Believe me when I say green!

Heterogeneous expectations and climate policy uncertainty

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June 24, 2022

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- Urgent to mitigate climate change
  - $\rightarrow$ 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

Policy-makers come and go

Tony Abbott (2014)

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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)

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Transition-related disruptions

- Transition-related costs (unemployment, stranding, financial volatility)
- → Diversion from plans

Gilets Jaunes movement (2018)

Heterogenous climate policy sentiments

- Evidence of heterogeneous expectations in climate policy

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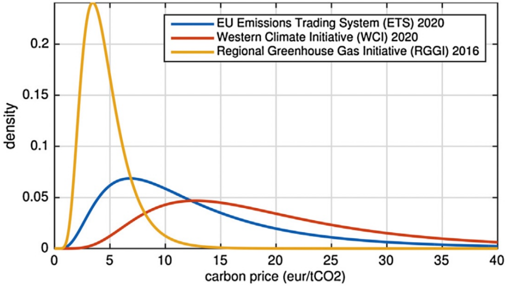
  - See Refinitiv Carbon Market Survey



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

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

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

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Cost expectations

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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

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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    - $\gamma = 0 \rightarrow$ random choice
    - $\gamma \rightarrow \infty \rightarrow$ perfect rationality

Aggregate investment and capital allocation

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

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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
  - $\eta = 1$
  - $\epsilon_s = 0 \rightarrow E_s(\tau_t) = \tau_0 \forall t$
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where $n_{b,t+1}$ is a function of κ_t:

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

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

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

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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

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

$$c > \frac{1}{2} + b_l + d_l. \quad (2)$$

- $\lambda > \lambda_l$, $A \equiv \frac{1-\rho^{R+1}}{1-\rho}$, $\tilde{\lambda} \equiv \frac{\chi_b - 1 + \lambda}{1-\lambda-\chi_s}$
- $b_l \equiv \frac{\bar{\tau}_0}{2\bar{\tau}} + \frac{\bar{\tau}_0 - \bar{\tau}}{2a\lambda\bar{\tau}^2} < 0$
- $d_l \equiv \frac{\left|\ln(\tilde{\lambda})\right|}{2\beta\bar{\tau}}\left(\frac{1}{a\lambda\bar{\tau}} + 1\right) > 0$

⇒ Policy announcements have to be sufficiently ambitious and policy-maker sufficiently committed!

⇒ The lower firms' reaction to cost differences (γ) is, the more ambitious the policy-maker needs to be!

⇒ The lower firms' reaction to prediction errors (β) is, the more committed the policy-maker needs to be!

High-carbon trap I

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

$$c < \frac{1}{2} + b_{hb}$$

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

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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

$$c < \frac{1}{2} + b_h + d_h$$

where

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

⇒ The lower firms' reaction to prediction errors (β), the less committed the policy-maker is allowed to be

- To sum up:
  - Higher firms' reaction to cost differences (γ) speeds up the transition
  - Firms' reaction to prediction errors has ambiguous effect: higher β rewards the committed policy-maker more, improving the unique equilibrium, but punishes the uncommitted policy-maker more, creating the high-carbon trap

Safe threshold for policy-maker's commitment

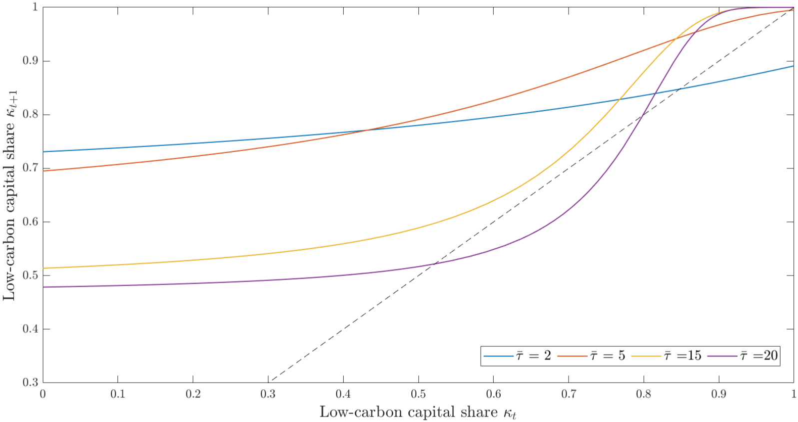
- **Proposition 2.** A sufficient condition for uniqueness of equilibrium is

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

Proof

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

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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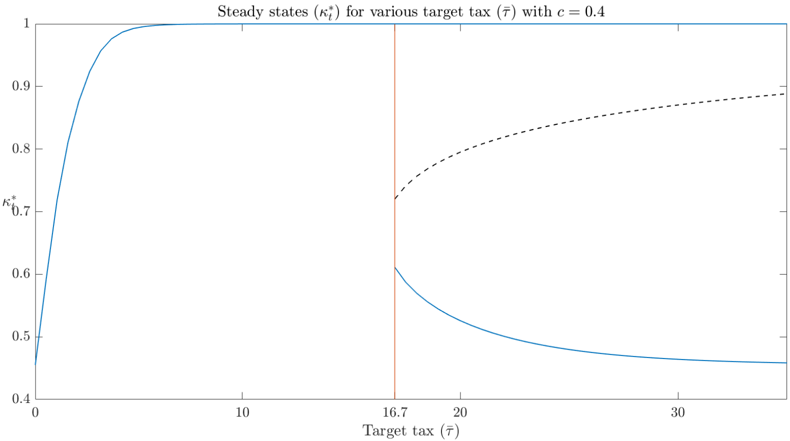
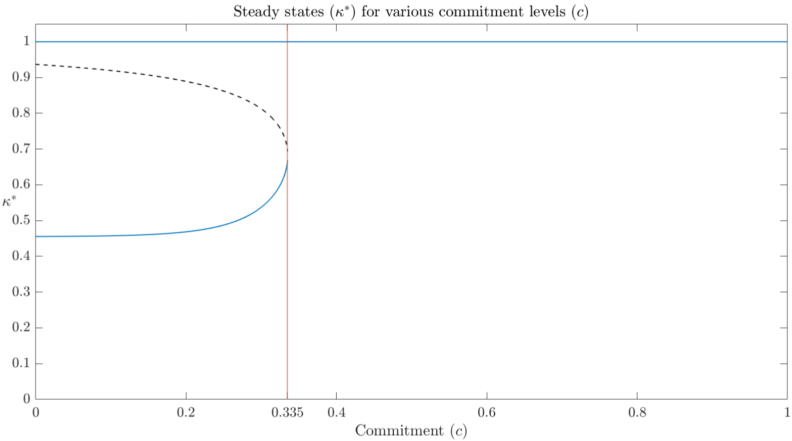


Bifurcation diagram of $\bar{\tau}$

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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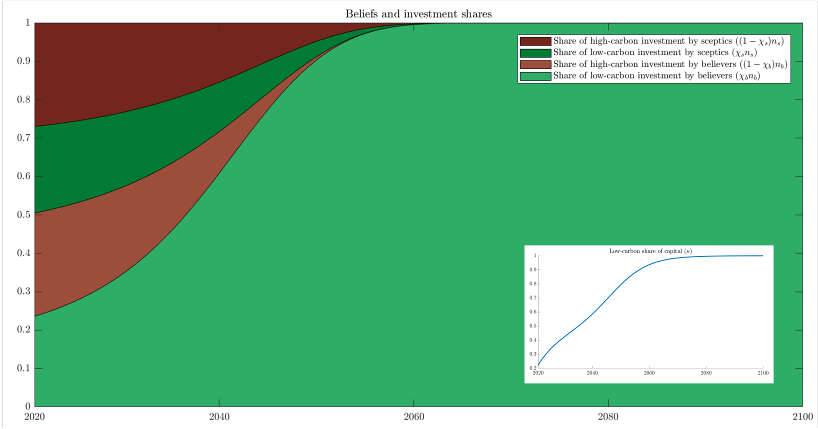
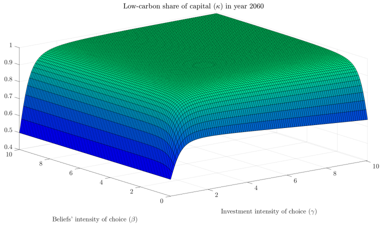
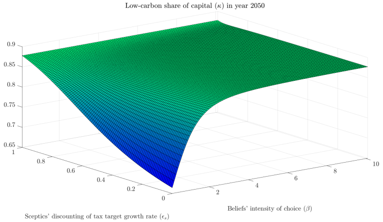
Benchmark scenario



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

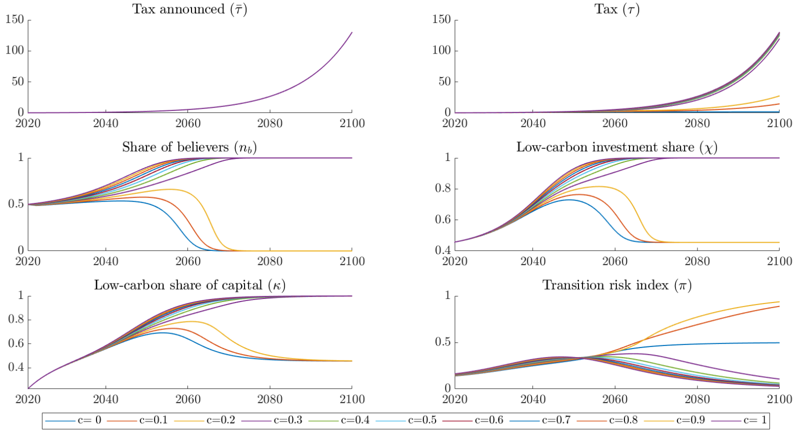
Belief/investment intensity of choice and beliefs polarisation





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

Transition dynamics under various commitment levels



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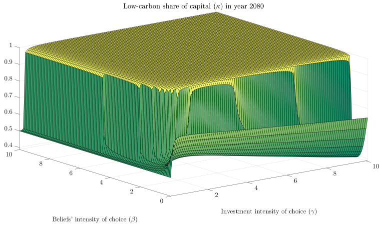
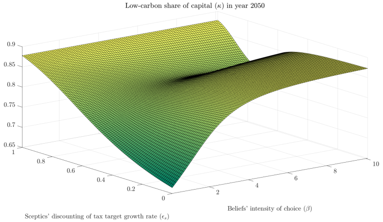
Interaction between commitment, belief/investment intensity of choice and beliefs polarisation





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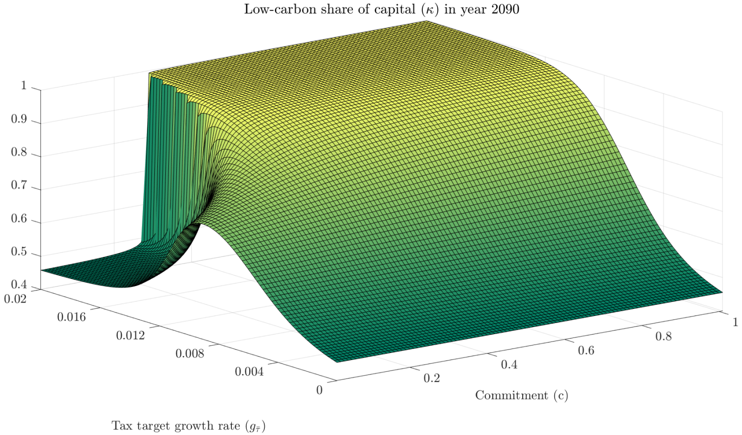
Commitment and tax announcements



Low-carbon capital share κ as a function of g_{τ} and c

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- Polarised beliefs lead to a faster transition under poor commitment

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European Research Council
Established by the European Commission

Thank you!

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 853050 - SMOOTH)

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

→ Generally an overall odd number of steady states exists. Back

Proof of proposition 2

- The second derivative of $f(\kappa)$ is: $f''(\kappa) =$
$$-\frac{G\left((a\,\bar{\tau}-\bar{\tau}\,\beta+\bar{\tau}\,\beta\,c-a\,\bar{\tau}\,\kappa_t+1)+\mathrm{e}^{\beta\,(\bar{\tau}_0-2\tau_t+\bar{\tau})}\,(a\,\bar{\tau}+\bar{\tau}\,\beta-\bar{\tau}\,\beta\,c-a\,\bar{\tau}\,\kappa_t+1)\right)}{\left(\mathrm{e}^{\beta\,(\bar{\tau}_0-2\tau_t+\bar{\tau})}+1\right)^3\,(a\,\bar{\tau}-a\,\bar{\tau}\,\kappa_t+1)^4},$$
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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