Believe me when I say green!

Heterogeneous expectations and climate policy uncertainty

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Motivation

- Urgent to mitigate climate change
  - $\rightarrow$ Decarbonisation
- 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)

"..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)

Transition-related and landscape disruptions

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

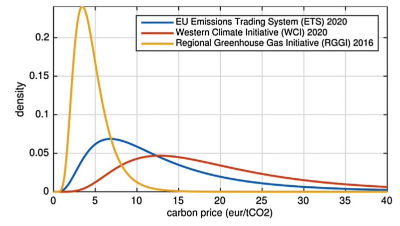
Anti-nuclear protests in Germany (2011)

Gilets Jaunes movement (2018)

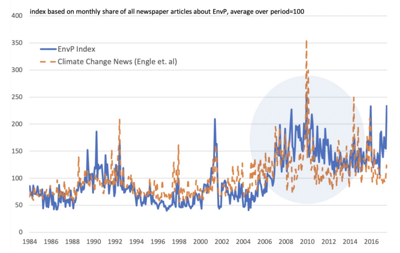
Ukraine war (2022)

Heterogeneous and evolving climate policy sentiments

- Context of uncertainty → Heterogeneity of expectations
- Sentiments change in time, adapting to new information



Carbon price expectations. Source: Nemet et al. (2017)



Climate sentiment indices. Source: Noailly et al. (2022)

Our contribution

- Research questions
  - How could heterogeneity/volatility of climate policy expectations affect the transition?
  - How is the policy-maker affected and how should it behave?

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  - How could heterogeneity/volatility of climate policy expectations affect the transition?
  - How is the policy-maker affected and how should it behave?
- We develop small macroeconomic model with:
  - Low- and high-carbon capital stocks
  - Heterogeneous and dynamic
    - Policy expectations
    - Trust in policy-makers (‘beliefs’)
  - Announcement of increasing carbon tax
  - Policy-maker concerned about transition costs

Overview of results

- Decarbonisation requires:
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  - A sufficiently committed policy-maker

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Overview of results

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  - A sufficiently strong carbon tax announcement
  - A sufficiently committed policy-maker
- Heterogeneity matters under full commitment
  - Higher expectation/beliefs dispersion $\rightarrow$ slower transition
  - Higher policy expectation dispersion $\rightarrow$ more ambitious policy announcements needed
- Commitment and the 'high-carbon trap'
  - A weakly committed policy-maker generates multiple equilibria
  - Higher announced tax $\rightarrow$ higher commitment needed
  - Higher belief dispersion $\rightarrow$ ambiguous effects
  - With weak commitment: more polarised expectations $\rightarrow$ faster transition

Related 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)
- Modelling framework
  - Rooted in discrete choice theory (McFadden 1973)
  - Heterogeneous expectations literature: Brock&Hommes 1997, 1998; De Grauwe&Macchiarelli 2015; Hommes&Lustenhouwer 2019; Assenza et al. 2021; Annicchiarico et al. 2022
  - Technological diffusion literature: Mercure et al 2014; Mercure 2015; Zeppini 2015

The model

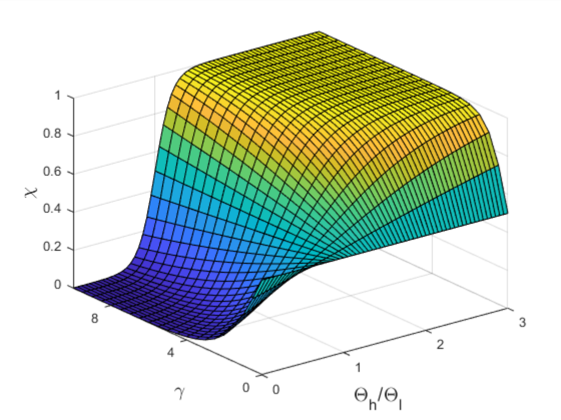
Physical productive system

- Two technologies ($i = l, h$)
  - High-carbon incumbent K_h
  - Low-carbon niche K_l
- Mass 1 of infinitesimal firms
  - Firms split into j 'sentiment populations'
- The j-specific share of low-carbon investment $\chi_{j,t} \in [0, 1]$ is

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

where γ is the investment intensity of choice (inversely related to expectation dispersion); $E_j(\Theta_i)$ the expectation of population j on technology i production costs

The investment allocation choice



Share of low-carbon investment χ as a function of expected NPV costs Θ_h/Θ_l and intensity of choice γ

- $\gamma = 0 \rightarrow \chi = 0.5 \ \forall \Theta_i$
- $\Theta_h = \Theta_l \rightarrow \chi = 0.5 \ \forall \gamma$

Cost expectations

- Firms evaluate the net present value Θ_i of expected costs of producing with technologies h and l:

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

where

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

Tax announcements

- To form expectations on future taxes, firms first look at policy-maker announcements
  - Long-term decarbonisation objectives (EU: net-zero by 2050)
  - $\rightarrow$ Implied optimal carbon tax (IAMs: ENGAGE scenarios)
- We assume an exponential tax announcement

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

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

Firms' beliefs

- Firms have heterogeneous beliefs about credibility of policy commitment. We assume two belief categories $j = b, s$
  - Believers (b) trust policy-makers' announcements more
  - Skeptics (s) trust policy-makers' announcements less
- At every time $t + r$, expected tax rate is:

$$E_{j,t}(\tau_{t+r}) = \bar{\tau}_t(1 + \epsilon_j \bar{g}_\tau)^r$$

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?

- The share of firms adopting each belief type $n_j \in [0,1]$ is then determined by

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

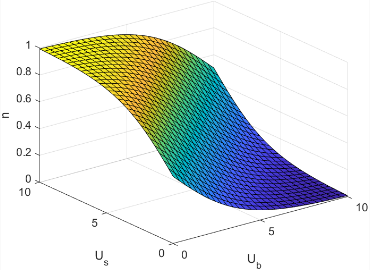
  with β is the belief intensity of choice (inversely related to dispersion of opinions)

- Firms evaluate the accuracy of their past beliefs via a fitness function U (Brock&Hommes, 1997, 1998):

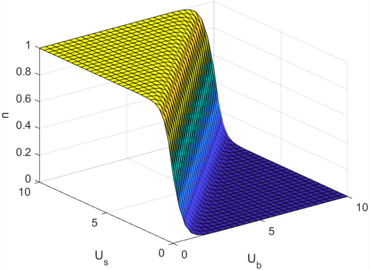
$$U_{j,t} = \eta(E_{j,t-1}(\tau_t) - \tau_t)^2 + (1-\eta)U_{j,t-1}$$

  where $\eta \in [0,1]$ is a memory (or belief inertia) parameter

The role of belief intensity choice β



$\beta = 0.5$



$\beta = 3$

Share of believers n_b as a function of fitness measures U_b and U_s

- $\beta \to 0$: random choice ($n_j = 0.5$)
- $\beta \to \infty$: all agents switch at the margin (n_j either 0 or 1)

Aggregate investment allocation

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

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

- Population shares

	Low-carbon	High-carbon	j shares
Believers	$n_b\chi_b$	$n_b(1-\chi_b)$	n_b
Sceptics	$n_s\chi_s$	$n_s(1-\chi_s)$	n_s
i shares	χ	$1-\chi$	1

Transition risks and policy commitment

- Transition risk index π function of low-carbon capital share κ and planned tax rate $\bar{\tau}_t$:

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

where a represents vulnerability to transition risks

  - Transition disruption amplification: financial exposure; welfare system fragility; social turmoil; etc.

- 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

Analytical results

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:

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

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

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

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

Long-term 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 neoclassical limit), 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 $A \equiv \frac{1-\rho^{R+1}}{1-\rho}$
$\Rightarrow$ The higher policy expectation dispersion (the lower γ), the more ambitious policy announcements need to be!

High-carbon steady state I

- **Benchmark scenario**. Under $\beta = \gamma = \infty$ (the neoclassical limit), 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 steady state 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

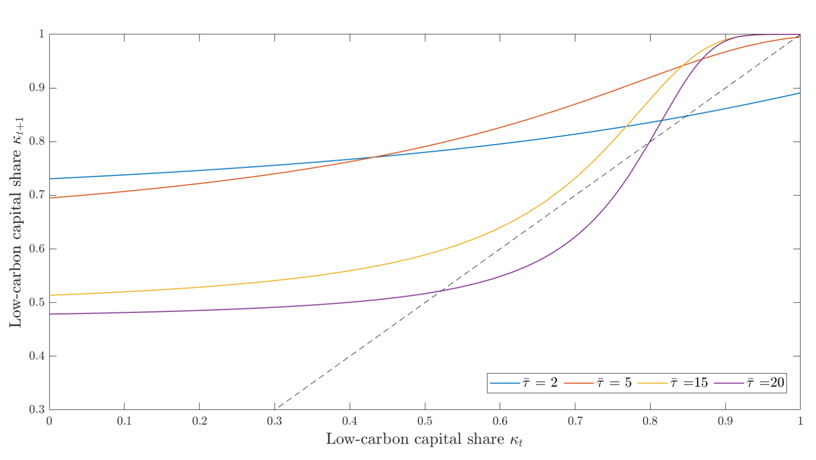
$$c > 1 - \frac{1}{\bar{\tau}\beta}$$

Proof

$\Rightarrow$ The higher belief dispersion (the lower β), the less committed the policy-maker is allowed to be

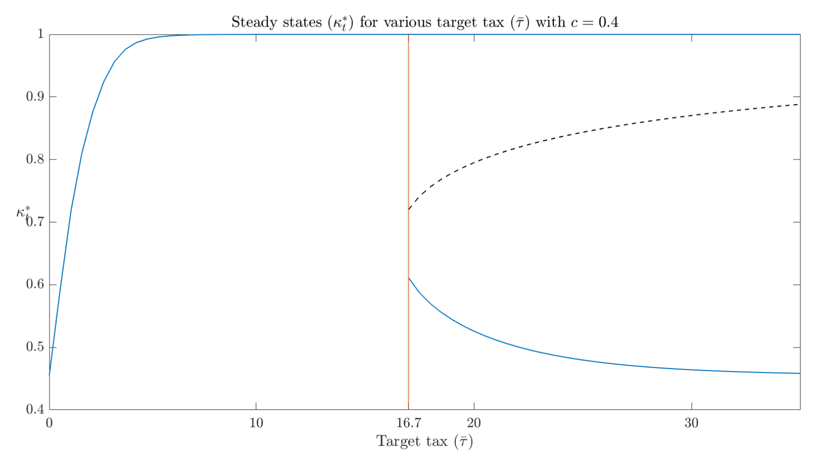
$\Rightarrow$ The higher the announced tax, the higher will the policy-maker's commitment need to be

When commitment is low, no ambitious announcements



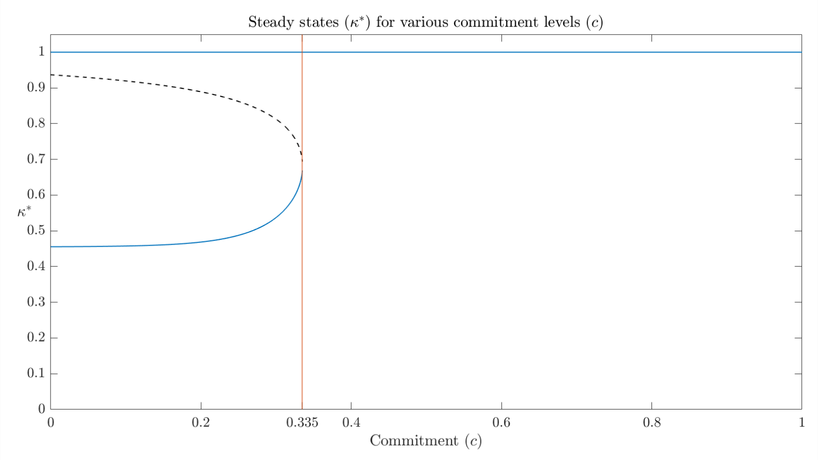
κ_{t+1} as a function of κ_t, for various values of τ (with $c = 0.4$)

When commitment is low, no ambitious announcements



Bifurcation diagram of $\bar{\tau}$

Low commitment creates a high-carbon trap



Bifurcation diagram of c

Calibration

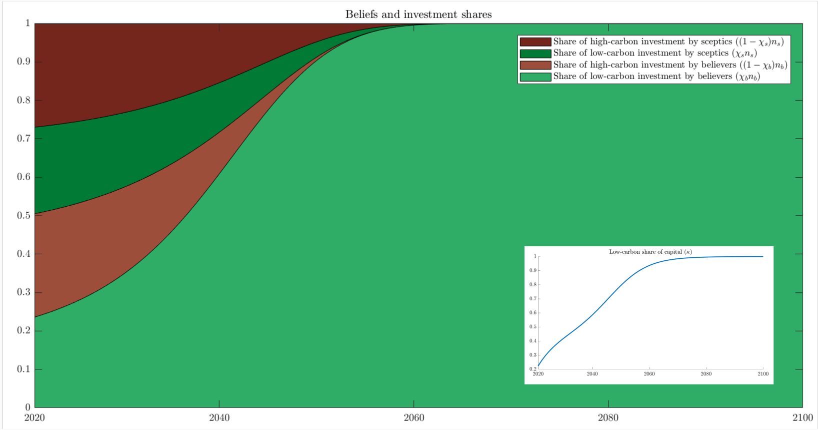
Calibration strategy

- Technological parameters (e.g. production costs)
  - Calibrated to European power sector
- Investment and opinion behaviours
  - Esp. intensity of choice parameters β and γ
  - Literature + sensitivity analysis
- Policy parameters
  - Calibrated on IAM projections
  - Scenario analysis
- Time: 320 quarters (2020-2100)

Details

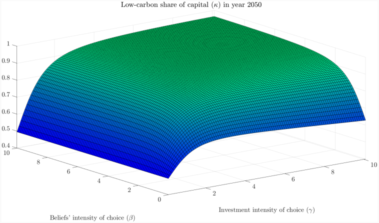
Results

Full-commitment benchmark scenario

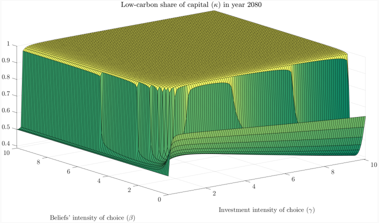


Evolving shares of low/high-carbon investments by sceptics/believers

Belief/investment choice intensities



$c = 1$ (full commitment)

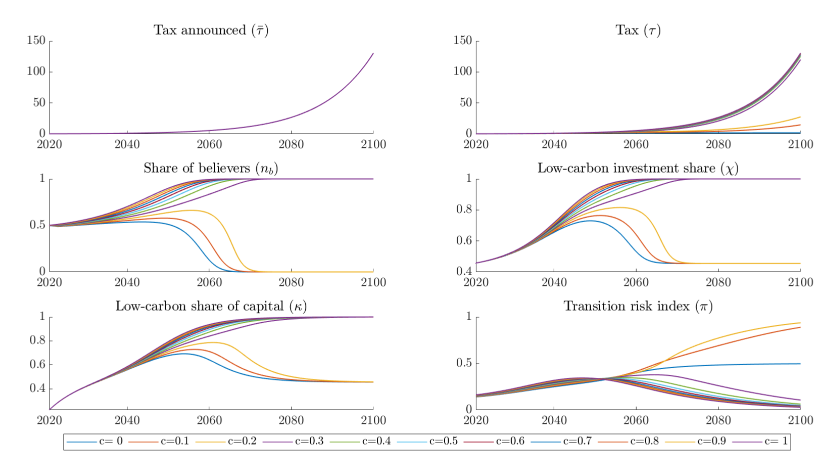


$c = 0.4$ (weak commitment)

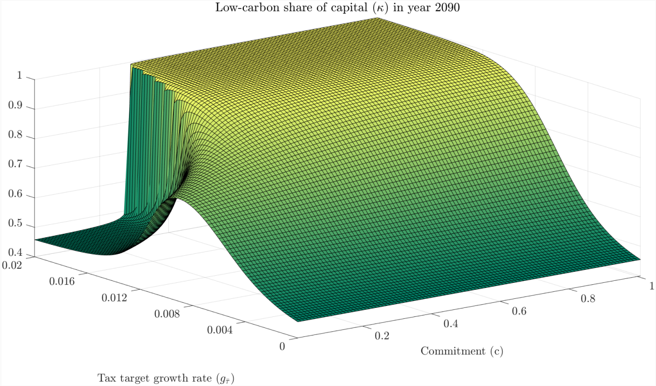
Low-carbon capital share κ as function of belief/investment choice intensities (β,γ)

- Under full commitment, higher belief/expectation heterogeneity $\rightarrow$ slower transition
- Under weak commitment and high belief heterogeneity $\rightarrow$ transition failure

Transition dynamics under various commitment levels



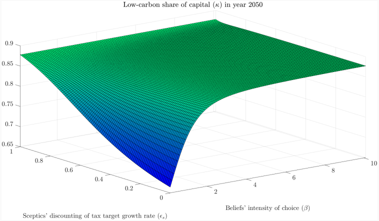
Commitment and tax announcements



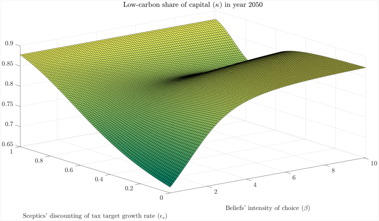
Low-carbon capital share κ as a function of g_τ and c

- Weakly committed policy-makers should not announce excessively ambitious tax targets

Beliefs polarisation and transition speed



$c = 1$ (full commitment)



$c = 0.4$ (weak commitment)

Low-carbon capital share κ as function of sceptics' degree of trust ϵ_s and belief choice intensity β

- Less heterogeneous beliefs (high belief choice intensity β) $\rightarrow$ more polarised expectations accellerate the transition

Conclusions

Conclusions

- Heterogeneity of expectations/beliefs will affect:
    - Technological investment choices
    - Dynamics expectations and trust in the policy-makers
    - Policy-maker's commitment
    - $\rightarrow$ Low-carbon transition speed and shape
- Policy take-away messages
    - More heterogeneous policy expectations $\rightarrow$ More ambitious announcements
    - But: danger! Ambitious announcements without strong commitment $\rightarrow$ Transition fails
    - Belief dispersion can be tricky: makes it easier to have unique equilibrium, but makes things worse if commitment is too low

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