Believe me when I say green!

Heterogeneous expectations and climate policy uncertainty

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Motivation

- Urgent to mitigate climate change
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  - 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

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)

Transition-related disruptions

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

Gilets Jaunes movement (2018)

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Heterogenous climate policy sentiments

- Evidence of heterogeneous expectations in climate policy

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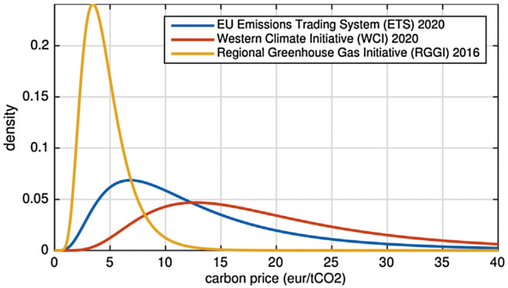
  - See Refinitiv Carbon Market Survey



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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+ 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)
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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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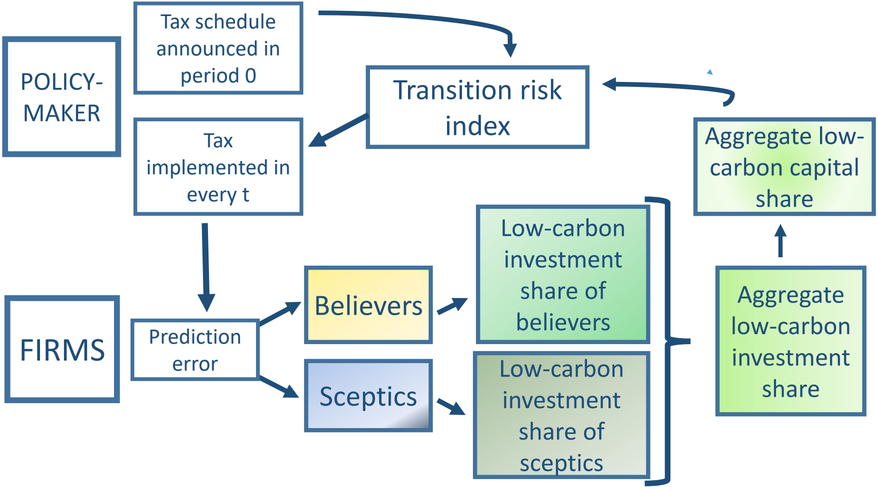
Structure of the model

- 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


POLICY-MAKER
Tax schedule announced in period 0
Tax implemented in every t
Transition risk index
Aggregate low-carbon capital share
FIRMS
Prediction error
Believers
Sceptics
Low-carbon investment share of believers
Low-carbon investment share of sceptics
Aggregate low-carbon investment share

Firms' beliefs

- Believers and sceptic form their expectations of future tax: $\epsilon_j \in [0, 1]$ indicates the degree of trust in the announced policy, and $\epsilon_b > \epsilon_s$

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Firms' beliefs

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→ Share of firms adopting each belief type $n_j \in (0,1)$ is determined

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

- U: prediction error
- β: beliefs intensity of choice

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Capital investments

- Based on expected tax, firms evaluate the net present value of expected production costs associated to each technology i and allocate their investment between technologies

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  $\rightarrow$ The low-carbon investment share for belief type j $\chi_j \in (0,1)$ is determined:

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

  - $E_{j,t}(\Theta_{i,t})$: expected production costs of technology i
  - γ: investment intensity of choice

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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→ χ_t then determines the low-carbon share of capital

$$\kappa_t$$

Transition risks and policy commitment

- Policy-maker observes κ and estimates transition risk index ($\pi \in [0, 1)$) which increase in the tax target and in the high-carbon capital share

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- Policy-maker observes κ and estimates transition risk index ($\pi \in [0, 1)$) which increase in the tax target and in the high-carbon capital share
- 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

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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Steady states

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

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

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
- $\tilde{\lambda}_h \equiv \frac{\chi_b - \chi_s - \lambda_\kappa}{\lambda_\kappa}$

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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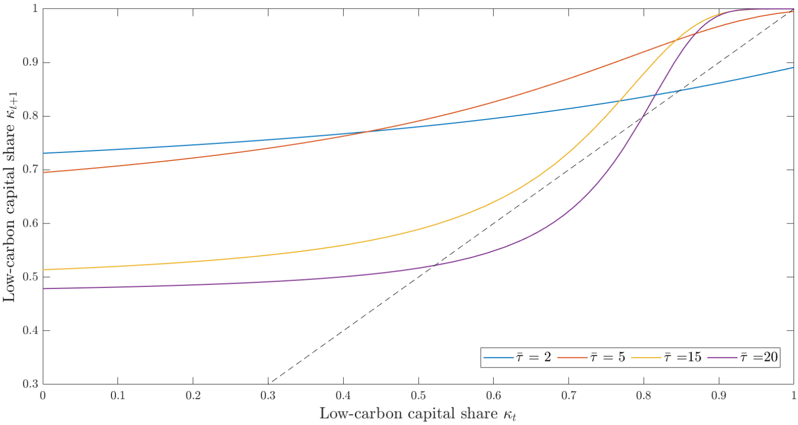
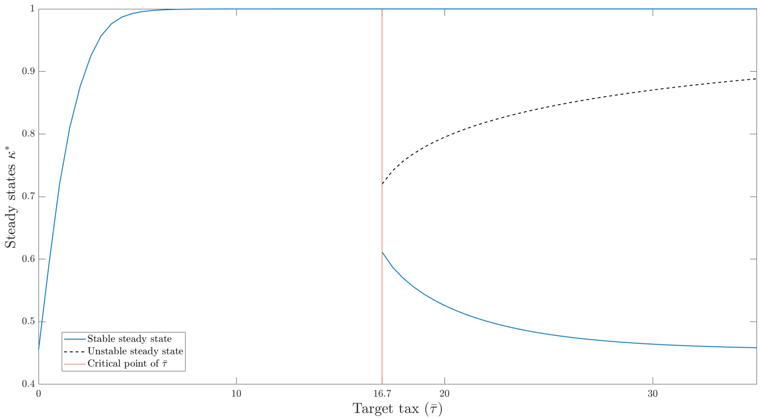
When commitment is low, no ambitious announcements



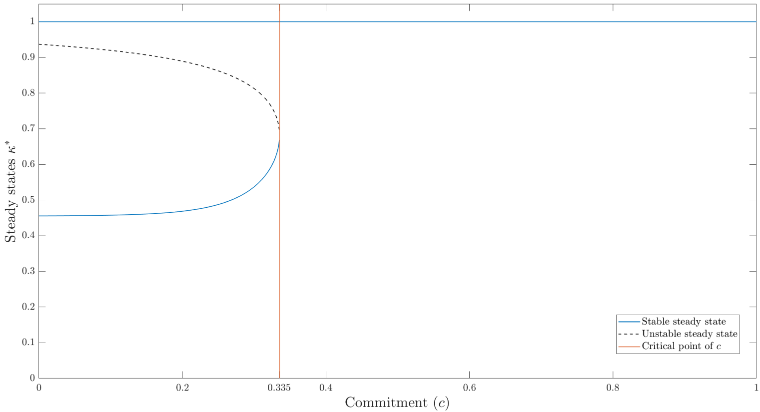
κ_{t+1} as a function of κ_t, for various values of τ (with $c = 0.4$)

When commitment is low, no ambitious announcements



Bifurcation diagram of $\bar{\tau}$

Low commitment creates a high-carbon trap



Bifurcation diagram of c

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- Technological parameters (e.g. production costs)
  - Calibrated to European power sector

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- Policy parameters
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- Time: 320 quarters (2020-2100)

Details

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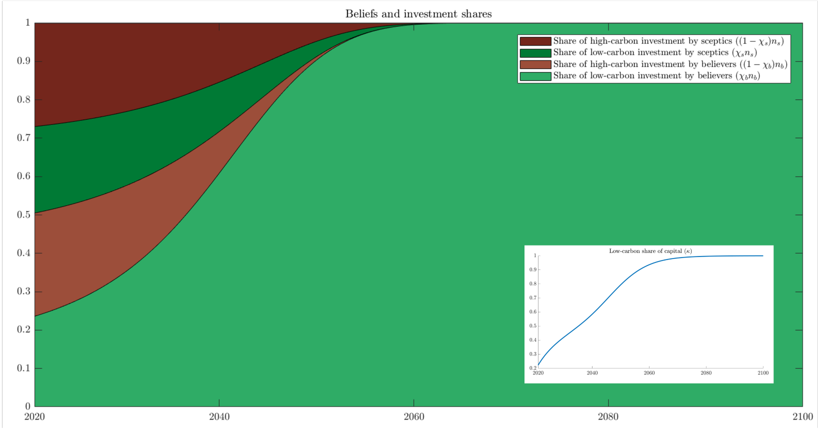
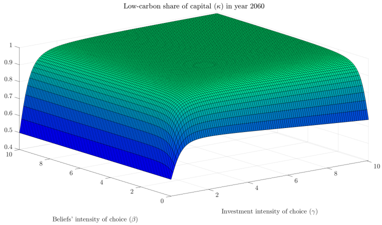
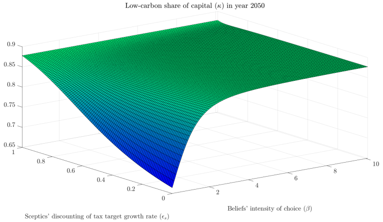
Benchmark scenario



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

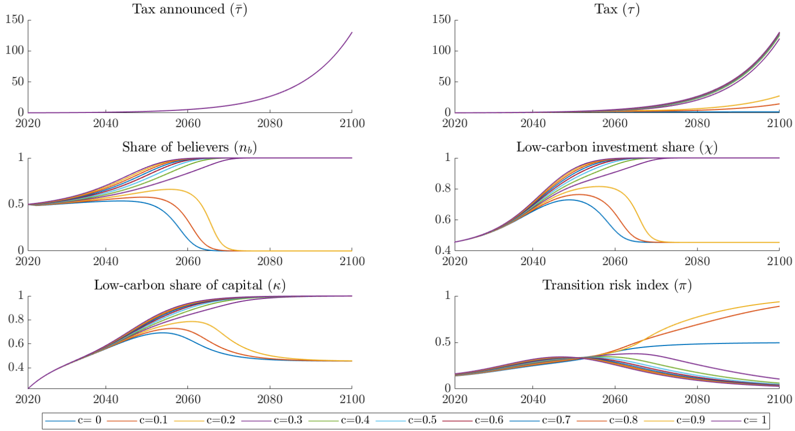
Belief/investment intensity of choice and beliefs polarisation



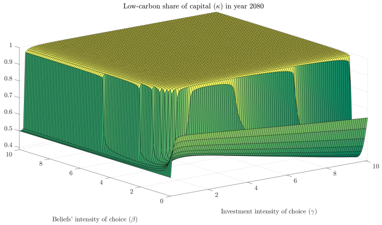


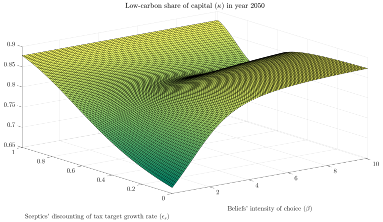
Low-carbon capital share κ as a function of β and γ (left), ϵ_s and β (right)

Transition dynamics under various commitment levels



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





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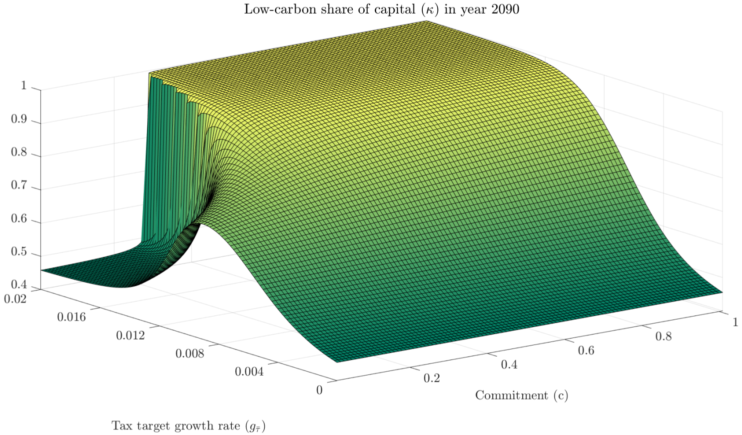
Commitment and tax announcements



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

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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

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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	ϵ_b;ϵ_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]

Back