Models-as-usual for unusual risks? On the value of catastrophic climate change

Antoine Bommier

ETH Zürich

for presentation at:
CRAG-IRGC Symposium 2013

About the talk

The presentation:

- is based on a paper written with Bruno Lanz (Graduate Institute, Geneva, and ETH Zurich) and Stéphane Zuber (CNRS and ETH Zurich). The paper is targeted to an economic journal.
- emphasizes the motivation for such a paper.
- gives an overview of the main findings.
- will not present the model in details.

Outline of the presentation

- The standard approach in climate change economics (Stern review, Nordhaus DICE model, etc.)
- New aspects coming from climate science (irreversibilities, non linearities, tipping points)
- Is the standard approach still adapted?
  - The assumption of temporal risk neutrality.
  - Maintaining temporal risk neutrality while considering the risk of irreversible damages?
- Another approach assuming temporal risk aversion.
- Overview of how the models with/without temporal risk aversion compare:
  - when considering that there is no endogenous risk of irreversible change.
  - when endogenous climate change may lead to irreversible damages.
- Concluding remarks

The standard approach - principles

- The economic literature on climate change has mostly considered climate policy as a consumption/investment problem.
- How much should we invest now to mitigate climate change, knowing that what is not done today should be done tomorrow?
- This is a problem of intertemporal allocation of resources.
- The time discounting parameter was shown to play a key role.
- Many contributions debate about the right values of the discount rate, and how it should be modified to account for uncertainty.
- The structure of the model itself is not challenged.

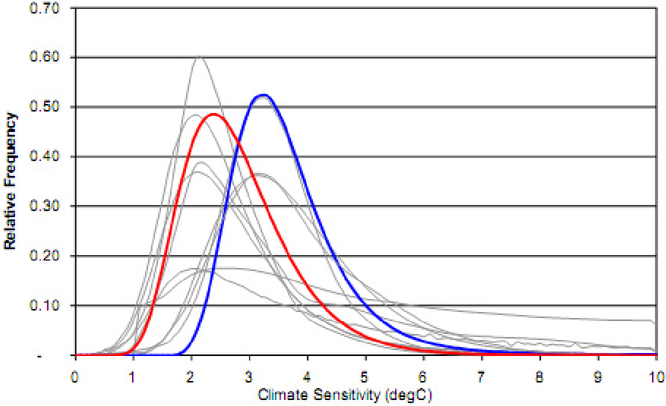
The standard approach - formalization

- The society aims at maximizing an intertemporal objective given by

$$E[\sum_{t=0}^{+\infty} \beta^t u(x_t)]$$

  where x_t is a variable (or a vector of variables) -most often consumption- that determines the happiness of agents alive in period t.
- There is a technology ("investment") which makes it possible to transfer resources from time t to time $t+1$.
- The role of climate is most often embedded in the technology. Investing in climate mitigation today makes it possible to use more efficient technology later on.
- A very simple extension to the standard Ramsey growth model, with specific technological constraints related to the climate.

Climate sensitivity is highly uncertain



With feedbacks, prob($\Delta T > 20^{\circ c}$) $= 0.01$ (see Weitzman, 2009)

Non-linear climate system

- Non-marginal and irreversible impacts (Lenton and Ciscar, 2012). Tipping-points (e.g. arctic ice melting).
- Preventive measures that could be taken today may no longer be available in the future (Sterner and Persson, 2008)
- Society faces a trade-off between consumption and the risk of an irreversible change.
- The problem is no longer that of intertemporal allocation of resources, but to evaluate the willingness to pay for risk reduction (Weitzmann, 2009).
- Risk aversion becomes a key aspect (Bommier and Villeneuve, 2012).

Temporal risk neutrality

- Expectation is a linear operator

$$E[a\tilde{X} + b\tilde{Y}] = aE[\tilde{X}] + bE[\tilde{Y}]$$

- Thus

$$E[\sum_{t=0}^{+\infty} \beta^t u(x_t)] = \sum_{t=0}^{+\infty} \beta^t E[u(x_t)]$$

- The correlation between what happens at different time periods does not matter.
- However, in case of durable consequences -and in particular irreversible damages- what happens at different time periods is strongly positively correlated.
- Question: How is the analysis modified if correlation aversion is assumed?

A model with temporal risk aversion

- One may consider agents that are more risk averse than in the standard model.
- Within the expected utility framework, that involves considering the objective given by:

$$E[\phi\left(\sum_{t=0}^{+\infty}\beta^t u(x_t)\right)]$$

  where ϕ is an increasing and concave function.
- In the paper, we will focus on the case where $\phi(x) = \frac{1-e^{-\varepsilon x}}{\varepsilon}$ and take $\beta = 1$ to assume preference stationarity.
- In contradistinction with the standard approach, we do not assume exogenous time preferences. Time discounting will however arise from the combination of the risk of having irreversible changes and risk aversion.

Problem

A single problem of growth with pollution and a risk of society's collapse:

- The society can produce using more or less polluting technologies.
- Polluting technologies are cheaper.
- There is a risk of collapse, that depends on accumulated pollution.
- Post collapse trajectories are exogenous.

The economy: a standard neoclassical growth model

- Output is a function of capital and technology $z_t \in [0, 1]$:

$$y_t = z_t\, f(k_t)\,, \quad f' > 0\,, \quad f'' < 0$$

- Output can be consumed c_t or invested in k_t

$$\dot{k}_t = z_t f(k_t) - c_t - \delta k_t$$

The economy: a standard neoclassical growth model

- Output is a function of capital and technology $z_t \in [0,1]$:

$$y_t = z_t\, f(k_t)\,, \quad f' > 0\,, \quad f'' < 0$$

- Output can be consumed c_t or invested in k_t

$$\dot{k}_t = z_t f(k_t) - c_t - \delta k_t$$

- The rate of emissions per unit of output is a function of z_t:

$$E_t = \varphi(z_t) f(k_t)\,, \quad \varphi' > 0\,, \quad \varphi'' > 0$$

- Emissions accumulate into a stock:

$$\dot{M}_t = E_t - \psi M_t = \varphi(z_t) f(k_t) - \psi M_t$$

In each period, the risk of catastrophic collapse is a function of the emissions stock (Cropper, 1976; Tsur and Zemel 1996, 1998)

- Hazard rate $\mu_t = \mu(M_t)$, $\mu' > 0$
- After a collapse, the economy follows an exogenous trajectory.
- Post-collapse welfare is equivalent to the welfare associated with consuming $\underline{c}$ for ever.
- The nature of the collapse makes it impossible to invest for post-collapse welfare.

$\rightarrow$ Reduce emissions/risk through z_t or k_t, trading-off with output / consumption.

Objectives

Two possible models of social objectives:

- The standard additive model assuming temporal risk neutrality and positive time preference:

$$E[\sum_{t=0}^{+\infty} \beta^t u(x_t)]$$

- The multiplicative model assuming temporal risk aversion and no time preference:

$$\frac{1 - E[\exp(-\varepsilon\left(\sum_{t=0}^{+\infty} u(x_t)\right))]}{\varepsilon}$$

- Note: these classes of models intersect for $\beta = 1$ and $\varepsilon = 0$.

Analysis

- Analytical resolution for steady states.
- Numerical solutions for non steady-states trajectories.
- Comparison of both models when the collapse risk is exogenous.
- Comparison of both models when the collapse risk is endogenous.

Results under the assumption of an exogenous collapse risk

- When the risk of collapse is considered as exogenous, then both models look very similar.
- It's actually possible to calibrate both models to generate exactly the same steady state (same interest rate, etc.)
- Both models react in very similar ways to changes in productivity.
- These are two possible candidates to rationalize what we call a Business-as-Usual-Economy (an economy with no endogenous climate risk).

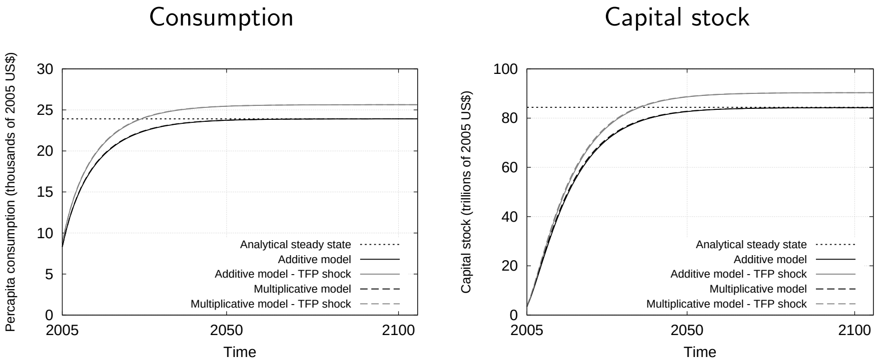
Results under the assumption of an endogenous collapse risk

- When the risk of collapse is considered as endogenous then the multiplicative model recommends a stronger climate mitigation than the additive model.
- Both models get very close when $\beta \simeq 1$ and $\varepsilon \simeq 0$. They predict then a low interest rate and significant climate mitigation (as in Stern's review).
- When models are calibrated to generate usual values for the rate of interest, the multiplicative model advises much greater mitigation than the additive one.
- With the multiplicative model, it is possible to simultaneously have significant time discounting and strong concerns for the climate.

Numerical simulations

- The parameters of the model are calibrated to reproduce the dynamics of the DICE model by Nordhaus in absence of endogenous risks (no climate externalities)
- Social preferences:
  - Instantaneous utility function: $u(c_t) = \frac{c_t^{1-\gamma} - \underline{c}^{1-\gamma}}{1-\gamma}$
  - For both additive and multiplicative models, we calibrate $\gamma = 2$ and set $\underline{c} = 1$ (note: $c_{2005} = 10$)
  - In the additive model, we use $\theta = 1.5\%$ as in DICE.
  - In the multiplicative model we calibrate ε such that both models admit the same steady state interest rate under BAU.

Assuming an exogenous collapse risk μ_0

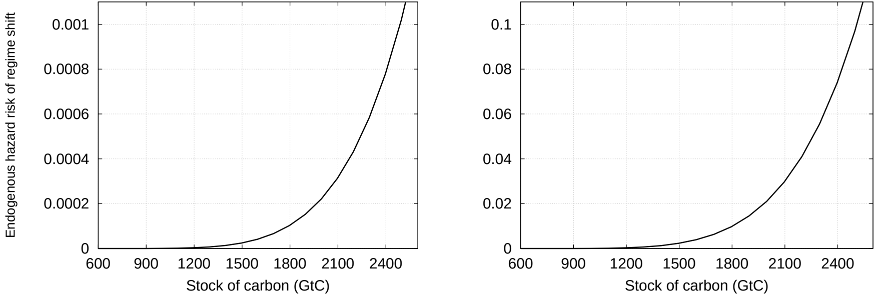


- Both models have very similar predictions
- Similar response to a TFP shock

Assuming an endogenous risk

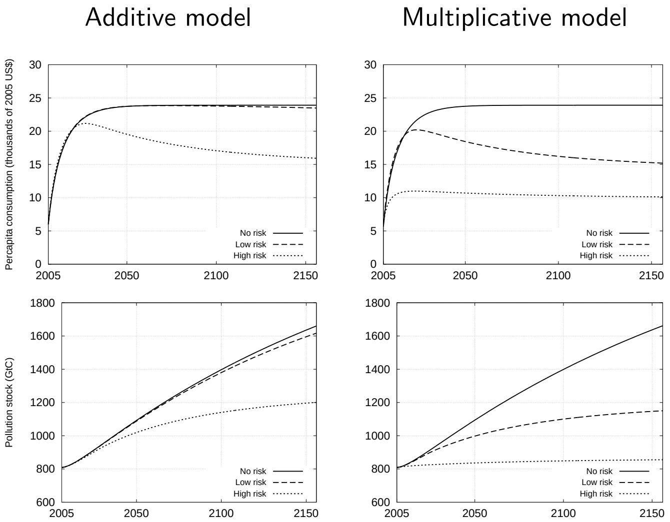
Hazard rate: $\mu(M) = \mu_0 + \mu_1(M - \overline{M})^{\sigma}$

Low risk schedule | High risk schedule



- High risk: A doubling of the stock reduces s_t by 3% after 100 years
- Low risk: A tripling of the stock reduces s_t by 3% after 1,000 years

Optimal paths under endogenous catastrophic risk



- Using alternative models equivalent to an increase of risk by a factor of 100

Concluding remarks

- Different forms of social objectives -with or without temporal risk aversion - may lead to very similar predictions when ignoring endogenous climate risk.
- However, when an endogenous risk is introduced, temporal risk aversion becomes a crucial element.
- For a given level of time discounting, assuming temporal risk neutrality (as is usually done), rather than temporal risk aversion, was found to be roughly equivalent as underestimating the risk by a factor 100.
- **Key question**: Should we assume temporal risk aversion (also called preference for catastrophe avoidance) for social evaluation?

Reformulating the question

- Assume that there is a disease that randomly kills individuals at age 20 with a probability of 1 %.
- Assume that someone invents a vaccine that prevents having this disease.
- You know that:
  - With a probability of 99.1 %, the vaccine is safe and efficient.
  - With a probability of 0.9 % it will kill for sure.

QUESTION: Do you give the vaccine to:

- the whole population?
- nobody?
- a fraction of the population?