Climate Treaties II

Approaching Catastrophes

11:30-1:00

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“Dangerous” climate change

- Framework Convention
  - Says that atmospheric concentrations of greenhouse gases should be stabilized “at a level that would prevent dangerous anthropogenic interference with the climate system.”
- Copenhagen Accord
  - recognizes “the scientific view that,” to avoid dangerous anthropogenic interference with the climate system, “the increase in global temperature should be below 2 degrees Celsius….”

Gambling for global public goods

- Experiment by Milinski et al. (2008).
- 6 players, each given €40.
- Game is played in 10 periods.
- In each period, each player can contribute €0, €2, or €4.
- If at the end of the game at least €120 has been contributed, catastrophe avoided, and each player gets what she/he has left.
- If less than €120 is contributed, each player loses what he/she has left with probability 0.9.

What happened?

- In the experiment carried out with 10 groups of students, half averted catastrophe and half did not.

Is this the real game?

- Imagine that every other player plays Give €2 each period. Then your best response is to play Give €2 each period.
  - For then you get €20 for certain.
  - Otherwise, you get an expected payoff of 0.1×€40 = €4.
- However, in the experiment, the players were not allowed to communicate.

Treaty

- Three stages:
  1. Signatory or non-signatory.
  2. Signatories choose their actions collectively.
  3. Non-signatories choose their actions.
- To simplify, assume contributions made in a single period. Players can contribute any amount between €0 and €40.
- If participation is full, signatories will contribute €20 each, and get a payoff of €20 each.

A deviation

- Suppose signatories contribute *Y* in total. Then the sole non-signatory will play *Z* = 120 – Y for 120 ≥ *Y* ≥ 84 and *Z* = 0 for 84 > *Y* > 120.
- Knowing this, the 5 remaining signatories could do no better than to play *Y* = 84 (€16.80 each). This would net each of the 5 parties €23.20, whereas the sole non-signatory would get just €4.
- This is less than this country will get if it remains in the agreement with full participation (€20).
- So, obviously, the treaty comprising 6 signatories, each of which contributes €20, is self-enforcing.

Summary so far

- When the threshold contribution level is known, free riding should not be a problem.
- A treaty can really help here. It coordinates the actions needed to avoid catastrophe.

The Catastrophe Avoidance Game

$$\pi_i = \begin{cases} bQ - \frac{cq_i^2}{2} \text{ if } Q \geq \bar{Q} \\ bQ - X - \frac{cq_i^2}{2} \text{ if } Q < \bar{Q} \end{cases}$$

Differences with Milinski et al. (2008):

1. Abatement reduces gradual as well as catastrophic climate change.
2. Marginal abatement costs are increasing.
3. Can vary *X* and the threshold.

“Dangerous” climate change

- Three discontinuities:
  - Coral reefs, disintegration of the West Antarctic Ice Sheet, and collapse of the thermohaline circulation.
  - All three can probably be avoided by limiting long term warming to 1 °C.
  - Last two can probably be avoided by limiting long term warming to 2 °C.
  - Last one can probably be avoided by limiting change to 3 °C above 1990 mean global temperature.

O’Neill, B.C. and M. Oppenheimer (2002). “Dangerous Climate Impacts and the Kyoto Protocol,” *Science* **296**: 1971-1972.

So it’s important that we can vary *X* and the threshold.

Full cooperation

$$\Pi^{FC} = \begin{cases} bQN - \sum_i \frac{cq_i^2}{2} \text{ if } Q \geq \bar{Q} \\ bQN - XN - \sum_i \frac{cq_i^2}{2} \text{ if } Q < \bar{Q} \end{cases}$$

So, if $X = 0$,

$$Q^{FC} = bN^2/c$$

Assume

$$\bar{Q} > bN^2/c$$

Then countries will either ignore the threshold or meet it, just.

Full cooperation

Countries will want to meet the threshold, just, if

$$b\bar{Q}N - \sum_i \frac{c}{2}\left(\frac{\bar{Q}}{N}\right)^2 \geq b\left(\frac{bN^2}{c}\right)N - XN - \sum_i \frac{c}{2}\left(\frac{bN}{c}\right)^2$$

Reducing gives

$$X \geq \frac{b^2N^2}{2c} - \left(b\bar{Q} - \frac{c\bar{Q}^2}{2N^2}\right).$$

FIGURE 1a

Effect of catastrophe on full cooperative outcome

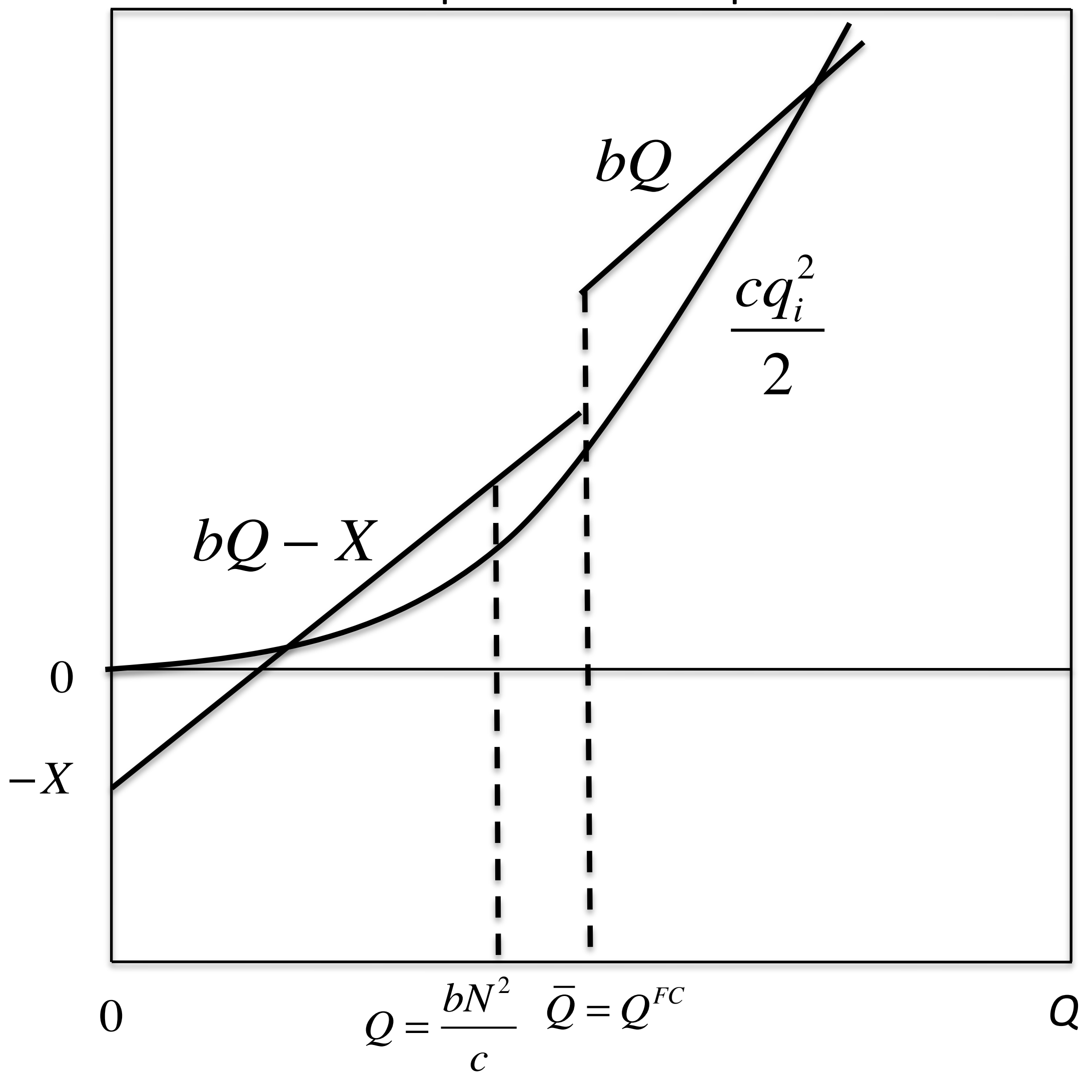
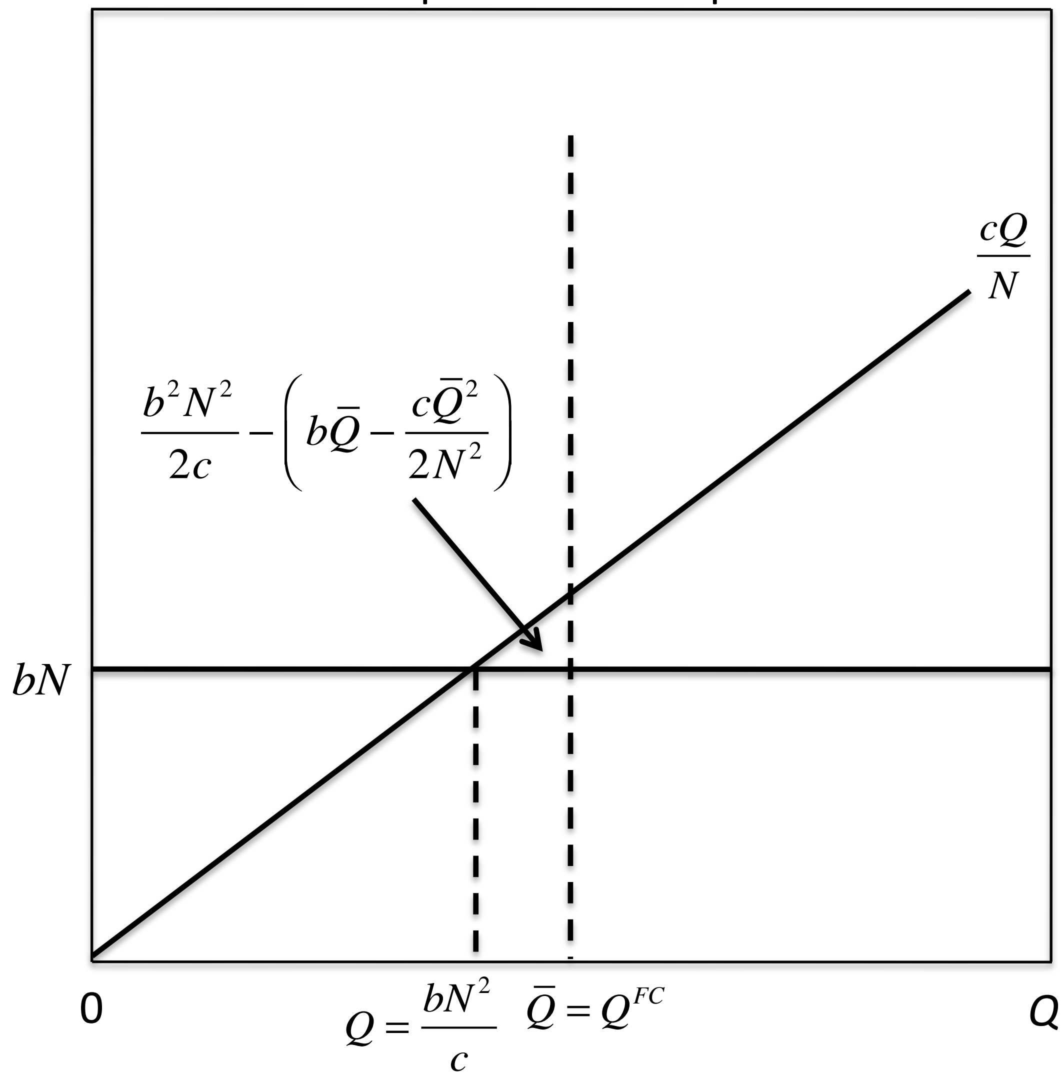
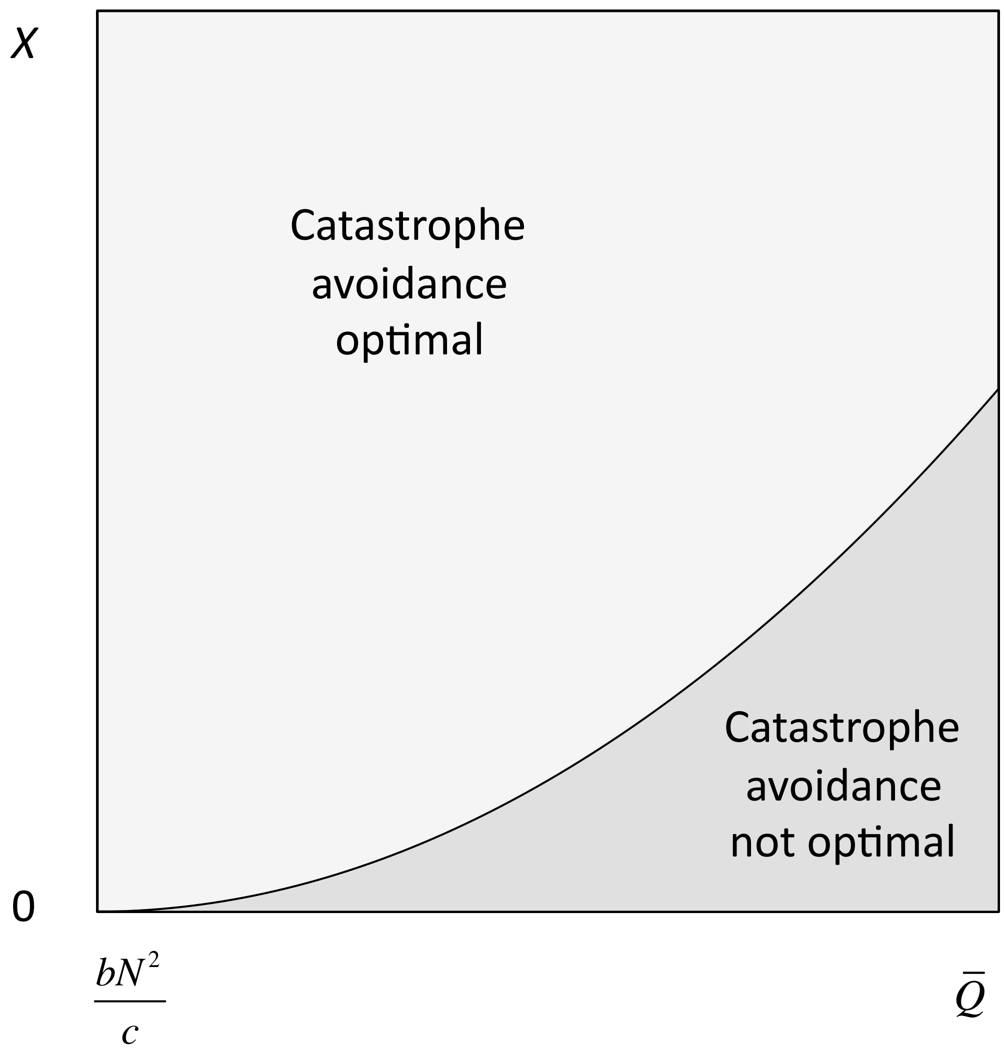


FIGURE 1b
Effect of catastrophe on full cooperative outcome



If *X* is bigger than the triangle, it will pay to meet the threshold.

FIGURE 2
Optimal catastrophe avoidance



Non-cooperation

There are two symmetric Nash equilibria in pure strategies.

$$q_i = b/c \qquad\qquad q_i = \bar{Q}/N$$

Suppose every country $j \neq i$ plays

$$q_j = \bar{Q}/N$$

Then, if *i* plays

$$q_i = \bar{Q}/N$$

i gets

$$\pi_i(\bar{Q}/N; \bar{Q}(N-1)/N) = b\bar{Q} - \frac{c}{2}\left(\frac{\bar{Q}}{N}\right)^2.$$

Non-cooperation

If *i* plays

$$q_i = b/c$$

i gets
$$\pi_i(b/c;\bar{Q}(N-1)/N) = b\left(\frac{\bar{Q}(N-1)}{N} + \frac{b}{c}\right) - X - \frac{c}{2}\left(\frac{b}{c}\right)^2.$$

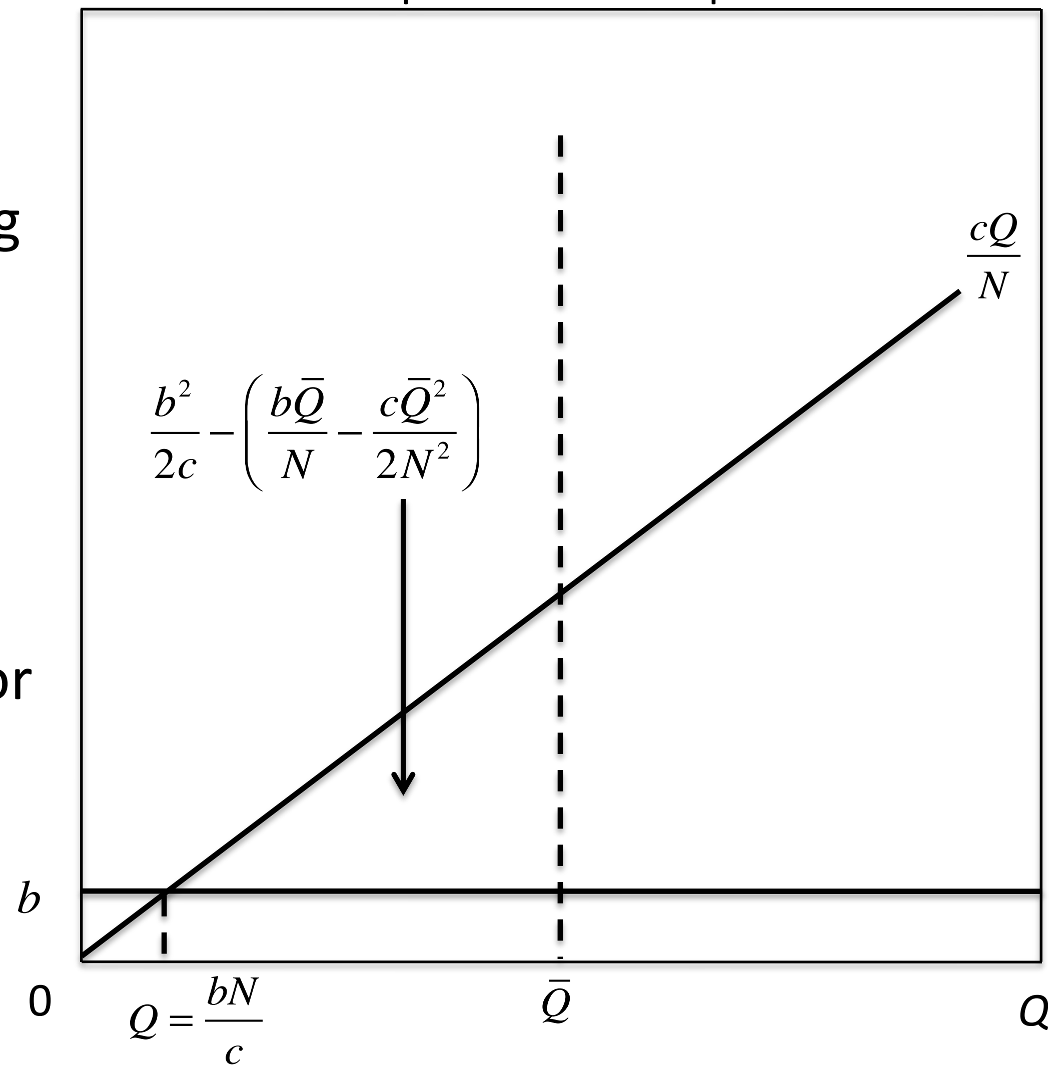
i will prefer to play

$$q_i = \bar{Q}/N$$

if
$$X \geq \frac{b^2}{2c} - \left(\frac{b\bar{Q}}{N} - \frac{c\bar{Q}^2}{2N^2}\right).$$

FIGURE 3

Effect of catastrophe on non-cooperative outcome

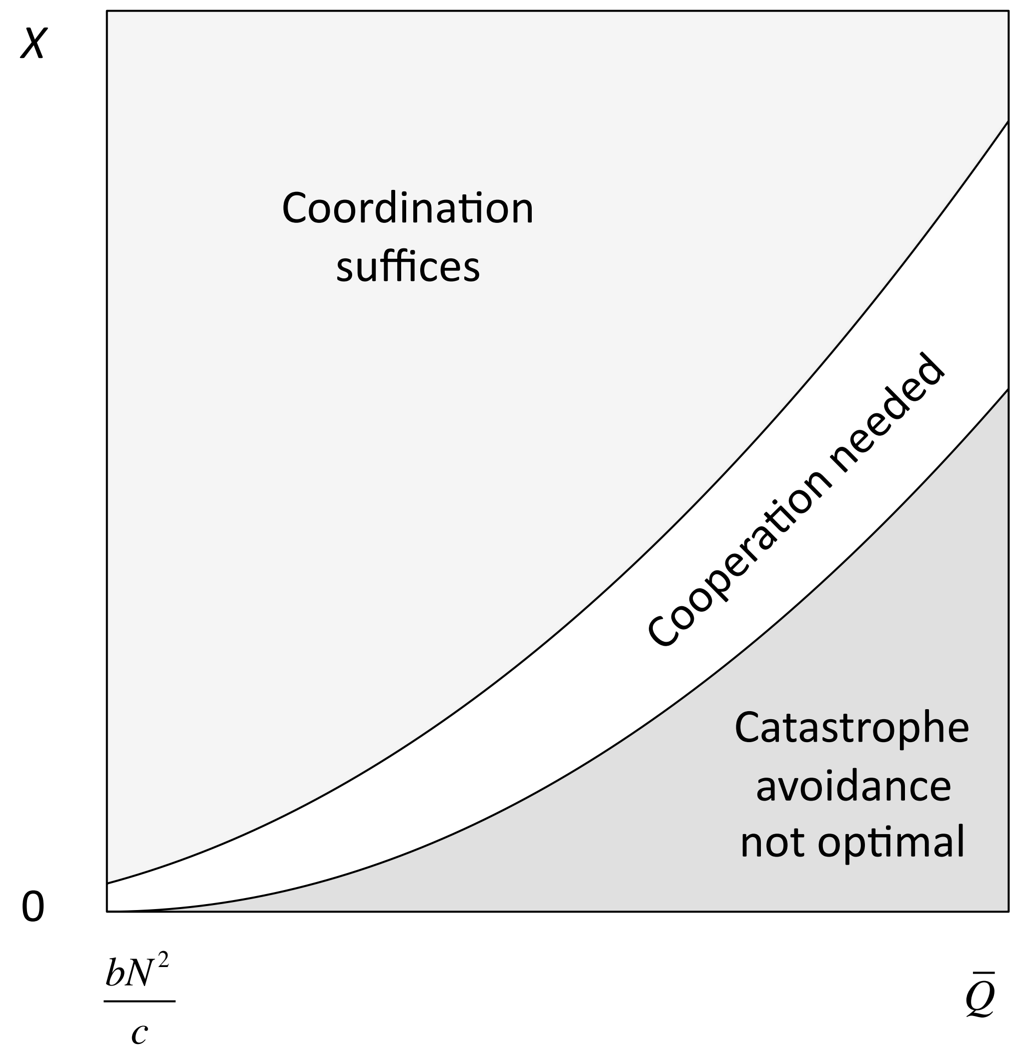


Note that this triangle is decreasing in *N*. So for catastrophe to matter in the NC outcome, it also helps for *N* to be "small."

If *X* is bigger than the triangle, it will pay to meet the threshold.

This triangle is much bigger than for FC outcome.

FIGURE 4
When coordination suffices and cooperation is needed



Sustaining FC by means of an IEA

Start with a treaty with full participation requiring each party to play

$$q_i = \bar{Q}/N$$

If *i* withdraws, others play

$$Q_{-i}$$

i will then want to play either

$$q_i = \bar{Q} - Q_{-i} \qquad \text{or} \qquad q_i = b/c$$

i will prefer to play the former rather than the latter if

$$b\bar{Q} - \frac{c}{2}(\bar{Q} - Q_{-i})^2 \geq b\left(Q_{-i} + \frac{b}{c}\right) - X - \frac{c}{2}\left(\frac{b}{c}\right)^2$$

Sustaining FC by means of an IEA

So the remaining signatories can ensure catastrophe is avoided by setting $\hat{Q}_{-i} = \bar{Q} - b/c - \sqrt{2X/c}$.

If they play this abatement level, *i* will prefer not to withdraw if

$$b\bar{Q} - \frac{c}{2}\left(\frac{\bar{Q}}{N}\right)^2 \geq b\bar{Q} - \frac{c}{2}\left(\frac{b}{c} + \sqrt{\frac{2X}{c}}\right)^2$$

Which reduces to

$$X \geq \frac{b^2}{2c} - \left(\frac{b\bar{Q}}{N} - \frac{c\bar{Q}^2}{2N^2}\right).$$

This is the same result we obtained before for when the full cooperative outcome can be sustained as a NE by coordination.

Sustaining FC by means of an IEA

Alternatively, the $N - 1$ signatories may play

$$Q_{-i} = b(N-1)^2/c$$

In which case i will play

$$q_i = b/c$$

Sustaining FC by means of an IEA

Country *i* will prefer not to deviate if

$$b\bar{Q} - \frac{c}{2}\left(\frac{\bar{Q}}{N}\right)^2 \geq b\left(\frac{b(N-1)^2}{c} + \frac{b}{c}\right) - X - \frac{c}{2}\left(\frac{b}{c}\right)^2$$

Rearranging

$$X \geq \frac{b^2[2(N-1)^2+1]}{2c} - \left(b\bar{Q} - \frac{c\bar{Q}^2}{2N^2}\right)$$

It is easy to show that an IEA can sustain full cooperation only for $N \leq 3$. This is the same result as when $X = 0$. So, when coordination alone fails, the prospect of catastrophe cannot help cooperation.

Summary on certain catastrophe

- Provided the costs of avoiding the threshold are low relative to the consequences of exceeding it, the challenge becomes one of *coordinating* abatement so as to avoid the threshold, not cooperating just to limit emissions.
- Treaty can facilitate coordination.
- Where these conditions do not apply, international cooperation in cutting emissions, though efficient, is still difficult to enforce.
- In this case, a treaty will not be able to help much.

Backstop technologies

Avoiding catastrophe with backstop technologies

$$\pi_i = \begin{cases} b(Q+Z) - \dfrac{cq_i^2}{2} - \gamma z_i \text{ if } Q+Z \geq \bar{Q} \\ b(Q+Z) - X - \dfrac{cq_i^2}{2} - \gamma z_i \text{ if } Q+Z < \bar{Q} \end{cases}$$

where z_i is *i*'s level of air capture and

$$Z = \sum_{i=1}^{N} z_i$$

Full cooperation with backstop technologies

$$\Pi^{FC} = \begin{cases} b(Q+Z)N - \sum_{i=1}^{N} \frac{cq_i^2}{2} - \sum_{i=1}^{N} \gamma z_i \text{ if } Q+Z \geq \bar{Q} \\ b(Q+Z)N - XN - \sum_{i=1}^{N} \frac{cq_i^2}{2} - \sum_{i=1}^{N} \gamma z_i \text{ if } Q+Z < \bar{Q} \end{cases}$$

Assuming

$$\gamma > bN$$

full cooperation requires

$q^{FC} = bN/c$ and $z^{FC} = 0$ for $X = 0$

So backstop will only be used to avert catastrophe.

Full cooperation with backstop technologies

In the full cooperative outcome, policy must be cost-effective. So countries will abate to

$$q_i = \gamma / c$$

For air capture to be used we must have

$$\bar{Q} > \gamma N / c$$

With air capture, it will pay to avert catastrophe if

$$b\bar{Q}N - \frac{c}{2}\left(\frac{\gamma}{c}\right)^2 N - \gamma\left(\frac{\bar{Q}}{N} - \frac{\gamma}{c}\right)N \geq b\left(\frac{bN^2}{c}\right)N - XN - \frac{c}{2}\left(\frac{bN}{c}\right)^2 N$$

or

$$X \geq \frac{-(\gamma - bN)(\gamma + bN)}{2c} + \frac{(\gamma - bN)\bar{Q}}{N}$$

Non-cooperation with backstop technologies

Suppose now that every country $j \neq i$ plays

$$q_j = \gamma/c \qquad z_j = \left(\bar{Q}/N - \gamma/c\right)$$

Then, if i plays the same levels, it gets

$$b\bar{Q} - \frac{c}{2}\left(\frac{\gamma}{c}\right)^2 - \gamma\left(\frac{\bar{Q}}{N} - \frac{\gamma}{c}\right)$$

If i deviates it will play $q_i = b/c$

and get

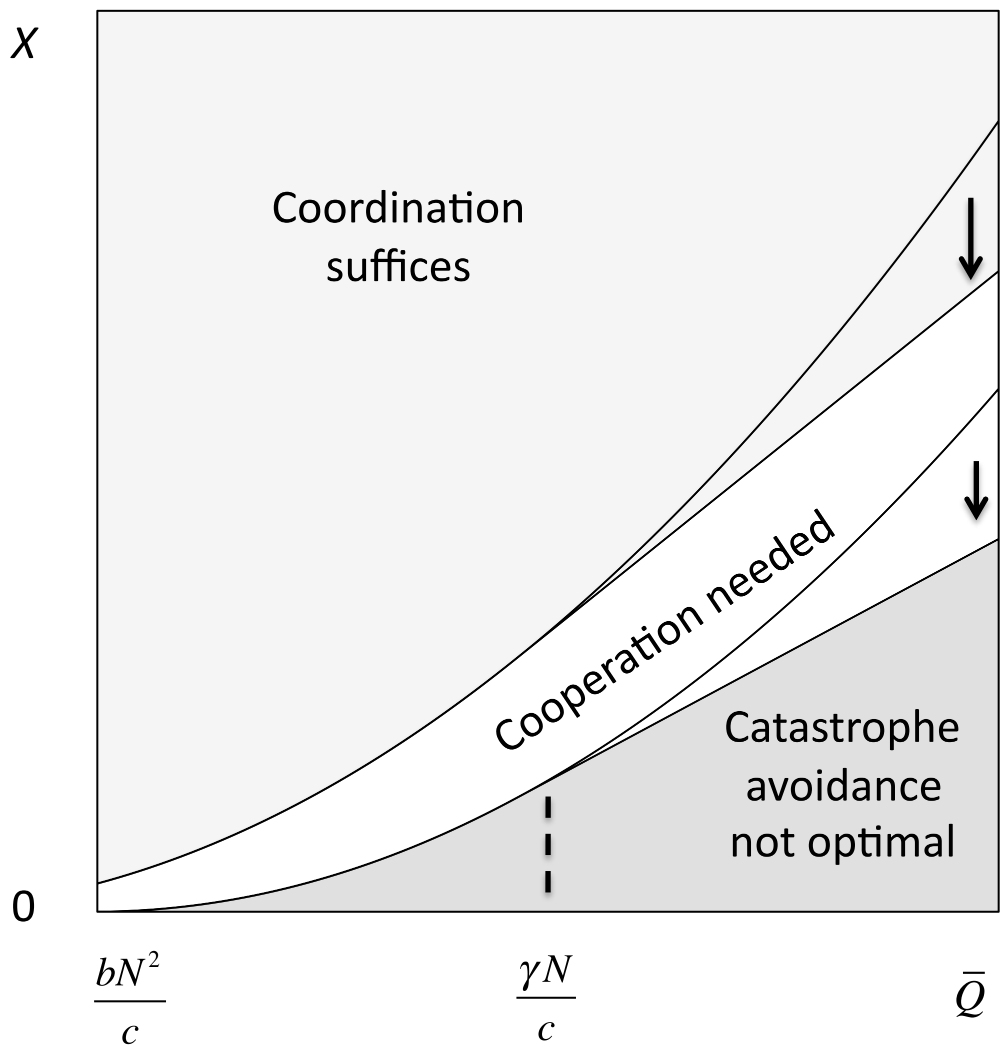
$$\pi_i(b/c;\bar{Q}(N-1)/N) = b\left(\frac{\bar{Q}(N-1)}{N} + \frac{b}{c}\right) - X - \frac{c}{2}\left(\frac{b}{c}\right)^2.$$

Non-cooperation with backstop technologies

i will prefer not to deviate if

$$X \geq -\frac{(\gamma + b)(\gamma - b)}{2c} + \frac{(\gamma - b)\bar{Q}}{N}$$

FIGURE 5
Avoiding catastrophe with a backstop technology



Summary on avoiding catastrophe with backstop technologies

- Expands space where coordination suffices to sustain full cooperation.
- Expands space in which full cooperation commends avoiding catastrophe.

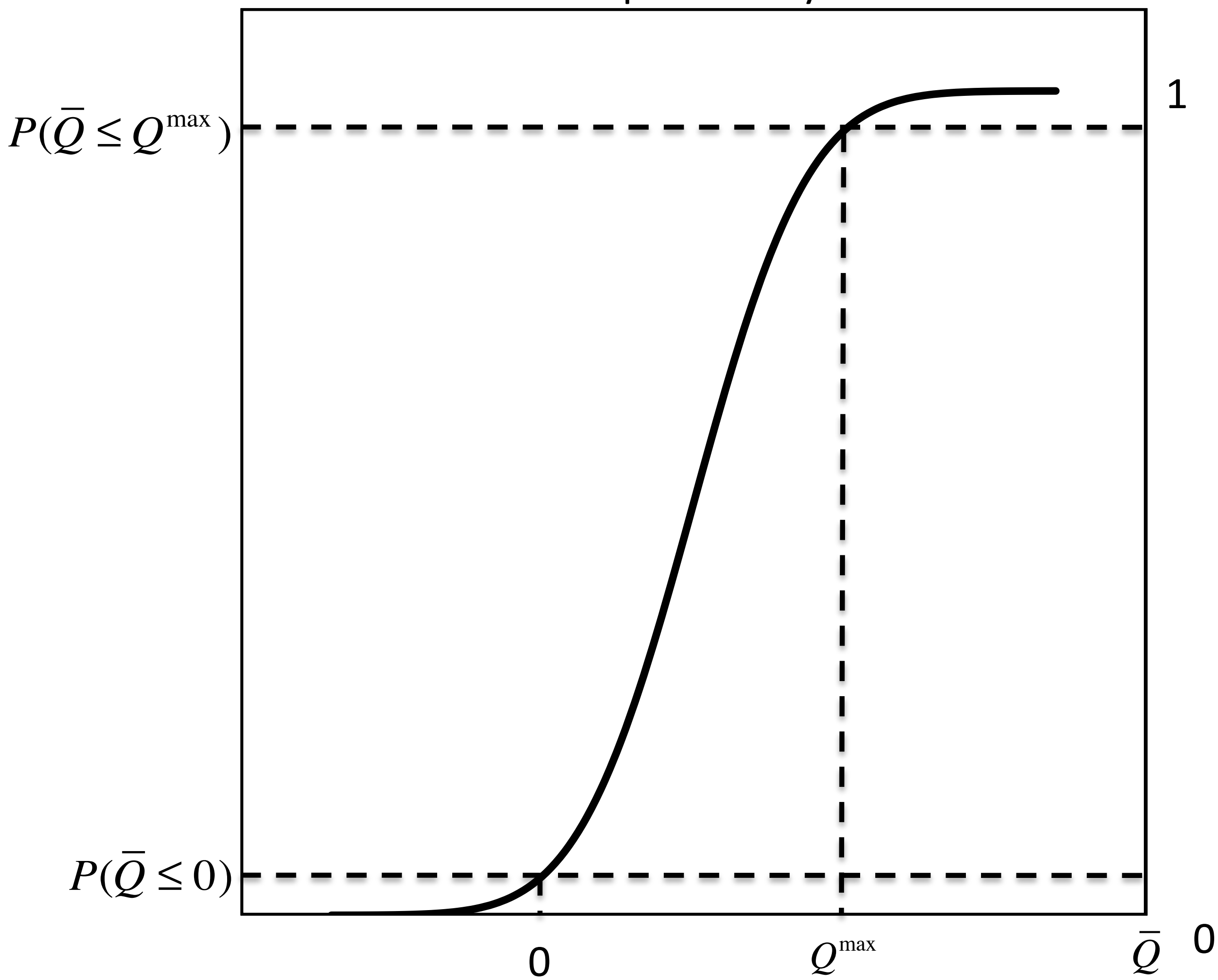
Uncertain thresholds

Now suppose that the threshold abatement level is a random variable with cumulative probability distribution

$$F(Q) = \Pr\left(\bar{Q} \leq Q\right)$$

You can think of the threshold as being the level of abatement necessary to avoid 2 °C.

FIGURE 6
Cumulative probability function



This is a plausible cpf. Even if no abatement, probability of avoiding catastrophe is positive; even if maximal abatement, probability of avoiding catastrophe is less than one.

Full cooperation with uncertain thresholds

Were countries to cooperate fully they would maximize

$$E(\Pi^c) = bQN - \sum_j \frac{cq_j^2}{2} - XN\left[1 - F(Q)\right]$$

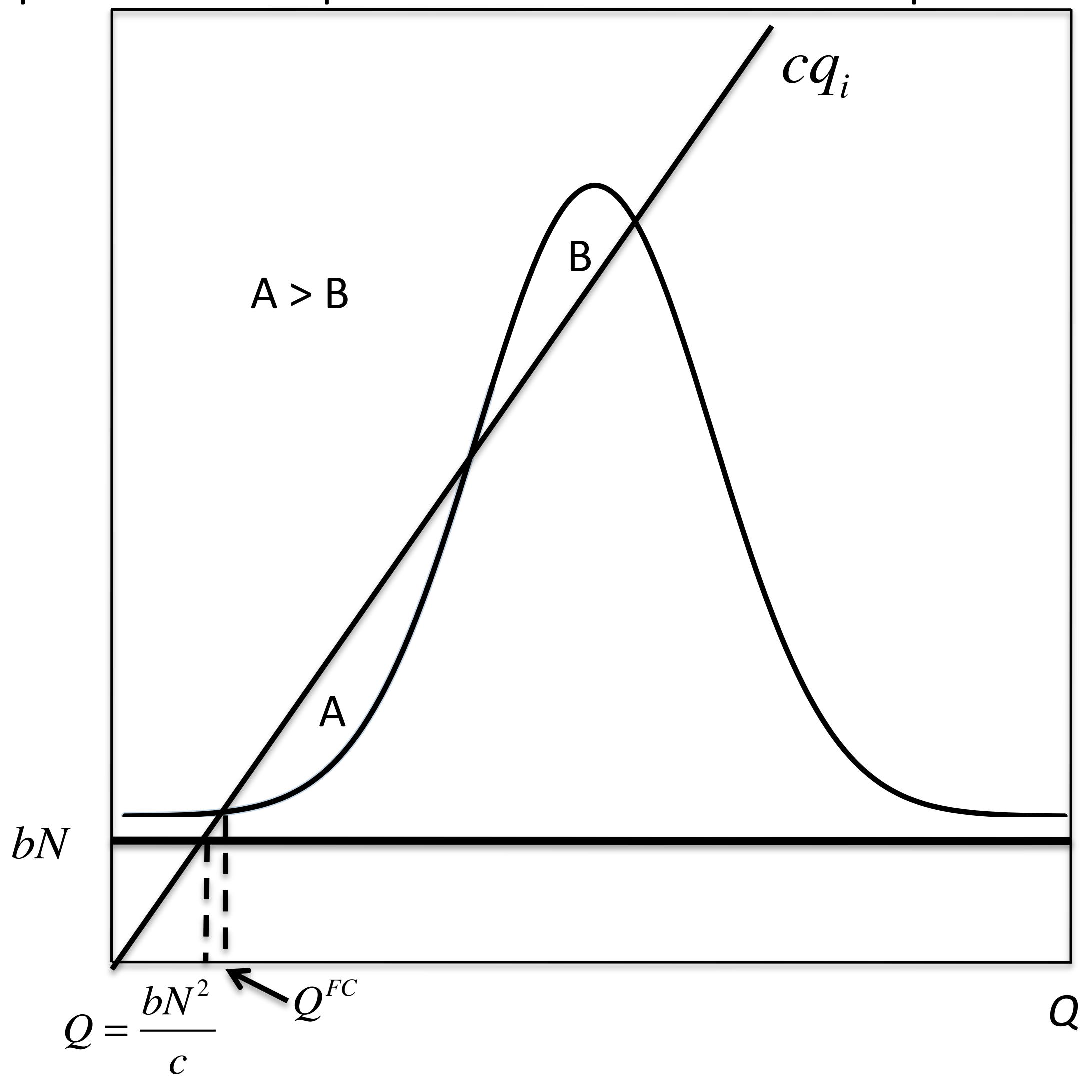
which requires

$$bN - cq_i + XNf(Q) = 0$$

Where *f* is the pdf. Note that, in general, this foc will not be sufficient. However, as long as *f* has infinite supports, uncertain catastrophe will always commend more abatement compared to the certainty case.

FIGURE 7a

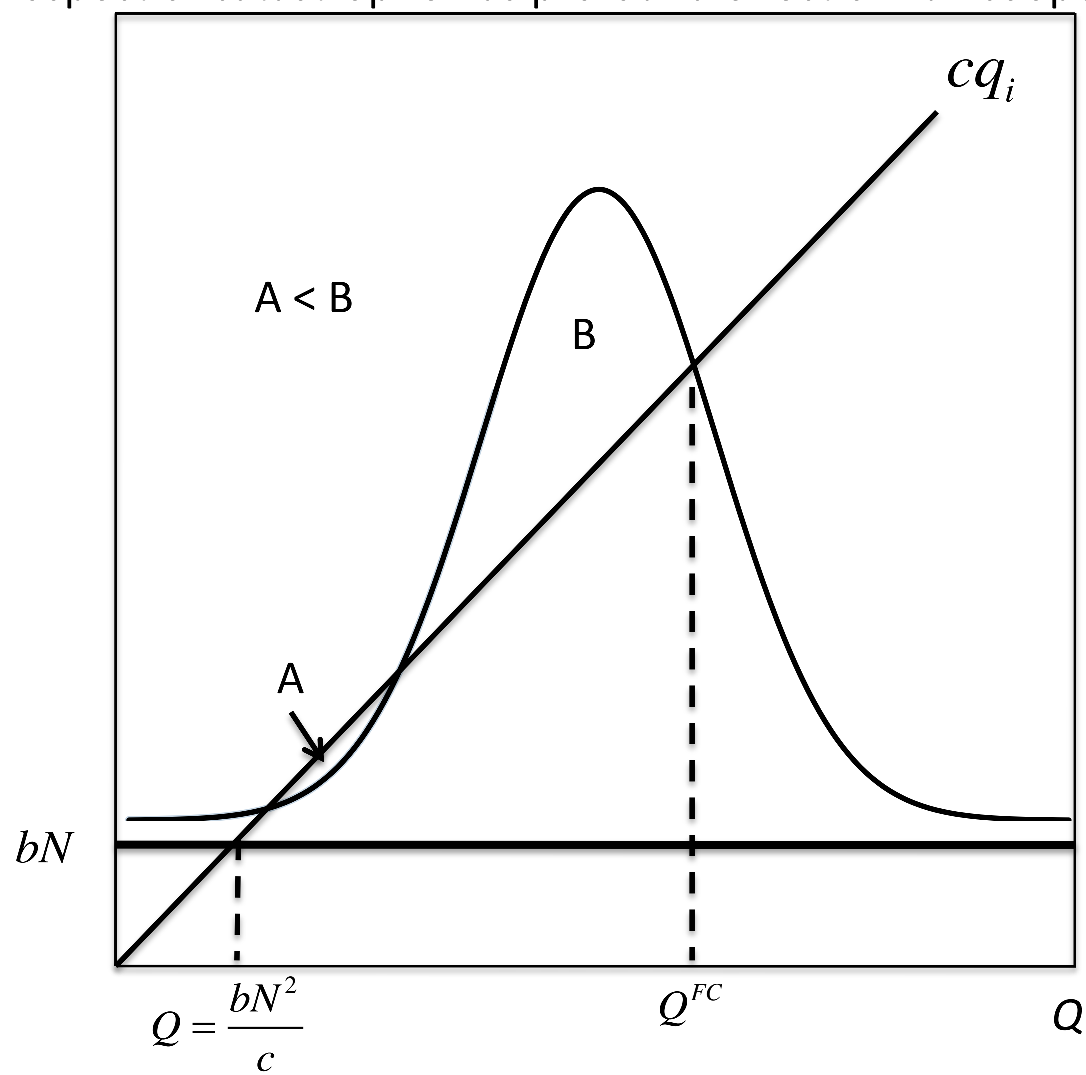
Prospect of catastrophe has little effect on full cooperative outcome



Here, uncertainty about catastrophe makes little difference to full cooperation.

FIGURE 7b

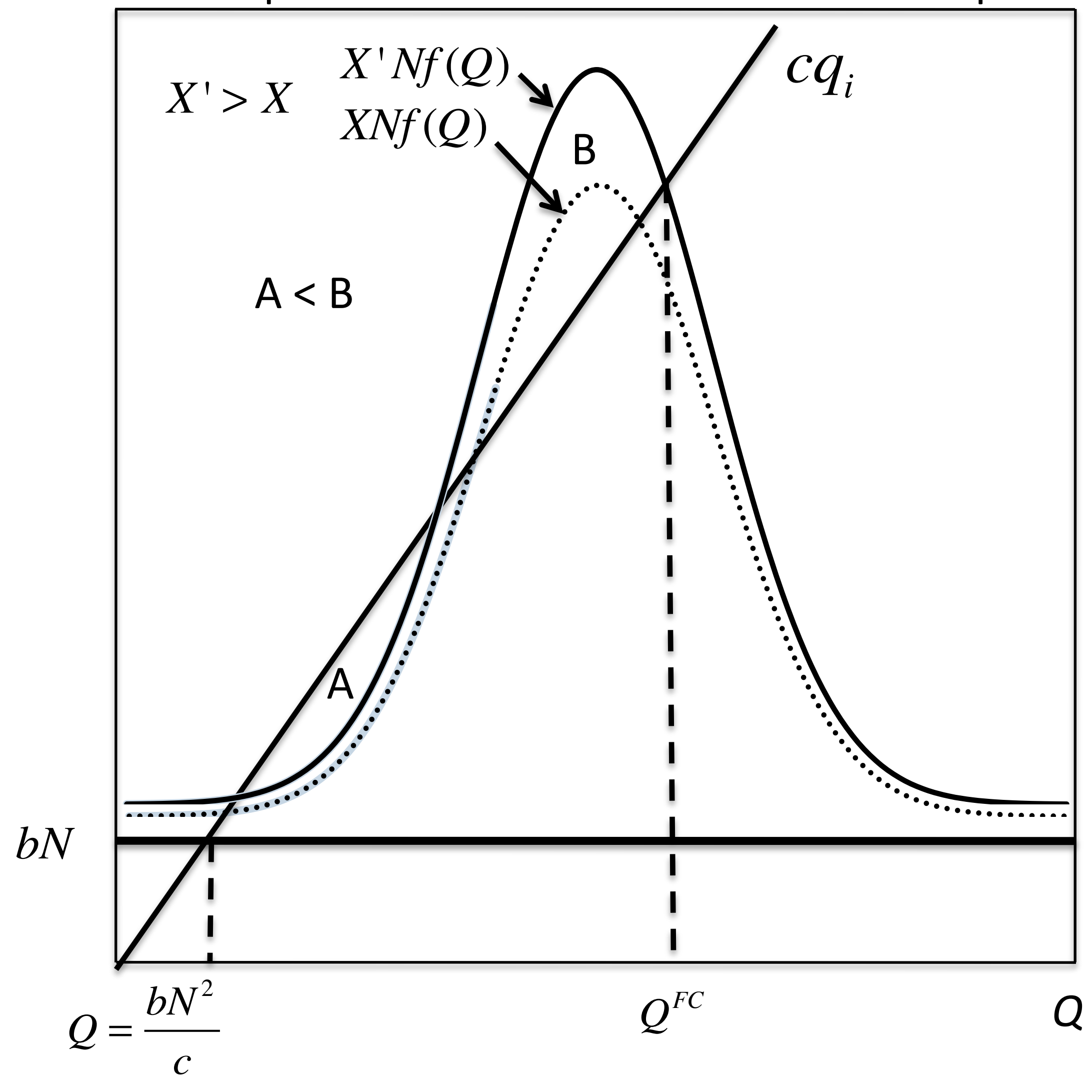
Prospect of catastrophe has profound effect on full cooperation



Lower marginal costs a little and this situation changes dramatically.

FIGURE 7c

Prospect of catastrophe has substantial effect on full cooperative outcome



An increase in *X* has a similar effect.

And so would a change in *b*.

Implication

- Suppose we wish to avoid 2 °C change. Given climate sensitivity, what ppm should we aim for?
  - 550 CO_2e? Then we meet goal with prob. 18%.
  - 350 CO_2e? Then we meet it with prob. 93%.
- Former case looks like Fig. 7a.
- Latter looks like Fig. 7b.
- What we should do depends not only on the pdf but on *b, X,* and *c* as well.

Another perspective

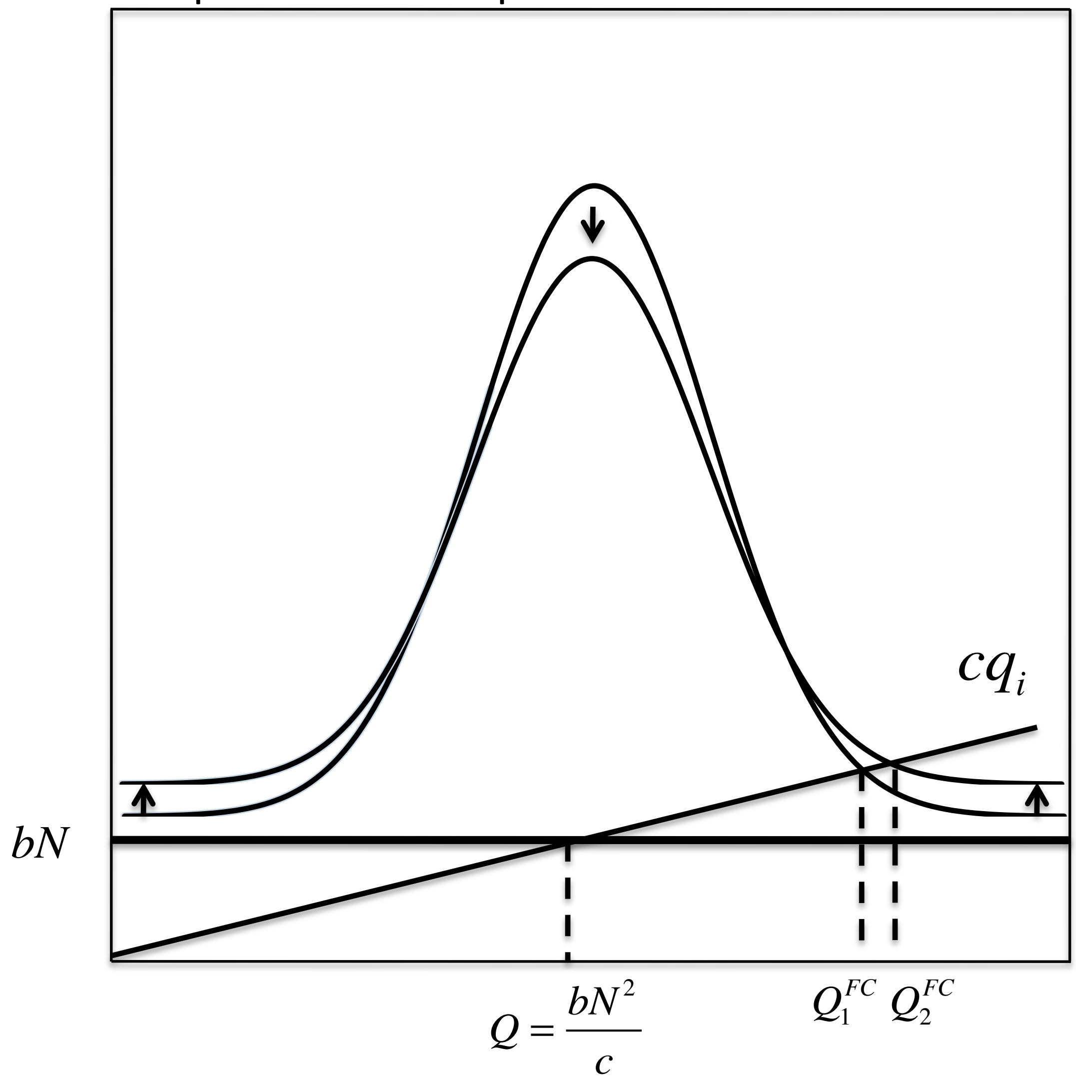
- Rockstrom *et al.* (2009) recommend 350 ppm as a "planetary boundary." They say
  - "Paleoclimate data from the past 100 million years show that CO_2 concentrations were a major factor in the long-term cooling of the past 50 million years. Moreover, the planet was largely ice-free until CO_2 concentrations fell below 450 ppmv (± 100 ppmv), suggesting that there is a critical threshold between 350 and 550 ppmv. Our boundary of 350 ppmv aims to ensure the continued existence of the large polar ice sheets."
- But even at 350 there remains a positive probability of collapse of the ice sheets. Shouldn't we take into account X, b, and c in addition to the pdf?

Fat tails

- Do they matter?

FIGURE 8

Prospect of catastrophe with "thin" and "fat" tails



Here, fat tails make little difference.

Of course, I am assuming constant MU.

Non-cooperation with uncertain thresholds

In a Nash equilibrium,

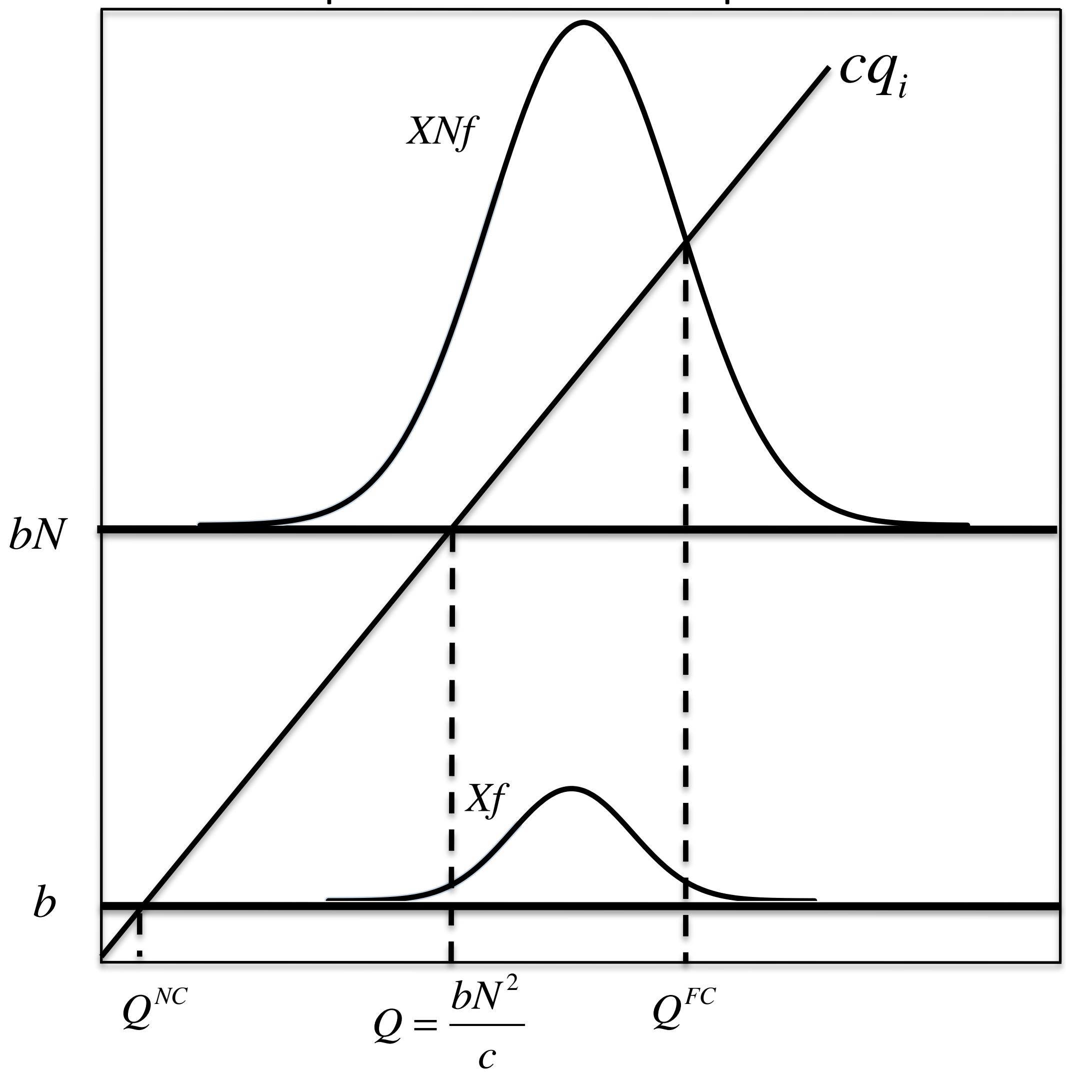
$$E(\pi_i) = bQ - \frac{cq_i^2}{2} - X[1 - F(Q)]$$

which requires

$$b - cq_i + Xf(Q) = 0 \forall i$$

FIGURE 9a

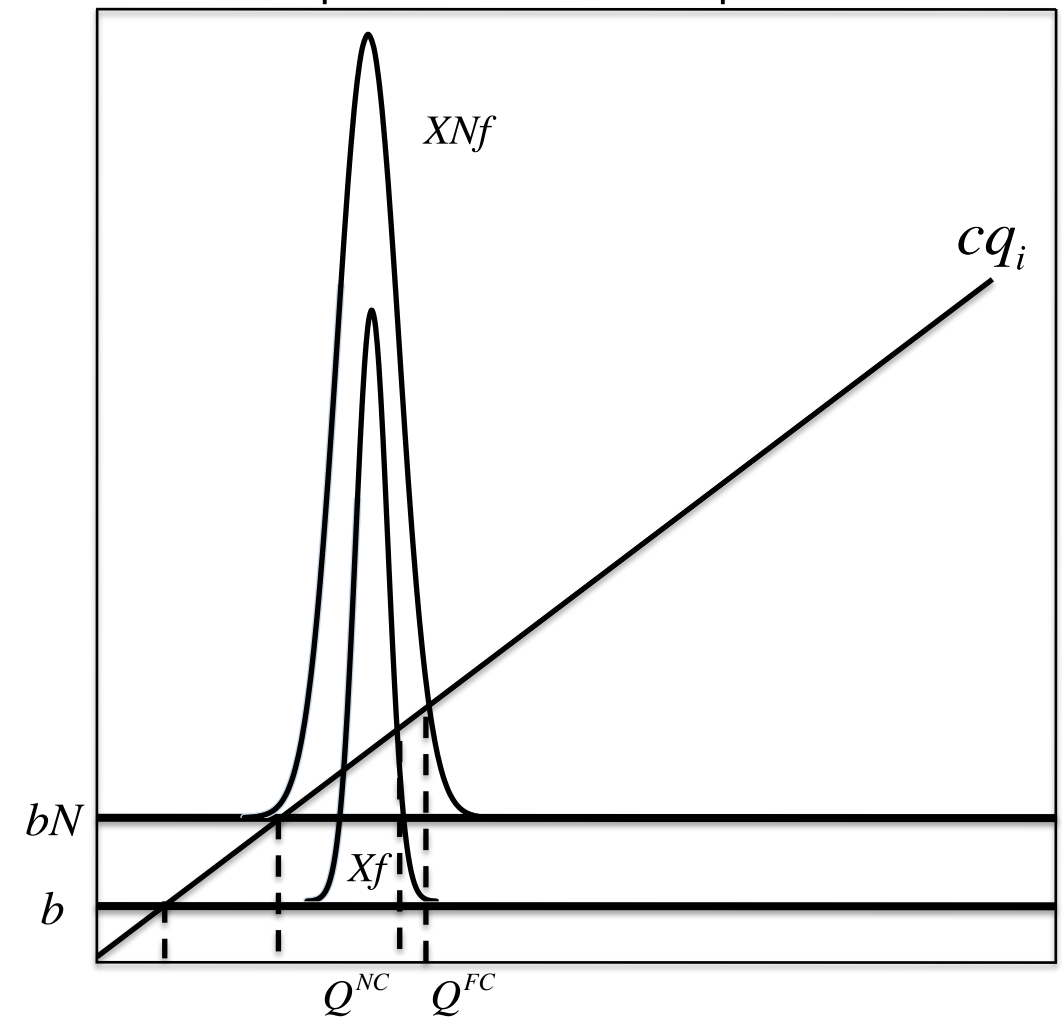
The non-cooperative and full cooperative outcomes



Here, uncertain prospect of catastrophe has a profound effect on the full cooperative outcome but virtually no effect on the non-cooperative outcome

FIGURE 9b

The non-cooperative and full cooperative outcomes



Here, prospect of uncertainty has a big effect on both the full cooperative and the non-cooperative outcomes.

But the variance is small.

And *N* must also be small.

Summary on uncertain catastrophe

- Unlike Weitzman, I find that uncertain prospects of catastrophe may have little effect on FC.
- Even when these prospects do have a big effect on FC, they have little effect on NC.
- They can have a *relatively* large effect on NC only when variance is small and *N* is small.
  – Small variance approaches the certainty case.
  – Small *N* means that the gains to cooperation will be small in absolute terms.

Main observations

- Uncertainty removes the discontinuity that drives the results with certain catastrophe thresholds. With uncertainty, cooperation is still needed, and still difficult to enforce.
- Uncertain catastrophe increases the full cooperative level of abatement, but has very little effect on the non-cooperative outcome, or the ability to sustain cooperation.
- A different kind of "dismal" result.