Climate change, Carbon price and LT discount rates Webinar SCOR

Christian Gollier
Toulouse School of Economics

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Social Cost of Carbon in the U.S. (2022)

Year	R=2.5%	R=2.0%	R=1.5%
2020	$120	$190	$340
2030	$140	$230	$380
240	$170	$270	$430
2050	$200	$310	$480

Table: Social cost of carbon (in 2020 dollars per metric ton of CO2) as a function of time and of the discount rate *R*. Source: U.S. EPA External Review Draft of Report on the Social Cost of Greenhouse Gases (September 2022).

Why do we discount, and why by that much?

- Do we take care enough about future generations and sustainability issues?
  - The operational answer is in the choice of LT discount rates.
- Why do we discount the future? Under certainty:
  - Because we believe in economic growth (Ramsey rule).
  - Because of the shadow cost of capital (pricing by arbitrage).
- But the future is uncertain.
  - Precautionary motive to invest in safe projects.
  - Give a bonus to projects that hedge the macro risk: Adaptation, strategic oil reserve, ICU,...
- What is the risk profile of the long-term benefits of the energy transition?

Part 1: Initial phase:
Integrated Assessment Models
and the Ramsey rule

Integrated Assessment Models (IAM)

- The initial estimations of the SCC did not use a discount rate.
- They were based on a direct measure of the impact of reducing emissions on the intertemporal social welfare embedded within IAMs.
  - IAMs assumed no uncertainty.
- Discounting is hidden behind the SWF through the Ramsey rule.
  - In a growing economy, investing raises intergenerational inequalities.
  - Because of the embedded inequality aversion in SWF, IAMs generate SCC smaller than the sum of marginal damages.
  - This is equivalent to discounting.
  - In a growing economy, the discount rate (DR) is the minimum IRR that compensates for the increased intergenerational inequalities that a safe investment generates.
  - The Ramsey rule translates this idea into an equation.

Social preferences

- Preferences under the veil of ignorance about when and in which state of nature one will be born.
- Independence axiom: If one prefers X over Y, one also prefers X with probability p over Y with probability p.
- This implies the Discounted Expected Utility model:

$$V_0 = E_0 \int_0 e^{-\delta t} U(C_t) dt$$

- Constant Relative Risk Aversion: $U(C_t) = \frac{C_t^{1-\gamma}}{1-\gamma}$.

Pricing formula for safe assets

- Consider a claim yielding a sure payoff B in t years.

$$U(C_0 - PV) + e^{-\delta t} E_0 U(C_t + B) = U(C_0) + e^{-\delta t} E_0 U(C_t)$$

$$PV = \underbrace{e^{-\delta t} \frac{E_0 U'(C_t)}{U'(C_0)}}_{=\exp(-r_{ft} t)} B$$

$$r_{ft} = \delta - t^{-1} \log E_0 \left(\frac{C_t}{C_0} \right)^{-\gamma}$$

- Suppose $C_t = C_0 \exp(gt)$. Then, this implies the Ramsey rule:

$$r_{ft} = \delta + \gamma g$$

$$r_f = \delta + \gamma g$$

Calibration	δ	γ	g	r_f	SCC
Nordhaus	1.5%	1.45	2.15%	4.62%	$\sim 20\$/tCO_2$
Stern	0.1%	1.00	1.30%	1.40%	$\sim 200\$/tCO_2$

Measure of inequality aversion: Experts' view

author	inequality aversion	growth rate	discount rate (with $\delta = 0$)
Stern (1977)	2		
Cline (1992)	1.5	1%	1.5%
IPCC (1995)	1.5-2	1.6%-8%	2.4% - 16%
Arrow (1995)	2	2%	4%
UK: Green Book (2003)	1	2%	2%
Stern (2007)	1	1.3%	1.3%
Arrow (2007)	2-3		
Dasgupta (2007)	2-4		
Weitzman (2007)	2	2%	4%
Nordhaus (2008)	2	2%	4%
Nordhaus (2018)	1.45	2.15%	3.1%

My take on this debate

- Morale issue on the rate of pure preference for us (the present). Consensus at $\delta = 0$.
- Risk aversion $=$ Inequality aversion under the veil of ignorance. Consensus at $\gamma = 2$.
- What about g? Long-term growth rates are deeply uncertain.
  - It makes little sense to build an answer to our sustainability concerns by assuming a large growth rate for the future.
  - What is the impact of long-term uncertainties on the estimation of the SCC?

Part 2: New phase:
Integration of uncertainty in our models

Precautionary motive to invest safely: Extended Ramsey rule

- Precautionary behavior: we save more when our future becomes more uncertain.
- At the collective level, this is done by reducing the discount rate. By how much?
- Suppose that C_t follows a geometric brownian motion with trend μ and volatility σ. This implies that

$$r_{ft} = -t^{-1} \log E \left(\frac{C_t}{C_0} \right)^{-\gamma} = \gamma\mu - \underbrace{\frac{1}{2}\gamma^2\sigma^2}_{\begin{bmatrix} \simeq 2(3\%)^2 \\ \simeq 0.2\% \end{bmatrix}}$$

- The risk-free discount rates are the same for all maturities.

Adjusting the DR to the risk of the project

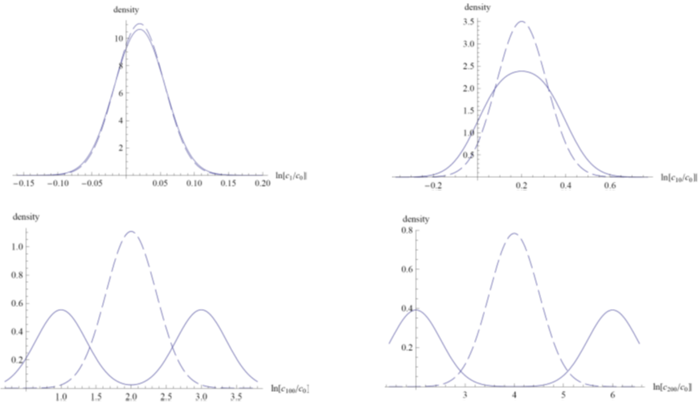
- Projects that raise the macro risk should be penalized.
- The risk-adjusted discount rate ρ_t combines r_{ft} with a risk premium.
- Consider an asset that delivers a single benefit C_t^β in t years.
- β measures the contribution of the asset to macro risk at t.
- Assuming as before a Brownian motion for consumption, then

$$DR_t = r_{ft} + \beta \underbrace{\gamma\sigma^2}_{\begin{bmatrix} \simeq 2(3\%)^2 \\ \simeq 0.2\% \end{bmatrix}}$$

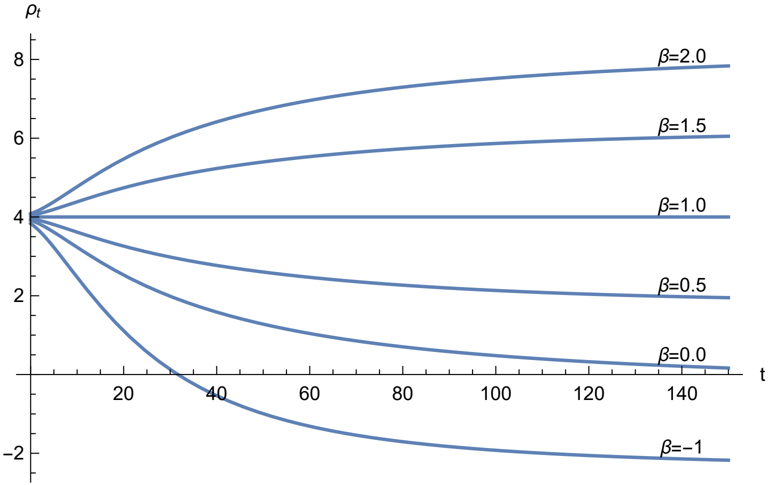
Deep uncertainties

- Uncertainties on long-term growth are deeper than under a Brownian motion.
  - What is the trend of growth for the XXIth century?
  - Existence of extreme events with uncertain probabilities: pandemic, war, financial crisis,,...
  - Persistence of shocks to growth.
- Compared to the benchmark (Brownian motion), these parametric uncertainties magnify the long term risk.
- This provides a strong argument to use a lower safe DR and a larger risk premium to value more distant benefits.

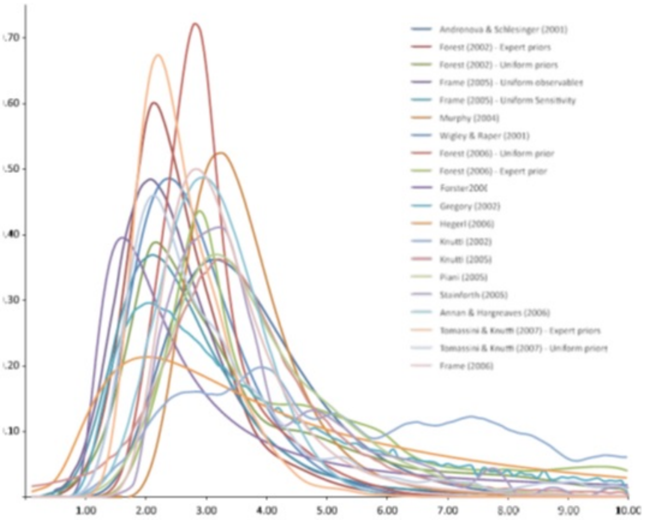
- Parametric uncertainty generates an increasing term structure of risk on future consumption.
- Example with $\mu \sim (1\%, 1/2; 3\%, 1/2)$ and $\sigma = 3.6\%$.



Term structures of DR under deep uncertainty



Uncertain climate sensitivity



Uncertain climate damages

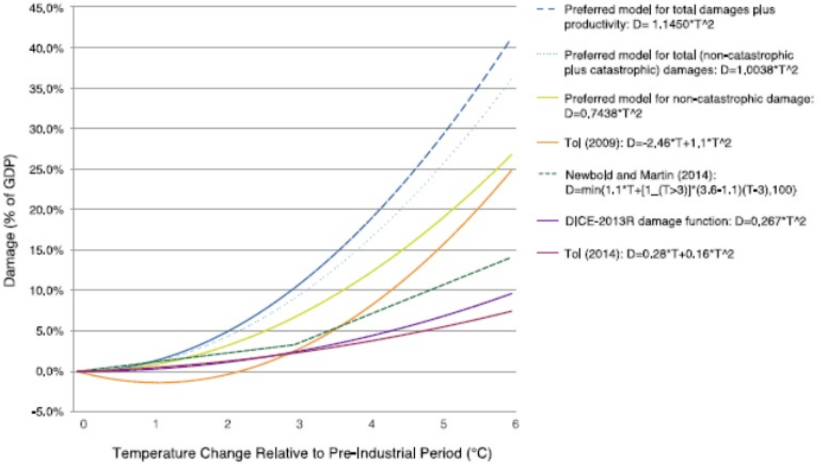
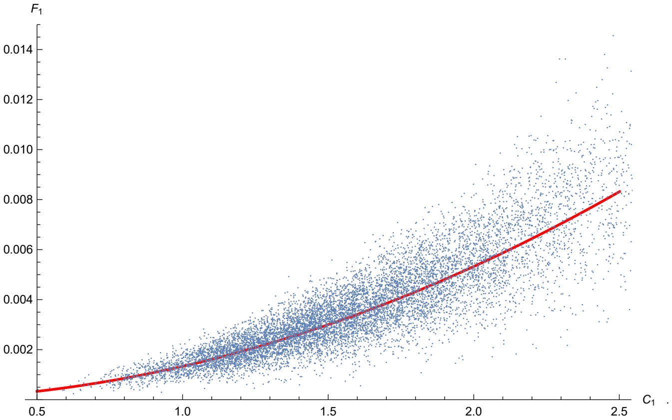


Fig. 1 Temperature–damage relationship for previous meta-analyses and the preferred regression [regression (4) on Table 2] from our study. This figure compares damage functions corresponding to previous meta-analyses to damage functions corresponding to the preferred regression [i.e., regression (4) in Table 2]. Following Nordhaus (2013), we multiply the coefficients of the preferred regression specification corresponding to non-catastrophic impacts ($t2$ and $prod\_t2$) by 25% when constructing the damage functions to account for potential omitted non-catastrophic impacts of climate change

Climate beta

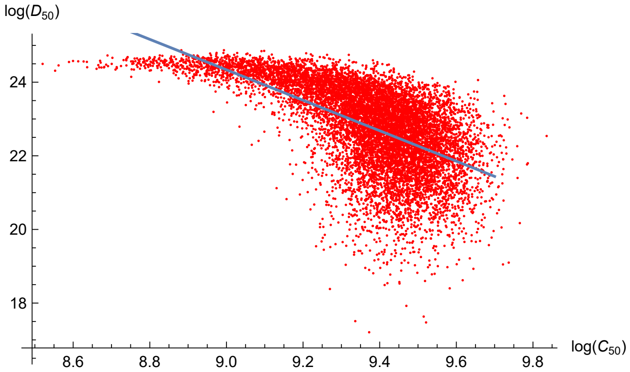
- What is the beta of investments whose aim is to reduce emission of CO_2?
- Two opposite stories:
  - Negative beta: A larger climate sensitivity raises the marginal damages and reduces consumption.
  - Positive beta: Climate damages are proportional to wealth and consumption $\rightarrow \beta = 1$.
- The combination of these two effects suggests that the climate beta is less than 1. By how much?
- More research is needed on this key topic.

Monte-Carlo simulation of DICE (Dietz, Gollier and Kessler, 2017)



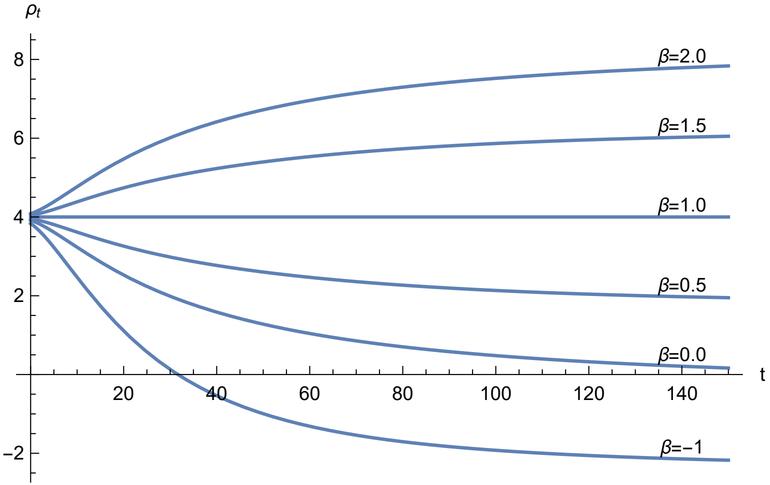
- Estimated $\beta_{50} \sim 0.7$.

Monte-Carlo simulation of Golosov's model: 50 years



- Estimated $\beta_{50} \sim -3.5$.

Term structures of DR under deep uncertainty



My take on this debate

- The deep uncertainties surrounding LT economic growth and climate damages justifies using a relatively low climate discount rate between 1% and 2%.
- This implies a carbon value closer to Stern's estimation than to Nordhaus' one.
- Using EPA recent estimates, a value around 200 $\$/tCO_2$ seems reasonable.

Part 3: Last phase:
The SCC as the shadow price of the 2°C constraint

The cost-efficiency approach to the SCC

- Paris Agreement:
  - Limit ΔT to a certain amount.
  - This corresponds to a certain intertemporal carbon budget.
- How should one allocate this budget over the next few decades?
- Equivalent the Hotelling problem of the extraction of an exhaustible natural resource.
- The carbon value should grow at the risk-free DR.
  - Transferring abatement efforts through time is a risk-free investment whose rate of return is the rate of growth of the carbon value (also the growth rate of the marginal abatement cost).
  - Along the optimal abatement path, the growth rate of the carbon value should be equal to the risk-free DR.

Social Cost of Carbon in France (2019)

	Boiteux (2001)	Quinet 1 (2009)	Quinet 2 (2019)
2010	32	32	
2020	43	56	69
2030	58	100	250
2050	104	250	775
Growth rate	2.9%	4.9%	8.0%

Table: Social cost of carbon (in 2018 euros per metric ton of CO_2) recommended in France by three different commissions. Source: France Stratégie.

Growth rates of carbon price in the IPCC 5th report

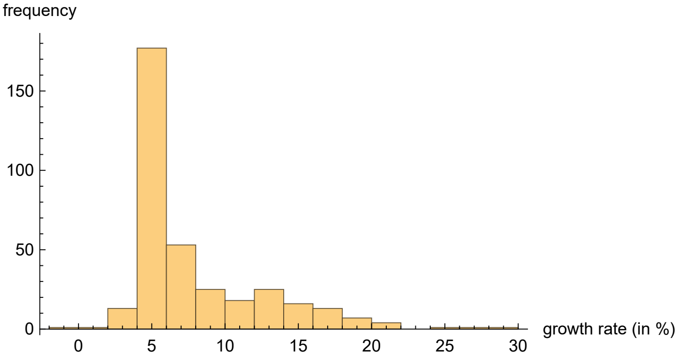


Figure: Histogram of the annual growth rate of real carbon prices 2020-2050 from 356 IAM models extracted from the IPCC database (https://tntcat.iiasa.ac.at/AR5DB). We selected the models that exhibit a 450 ppm concentration target.

- Mean: 7.90%; Median: 5.71%; St dev: 4.51%

The cost-efficiency carbon pricing puzzle

- It seems that economists have give up recommending intertemporally efficient carbon prices.
  - The growth rate of carbon price is much larger than the risk-free discount rate.
  - Frontloading the abatement effort has a positive NPV.
- But the future marginal abatement cost (MAC) is deeply uncertain.
  - Frontloading is a risky project whose future benefit is the future MAC.
  - What is the income-elasticity of the MAC?
  - I show that the beta of the MAC is positive.
  - This implies that the expected growth rate of the carbon value must be larger than the risk-free rate.
  - I obtain an efficient expected growth rate of the carbon value around 3.5%.
- This justifies using an initial carbon value around 200 $\$/tCO_2$.

Global conclusion

- This short history about the economics of the carbon value shows that, although we made much progress, many things remain to be done.
  - At the frontier between environmental econ, , social choice theory, decision theory, finance and actuarial science.
- Uncertainty plays a crucial role
  - to solve sterile debates à la Stern-Nordhaus;
  - to rationalize the choice of the climate discount rate.
- It seems that a consensus dynamics is emerging for a carbon value around 200 $\$/tCO_2$.