Virtual Seminar on Climate Economics

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The cost-efficiency carbon pricing puzzle

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October 30, 2021

- 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.

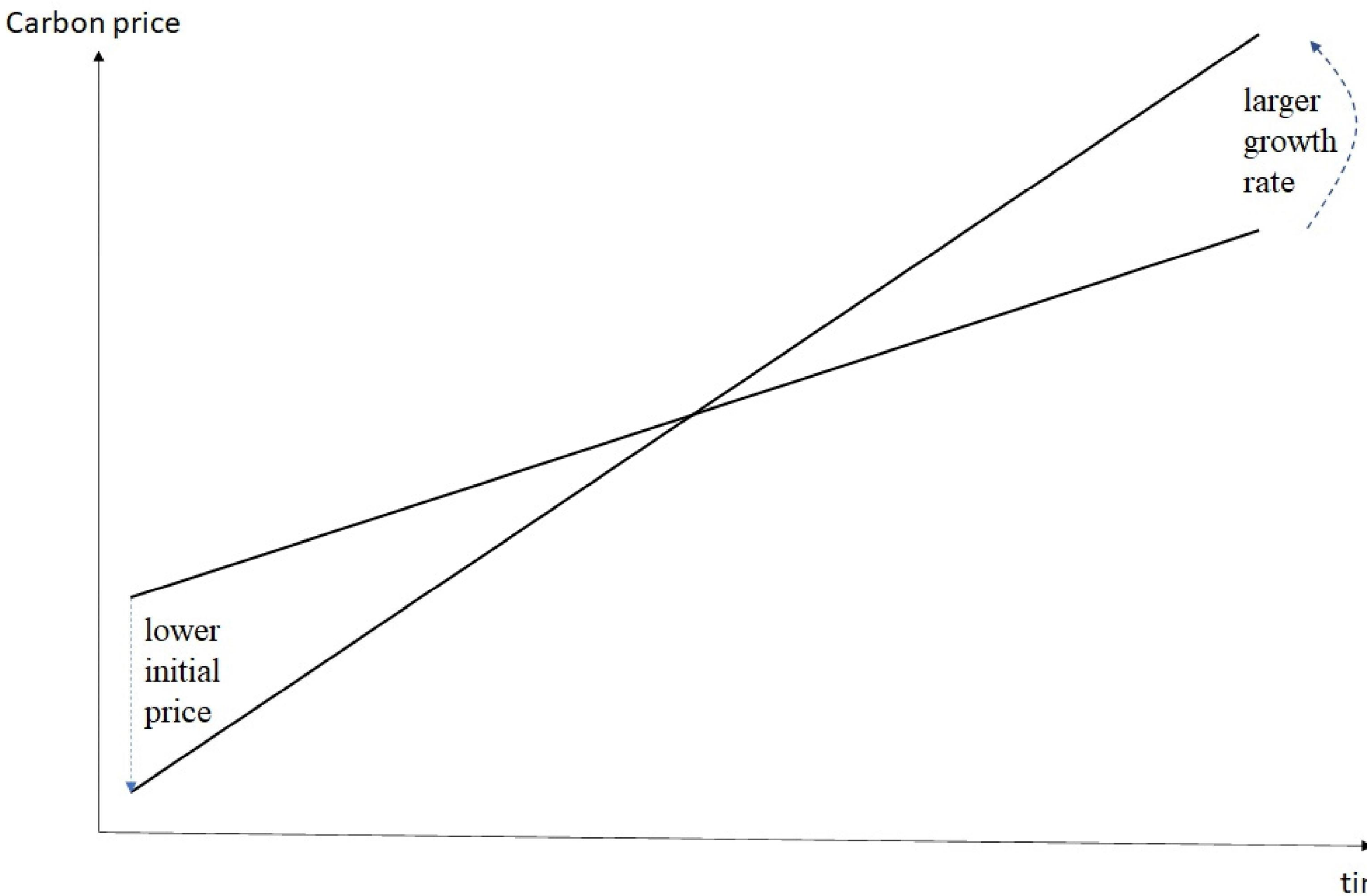

Carbon price
larger
growth
rate
lower
initial
price
time

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!

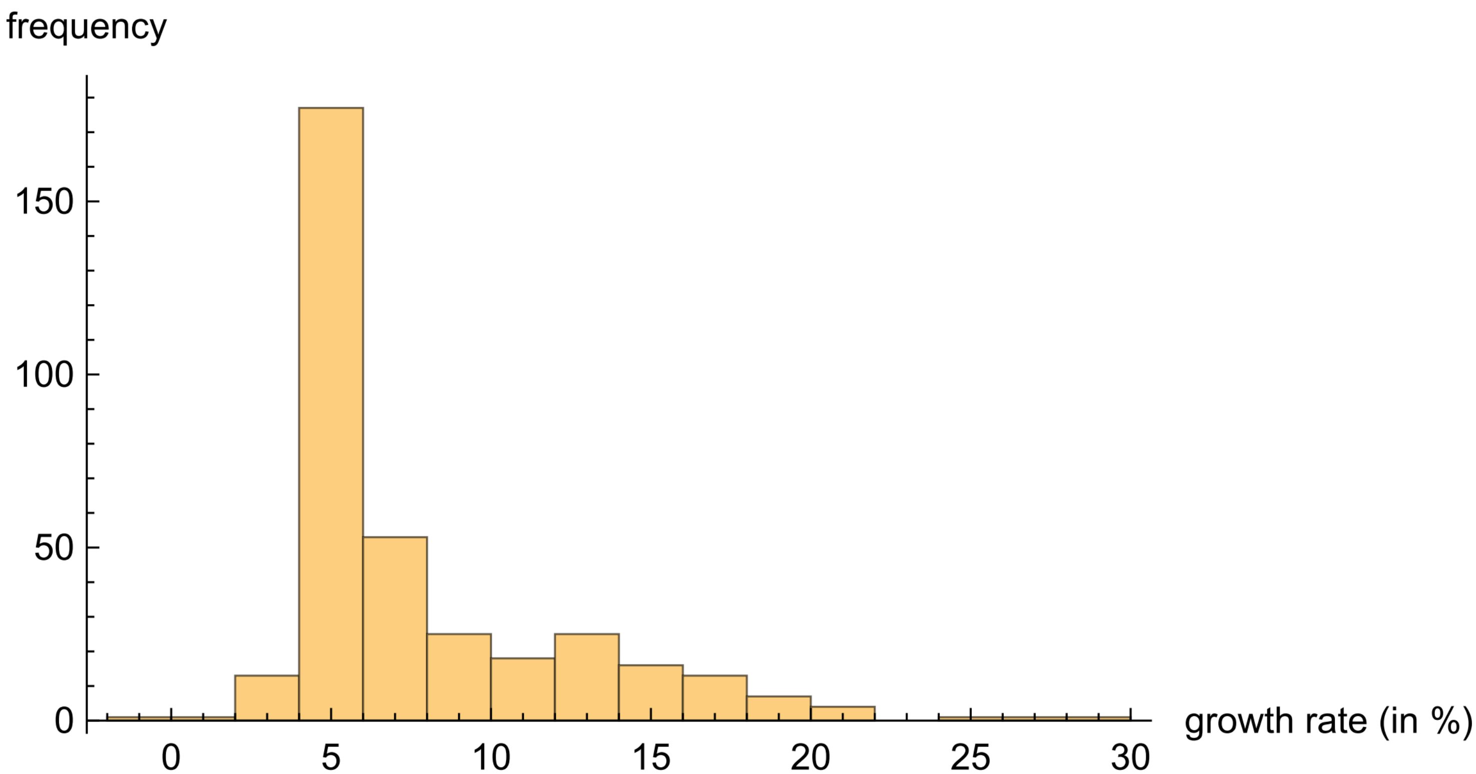


Figure: Histogram of the annual growth rate of real carbon prices 2020-2050 from 356 IAM models extracted from the IPCC database (https://tntcat.iiasa.ac.at/AR5DB). We selected the models that exhibit a 450 ppm concentration target.

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

	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 CO2) recommended in France by three different commissions. Source: France Stratégie.

- *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.

- Uncertainties affecting future abatement costs:
    - *Green innovations*
    - *Economic prosperity*
    - *Carbon budget*
- Suppose that in 2050, larger Marginal Abatement Costs (MAC) will materialize when consumption is 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.

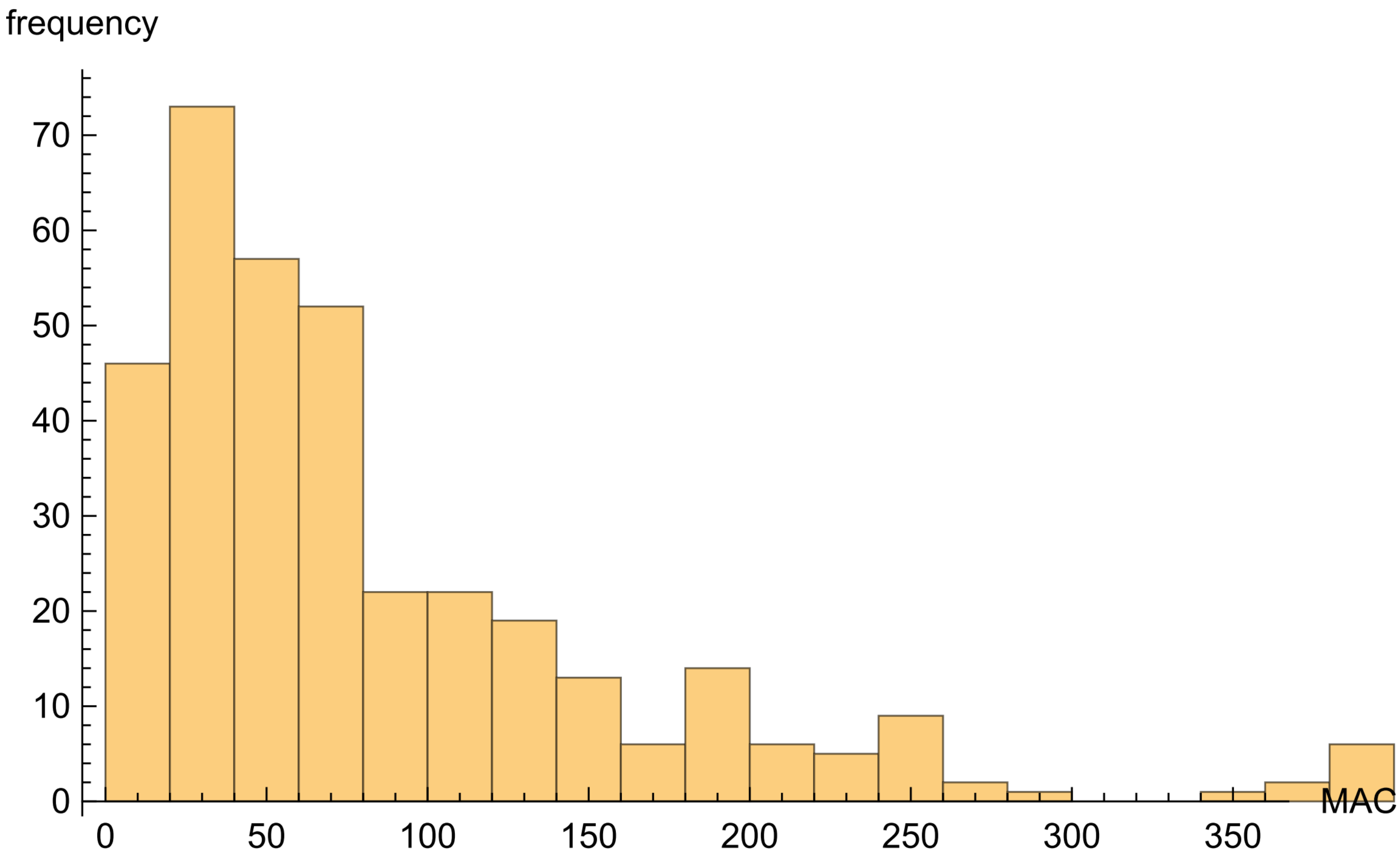


Figure: Histogram of the world marginal abatement costs for 2030 extracted from the IPCC database (https://tntcat.iiasa.ac.at/AR5DB). We have selected the 374 estimates of carbon prices (in US$2005/t$CO_2$) in 2030 from the IAM models of the database compatible with a target concentration of 450ppm.

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

- 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, θ, T):

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

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

- 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 ϕ of marginal abatement cost.
- The growth rate of expected carbon price should be smaller than $\delta + r_f$ in that case.

- 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 ϕ of marginal abatement cost.
- The growth rate of expected carbon price should be larger than $\delta + r_f$ in that case.

- Two periods of 15 years: 2021-2035 and 2035-2050.
- A crucial contribution of this analysis comes from the consistency between carbon pricing, financial incentives and asset prices.
- A problem arises with the standard asset pricing puzzles on the underlying CCAPM that we use in this paper.
- We solve them by using the Barro's approach of introducing potential macro catastrophes:

$$
\begin{aligned}
\log\left(\frac{Y_1}{Y_0}\right) &= \sum_{i=1}^{15} x_i \\
x_i &\sim (h_{bau}, 1-p; h_{cat}, p) \\
h_{bau} &\sim N(\mu_{bau}, \sigma_{bau}^2) \\
h_{cat} &\sim N(\mu_{cat}, \sigma_{cat}^2).
\end{aligned}
$$

$$p = 1.7\% \quad \mu_{bau} = 2\% \quad \sigma_{bau} = 2\% \quad \mu_{cat} = -35\% \quad \sigma_{cat} = 25\%$$

- EU-28 currently emits 4.4 $GtCO_2e$ per year. Over 15 years: 66 $GtCO_2e$ under the BAU.
- Current annual GDP: 19,000 GUS\$. Assuming a growth rate of 1.4% per year, this implies a GDP of 315,000 GUS\$ in the first period.
- This yields $Q_0 = 2.10 \times 10^{-4}$ $GtCO_2e$/GUS\$.
- IPCC (2014): The carbon intensity of GDP has decreased over the period 1970-2010 at a rate of 0.8% per year.
- This implies $Q_1 = 1.85 \times 10^{-4}$ $GtCO_2e$/GUS\$.
- Given economic growth, this implies an expected emission of 72 $GtCO_2e$ in the second period under the BAU.

Cumulated expected emissions 2021-2050 EU-28 BAU: 138 $GtCO_2e$

- No consensus.
- Highly non-linear dynamics of the carbon cycle involving the atmosphere and different layers of oceans.
- The existing literature on the half-life of carbon dioxide offers a wide range of estimates, from a few years to several centuries.
- I conservatively assume a rate of natural decay of CO_2 in the atmosphere of 0.5% per year.

Cumulated expected emissions 2021-2050 EU-28 BAU, net of natural decay: 133 $GtCO_2e$

- $\Delta T \leq 2°C \Rightarrow$ max concentration of 450 ppm.
- This leaves us with a carbon budget of 750 $GtCO_2e$ for the planet.
- EU-28 is home for 7% of the world population.
- Assuming an egalitarian allocation of the carbon budget and assuming that one-fifth of the budget needs to be reserved for after 2050, this implies a carbon budget of $T = 40$ $GtCO_2e$ for EU-28 for the two periods.
- We assume uncertainty: $T \sim N(\mu_T, \sigma_T^2)$ with

$$\mu_T = 40 \quad \sigma_T = 10.$$

- We assume a quadratic abatement cost function:

$$A_t(K_t) = a_t K_t + \frac{1}{2} b K_t^2.$$

- Slope b: The MIT-EPPA has developed computable general equilibrium models with a very detailed energy sector. They have estimated the shadow price of carbon associated to various carbon budgets for different regions of the world, thereby generating regions-specific MAC curves.
    - For EU, MAC increases by 25 US$ when annual effort is increased by 1 $GtCO_2$.
- MAC today-BAU: $a_0 = 23$ US$/$tCO_2$e (current price on EU-ETS).
- MAC in the future in the BAU is uncertain $a_1 = \theta$.
    - From R5-WG3-IPCC, I have collected the 374 estimations of carbon prices for 2030 that are in line with the objective of not exceeding 450ppm over the century.

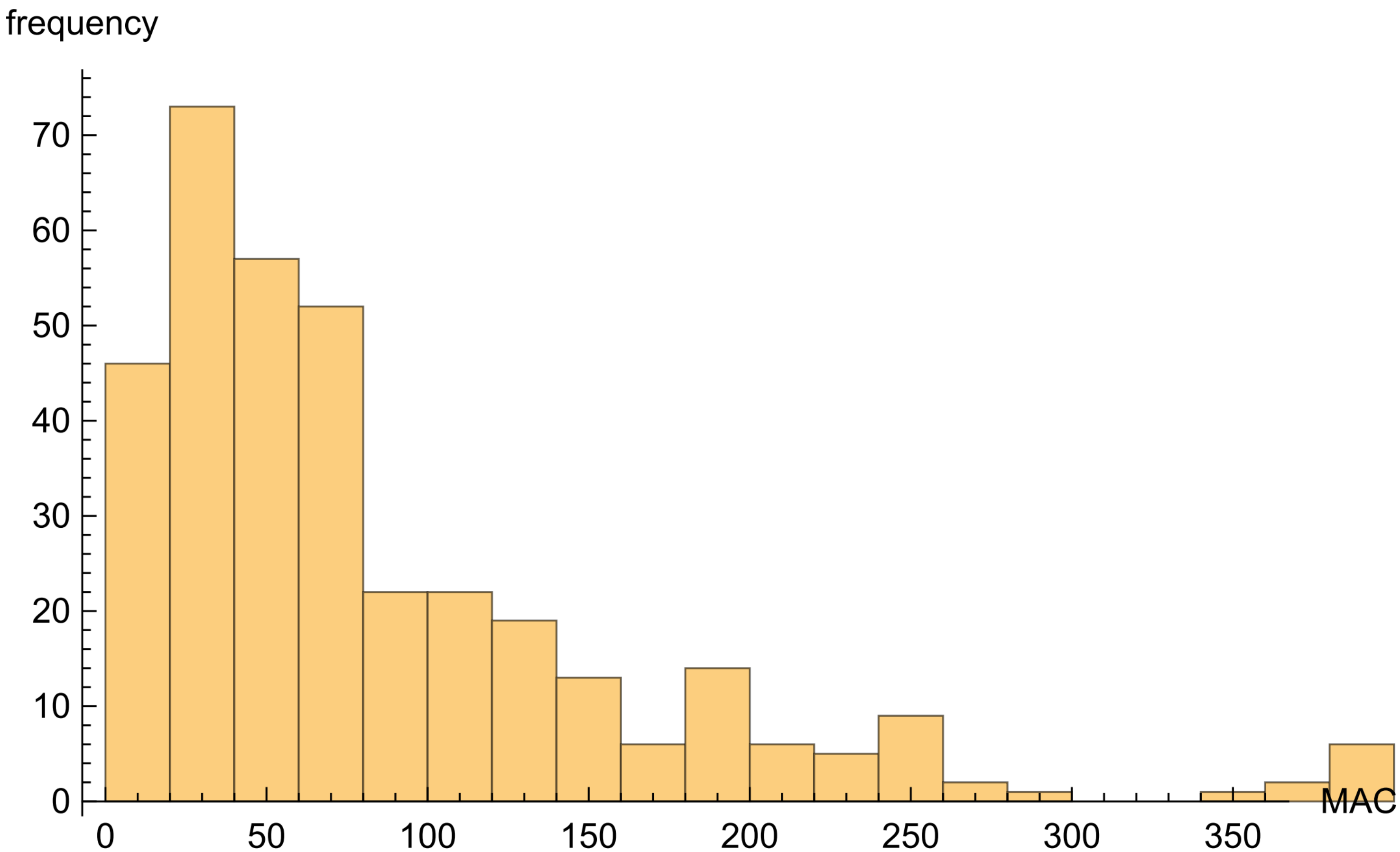


Figure: Histogram of the world marginal abatement costs for 2030 extracted from the IPCC database (https://tntcat.iiasa.ac.at/AR5DB). We have selected the 374 estimates of carbon prices (in US$2005/t$CO_2$) in 2030 from the IAM models of the database compatible with a target concentration of 450ppm.

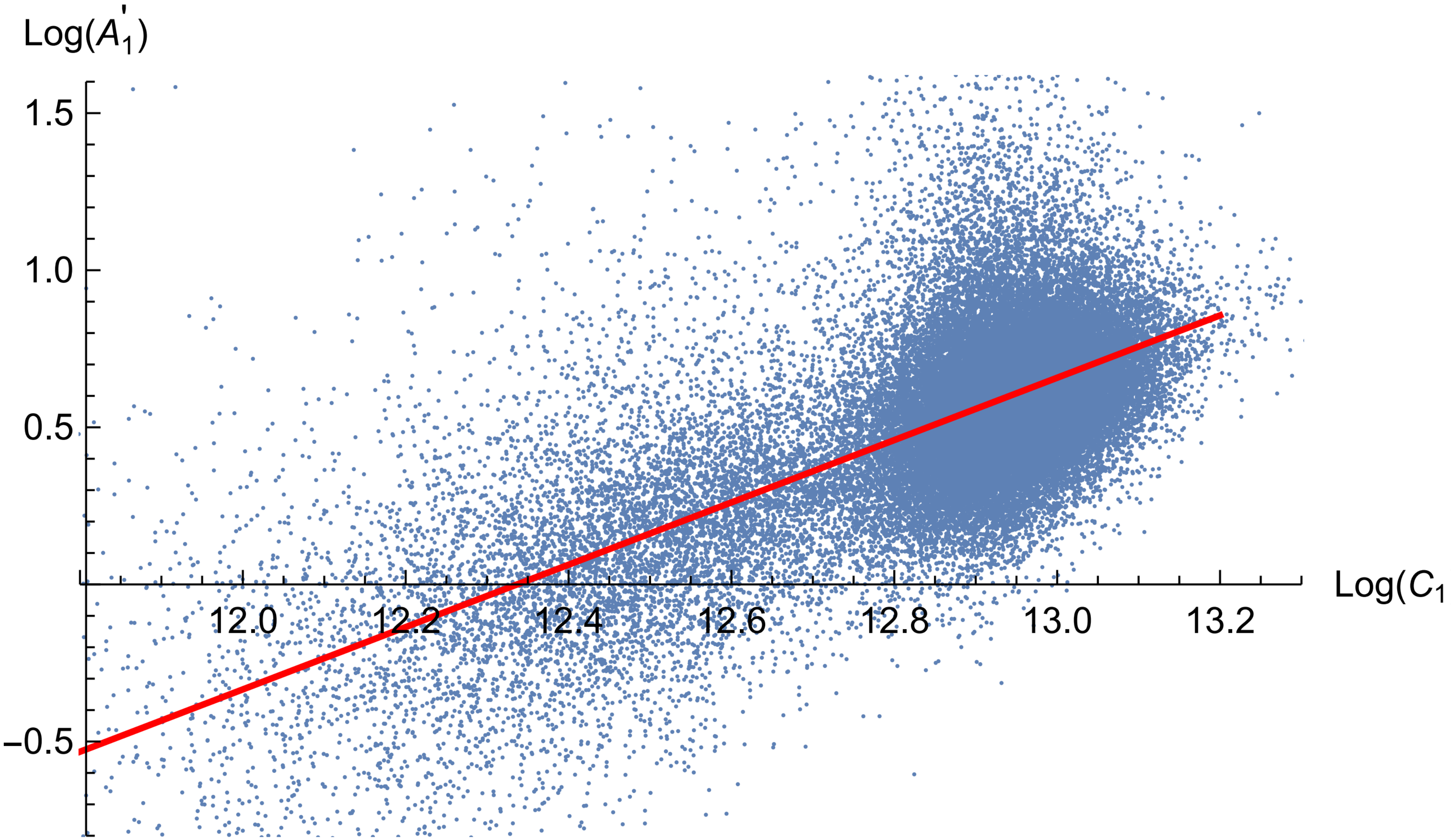
- We use this sample to estimate the standard deviation of $a_1 = \theta$.
- We also assume a 20% reduction in the expected MAC compared to the first period.
- We assume a lognormal distribution for the MAC under BAU.

$$\log(\theta) \sim N(2.30, 1.21^2)$$

$$E\theta \simeq 18 US\$/tCO_2$$

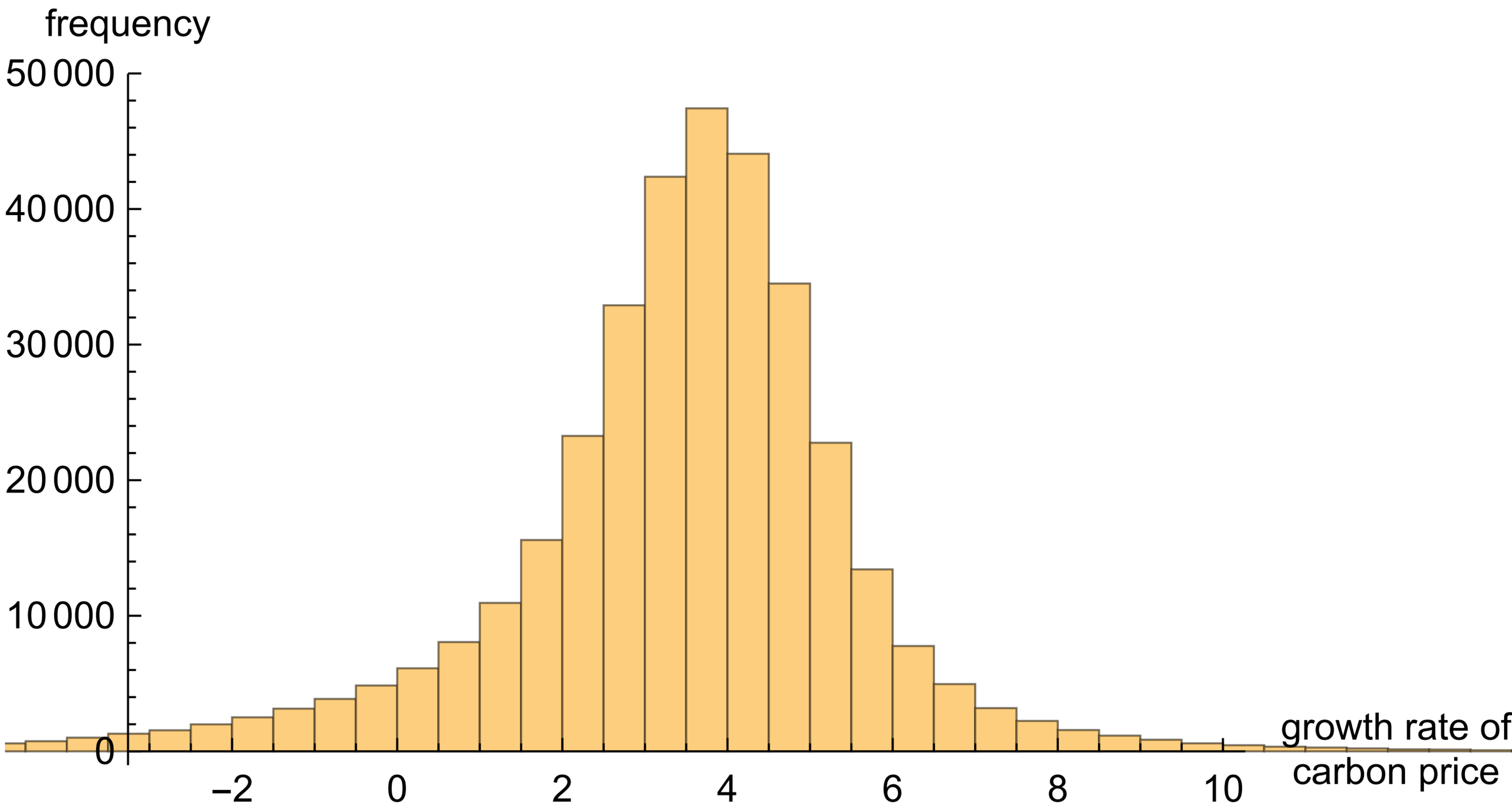
parameter	value	description
ρ	0.5%	annual rate of pure preference for the present
γ	3	relative risk aversion
Y_0	315,000	production in the first period (in GUS$)
p	1.7%	annual probability of a macroeconomic catastrophe
μ_{bau}	2%	mean growth rate of production in a business-as-usual year
σ_{bau}	2%	volatility of the growth rate of production in a business-as-usual year
μ_{cat}	-35%	mean growth rate of production in a catastrophic year
σ_{cat}	25%	volatility of the growth rate of production in a catastrophic year
δ	0.5%	annual rate of natural decay of CO_2 in the atmosphere
Q_0	2.10×10^{-4}	carbon intensity of production in period 0 (in $GtCO_2e$/GUS$)
Q_1	1.85×10^{-4}	carbon intensity of production in period 0 (in $GtCO_2e$/GUS$)
μ_T	40	expected carbon budget (in $GtCO_2e$)
σ_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$)
a_0	23	marginal cost of abatement in the BAU, first period (in GUS$/$GtCO_2e$)
μ_θ	2.30	expected future log marginal abatement cost in BAU
σ_θ	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, θ, T).


Log(A_1')
1.5
1.0
0.5
−0.5
12.0
12.2
12.4
12.6
12.8
13.0
13.2
Log(C_1)

variable	value	description
K_0	31	optimal abatement in the first period (in $GtCO_2$e)
$E[K_1]$	66	optimal expected abatement in the second period (in
p_0	75	optimal carbon price in the first period (in US$/tCO
g	3.47%	annualized growth rate of expected carbon price
r_f	1.14%	annualized interest rate
π	2.42%	annualized systematic risk premium
ϕ	1.04	OLS estimation of the income-elasticity of MAC

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


frequency
50 000
40 000
30 000
20 000
10 000
0
−2
0
2
4
6
8
10
growth rate of
carbon price

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%
π	2.42%	0.13%	0.00%	2.51%	2.42%
ϕ	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 μ_{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 σ_{bau} to zero. In the "no tech risk" context, we switched σ_θ to zero compared to the benchmark. In the "no budget risk" case, we reduced σ_T to zero compared to the benchmark.

- 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.