Weitzman Meets Taylor:

ETS Futures Drivers and Carbon Cap Rules

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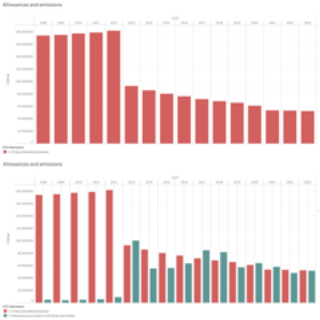
Motivation

Carbon pricing 1.0: ‘single order’ policies

- Most existing cap-and-trade systems (aka ETSs) are ‘single order’ policies
    - fixed cap & rigid permits allocation schedule



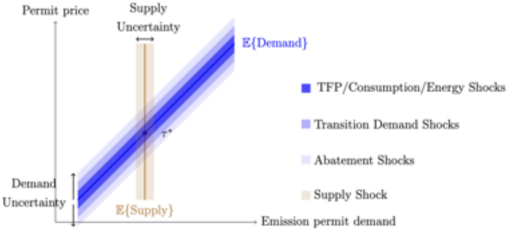
Features to respond to temporary shocks:

- banking and borrowing (temporal flexibility)
- cost and price containment mechanism
- auction reserve price

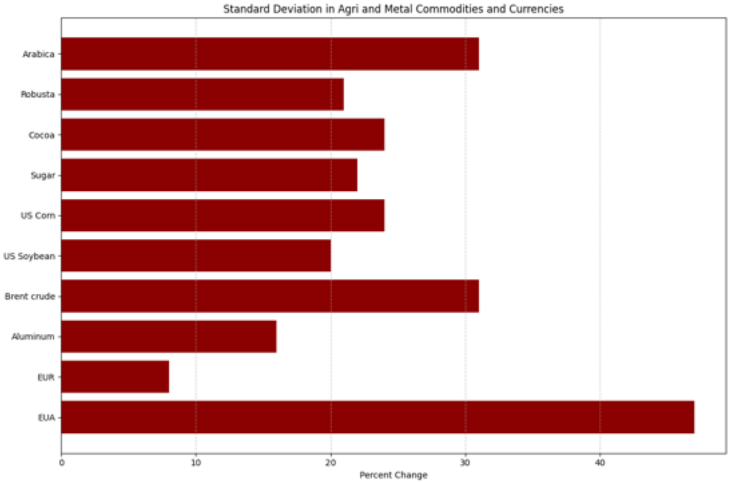
Emission demand and supply shocks

- Emission permits price should reflect stringency of the system (*supply*) and the market fundamentals associated with the demand of permits
- Large and/or persistent shocks can affect the policy outcome:

- economic activity
- technological innovation and progress Tech
- changes in regulations (allocation & companion policies) Policy



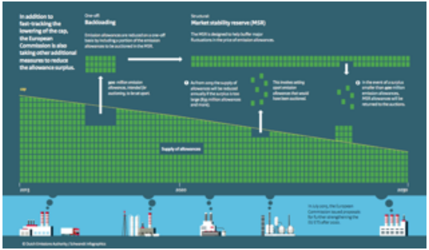
Carbon prices are extremely volatile



Enter carbon pricing 2.0: contingent policy design

Ideal instrument → contingency message whose instructions depend on which state of the world is revealed (economic shock, technology advancement, changes in policies, etc.).

- Knew for long: Weitzman (1974) and Roberts and Spence (1976).
- Indexed regulation on (more or less) observable indicators: Ellerman and Wing (2003), Newell and Pizer (2008), Heutel (2012), Golosov et al (2014), Karp and Traeger (2023).



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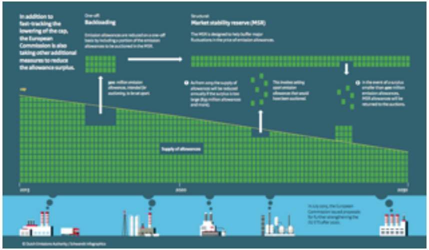


Contingent policy design: supply and demand shocks

- Respond to what really drives the price of emission allowances

- Combination of low frequency and lack of observability for some drivers poses a challenge in identifying shocks

In this paper

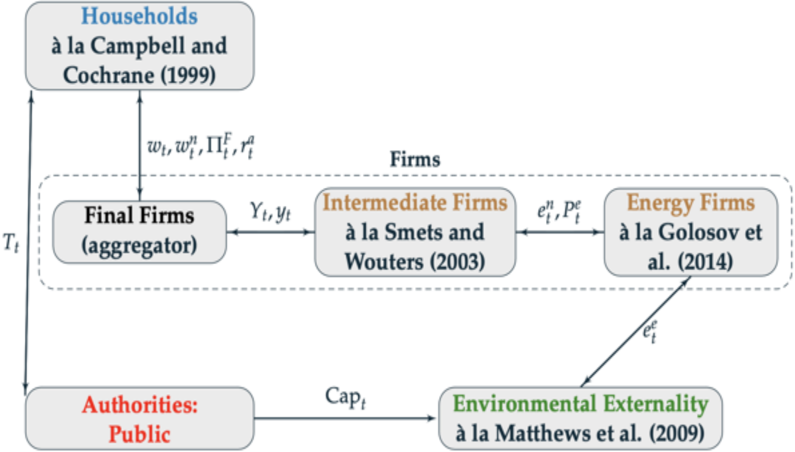
What we do

- Empirical: identify key determinants of EU ETS price
  - General equilibrium model that account for key demand and supply shocks
  - Novel estimation of less-frequently observable factors
  - Primary price drivers: energy prices, transition sentiment, abatement, and policy (supply) shocks.
- Theoretical: propose carbon cap rule (CCR) counterpart of Taylor rule
  - CCR function: cap management (responsive cap)
  - CCR responds to deviation in both emission and abatement costs.

→ CCR reduces overall price uncertainty over the business cycle

Model

Model elements: a quick overview



Households
à la Campbell and Cochrane (1999)

Firms

Final Firms
(aggregator)

Intermediate Firms
à la Smets and Wouters (2003)

Energy Firms
à la Golosov et al. (2014)

Authorities: Public

Environmental Externality
à la Matthews et al. (2009)

Demand and supply uncertainty

- Climate change and emissions dynamics: ▸▸ more
  - Carbon intensity shock
- Energy Firms: ▸▸ more
  - Energy productivity shock; energy prices shocks; abatement shock
- Non-energy Firms: ▸▸ more
  - Total factor productivity shock; energy prices shocks
- Households: ▸▸ more
  - Consumption shock
- Government: ▸▸ more
- Environmental Authority: ▸▸ more
  - Policy (supply) shock

Estimation

Data and estimation strategy

- Data and estimation strategy:
  - Eurostat: productivity and consumption patterns;
  - OECD and Bloomberg: energy supply and prices;
  - EDGAR[1] (CO_2 emissions): policy/supply shock;
  - ICE (EUA futures prices): abatement shock;
  - Bua et al (2022): carbon transition (sentiment) shock.
- Time frame: January 2013 - December 2019.

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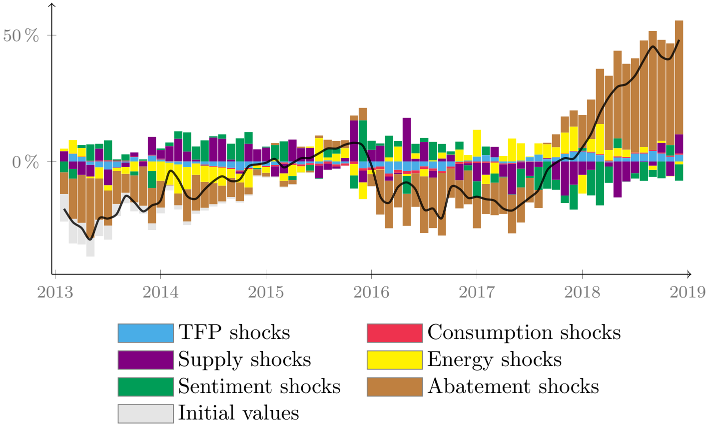
[1] EDGAR is the Emissions Database for Global Atmospheric Research

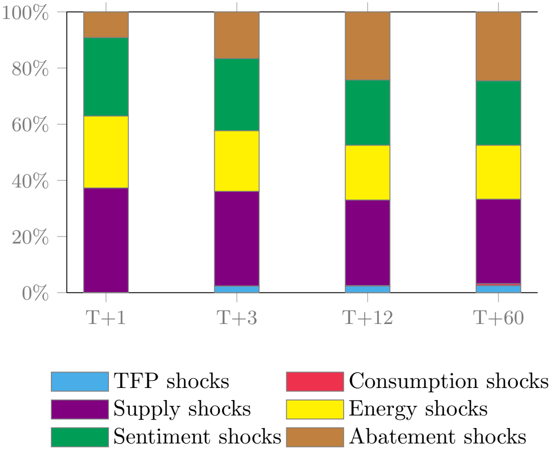
Results

EUA futures price decomposition



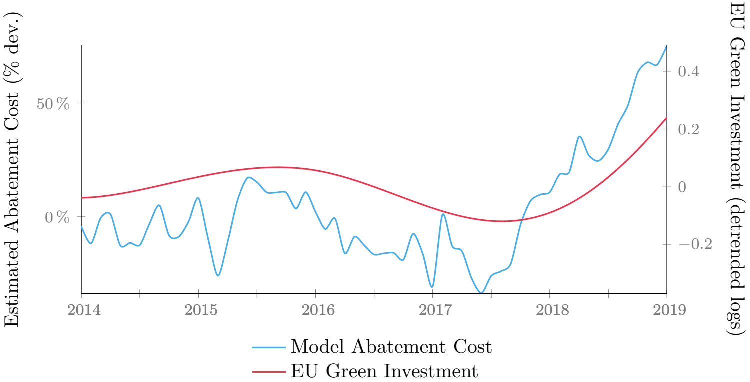
De-trended EUA futures price (black line) broken down into different drivers over the estimated period 2013–2019.

EUA futures price variance decomposition



EUA futures price variance decomposition over different horizons.

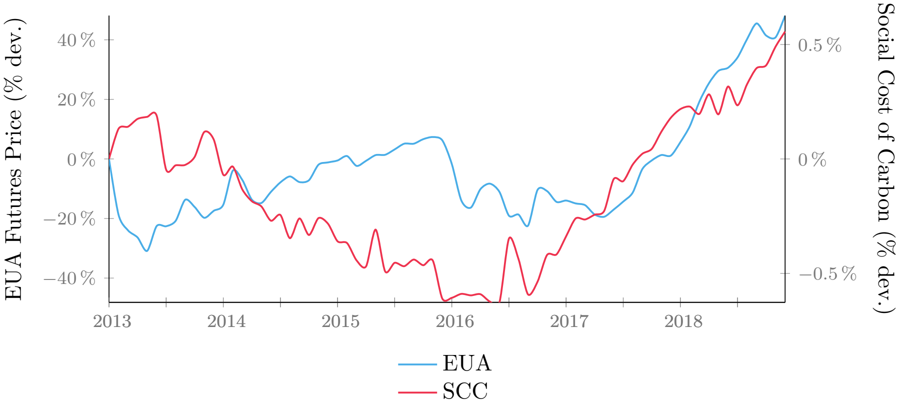
Estimated abatement costs and abatement investment



Notes: The figure displays the estimated abatement costs as a deviation of their steady state, alongside the actual data on climate mitigation investment for the EU in detrended log million euros.

Comparison

EU ETS and optimal policy (SCC): how much 'excess' volatility



Deviations of estimated EUA price and SCC in percentage from their respective steady states.

EU ETS carbon price vs. SCC: a less volatile carbon price

	ETS Cap Policy Estimated Column (1)	Social Cost of Carbon Optimal Column (2)
Emissions (Std. Dev.)	0.9 %	2.44 %
Abatement Cost (Std. Dev.)	18.33 %	9.33 %
Carbon Price (Std. Dev.)	19.17 %	0.31 %

Adaptive cap

Adaptive cap and rule for a central carbon bank

- Fear of making costly mistakes due to volatile prices deter businesses from investing in capital-intensive projects or adopting new technologies.
- Adaptive cap adjusts the quantity of emission permits (Q_t) in the market:

$$Q_t = \overline{Q} + \phi_e \frac{(e_t^E - \bar{e}^E)}{\bar{e}^E} + \phi_z \frac{(z_t - \bar{z})}{\bar{z}},$$

  $\bar{e}^E$ and $\bar{z}$ are the de-trended steady-state emissions and abatement cost.
- Carbon cap rule counterpart of Taylor rule: respond to deviations in both emissions and abatement costs.

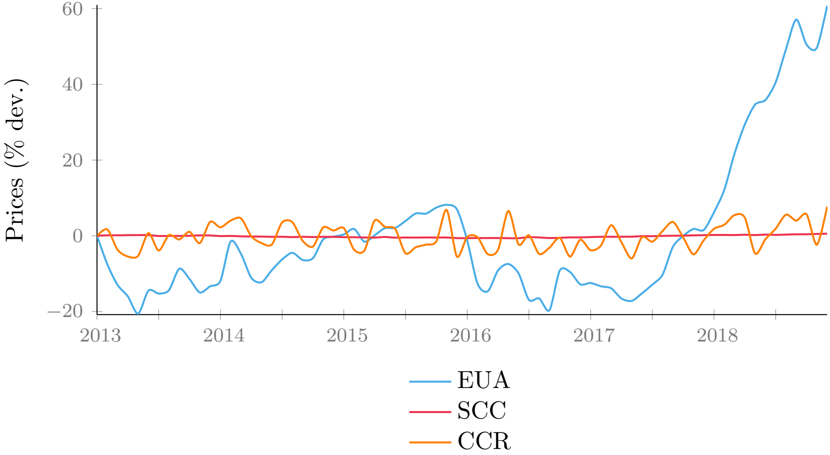
Carbon Cap Rules that minimize std. carbon price

	ETS Cap Policy Estimated Column (1)	Social Cost of Carbon Optimal Column (2)	Carbon Cap Rule $\phi_z = 0.1853$ and $\phi_e = -0.0027$ Column (3)
Consumption (Std. Dev.)	1.74 %	1.78 %	1.73 %
Output - Industrial Prod (Std. Dev.)	1.11 %	1.11 %	1.11 %
Emissions (Std. Dev.)	0.9 %	2.44 %	2.46 %
Abatement Cost (Std. Dev.)	18.33 %	9.33 %	8.29 %
Carbon Price (Std. Dev.)	19.17 %	0.31 %	3.51 %

Table: Policy Scenarios Estimated Second Moments

- CCR prioritizes control of abatement costs over strictly adhering to per-period emission level.

EUA, SCC, and CCR variation



Conclusion

Conclusion

- Novel strategy to estimate and decompose the drivers of the EU ETS.
  - Key driving factors: Energy fundamentals, transition demand, abatement, and policy (supply).

- Compared to the SCC, the EU ETS price is 80 times more volatile
  - Volatility in EU ETS prices generates yearly losses of 0.006 percent in consumption-equivalent terms compared to the SCC case.

- Carbon cap rule can significantly reduce price volatility and welfare losses (close to SCC)
  - Possible rule to operate a Central Carbon Bank

THANK YOU!

Appendix

Drivers: mitigation technologies and abatement innovation

Rio Tinto and Alcoa announce world's first carbon-free aluminium smelting process

Media release

10 May 2018

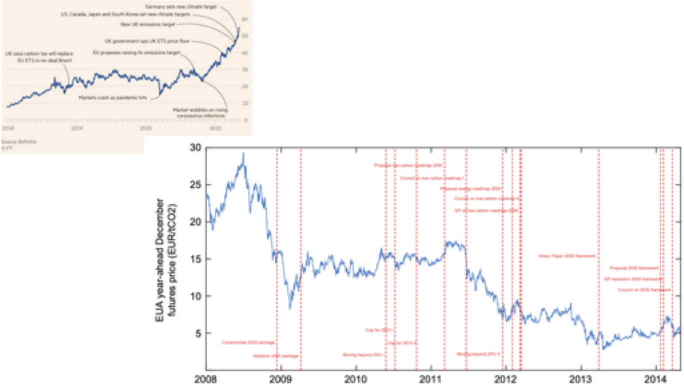
MONTREAL, May 10, 2018 – Rio Tinto and Alcoa Corporation today announced a revolutionary process to make aluminium that produces oxygen and eliminates all direct greenhouse gas emissions from the traditional smelting process.

This Carbon-Neutral Cement Is the Future of Infrastructure

It could eliminate the 2 gigatons of carbon dioxide annually pumped into the atmosphere through traditional cement production.

- Cement, a key ingredient in concrete, requires mined limestone. Now, researchers are replacing the limestone with microalgae.
- Adding in this biogenic limestone can make concrete carbon neutral, and potentially carbon negative, by pulling carbon dioxide from the atmosphere.
- By growing calcium carbonate through photosynthesis, the biogenic limestone can replace quarried limestone.

Drivers: policy and regulatory changes



- Koch et al. (2016) and Deeney et al. (2016)

Return

Climate change and emissions dynamics 1/2

- Global temperature:

$$T^o_{t+1} = \zeta^o_1(\zeta^o_2 X_t - T^o_t) + T^o_t,$$

- Cumulative CO_2 emissions:

$$X_{t+1} = \eta X_t + (E^E_t + E^{NE}_t) + E^*_t,$$

- E^E_t from energy production (Y^E_t) and E^{NE}_t non-energy sector
- E^*_t non-anthropogenic emissions and $0 < \eta < 1$ persistence of emissions

Climate change and emissions dynamics 2/2

- Flow of emission (abated for energy sector):

$$E_t^E = (1-\mu_t)\,\varphi_{\mathrm{E}}\epsilon_t^{\varphi_{\mathrm{E}}} Y_t^E \Gamma_t^X, \quad \text{and} \quad E_t^{NE} = \varphi_{\mathrm{NE}} Y_t^{NE} \Gamma_t^X$$

- Γ_t^X exogenous carbon transition trend (decoupling emissions and production)
- $\varphi_{\mathrm{E}} \geq 0$ carbon-intensity and $0 \leq \mu_t \leq 1$ fraction of abated emissions
- Carbon intensity shock of energy production:

$$\log\left(\varepsilon_t^{\varphi_{\mathrm{E}}}\right) = \rho_{\varphi_{\mathrm{E}}} \log\left(\varepsilon_{t-1}^{\varphi_{\mathrm{E}}}\right) + \eta_t^{\varphi_{\mathrm{E}}},$$

with $\eta_t^{\varphi_{\mathrm{E}}} \sim N(0, \sigma_{\varphi_{\mathrm{E}}}^2)$.

Energy Firms: Production

- Production:

$$\tilde{Y}_t^E = \varepsilon_t^{A_E} A_t^E (K_t^E)^{\alpha_E} (\Gamma_t^Y l_t^E)^{1-\alpha_E} \Gamma_t^{Y^E},$$

- Energy productivity shock:

$$\log\left(\varepsilon_t^{A^E}\right) = \rho_{A^E} \log\left(\varepsilon_{t-1}^{A^E}\right) + \eta_t^{A^E}$$

with $\eta_t^{A^E} \sim N(0, \sigma_{A^E}^2)$.

Energy Firms: Profits and abatement

- Profits:

$$\Pi_t^E = \varepsilon_t^p p_t^E Y_t^E - w_t^E l_t^E - I_t^E - \left(f\left(\mu_t\right) Y_t^E\right) - \tau_t E_t^E.$$

- Energy price shock:

$$\log\left(\varepsilon_t^p\right) = \rho_p \log\left(\varepsilon_{t-1}^p\right) + \eta_t^p,$$

with $\eta_t^p \sim N(0, \sigma_p^2)$.

- Abatement cost function per unit of production and abatement shock:

$$f\left(\mu_t\right) = \theta_1 \mu_t^{\theta_2} \varepsilon_t^z \quad \text{and} \quad \log\left(\varepsilon_t^z\right) = \rho_z \log\left(\varepsilon_{t-1}^z\right) + \eta_t^z$$

with $\eta_t^z \sim N(0, \sigma_z^2)$.

Final good firms: Production

- Production:

$$Y_t^{\mathrm{NE}} = \varepsilon_t^{A^{\mathrm{NE}}} A_t^{\mathrm{NE}} (K_t^{\mathrm{NE}})^{\alpha_{\mathrm{NE}}} (\Gamma_t^Y l_t^{\mathrm{NE}})^{1-\alpha_{\mathrm{NE}}}$$

- Total factor productivity (TFP) shock:

$$\log\left(\varepsilon_t^{A^{\mathrm{NE}}}\right) = \rho_{A^{\mathrm{NE}}} \log\left(\varepsilon_{t-1}^{A^{\mathrm{NE}}}\right) + \eta_t^{A^{\mathrm{NE}}}$$

with $\eta_t^{A^{\mathrm{NE}}} \sim N(0, \sigma^2_{A^{\mathrm{NE}}})$

Households

- Households' consumption:

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \varepsilon_t^B u\left(C_t - H_{t-1} - D_u(T_t^o)\right)$$

- Preference shock

$$\log \varepsilon_t^B = \rho_B \log \varepsilon_{t-1}^B + \eta_t^B$$

  with $\eta_t^B \sim N(0, \sigma_B^2)$

- Budget constraint:

$$w_t^{\text{NE}} l_t^{\text{NE}} + w_t^{\text{E}} l_t^{\text{E}} + r_t B_t + \Pi_t^E + \Pi_t^F - T_t = C_t + B_{t+1}$$

Government

- Government's budget

$$G_t = T_t + \tau_t E_t.$$

- The resource constraint of the economy

$$Y_t = C_t + I_t^{\mathrm{NE}} + I_t^{\mathrm{E}} + G_t + Z_t.$$

Environmental authorities

- Environmental regulation

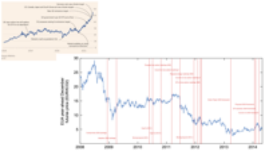
$$E_t^E = Q_t \epsilon_t^S$$

where Q_t is allowance emissions allocation

- *Supply* shock

$$\log \varepsilon_t^S = \rho_S \log \varepsilon_{t-1}^S + \eta_t^S$$

with $\eta_t^S \sim N(0, \sigma_S^2)$



Parameters Value

Parameter	Value	Definition
σ^U	1.5	Risk Aversion
β	0.9986	Discount Factor
α^E	0.33	Elasticity to Capital Input in Energy Production
α^{NE}	0.33	Elasticity to Capital Input in Non-Energy Production
χ	0.02	Share of Energy in the CES
σ	0.20	Substitution Parameter in the CES
δ	0.0083	Depreciation of Energy and Non-Energy Capital
φ^E	0.0055	Emission Intensity in Energy Production
φ^{NE}	0.0002	Emission Intensity in Non-Energy Production
Θ^T	26.29	Dis-utility Sensitivity to Temperature
η	0.0004	Decay Rate of Emissions in the Atmosphere
ζ_1^o	0.50	Climate Transient Parameter
ζ_2^o	0.00125	Climate Transient Parameter
θ_1	0.239	Level of the Abatement Cost Function
θ_2	2.7	Curvature of the Abatement Cost Function
$\frac{\bar{g}}{\bar{y}}$	0.22	Government Spending to Output Ratio

Moments matching

Variable	Label	Target	Source
ETS Mean Carbon Price (euros)	τ	7.54	ICE
Cumulative Emission (World, GtC)	X	800	Copernicus (EC)
Monthly Emission Flow (World, GtCO2)	$E^T + E^*$	4.51	Ourworldindata
Share of EU27 in World Emissions (%)	$E^T/(E^T + E^*)$	6.73	Ourworldindata
Share of Emissions from Energy Generation in the EU (%)	E^E/E^T	33.56	OECD
Emission intensity in the EU (kCO2 / euros)	E^T/Y	0.20	OECD
Emission intensity from Energy Generation in the EU (kCO2 / euros)	E^E/Y	0.07	OECD
Abatement level (percentage of energy emissions)	μ	0.20	EDGAR (EC)
Temperature	T^o	1.00	NOAA

Notes: All the values reported in this table are perfectly matched by the model at the steady state.

Estimated Parameters

		Prior Distributions			Posterior Distributions	
		Distribution	Mean	Std. Dev.	Mean	[0.05 ; 0.95]
Shock processes:						
Std. Dev. Goods Productivity	σ_A	$\mathcal{IG}_2$	0.10	0.05	0.02	[0.01 ; 0.02]
Std. Dev. Energy Productivity	σ_{A_n}	$\mathcal{IG}_2$	0.10	0.05	0.01	[0.01 ; 0.02]
Std. Dev. Energy Price	σ_p	$\mathcal{IG}_2$	0.10	0.05	0.09	[0.07 ; 0.11]
Std. Dev. Climate Sentiment	σ_{φ_E}	$\mathcal{IG}_2$	0.10	0.05	0.02	[0.01 ; 0.02]
Std. Dev. Consumption	σ_B	$\mathcal{IG}_2$	0.10	0.05	0.10	[0.09 ; 0.13]
Std. Dev. Abatement Cost	σ_Z	$\mathcal{IG}_2$	0.10	0.05	0.06	[0.05 ; 0.07]
Std. Dev. Allowances Supply	σ_S	$\mathcal{IG}_2$	0.10	0.05	0.02	[0.01 ; 0.02]
AR(1) Goods Productivity	ρ_A	$\mathcal{B}$	0.30	0.10	0.49	[0.32 ; 0.68]
AR(1) Energy Productivity	ρ_{A_n}	$\mathcal{B}$	0.30	0.10	0.35	[0.018 ; 0.54]
AR(1) Energy Price	ρ_p	$\mathcal{B}$	0.30	0.10	0.36	[0.22 ; 0.49]
AR(1) Climate Sentiment	ρ_{φ_E}	$\mathcal{B}$	0.30	0.10	0.34	[0.21 ; 0.50]
AR(1) Consumption	ρ_C	$\mathcal{B}$	0.30	0.10	0.21	[0.09 ; 0.30]
AR(1) Abatement Cost	ρ_Z	$\mathcal{B}$	0.30	0.10	0.86	[0.83 ; 0.89]
AR(1) Allowances Supply	ρ_S	$\mathcal{B}$	0.30	0.10	0.31	[0.15 ; 0.50]
Measurements errors:						
Consumption Survey		$\mathcal{U}$	0.0001	0.003	0.010	[0.009 ; 0.010]
Industrial Production		$\mathcal{U}$	0.0001	0.003	0.010	[0.009 ; 0.010]
Emissions		$\mathcal{U}$	0.0001	0.007	0.025	[0.024 ; 0.025]
Structural Parameters:						
TFP Trend	$(\gamma^y - 1) \times 100$	$\mathcal{U}$	0.00	0.29	0.17	[0.05 ; 0.27]
Emissions Trend	$(\gamma^x - 1) \times 100$	$\mathcal{U}$	0.00	0.29	-0.28	[-0.50 ; -0.07]

Notes: $\mathcal{IG}_2$ denotes the Inverse Gamma distribution (type 2), $\mathcal{B}$ the Beta distribution, and $\mathcal{N}$ the Gaussian distribution.