Believe me when I say green!

Heterogeneous expectations and climate policy uncertainty

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  - $\rightarrow$ Decarbonisation

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- Markets won't go low-carbon by themselves
  - $\rightarrow$ Policies needed to modify relative prices
  - Long-lived capital assets $\rightarrow$ Future policies matter!
- Expectations on future policies
  - Policy-makers announced objectives (e.g. net-zero by 2050)
  - Degree of trust in policy-maker's commitment

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Policy-makers come and go

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"On energy, I will cancel job-killing restrictions on the production of American energy - including shale energy and clean coal - creating many millions of high-paying jobs"

Donald Trump (2016)

Transition-related disruptions

- Transition-related costs (unemployment, stranding, financial volatility)
- $\rightarrow$ Diversion from plans

Gilets Jaunes movement (2018)

Heterogenous climate policy sentiments

- Evidence of heterogeneous expectations in climate policy

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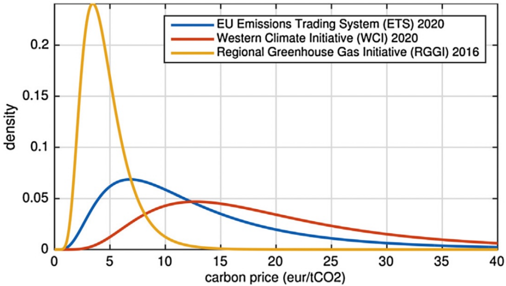
  - See Refinitiv Carbon Market Survey



Log normal distributions of carbon prices fitted to Refinitiv 2015 survey results.
Source: Nemet et al. (2017)

Research aims

Sentiments and transition

How is the low-carbon transition affected by heterogeneity/volatility of climate-related sentiments?

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How should the policy-maker behave when announcing and implementing climate policies?

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+ Methodological aim

Incorporate heterogeneous forward-looking expectations in discrete choice transition model

Links to literature

- Rapid and orderly transition to carbon-free economy
    - Economic effects of climate policy uncertainty: van der Ploeg & Rezai (2020); Fried et al (2021)
    - Climate sentiments: Engle et al. (2020); Noailly et al. (2022); Basaglia et al. (2022)
    - Credible commitment: Helm et al. (2003); Nemet et al. (2017)
    - Transition risks: Semieniuk et al. (2021)

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  - Transition risks: Semieniuk et al. (2021)
- Modelling framework
  - Rooted in discrete choice theory (McFadden 1973)
  - Heterogeneous expectations lit on finance & monetary policy: Brock&Hommes 1997, 1998; De Grauwe and Macchiarelli 2015; Hommes & Lustenhouwer 2019; Assenza et al. 2021)
  - Technological diffusion lit: Mercure et al 2014; Mercure 2015

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Overview of results

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Structure of the model

- Two technologies:
  - High- and low carbon
  - Firms decide how to invest based on expected costs which depend on expected carbon tax
- Two expectation rules:
  - Believers and sceptics in the policy-maker announcements
  - Firms switch beliefs depending on their prediction accuracy
- Policy-maker has two goals:
  - Achieve climate objectives
  - Reduce transition risks

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Climate policy announcement

- At the beginning of the simulation run, the policy-maker announces a schedule of future tax targets $\bar{\tau}_t \; \forall t$
- We assume an exponential tax announcement

$$\bar{\tau}_t = \bar{\tau}_0 (1 + \bar{g}_\tau)^t$$

where $\bar{\tau}_0$ is initial tax rate and $\bar{g}_\tau$ is the announced growth rate of τ

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  - Believers (b) trust policy-makers announcements more
  - Sceptics (s) trust policy-makers announcements less
- The expected tax growth rate is

$$E_j(g_\tau) = \epsilon_j \bar{g}_\tau$$

with $\epsilon_j \in [0, 1]$ indicating the degree of trust in the announced policy, and $\epsilon_b > \epsilon_s$

How do firms choose their beliefs?

- Firms observe previous tax implemented τ and compute fitness measure of both belief types (Brock and Hommes, 1997, 1998):

$$U_{j,t} = \eta \left| E_{j,t-1}(\tau_t) - \tau_t) \right| + (1-\eta) U_{j,t-1}$$

  where $\eta \in [0,1]$ is a memory (or belief inertia) parameter
- The share of firms adopting each belief type $n_j \in (0,1)$ is then determined by

$$n_{j,t} = \frac{\exp(-\beta U_{j,t-1})}{\sum_j \exp(-\beta U_{j,t-1})}$$

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  - β is the belief intensity of choice (to what extent firms react to prediction errors)

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  - $\beta = 0$: random choice ($n_j = 0.5$ independently of U_j)
  - $\beta \to \infty$: all agents switch to the more accurate belief ($n_j \to 0$ or $n_j \to 1$)

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$$E_{j,t}(\Theta_{h,t}) = \sum_{r=t+1}^{R} \rho^r \theta_{i,r}(1 + E_{j,t}(\tau_{h,r}))$$

where

- ρ: discount rate
- R: planning horizon
- θ i-specific production costs
- τ: tax rate on high-carbon production costs θ_h

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Capital investments

- Based on their expected costs, firms allocate their investment between technologies The low-carbon investment share for belief type j $\chi_{j,t} \in (0,1)$ is

$$\chi_{j,t} = \frac{\exp(-\gamma E_{j,t}(\Theta_{l,t}))}{\sum_i \exp(-\gamma E_{j,t}(\Theta_{i,t}))}$$

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  - Higher γ leads to higher adoption of most convenient technology
    - $\gamma = 0 \rightarrow$ random choice
    - $\gamma \rightarrow \infty \rightarrow$ perfect rationality

Aggregate investment and capital allocation

- The low-carbon investment share for the overall economy is

$$\chi_t = n_{b,t}\chi_{b,t} + n_{s,t}\chi_{s,t}$$

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- We define the low-carbon share of capital

$$\kappa_t \equiv \frac{K_{l,t}}{\sum_i K_{i,t}}$$

Transition risks and policy commitment

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- Policy-maker then sets actual tax rate τ following:

$$\tau_t = c\bar{\tau}_t + (1 - c)\bar{\tau}_t(1 - \pi_t)$$

where $c \in [0, 1]$ is the policy-maker weight given to climate objectives against transition cost mitigation

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Dynamics of the low-carbon capital share

- Simplifying assumptions for analytical tractability
  - $\bar{\tau}$ is treated as a fixed parameter
  - $\eta = 1$
  - $\epsilon_s = 0 \rightarrow E_s(\tau_t) = \tau_0 \forall t$
  - $\epsilon_b = 1 \rightarrow E_s(\tau_t) = \bar{\tau} \forall t$

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where $n_{b,t+1}$ is a function of κ_t:

$$n_{b,t+1} = \frac{1}{1 + \exp\left(-\beta\left(2\tau_t - \bar{\tau}_0 - \bar{\tau}\right)\right)}$$

$$\tau_t = \bar{\tau}\left(c + \frac{1-c}{1 + a(1-\kappa_t)\bar{\tau}}\right)$$

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Steady states

- **Proposition 1.** $f(\kappa)$ has at least one stable equilibrium and generally an overall odd number of equilibria exists Proof

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  - Equilibria with odd index are stable
  - Equilibria with even index are unstable

Low-carbon steady state I

- **Benchmark scenario** Under $\beta = \gamma = \infty$, the low-carbon steady state $\kappa^* = 1$ exists if

$$\bar{\tau} > \left(\frac{\theta_l - \theta_h}{\theta_h} \right)$$

where $\frac{\theta_l - \theta_h}{\theta_h}$ is the percentage difference between low- and high-carbon production costs

Low-carbon steady state II

- **Bounded rationality scenario** Under finite β and γ, the low-carbon steady state $\kappa^* = 1 - \lambda_l$, with λ_l a small positive number, exists if

$$\bar{\tau} > \frac{\left|\ln\left(\frac{\lambda}{1-\lambda}\right)\right|}{A\gamma\theta_h} + \left(\frac{\theta_l - \theta_h}{\theta_h}\right)$$

where $\lambda > \lambda_l$ and $A \equiv \frac{1-\rho^{R+1}}{1-\rho}$
$\Rightarrow$ Policy announcements have to be sufficiently ambitious!

High-carbon trap I

- **Benchmark scenario** Under $\beta = \gamma = \infty$, the high-carbon steady state $\kappa^* = \chi_s$ exists if

$$c < \frac{1}{2} + b_1$$

where $b_1 \equiv \frac{\bar{\tau}_0}{2\bar{\tau}} + \frac{\bar{\tau}_0 - \bar{\tau}}{2a(1-\chi_s))\bar{\tau}^2} < 0$

High-carbon trap II

- **Bounded rationality scenario** Under finite β and γ, the additional high-carbon steady state, $\kappa^* = \chi_s + \lambda_h$, with λ_h a small positive number, exists if

$$c < \frac{1}{2} + b_2 + d$$

where

- $b_2 \equiv \frac{\bar{\tau}_0}{2\bar{\tau}} + \frac{\bar{\tau}_0 - \bar{\tau}}{2a(1-(\chi_s+\lambda_\kappa))\bar{\tau}^2} < 0$
- $d \equiv -\frac{1}{\beta 2\bar{\tau}} \ln(\tilde{\lambda}_h) \left(\frac{1}{a(1-(\chi_s+\lambda_\kappa))\bar{\tau}} + 1 \right) < 0$
- $\lambda_\kappa > \lambda_h$ is a sufficiently small positive number
- $\tilde{\lambda}_h \equiv \frac{\chi_b - \chi_s - \lambda_\kappa}{\lambda_\kappa}$

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Safe threshold for policy-maker's commitment

- **Proposition 2.** A sufficient condition for uniqueness of equilibrium is

$$c > 1 - \frac{1}{\bar{\tau}\beta}$$

Proof

→ The higher the tax announced and β, the higher should be c

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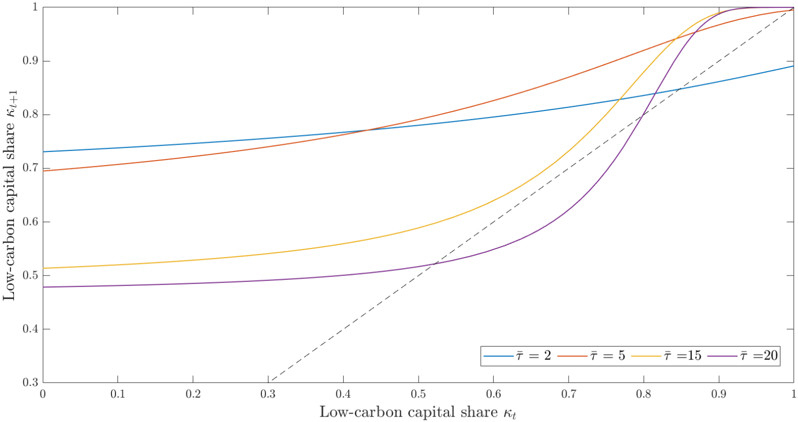
When commitment is low, no ambitious announcements



κ_{t+1} as a function of κ_t, for various values of τ (with $c = 0.4$)

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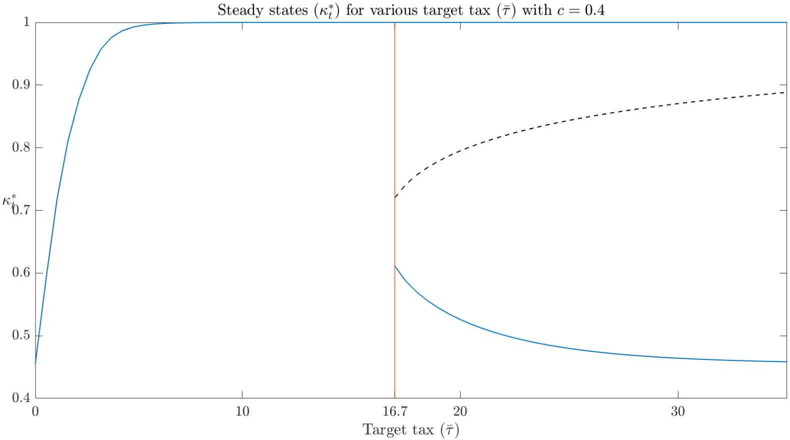
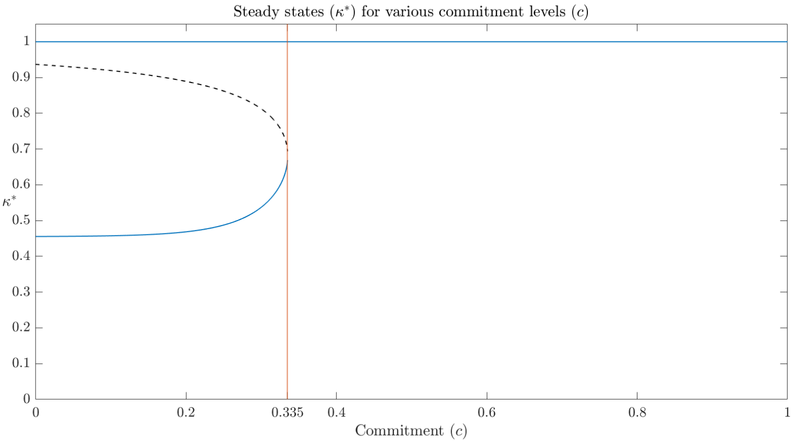


Bifurcation diagram of $\bar{\tau}$

Low commitment creates a high-carbon trap



Bifurcation diagram of c

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- Time: 320 quarters (2020-2100)

Details

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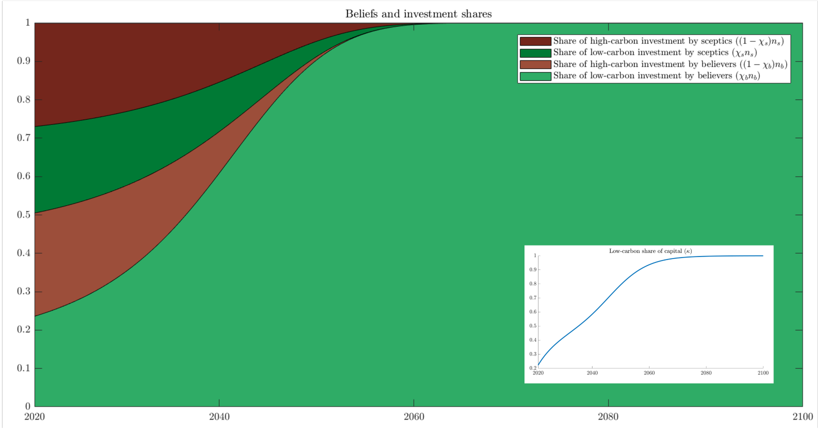
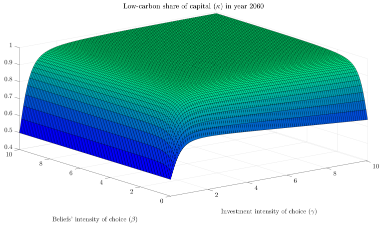
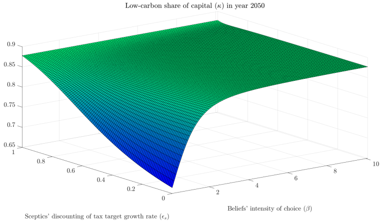
Benchmark scenario



Evolving shares of low/high-carbon investments by sceptics/believers

Belief/investment intensity of choice and beliefs polarisation





Low-carbon capital share κ as a function of β and γ (left), ϵ_s and β (right)

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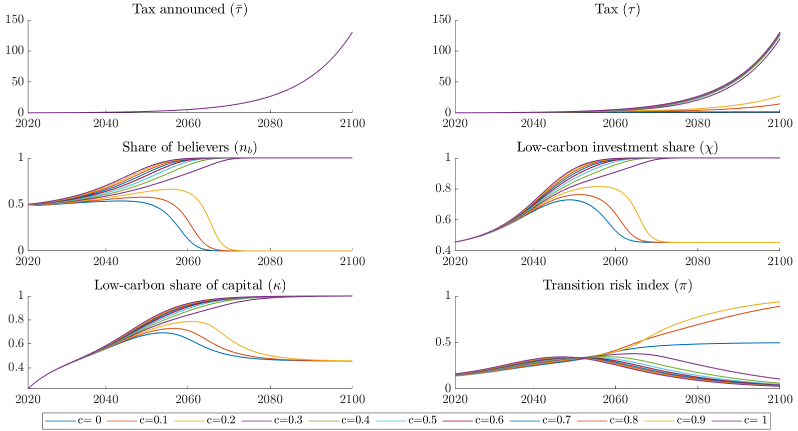
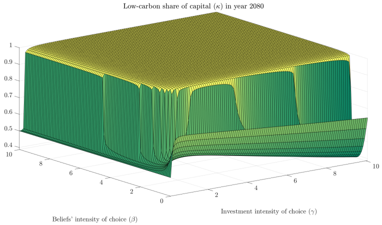
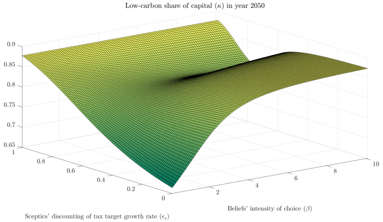
Transition dynamics under various commitment levels



Interaction between commitment, belief/investment intensity of choice and beliefs polarisation





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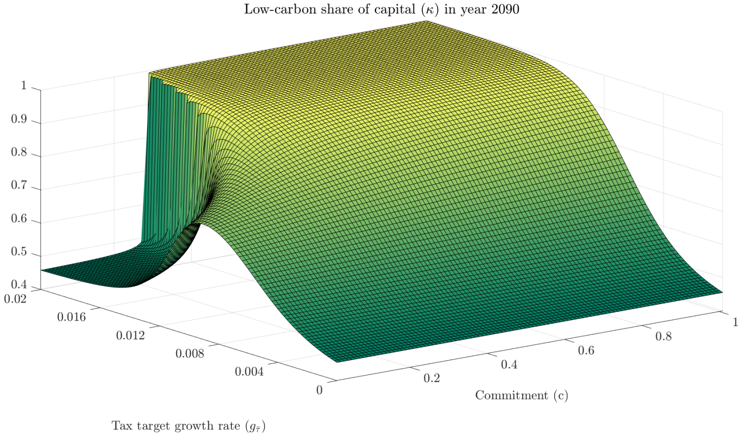
Commitment and tax announcements



Low-carbon capital share κ as a function of g_τ and c

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European Research Council
Established by the European Commission

Thank you!

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Additional slides

Proof of proposition 1

- Since $f(\kappa)$ is continuous in [0, 1] and $f(\kappa) \in [0,1]\ \forall \kappa$, f has at least one fixed point $\kappa = f(\kappa) \in [0,1]$
- $f(0) = \left(\frac{1}{1+\exp(-\beta(2\tau_t - \bar{\tau}_0 - \bar{\tau}))}\right)(\chi_b - \chi_s) + \chi_s \in (0,1)$ and $f(1) = \left(\frac{1}{1+\exp(-\beta(\bar{\tau} - \bar{\tau}_0))}\right)(\chi_b - \chi_s) + \chi_s \in (0,1)$, which implies that the map starts above the 45 degree line and ends below the 45 degree line

$\rightarrow$ Generally an overall odd number of steady states exists. Back

Proof of proposition 2

- The second derivative of $f(\kappa)$ is: $f''(\kappa) =$
$$-\frac{G\left(\left(a\,\bar{\tau}-\bar{\tau}\,\beta+\bar{\tau}\,\beta\,c-a\,\bar{\tau}\,\kappa_t+1\right)+\mathrm{e}^{\beta\,\left(\bar{\tau}_0-2\tau_t+\bar{\tau}\right)}\left(a\,\bar{\tau}+\bar{\tau}\,\beta-\bar{\tau}\,\beta\,c-a\,\bar{\tau}\,\kappa_t+1\right)\right)}{\left(\mathrm{e}^{\beta\,\left(\bar{\tau}_0-2\tau_t+\bar{\tau}\right)}+1\right)^3\left(a\,\bar{\tau}-a\,\bar{\tau}\,\kappa_t+1\right)^4},$$
where $G < 0$.
- The sign of the second order derivative depends on $(a\,\bar{\tau} - \bar{\tau}\,\beta + \bar{\tau}\,\beta\,c - a\,\bar{\tau}\,\kappa_t + 1) + \mathrm{e}^{\beta\,(\bar{\tau}_0-2\tau_t+\bar{\tau})}\,(a\,\bar{\tau} + \bar{\tau}\,\beta - \bar{\tau}\,\beta\,c - a\,\bar{\tau}\,\kappa_t + 1)$.
For $\beta \neq 0$, since $c, \kappa \in [0, 1]$, if $(a\,\bar{\tau} - \bar{\tau}\,\beta + \bar{\tau}\,\beta\,c - a\,\bar{\tau}\,\kappa_t + 1) > 0$, then $f''(\kappa) > 0$. The condition implies $c > 1 - \frac{1}{\bar{\tau}\beta}$. Back

Calibration: Production

- Exogenous macro landscape: $g_Y \approx 2\%$ per year
- European power sector (LCOE data from IEA)

Parameter	Symbol	Value
Output growth rate	g_Y	0.5%
Depreciation rate	δ	3%
Initial low-carbon capital share	κ_0	0.21
Low- to high-carbon production cost	$\frac{\theta_l}{\theta_h}$	1.33

Calibration: Beliefs and decisions

- Initial belief shares
  - Endogenously determined but in line with Refinitiv Carbon Market Survey)
- Belief intensity of choice
  - $\beta = 1$ following Hommes (2021) + sensitivity analysis
- Investment intensity of choice $\gamma = 2$
  - χ to fit initial investment shares values
  - transition as planned with full commitment

Parameter	Symbol	Value
Discount rate	ρ	0.5%
Planning horizon	R	120
Initial shares of belief types	$n_{b,0};n_{s,0}$	0.3; 0.7
Policy trust parameters	$\epsilon_b;\epsilon_b$	1; 0
Intensity of belief choice	β	1
Memory parameter	η	0.5
Intensity of investment choice	γ	2

Calibration: Policy decisions

- Current tax $\bar{\tau}_0$ calibrated on 2020 EU-ETS allowance prices
- Announced growth rate $\bar{g}_\tau$ calibrated on optimal mitigation pathways to reach 1.5-2°C
  - ENGAGE project involving 16 IAMs
- $a = 1$ to have low transition risk costs in 2020 ($\pi_0 \approx 0.15$) and have $\pi_0 \approx 0.5$ for $\bar{\tau} \approx 1.2$

Parameter	Symbol	Value
Announced initial tax rate	$\bar{\tau}_0$	0.24
Announced tax growth rate	$\bar{g}_\tau$	0.02
Transition risk index parameter	a	1
Policy-maker tax commitment	c	[0,1]

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