Believe me when I say green!

Heterogeneous expectations and climate policy uncertainty

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Motivation

- Urgent to decarbonise
  $\rightarrow$ Reorient private investment choices to low-carbon capital
- Firms' investment decisions depend on expected costs/profits
  $\rightarrow$ Expectations on strength/timing of future climate policies
- How do firms form climate policy expectations?
  - Policy objectives as expectation anchor
  - Several longer-term announcements recently (net-zero dates $\rightarrow$ implicit carbon price trajectory)
- But will policy-makers actually deliver?

Numerous recent cases of policy reversals

Tony Abbott (2014)

"..the repeal of the carbon tax means a $550 a year benefit for the average family"

"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)

Common reason for reversals: perceived transition costs

- Concerns regarding costs (unemployment, stranding, financial volatility) associated with low-carbon transition

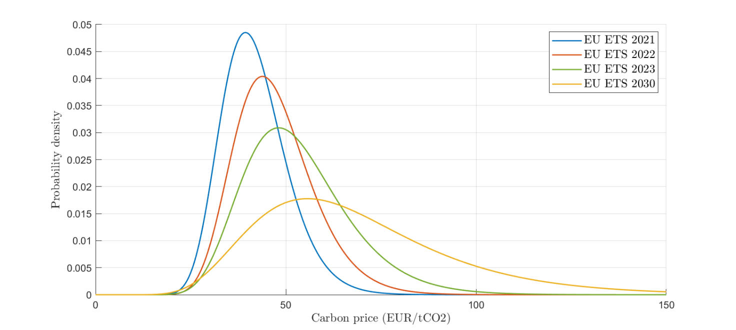
→ Revision/withdrawal of announced plans

Gilets Jaunes movement in France (2018)

Kazakhstan protests after LPG price cap lift (2022)

Heterogeneous climate policy sentiments

- Uncertainty + behavioural factors → Heterogeneous beliefs on policy credibility → Heterogeneous carbon price expectations
  - However.. scarce data available!



Distribution of expected carbon price in the EU Emission Trading Scheme for different time horizons. Source: Cahen-Fourot et al. (2022). Data from Refinitiv (2021)

Model overview

- Dynamic model focusing on investment allocation choices
  - Two technologies: low-carbon (l) vs high-carbon (h)
  - Investment allocation depends on heterogeneous expected cost differentials
- Carbon price expectations affect investment choices
  - Firms observe policy-maker climate policy announcements
  - They evaluate its credibility: believers (b) vs sceptics (s)
  - Policy-maker can default on goals with high transition risks
- Two key features of the model:
  - Heterogeneity of beliefs/expectations and behavioural frictions
  - Policy uncertainty and credibility

Overview of results

- Analytical results (using reduced version)
  - Two steady states can exist depending on tax announcement and policy-maker commitment level
  - Ambitious announcements and weak commitment create multiple equilibria (a 'high-carbon trap')
  - Behavioural frictions → 'behavioural premiums' on tax announcement and commitment minimum levels
- Numerical results (calibrated to EU economy)
  - Full commitment: decarbonisation almost always achieved but behavioural frictions affect transition speed
  - Weak commitment: loss of credibility can lead to vicious circles of increasingly high-carbon investments and weaker climate policies, ultimately leading to transition failure
  - In both cases: non-linear effects of belief polarisation

Literature

- Three broad literature connections
  - Climate policy credibility and uncertainty (e.g. Nemet et al. 2017; van der Ploeg and Rezai, 2020; Fried, 2021)
  - Policy time inconsistency (e.g. Kydland and Prescott, 1977; Barro and Gordon, 1983)
  - Bounded rationality and heterogeneous/biased expectations (Bordalo et al., 2022; Hommes, 2021)
- Few closely related papers
  - Cahen-Fourot et al. 2022: forward-looking probit model with capital ‘stranding’ expectations
  - Annicchiarico et al. 2022: belief switching in E-DSGE
  - Zeppini 2015; Mercure 2015: logit model for tech adoption
  - Cafferata et al. 2021; Davila-Fernandez et al. 2020: Switching green policy attitudes
  - Galanis 2022: International environmental agreements

The model

Methodological foundations

- Methodological foundations
    - Heterogeneous expectation framework a là Brock and Hommes (1997); see Hommes (2021)
    - Dispersion of beliefs/expectations due to ‘unobservables’ (discrete choice theory: McFadden, 1974)
    - Behavioural frictions interpretation
    - From ‘neoclassical limit’ without frictions to entirely random (full hedging) investment choices
- Two key behavioural dimensions in our model
    - Backward-looking responsiveness of beliefs to policy-maker credibility (β)
    - Forward-looking responsiveness of investment decisions to perceived cost differentials (γ)

Climate policy announcement

- At time t_0, the policy-maker announces a schedule of future carbon tax targets $\bar{\tau}_t$
- 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.

Firms' beliefs on carbon tax

- Firms have heterogeneous beliefs about credibility of policy commitment
  - Two belief categories: believers (b) trust policy-makers announcements more than sceptics (s)
- The expected tax growth rate is

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

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

How do firms choose their beliefs?

- In every t, firms
  - Observe tax actually implemented τ
  - Compute accuracy $U_{j,t}$ of both belief predictions

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

- Believers' share $n \in (0,1)$ is determined by

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

- β: belief responsiveness (to what extent firms react to prediction errors)
  - $\beta = 0$: high behavioural frictions and random choice
  - $\beta \to \infty$: 'neoclassical limit', no behavioural frictions and bang-bang solutions

Cost expectations

- Depending on expected tax, firms evaluate the net present value Θ_i of expected production costs of technology i

$$E_{j,t}(\Theta_{i,t}) = \sum_{r=1}^{R} D^r \theta_{i,t+r} \left[1 + E_{j,t-1}(\tau_{i,t+r})\right]$$

where

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

Capital investments

- Based on expected discounted technological costs ($E_{j,t}(\Theta_{l,t})$), firms allocate their investment between low- and high-carbon
- Low-carbon investment share for belief type j, $\chi_{j,t} \in (0,1)$:

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

- γ: investment responsiveness (to what extent firms react to cost differentials)
  - $\gamma = 0$: high behavioural frictions and random choice
  - $\gamma \to \infty$: 'neoclassical limit', no behavioural frictions and bang-bang solutions

Aggregate investment and capital allocation

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

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

- 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

- Policy-maker evaluates transition risks as a function of
  - Announced policy stringency ($\bar{\tau}$)
  - Carbon intensity of economic system (κ)
- Transition risk index $\pi \in [0, 1]$:

$$\pi_t = 1 - \frac{1}{1 + a(1 - \kappa_t)\bar{\tau}_t}$$

where a represents vulnerability to transition risks Chart

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

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

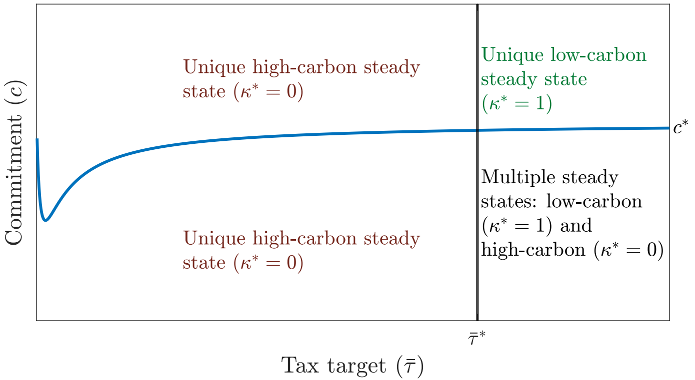
where $c \in [0, 1]$ is the policy-maker commitment to climate objectives against transition cost mitigation

Analytical results

Analytical results

- Reduced version of the model
  - e.g. $\bar{\tau}$ fixed; $\eta = 1$; $\epsilon_s = 0$; $\epsilon_b = 1$
- Dynamical system: $\kappa_{t+1} = f(\kappa_t)$ Details
- We consider two scenarios, differing in terms of belief and investments responsiveness
  - Neoclassical limit: $\beta = \gamma = \infty$
  - Behavioural frictions: $0 < \gamma < \infty$; $0 < \beta < \infty$

Steady states in the neoclassical limit



- Low-carbon steady state $\kappa_l^* = 1$ exists if $\bar{\tau} > \frac{\theta_l - \theta_h}{\theta_h} \equiv \bar{\tau}^*$
- High-carbon steady state $\kappa_h^* = 0$ exists if $\bar{\tau} < \bar{\tau}^*$ or $c < \frac{1}{2} - \mu_1 \equiv c^*$, where $\mu_1 = \frac{\bar{\tau} - \tau_0(1 + a\bar{\tau})}{2a\bar{\tau}^2} > 0$

Steady states under behavioural frictions

- A low-carbon steady state $\kappa_l^* = 1 - \lambda_l$ exists if a positive real number $\tilde{\lambda}_l$ exists such that Details

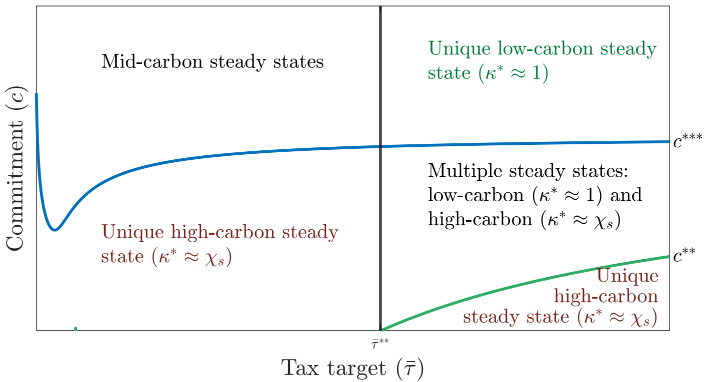
$$\bar{\tau} > \frac{\theta_l - \theta_h}{\theta_h} + \nu_{\tau l} \equiv \bar{\tau}^{**} \quad \text{and} \quad c > \frac{1}{2} - \mu_2 + \nu_{cl} \equiv c^{**}$$

- A high-carbon steady state $\kappa_h^* = \chi_s + \lambda_h$ exists if a positive real number $\tilde{\lambda}_h$ exists such that Details

$$c < \frac{1}{2} - \mu_3 + \nu_{ch} \equiv c^{***}$$

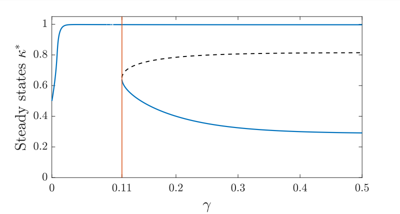
- ν parameters are 'behavioural premiums':
  - The higher behavioural frictions, the stronger should be tax announcements and commitment for low-carbon SS to exist
  - But they also decrease the commitment level below which a high-carbon SS exists

Steady states in the behavioural frictions

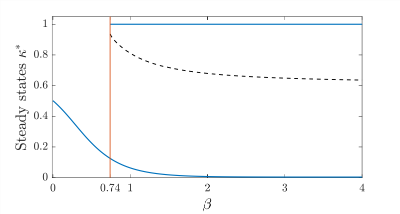


- Compared to neoclassical limit scenarios, two new regions:
  - Unambitious but committed policy-maker → mid-carbon SS
  - Very ambitious but weakly committed policy-maker → Unique high-carbon SS

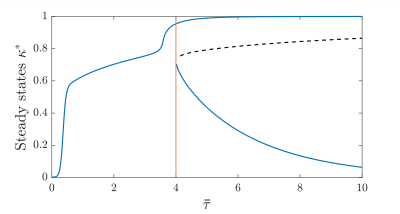
High-carbon trap drivers



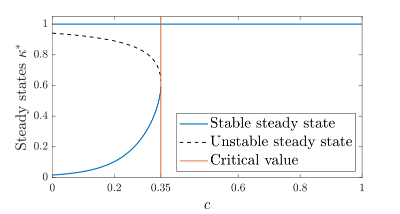
Investment responsiveness (γ)



Belief responsiveness (β)



Tax target ($\bar{\tau}$)



Commitment level (c)

Bifurcation diagrams. Default parameter values: $\bar{\tau} = 6$, $c = 0.3$, $\gamma = 0.5$, $\beta = 1$.

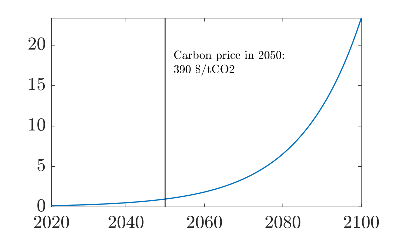
Numerical Results

Calibration strategy

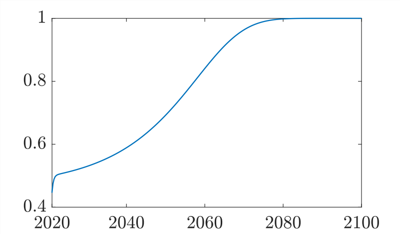
- Technological parameters (e.g. production costs)
  - Calibrated to European power sector
- Behavioural parameters
  - In particular: investment and belief responsiveness β and γ
  - Literature + sensitivity analysis
- Policy parameters
  - Calibrated on policy objectives + IAM projections
  - Scenario analysis
- Time: 320 quarters (2020-2100)

Details

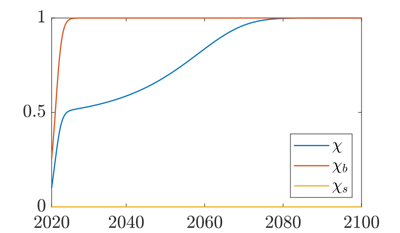
Benchmark transition scenario



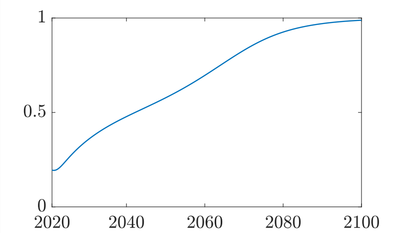
Tax announced ($\bar{\tau}$)



Share of believers (n)



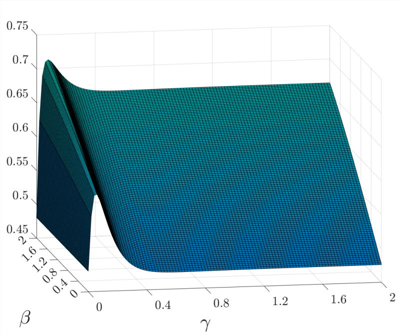
Low-carbon investment share (χ)



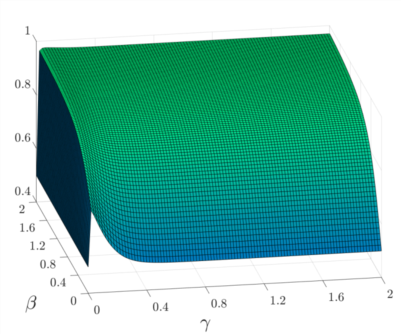
Low-carbon share of capital (κ)

Evolution over time of selected variables under full commitment ($c = 1$).

The role of behavioural frictions under full commitment



2050

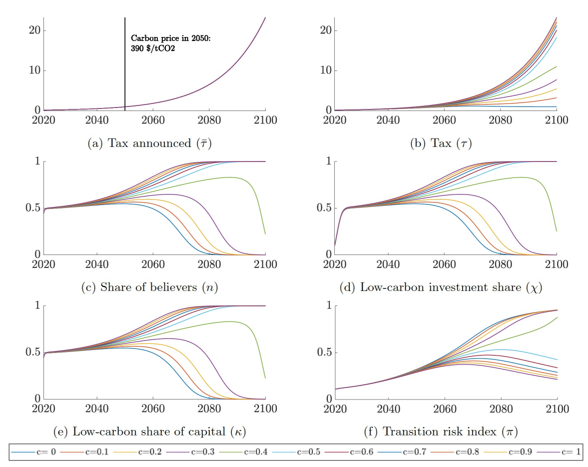


2080

Low-carbon capital share κ as a function of belief responsiveness β and investment responsiveness γ, under $c = 1$, in (a) 2050 and (b) 2080.

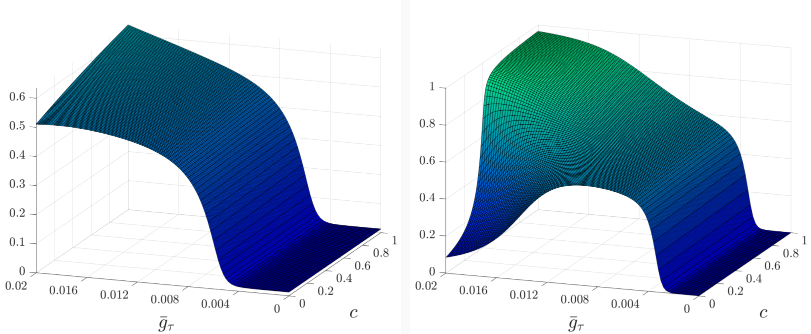
- Behavioural factors affect transition speed
- Higher belief frictions (low β) hamper the transition
- Non-linear impact of γ in the medium-run

The credible commitment problem



- Weak commitment → credibility loss → more high-carbon investments → higher transition risks → further distance from target → further loss of credibility → .. and so on

Tax announcements and policy-maker's commitment

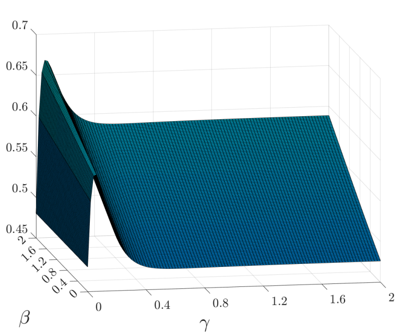


2050 2080

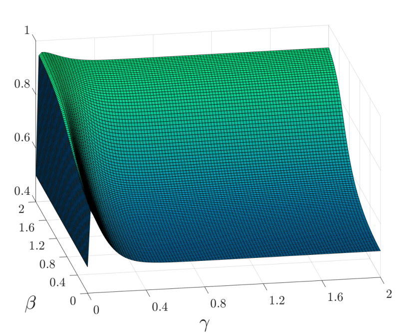
Low-carbon capital share κ as a function of the tax target growth rate $\bar{g}_\tau$ and commitment c, in (a) 2050 and (b) 2080.

- High ambition and low commitment endogenously lead to a transition failure

The role of behavioural frictions under weak commitment



2050

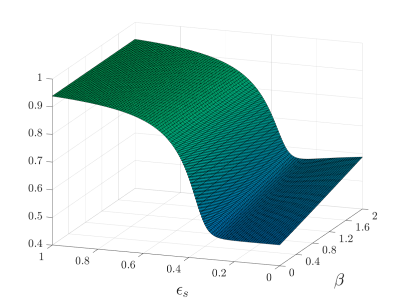


2080

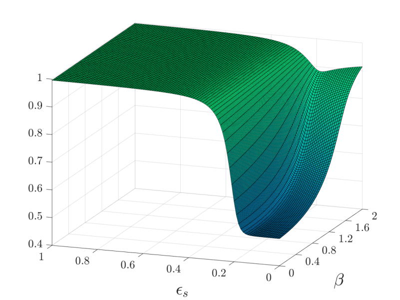
Low-carbon capital share κ as a function of belief responsiveness β and investment responsiveness γ, under $c = 0.3$, in (a) 2050 and (b) 2080.

- Higher β hampers transition as firms realise weak commitment
- Even higher β allows transition to take and keep enough momentum in early decades

Belief responsiveness and belief polarisation



2050



2080

Low-carbon capital share κ as a function of sceptics' discounting of the tax target growth rate ϵ_s and belief responsiveness β, under $c = 0.3$, in (a) 2050 and (b) 2080.

- For higher β, non-monotonic effect of belief polarisation
- But for lower β, strong polarisation leads to transition failure

Conclusions

Conclusions

- Transition model with
  - Behavioural frictions creating heterogeneity of expectations
  - Policy uncertainty and credibility
- Main results
  - Climate policy should be both ambitious and credible
  - Danger: Ambitious announcements by weakly committed policy-maker $\rightarrow$ emergence of high-carbon traps
  - Behavioural frictions (heterogeneity) makes the policy-maker's job harder, although they also help avoiding very bad equilibria
  - Belief polarisation can have non-linear effects on transition dynamics

Implications and future research

- Policy implications
    - Data on expectations and their distribution needed
    - Ability to orient expectations: what is most appropriate policy/institutional framework?
    - Get the ambition right: too little and too much are both dangerous for transition dynamics
- Further work
    - Endogenous commitment; electoral cycles
    - Wider macro behaviour (endogenous growth)
    - Financial investment choices
    - Climate physical impacts

Thank you!

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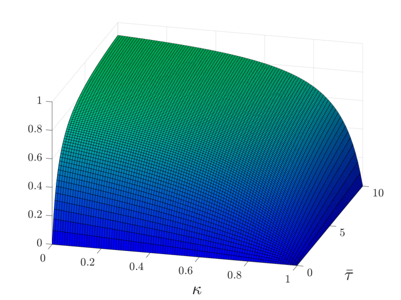
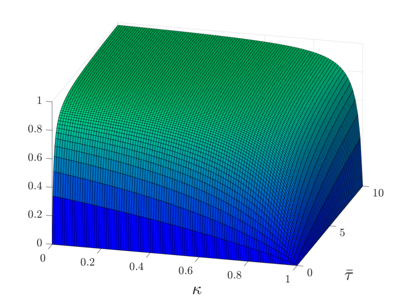
Additional slides

Transition risk index



$a = 1$



$a = 5$

Transition risk index π as a function of κ and $\bar{\tau}$, for two distinct levels of a.

Back

Dynamics of the low-carbon capital share

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

$$\kappa_{t+1} = n_{b,t+1}(\chi_{b,t+1} - \chi_s) + \chi_s$$

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

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

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

Dynamical system and steady states

Dynamical system in κ

$$\kappa_{t+1} = (\chi_b - \chi_s)n_{t+1} + \chi_s \equiv f(\kappa_t),$$

with

$$n_{t+1} = \left[1 + \exp\left(-\beta\left\{2\bar{\tau}\left[c + \frac{1-c}{1+a(1-\kappa_t)\bar{\tau}}\right] - \tau_0 - \bar{\tau}\right\}\right)\right]^{-1}$$

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

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

Back

Steady states under behavioural frictions (I)

Proposition 3 (part I) Under the assumption of finite β and γ,

(i) A low-carbon steady state $\kappa_l^* = 1 - \lambda_l$ exists if a positive real number $\tilde{\lambda}_l$ exists such that

$$\bar{\tau} > \frac{\theta_l - \theta_h}{\theta_h} + \nu_{\tau l} \equiv \bar{\tau}^{**} \quad \text{and} \quad c > \frac{1}{2} - \mu_2 + \nu_{cl} \equiv c^{**} \tag{1}$$

where

$\tilde{\lambda}_l = \lambda_l + \varepsilon_l$, with ε_l a small positive number and $\tilde{\lambda}_l \in (0, \frac{1}{2})$,

$\nu_{\tau l} = -\ln\left(\frac{\tilde{\lambda}_l}{1-\tilde{\lambda}_l}\right) \rho\{\gamma\theta_l(1+\rho)\left[1-(1+\rho)^{-(R+1)}\right]\}^{-1}$

$\nu_{cl} = -\ln\left(\frac{\chi_b - 1 + \tilde{\lambda}_l}{1-\tilde{\lambda}_l-\chi_s}\right)(2\bar{\tau}\beta)^{-1}\left(1 + \frac{1}{a\tilde{\lambda}_l\bar{\tau}}\right)$, and

$\mu_2 = \frac{\bar{\tau} - \tau_0(1+a\tilde{\lambda}_l\bar{\tau})}{2a\tilde{\lambda}_l\bar{\tau}^2} > 0$.

Back

Steady states in the behavioural frictions (II)

Proposition 3 (part II) Under the assumption of finite β and γ,

(ii) A high-carbon steady state $\kappa_h^* = \chi_s + \lambda_h$ exists if a positive real number $\tilde{\lambda}_h$ exists such that

$$c < \frac{1}{2} - \mu_3 + \nu_{ch} \equiv c^{***} \tag{2}$$

where

$\tilde{\lambda}_h = \lambda_h + \varepsilon_h$, with ε_h a small positive number and $\tilde{\lambda}_h \in (0, \chi_b - \chi_s)$,
$\nu_{ch} = -\ln\left(\frac{\chi_b - \chi_s - \tilde{\lambda}_h}{\tilde{\lambda}_h}\right)(2\bar{\tau}\beta)^{-1}\left\{1 + \frac{1}{a[1-(\chi_s+\tilde{\lambda}_h)]\bar{\tau}}\right\}$,
and
$\mu_3 = \frac{\bar{\tau} - \tau_0\{1 + a[1-(\chi_s+\tilde{\lambda}_h)]\bar{\tau})\}}{2a[1-(\chi_s+\tilde{\lambda}_h)]\bar{\tau}^2} > 0$

Back

A safe threshold for the low-carbon steady state

Proposition 4. Once the planned tax meets its condition set in (1), a sufficient but not necessary condition for the uniqueness of the low-carbon steady state is:

$$\bar{\tau} < \frac{1}{\beta(1-c)}. \tag{3}$$

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	1.77%
Initial low-carbon capital share	κ_0	0.2
Low- to high-carbon production cost	$\frac{\theta_l}{\theta_h}$	1.36

Calibration: Beliefs and investment decisions

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

Parameter	Symbol	Value
Discount rate	ρ	1.7%
Planning horizon	R	120
Initial shares of believers	n_0	0.3
Policy trust parameters	ϵ_b;ϵ_s	1; 0
Belief responsiveness	β	1
Memory parameter	η	0.5
Investment responsiveness	γ	1

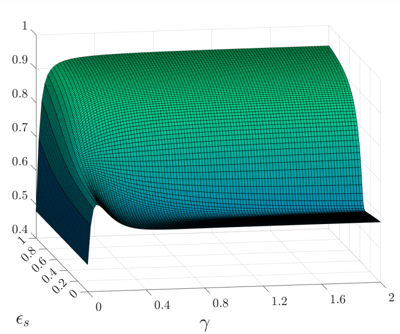
Calibration: Policy decisions

- 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 $\bar{\tau} \approx 1.2$

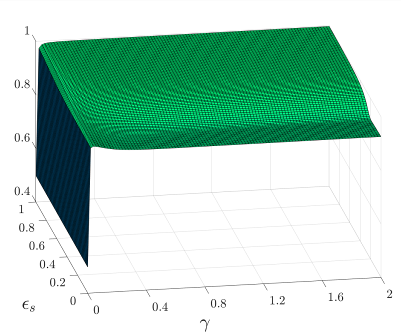
Parameter	Symbol	Value
Announced initial tax rate	$\bar{\tau}_0$	0.15
Announced tax growth rate	$\bar{g}_\tau$	0.016
Transition risk index parameter	a	1
Policy-maker tax commitment	c	[0,1]

Back

Investment responsiveness and belief polarisation ($c = 1$)



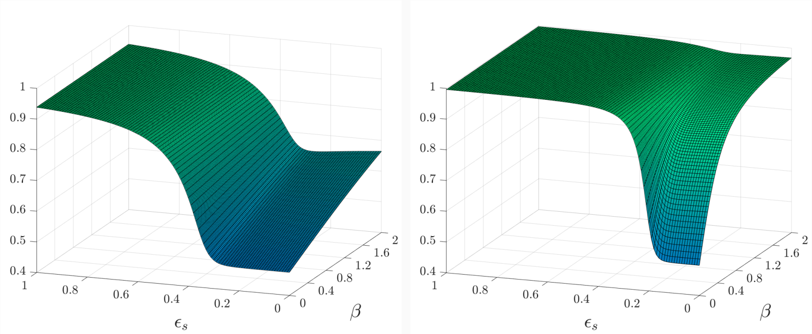
2050



2080

Low-carbon capital share κ as a function of sceptics' discounting of the tax target growth rate ϵ_s and investment responsiveness γ, under $c = 1$, in (a) 2050 and (b) 2080. All other parameters at their default value.

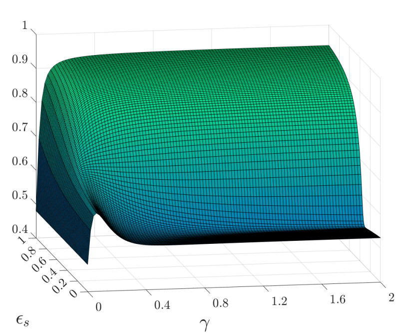
Belief responsiveness and belief polarisation ($c = 1$)



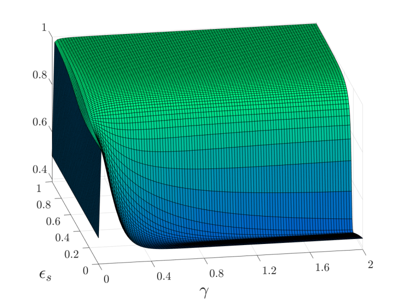
2050 2080

Low-carbon capital share κ as a function of sceptics' discounting of the tax target growth rate ϵ_s and belief responsiveness β, under $c = 1$, in (a) 2050 and (b) 2080. All other parameters at their default value.

Investment responsiveness and belief polarisation ($c = 0.3$)



2050



2080

Low-carbon capital share κ as a function of sceptics' discounting of the tax target growth rate ϵ_s and investment responsiveness γ, under $c = 0.3$, in (a) 2050 and (b) 2080. All other parameters at their default value.