# The cost-efficiency carbon pricing puzzle

Christian Gollier
Toulouse School of Economics
University Toulouse-Capitole

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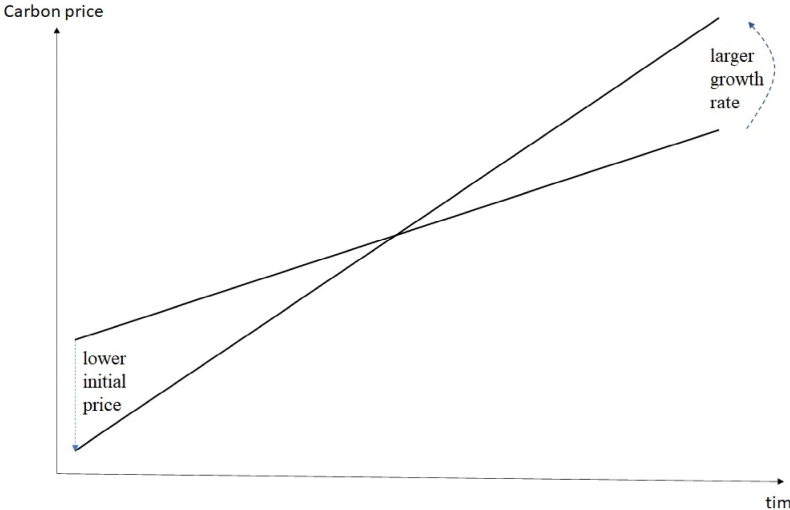
# Carbon pricing : Cost-efficiency approach

- Three "optimality concepts" for carbon pricing:
  - Cost-benefit approach: Holy grail of the social cost of carbon.
  - Cost-efficiency approach 1: target 2°C (optimal temporal allocation?).
  - Cost-efficiency approach 2: target -55% in 2030 and net-zero in 2050.
- I examine two related questions:
  - In CEA1, what is the optimal rate of growth of carbon price?
  - In CEA2, are we procrastinating to reduce our emissions?
- Main results:
  - Optimal growth rate of real carbon price should be ∼3.5%;
  - This is much smaller than what most existing CEA models (IPCC, UK, France, ...) recommend;
  - CEA modeling supports procrastination.

# Increasing the growth rate of price to reduce the initial price



# UK carbon prices for policy evaluations

**Table 1: BEIS updated short-term traded sector carbon values for policy appraisal, £/tCO2e (real 2018)**

| Year | Low | Central | High |
|---|---|---|---|
| **2018** | 2.33 | 12.76 | 25.51 |
| **2019** | 0.00 | 13.15 | 26.30 |
| **2020** | 0.00 | 13.84 | 27.69 |
| **2021** | 4.04 | 20.54 | 37.04 |
| **2022** | 8.08 | 27.24 | 46.40 |
| **2023** | 12.12 | 33.94 | 55.75 |
| **2024** | 16.17 | 40.64 | 65.11 |
| **2025** | 20.21 | 47.33 | 74.46 |
| **2026** | 24.25 | 54.03 | 83.82 |
| **2027** | 28.29 | 60.73 | 93.17 |
| **2028** | 32.33 | 67.43 | 102.53 |
| **2029** | 36.37 | 74.13 | 111.88 |
| **2030** | 40.41 | 80.83 | 121.24 |

- Growth rate = 15% per year real terms!

# Growth rates of carbon price in the IPCC 5th report

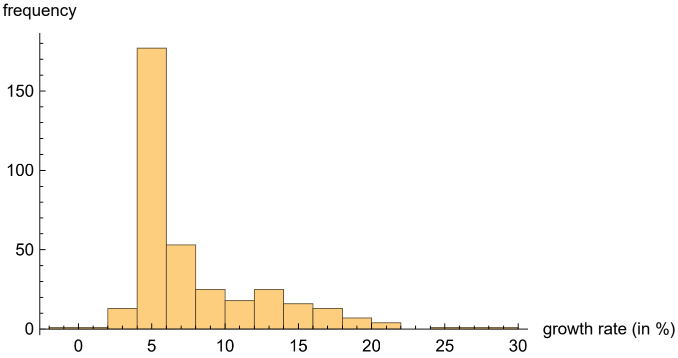



Figure: Histogram of the annual growth rate of real carbon prices 2020-2050 from 356 IAM models extracted from the IPCC database (https://tntcat.iiasa.ac.at/AR5DB). We selected the models that exhibit a 450 ppm concentration target.

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

# Social Cost of Carbon in France: Cost-Efficiency

| | Quinet 2 (2019) |
|---|---|
| 2020 | 69 |
| 2030 | 250 |
| 2050 | 775 |
| Growth rate | 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.

# Hotelling's rule under certainty

- *Normative approach*: Along the optimal path, one should be indifferent to a marginal reallocation of abatement effort.
  - Sacrifice 69 in 2020 to save 775 in 2050.
  - Indifference if 69 is the discounted value of 775 in 30 years, i.e., if the real discount rate is 8% per year.
- Hotelling's rule: *The growth rate of the carbon price should be equal to the risk-free discount rate*.
- *Positive approach*: An emission permit is an asset whose rate of return equals the growth rate of carbon price.
  - If risk-free, the no-arbitrage condition requires it to be equal to the interest rate.

# Revising Hotelling: Uncertainties and correlations

- Uncertainties affecting future abatement costs:
  - *Green innovations*
  - *Economic prosperity*
  - *Carbon budget*
- Suppose that in 2050, larger Marginal Abatement Costs (MAC) will materialize when consumption will be smaller.
  - Early abatement provides a hedge against the macro risk.
  - Early abatement has a larger social value.
  - Larger initial carbon price, and lower growth rate of expected price.
- Hotelling's rule under uncertainty:
  - If the MAC is negatively correlated with GDP, the expected carbon price should grow at a rate smaller than the interest rate.

# Uncertain MAC in 2030

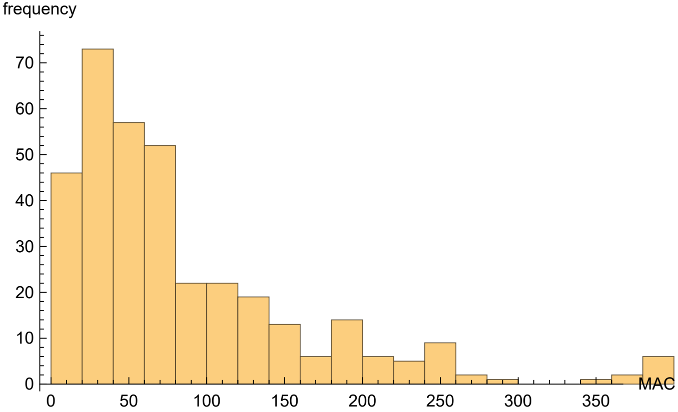



Figure: Histogram of the world marginal abatement costs for 2030 extracted from the IPCC database (https://tntcat.iiasa.ac.at/AR5DB). We have selected the 374 estimates of carbon prices (in US$2005/t$CO_2$) in 2030 from the IAM models of the database compatible with a target concentration of 450ppm.

# Outline of the paper

1. A continuous-time CCAPM model of carbon pricing with a carbon budget
2. Calibration of a two-period model with macro catastrophes
3. Calibration of a two-period model with Epstein-Zin preferences

# A simple two-period model

- Simultaneous determination of asset prices (bond, equity, carbon permit) in a framework with uncertain FTP growth and green innovations.
  - $Y_t$: production
  - $K_t$: abatement
  - $A_t(K_t)$: abatement cost
  - $Q_t$: carbon intensity of production
  - $T$: intertemporal carbon budget

Optimize abatement effort under uncertainty about $(Y_1, \theta, T)$:

$$\max_{K_0, K_1} \quad H(K_0, K_1) = u\left(Y_0 - A_0(K_0)\right) + e^{-\rho} E[u\left(Y_1 - A_1(K_1, \theta)\right)]$$

$$s.t. \quad e^{-\delta}\left(Q_0 Y_0 - K_0\right) + Q_1 Y_1 - K_1 \leq T,$$

# A negative correlation story: The technological channel

- Suppose that green technological progress be the main source of uncertainty in the economy.
- Suppose that green innovations be stronger than expected.
- This reduces total and marginal costs more than expected.
- Consumption is larger in the second period because of the reduced cost of mitigation.
- Thus, a negative income-elasticity of marginal abatement cost.
- The growth rate of expected carbon price should be smaller than the riskfree rate in that case.

# A positive correlation story: The growth channel

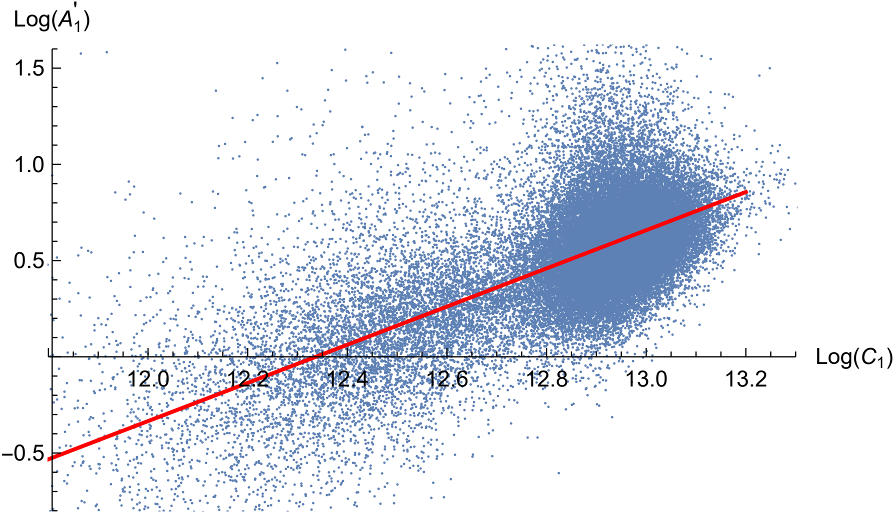
- Suppose that the future prosperity of the economy be the main source of uncertainty in the economy.
- Suppose that production $Y_1$ be larger than expected.
- This yields emissions under BAU larger than expected, so that it requires more abatement in the second period.
- Because the abatement cost function is convex, this yields a larger marginal abatement cost.
- Thus, a positive income-elasticity of marginal abatement cost.
- The growth rate of expected carbon price should be larger than the riskfree rate in that case.

# Benchmark value of the parameters

| parameter | value | description |
|---|---|---|
| $\rho$ | 0.5% | annual rate of pure preference for the present |
| $\gamma$ | 3 | relative risk aversion |
| $Y_0$ | 315,000 | production in the first period (in GUS$) |
| $p$ | 1.7% | annual probability of a macroeconomic catastrophe |
| $\mu_{bau}$ | 2% | mean growth rate of production in a business-as-usual year |
| $\sigma_{bau}$ | 2% | volatility of the growth rate of production in a business-as-usual year |
| $\mu_{cat}$ | -35% | mean growth rate of production in a catastrophic year |
| $\sigma_{cat}$ | 25% | volatility of the growth rate of production in a catastrophic year |
| $\delta$ | 0.5% | annual rate of natural decay of $CO_2$ in the atmosphere |
| $Q_0$ | $2.10 \times 10^{-4}$ | carbon intensity of production in period 0 (in $GtCO_2e$/GUS$) |
| $Q_1$ | $1.85 \times 10^{-4}$ | carbon intensity of production in period 0 (in $GtCO_2e$/GUS$) |
| $\mu_T$ | 40 | expected carbon budget (in $GtCO_2e$) |
| $\sigma_T$ | 10 | standard deviation of the carbon budget (in $GtCO_2e$) |
| $b$ | 1.67 | slope of the marginal abatement cost functions (in GUS$/$GtCO_2e^2$) |
| $a_0$ | 23 | marginal cost of abatement in the BAU, first period (in GUS$/$GtCO_2e$) |
| $\mu_\theta$ | 2.30 | expected future log marginal abatement cost in BAU |
| $\sigma_\theta$ | 1.21 | standard deviation of future log marginal abatement cost in BAU |

- Resolution of the model by Monte-Carlo simulations with 100.000 random draws of the triplet $(Y_1, \theta, T)$.

# Positive correlation between MAC and consumption

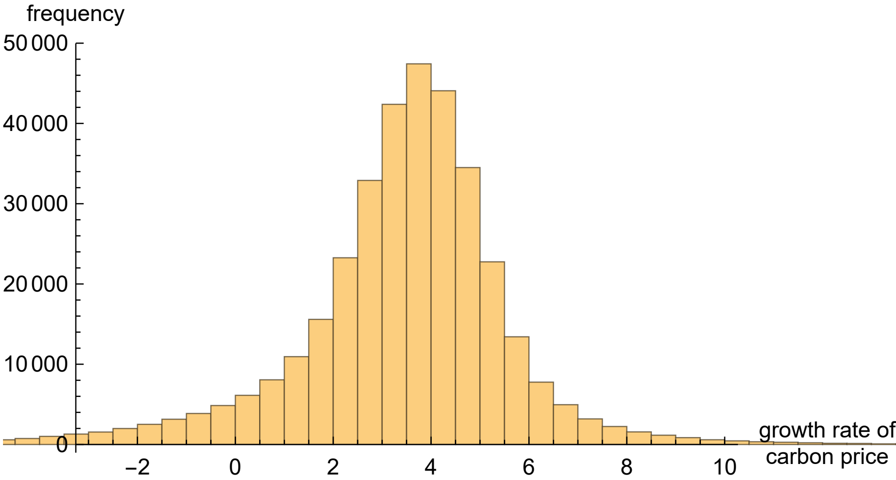


# Optimal solution in the benchmark

| variable | value | description |
|---|---|---|
| $K_0$ | 31 | optimal abatement in the first period (in $GtCO_2e$) |
| $E[K_1]$ | 66 | optimal expected abatement in the second period (in |
| $p_0$ | 75 | optimal carbon price in the first period (in US$/$tCO_2$ |
| $g$ | 3.47% | annualized growth rate of expected carbon price |
| $r_f$ | 1.14% | annualized interest rate |
| $\pi$ | 2.42% | annualized systematic risk premium |
| $\phi$ | 1.04 | OLS estimation of the income-elasticity of MAC |

Table: Description of the optimal solution in the benchmark case.

# The growth rate of carbon price is uncertain



# Sensitivity analysis

| variable | benchmark | no catastrophe | no macro risk | no tech risk | no budget risk |
|---|---|---|---|---|---|
| $K_0$ | 31 | 26 | 26 | 28 | 31 |
| $E[K_1]$ | 66 | 69 | 69 | 69 | 67 |
| $p_0$ | 75 | 67 | 66 | 70 | 74 |
| $g$ | 3.47% | 4.61% | 4.77% | 3.77% | 3.60% |
| $r_f$ | 1.14% | 4.31% | 4.49% | 1.04% | 1.12% |
| $\pi$ | 2.42% | 0.13% | 0.00% | 2.51% | 2.42% |
| $\phi$ | 1.04 | 0.66 | -25 | 1.04 | 0.96 |

Table 3: Sensitivity analysis. The "no catastrophe" context is obtained by shifting the probability of catastrophe $p$ to zero, and by reducing the trend of growth to $\mu_{bau}$ to 1.37% to preserves the expected growth rate of production as in the benchmark. The "no macro risk" context combines these changes with the shift of the volatility $\sigma_{bau}$ to zero. In the "no tech risk" context, we switched $\sigma_\theta$ to zero compared to the benchmark. In the "no budget risk" case, we reduced $\sigma_T$ to zero compared to the benchmark.

# Take-home message: Are we serious about the 2°C target?

- The intertemporal optimality of the allocation of the carbon budget requires a schedule of carbon prices that increases at a risk-adjusted discount rate.
- Marginal abatement costs are positively correlated with aggregate consumption along the optimal path, so that postponing mitigation is more desirable than in the risk-free case.
- Low initial carbon price, large growth rate of this price (3.5%).
- This is vastly smaller than the 8% recommended by the IPCC and other public institutions.
- Most IAMs do not optimize abatement path. They play the waiting game.