martin Weitzman's Dismal Theorem

- Consider a two-period model with uncertain future consumption, and normalise current consumption to 1:

$$W = U(1) + \beta \cdot EU(C)$$

- How much should we be willing to give up to increase future consumption by one sure unit?

$$M = \beta \cdot \frac{EU'(C)}{U'(1)}$$

Martin Weitzman's Dismal Theorem

- Suppose:
  1. Relative risk aversion > 0 as $C \to 0^+$
  2. Uncertain consumption growth $y \equiv sZ + \mu$ is given by

     $$h(y \mid s) = \left(\frac{1}{s}\right) \cdot f\left(\frac{y-\mu}{s}\right)$$

     μ is known but s (≈ climate sensitivity) is itself uncertain
  3. *Jeffreys'* prior on s, $p(s) \propto s^{-k}, k > 0$ and observations of y are finite

3. Then the posterior distribution of y, $q(y|\boldsymbol{y_n})$ is fat-tailed
4. Moreover $M = +\infty$!

The Dismal Theorem is a *reductio ad absurdum*

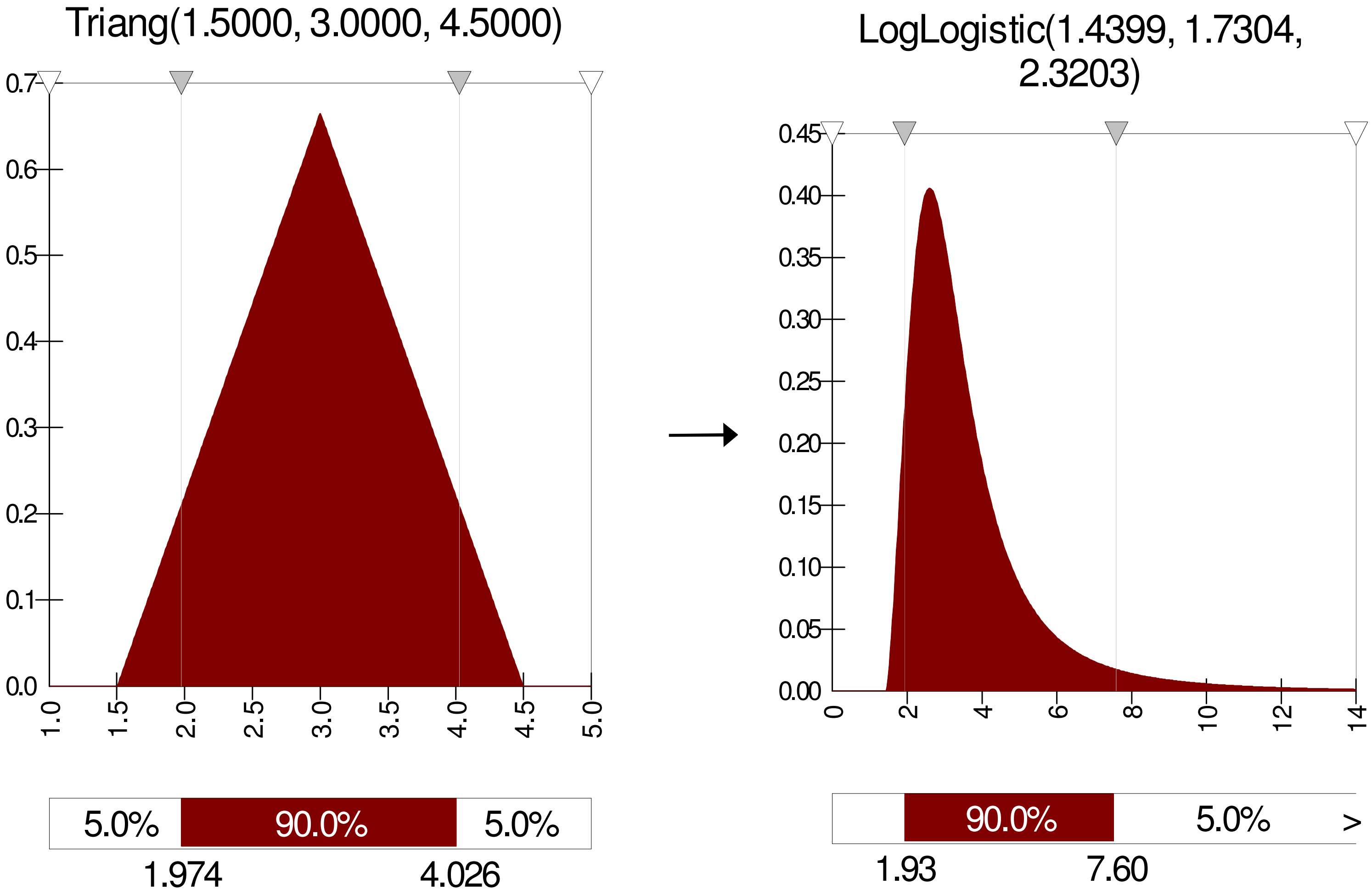
- Of course we're not willing to pay an infinite amount to increase future consumption
- Ways to make the Dismal Theorem go away:
  - Realise that total WTP can exist even if marginal WTP does not
  - Use a different prior on *s*
  - Bound the problem somehow, e.g. bound the utility function, or WTP

Nonetheless it has contributed to changing the narrative

Climate change mitigation as intergenerational justice

Climate change mitigation as planetary insurance

Re-doing the Stern Review analysis with fat tails



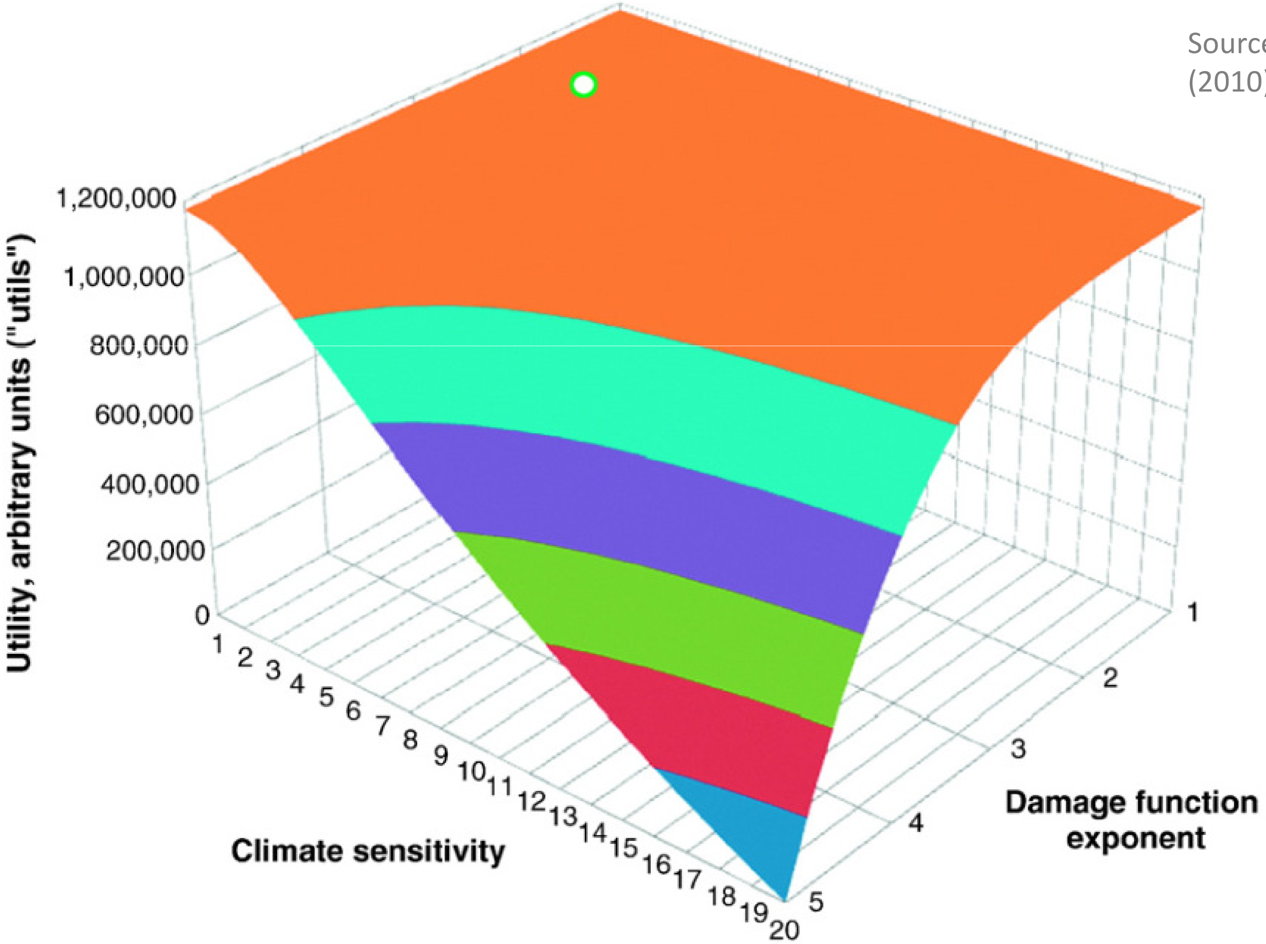
Source: Dietz (2011) in *Climatic Change*

Re-doing the Stern Review with fat tails

Scenario		Marginal damage cost of CO_2 on BAU ($US/tCO2e)		
Tails	**Discount rate**	**5%**	**Mean**	**95%**
Fat	Stern	21	445	1862
Thin	Stern	10	138	369
Fat	High	5	346	1741
Thin	High	8	101	141

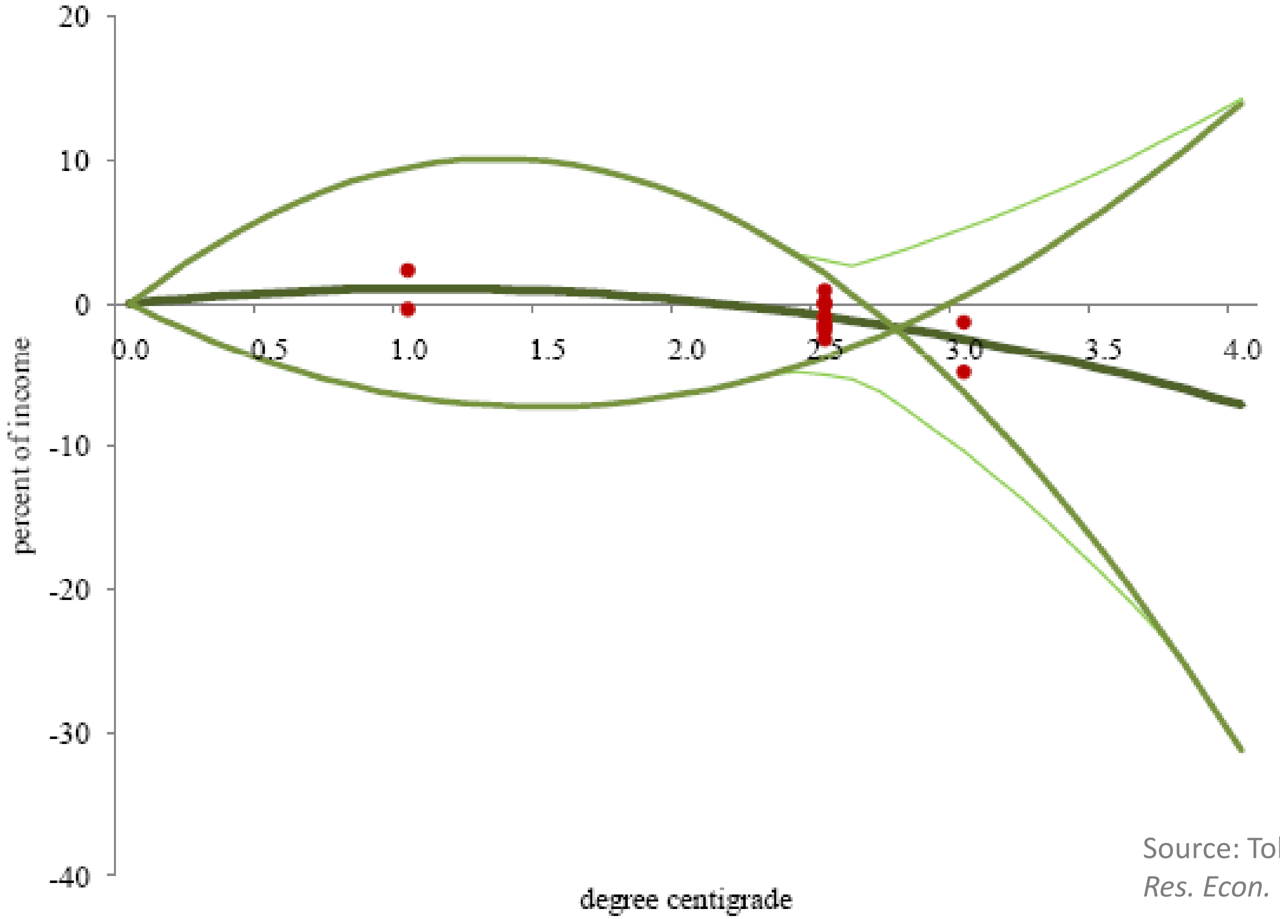
Source: Dietz (2011) in *Climatic Change*

But these results depend on the curvature of the damage function



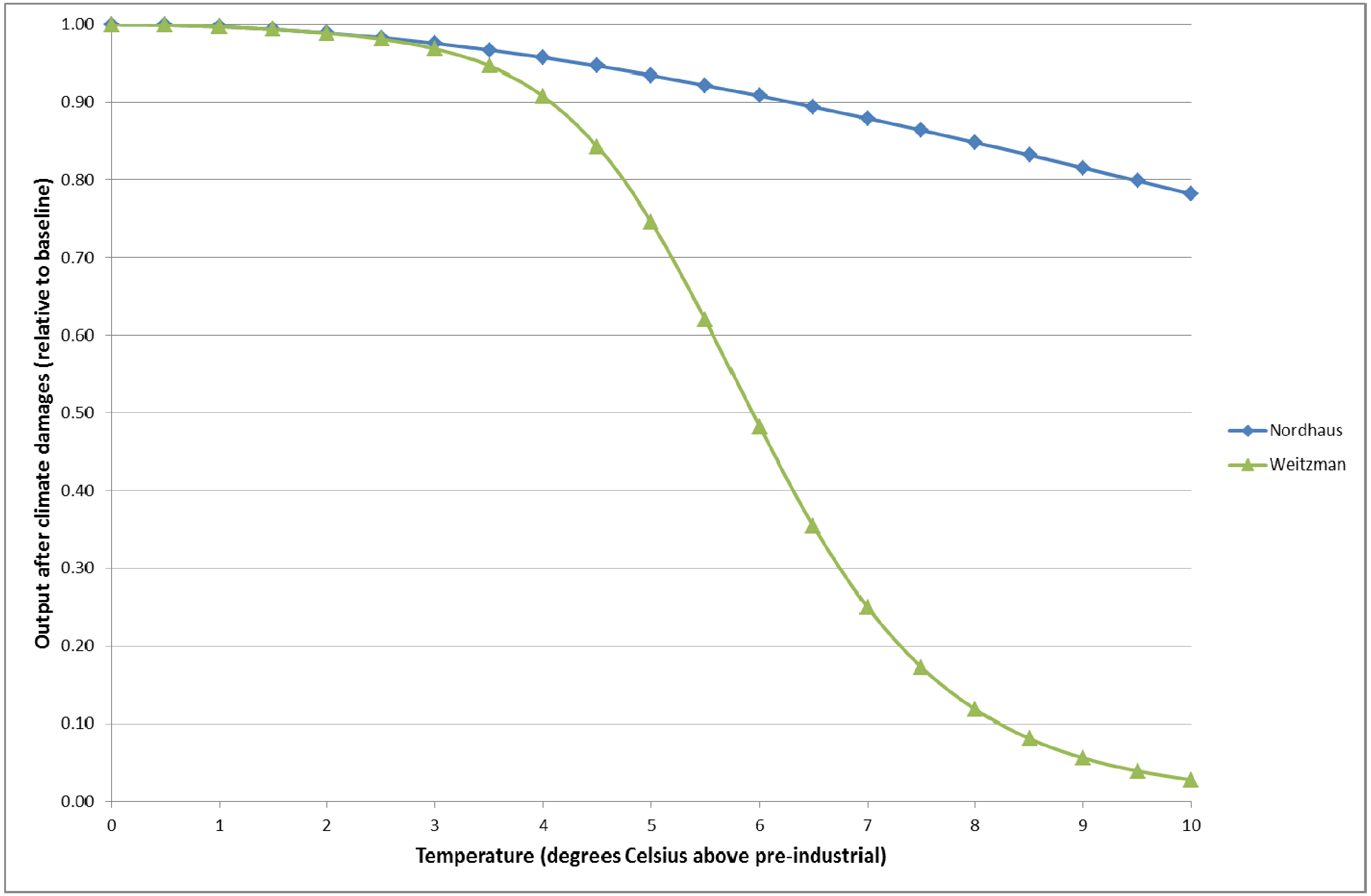
Source: Ackerman et al. (2010) in *Ecol. Econ.*

That's unfortunate, since the curvature of the damage function cannot be pinned down by empirical evidence



Source: Tol (2012) in *Env. & Res. Econ.*

Which of these do you believe is more likely?



We also see, with perhaps greater clarity than before, the limits of the standard tools of expected utility theory…

Results become sensitive to how and where WTP is bounded (Weitzman, 2009); for example…

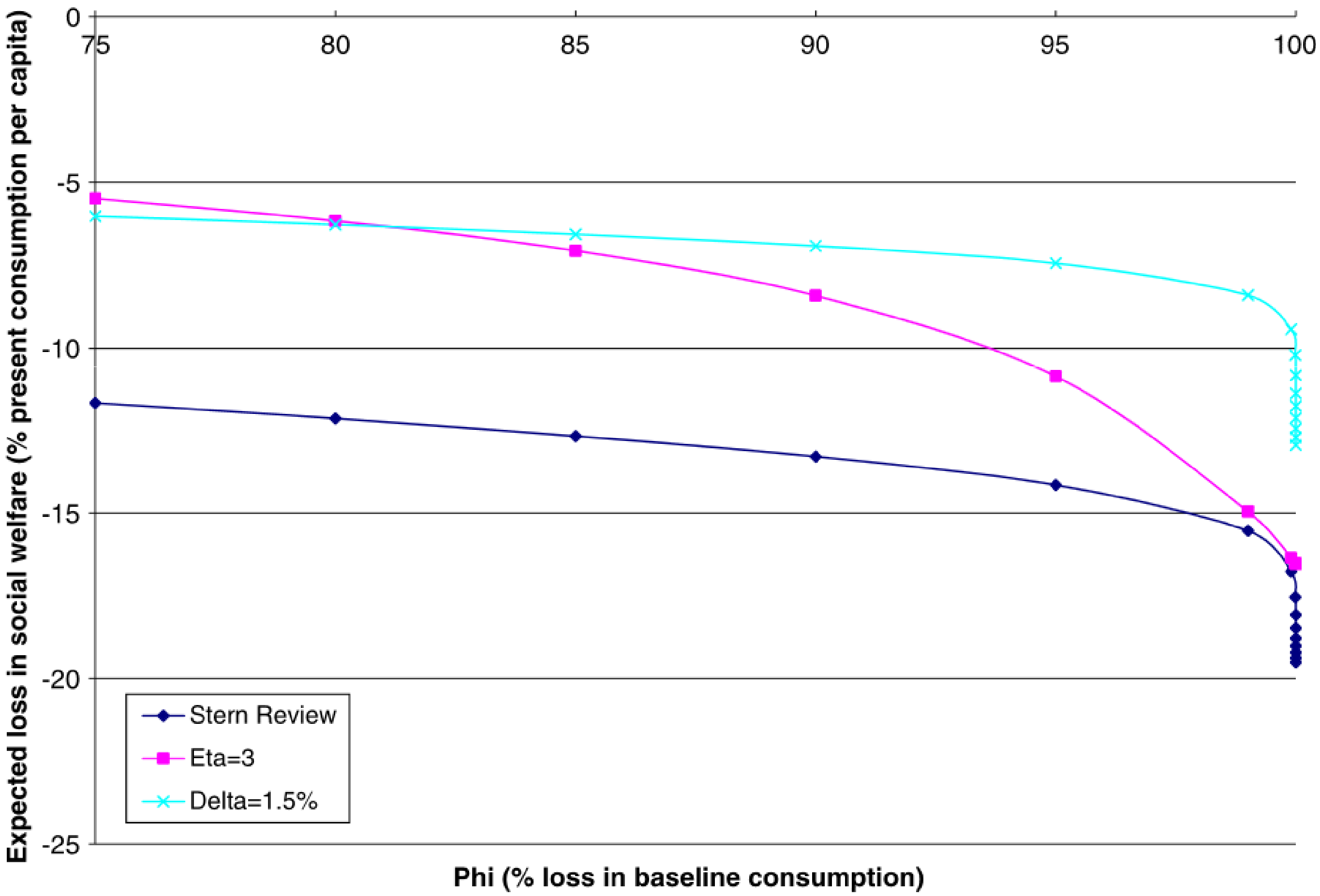


Fig. 4 Expected loss in social welfare as a function of the upper bound on damages (ϕ)

Source: Dietz (2011) in *Climatic Change*

What about structural uncertainty? What are the implications for policy choice?

- Expected utility theory requires unique estimates of probability, most plausibly subjective in nature (de Finetti, Ramsey and Savage)
- We don't appear to have those for climate sensitivity at the very least
- Options
  1. Choose the best estimate (the 'scientist's solution')
  2. Aggregate the various estimates into a single estimate (the 'Bayesian solution')
  3. Do something other than maximise expected utility

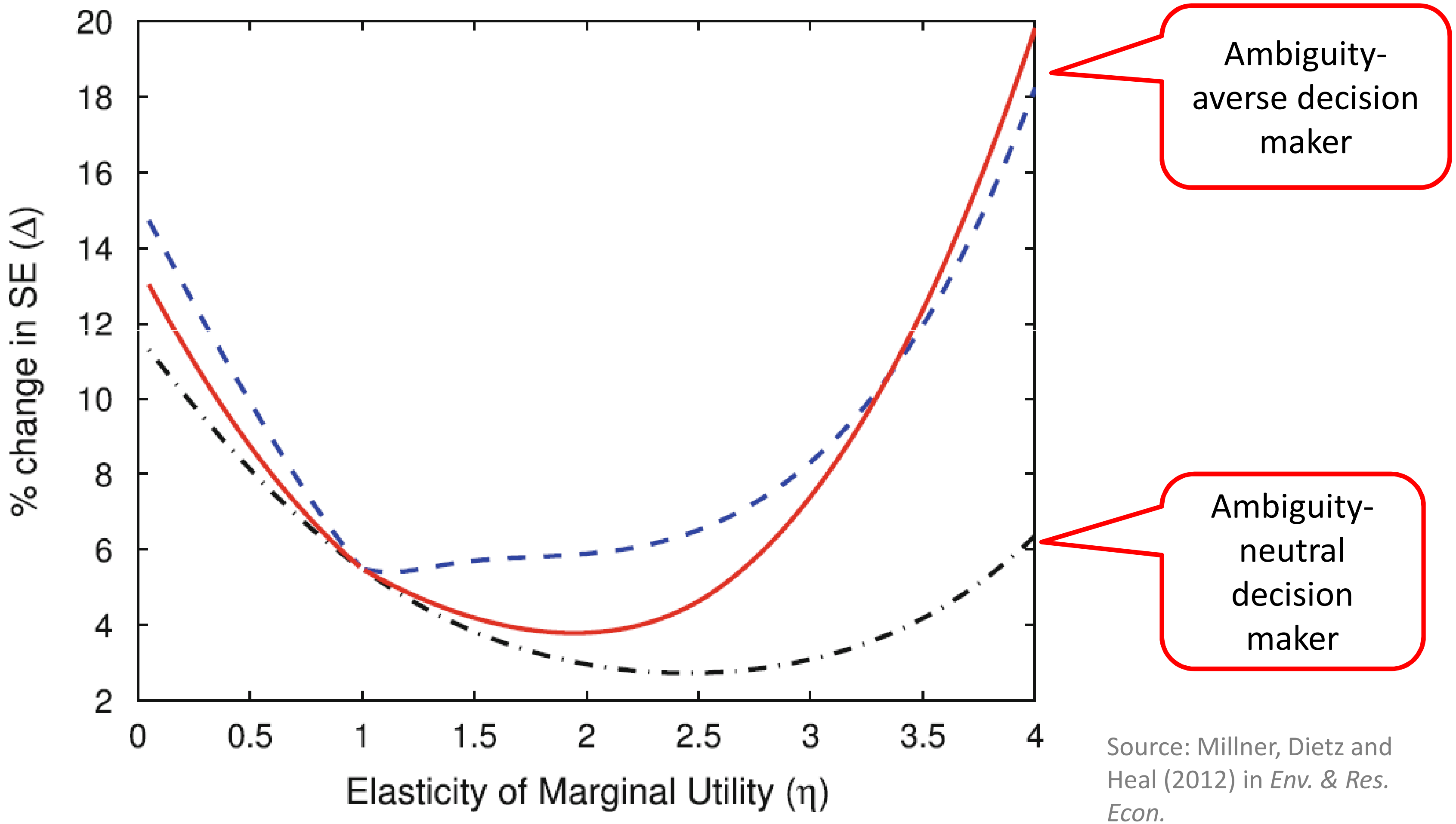
An alternative: the smooth model of decision making under ambiguity

- Klibanoff, Marinacci and Mukerji derive a smooth 'multiple priors' decision theory, which accounts for ambiguity aversion
- Value of a policy:

$$V(f) = \sum_m p_m \varphi(EU_m(f)) = E_{subj}\varphi(E_{obj}U(f))$$

- *Φ*(.) encodes ambiguity aversion iff *Φ*''(.)

Ambiguity aversion can significantly increase the value of emissions cuts



Source: Millner, Dietz and Heal (2012) in *Env. & Res. Econ.*

Another alternative: robust control

After Hansen and Sargent (e.g. *Robustness*, 2007, Princeton Univ. Press)

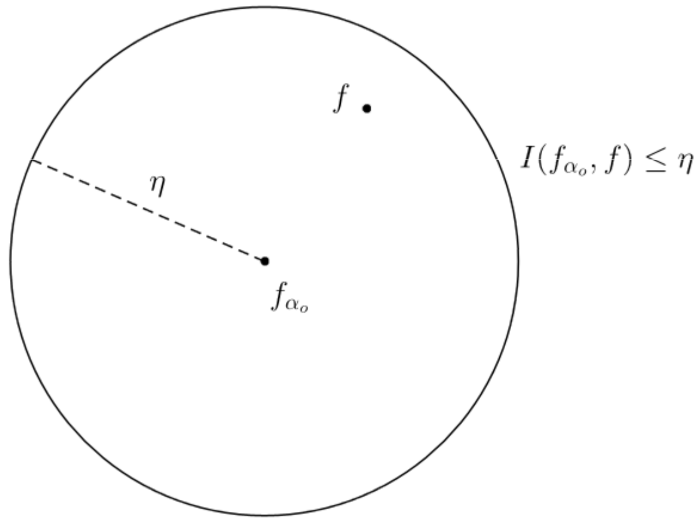


Figure 1.7.1: Robust decision making: A decision maker with model f_{α_o} suspects that the data are actually generated by a nearby model f, where $I(f_{\alpha_o}, f) \leq \eta$.

Another alternative: robust control

- Choice under model uncertainty:
  - Like a two player, zero-sum game
  - Between a *maximising* decision-maker and malevolent, *minimising* mother nature, who chooses the model distortion that gives the worst pay-off
  - Solution is therefore a form of *max-min*

$$\max V(f) = \min_{m} E_m U(f) \quad \overline{\eta} > \eta > 0$$

Robust control also points to deeper emissions cuts

- Athanassoglou and Xepapadeas (2012 in *JEEM*) – optimal emissions cuts "most probably" increasing in degree of model uncertainty
- Funke and Paetz (2011 in *Climatic Change*) – emissions cuts towards a stabilisation target should be deeper under robust control

Conclusion #1

- The case for deep cuts in global greenhouse gas emissions seems stronger than ever
  - even if the feasible set of cuts may be diminishing the longer we continue on something not too far from business as usual

Conclusion #2

- There is much still up for grabs academically, as the theoretical eclecticism that has characterised the last few years of research in climate-change economics leaves us in a period of intellectual flux

Supplementary slides

Why is (marginal) willingness to pay infinite?

- Switch to thinking in terms of *discrete* probability distributions:

$$EU'(C) = \sum_{i=0}^{k} p_i U'(C_i)$$

- i = 0 is defined as the catastrophic state, i = 1,2,...,k are non-catastrophic states
- In a catastrophic state C is very small but > 0

Why is (marginal) willingness to pay infinite?

State	Catastrophic state	Non-catastrophic states	
Probability	p_0	p_1,…	p_k
Outcome	$U'(C_0)$	$U'(C_1)$,…	$U'(C_k)$

Why is (marginal) willingness to pay infinite?

- Consider sequences of catastrophic futures

$$\left(C_0{}^{(n)}, p_0{}^{(n)}\right)$$

where $\lim_{n\to\infty} C_0{}^{(n)} = \lim_{n\to\infty} p_0{}^{(n)} = 0$

- Dismal Theorem occurs iff

$$\lim_{n\to\infty} p_0{}^{(n)} \cdot U'(C_0{}^{(n)}) = +\infty$$

The Ellsberg paradox (2-urn version): 1st urn

- Imagine an urn (call it #1) containing 100 balls
- 50 of the balls are red, and 50 are blue
- One ball is to be drawn at random from the urn, and you are offered a choice of the following bets:
  – A1) Bet on red
  – B1) Bet on blue
  – C1) I am indifferent…

	Red is drawn	Blue is drawn
Bet on red	You win $100	0
Bet on blue	0	You win $100

2^{nd} urn

- Now imagine a different urn (call it #2) containing 100 balls
- Each of the balls is either red or blue but this time in <u>unknown proportion</u>
- One ball is to be drawn at random from the urn, and you are again offered a choice of the following bets:
  - A2) Bet on red
  - B2) Bet on blue
  - C2) I am indifferent…

	Red is drawn	Blue is drawn
Bet on red	You win $100	0
Bet on blue	0	You win $100

Choice between urns (a)

- Recall that:
  - In **urn 1** you know that 50 of the balls are red, and 50 of the balls are blue
  - In **urn 2** you know nothing about the proportion of red and blue balls
- Which of the following bets would you prefer to take?
  - X1) Bet on red in **urn 1**
  - Y1) Bet on red in **urn 2**
  - Z1) I am indifferent between "Bet on red" in **urn 1** and "Bet on red" in **urn 2**

	Red is drawn	Blue is drawn
Bet on red	You win \$100	0
Bet on blue	0	You win \$100

Choice between urns (b)

- Recall that:
  - In **urn 1** you know that 50 of the balls are red, and 50 of the balls are blue
  - In **urn 2** you know nothing about the proportion of red and blue balls
- Which of the following bets would you prefer to take?
  - X2) Bet on blue in **urn 1**
  - Y2) Bet on blue in **urn 2**
  - Z2) I am indifferent between "Bet on blue " in **urn 1** and "Bet on blue " in **urn 2**

	Red is drawn	Blue is drawn
Bet on red	You win $100	0
Bet on blue	0	You win $100

How do people choose?

- Most people choose C1 (i.e. indifferent), C2 (i.e. indifferent again), and then X1 (i.e. bet on red in **urn 1**) and X2 (i.e. bet on blue in **urn 1**)
- Hold on a minute!
  - If you choose X1, apparently you believe there are more red balls in **urn 1** than **urn 2**
  - But then you cannot choose both C1 and C2 (must be <50 red balls in **urn 2**)
  - Moreover, X1 and X2 contradict each other
  - So these choices cannot be described by EU theory
  - But they can be explained by ambiguity aversion

	Red is drawn	Blue is drawn
"Bet on red"	You win $100	0
"Bet on blue"	0	You win $100