Climate Change Mitigation: How Effective is Green Quantitative Easing?

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Research Question and Results

- Comparison of Green QE to Carbon Tax with respect to
  - Emission reduction
  - Temperature reduction
- Green QE understood as ...
  - ... shift in central banks' private sector securities portfolio ...
  - ... towards green assets
  - Rationale for QE itself not modeled
- Results
  - Green QE can contribute to climate change mitigation
  - But less effective than a carbon tax
  - Green QE complementary, if insufficient carbon pricing

Approach

- Integrated Assessment Model (IAM)
  - World economy
  - General equilibrium
  - Two production sectors: **Clean** and **Dirty**
  - Dirty energy sector emits carbon
  - Climate module
  - Portfolio choice: clean and dirty capital
    - Idiosyncratic return-risk
    - Imperfect correlation of returns $\rightarrow$ partial crowding out
- Policy Experiments:
  - Carbon tax
  - Green quantitative easing (QE)
  - Carbon tax + green QE

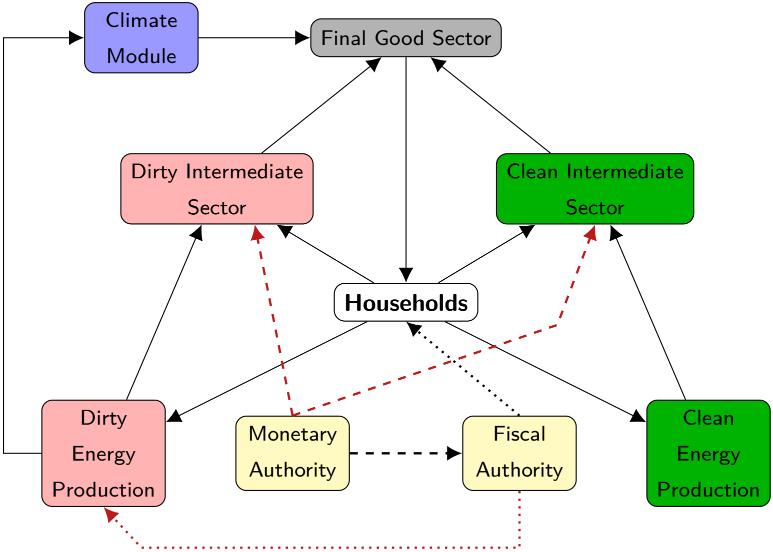
Green Policies

- **Maximum (Stylized) Green QE**
  - **Perfect** clean-dirty **taxonomy**
  - Central banks' **portfolio size is large and growing**
  - **Full immediate shift** towards green assets
  - **High elasticity of substitution** (between clean and dirty goods)
  - **Zero correlation** of asset returns
- **Modest Carbon Tax**
  - Carbon tax of 50 USD/tC ($\approx$ **13.6 USD/tCO2**)
  - Tax rate constant (relative to dirty energy costs)

Related Literature

- IAMs along the **transition**: Golosov et al. (2014), Kotlikoff et al. (2019, 2021), Nordhaus and Boyer (2000), Van Der Ploeg and Rezai (2021), Ferrari and Landi (2022) etc.
- **DSGEs** with climate module and green monetary policy: Heutel (2012), Giovanardi, Kaldorf, Radke, and Wicknig (2021), Ferrari and Landi (2020), Benmir and Roman (2020)
- Papoutsi, Piazzesi and Schneider (2021): Carbon bias in Eurosystem's corporate bond portfolio

Model Overview



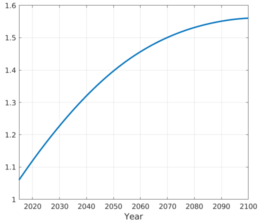
Results

Steps

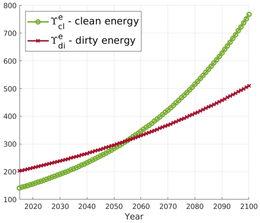
1. Transition profiles of baseline scenario (2015 - 2100 shown)
   - Central bank's capital proportional to private clean and dirty capital
   - No carbon tax
2. Three policy scenarios (introduced in 2021):
   - Carbon tax
   - Green QE
   - Carbon tax + green QE
3. Comparison of transition profiles of baseline and 3 counterfactuals

Results - Baseline

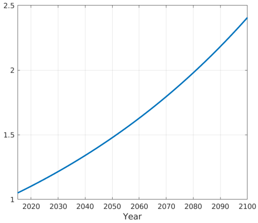
Exogenous Driving Forces



(a) Labor



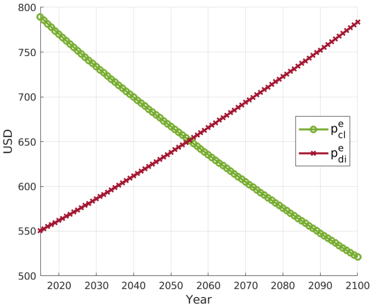
(b) Energy productivity



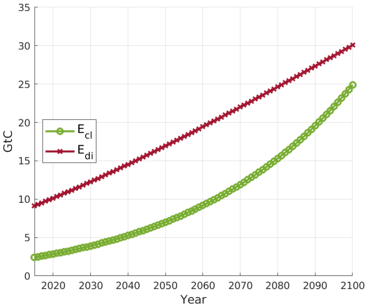
(c) Final good productivity

Results - Baseline

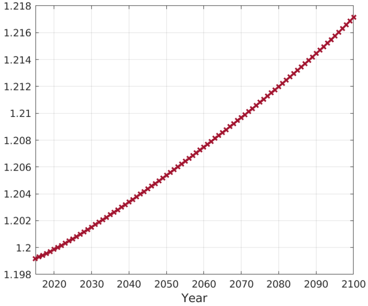
Intermediate Production - Energy Input



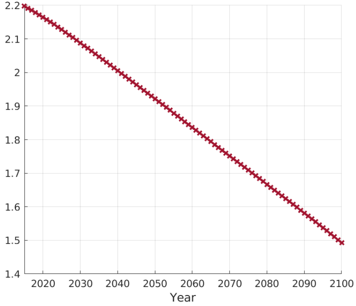
(a) Energy price



(b) Energy input



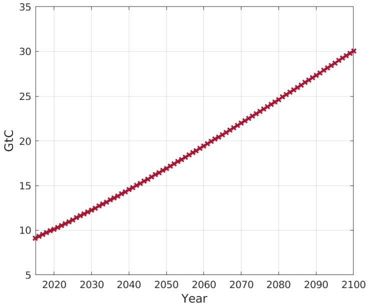
(a) Relative price dirty to clean $\left(\frac{p_{di}}{p_{cl}}\right)$



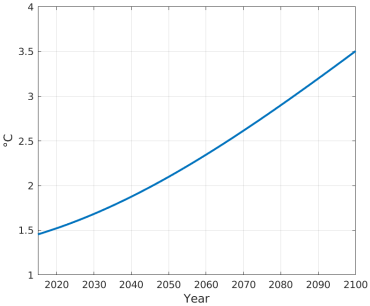
(b) Relative good use dirty/clean $\left(\frac{Y_{di}}{Y_{cl}}\right)$

Results - Baseline

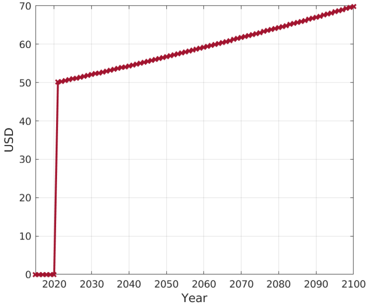
Climate Variables



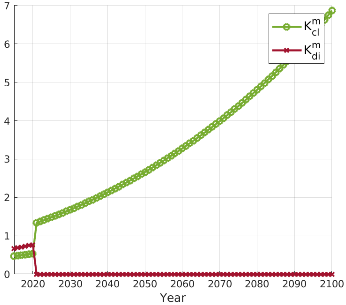
(a) Carbon emissions



(b) Temperature



(a) Carbon tax

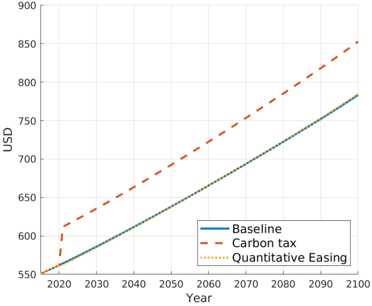


(b) Capital holdings by monetary authority

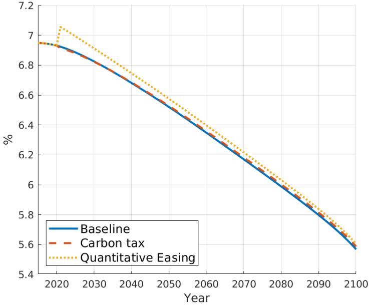
1. **Carbon tax**: $\tau^{e}_{2021,di} = 50$ USD/tC = **13.6 USD/tCO2**, growing with dirty energy price ($\approx 0.4\%$)
2. **Green QE**: **full shift** to K_{cl}, growing with capital ($\approx 2.0\%$)

Results - Scenarios

Dirty Energy Price & Capital Return

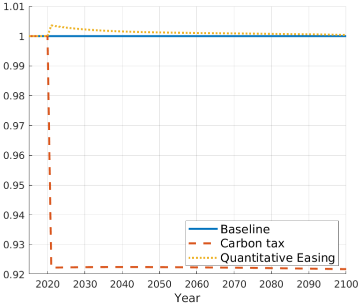


(a) Dirty energy price

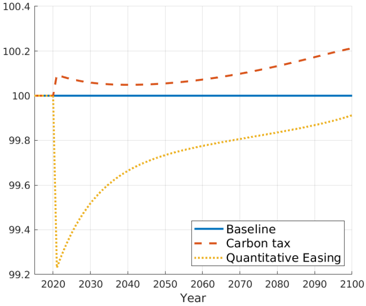


(b) Dirty rate of return

- **Carbon tax** increases dirty energy price: $p_{di}^{e} \uparrow$
- **Green QE** increases cost of dirty capital: $r_{di} \uparrow$



(a) Dirty energy intensity $\left(\frac{E_{di}}{Y_{di}}\right)$

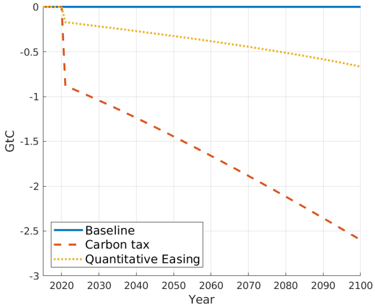


(b) Dirty capital intensity $\left(\frac{K_{di}}{Y_{di}}\right)$

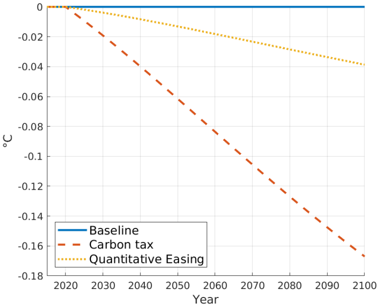
- **Carbon tax**: Lowers energy intensity, $E_{di}/Y_{di}\downarrow$ increases dirty capital intensity, $K_{di}/Y_{di}\uparrow$
- **Green QE**: Increases energy intensity, $E_{di}/Y_{di}\uparrow$ decreases dirty capital intensity, $K_{di}/Y_{di}\downarrow$

Results - Scenarios

Climate Variables - Reductions



(a) Emission reduction

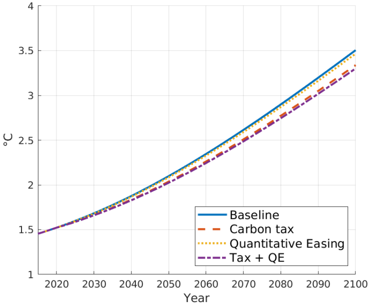


(b) Temperature reduction

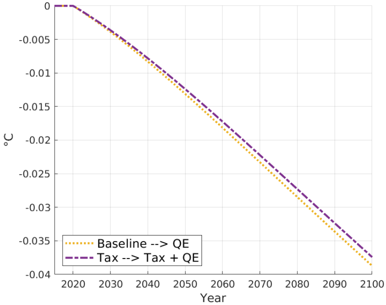
Year 2100 temperature reduction of **Green QE equivalent** to $\approx$ 11 USD/tC $\approx$ **3 USD/tCO2 carbon tax**

Results - Scenarios

Combining Carbon Tax & Green QE



(a) Temperature

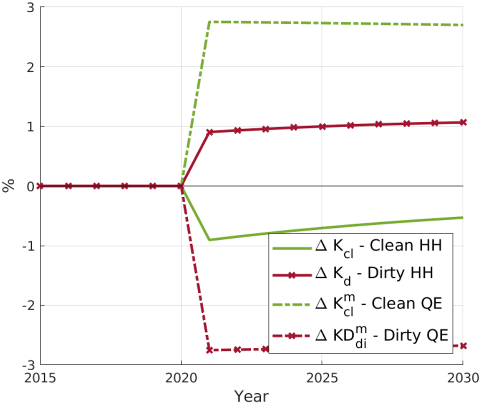


(b) Temperature reduction

Green QE on top of carbon tax (somewhat) less effective than standalone.

Results - QE-Scenario

Why no crowding out?



Imperfect crowding out of private held capital K_{cl}^{HH} through quantitative easing K_{di}^{HH} due to **imperfect correlation** of clean and dirty capital returns.

Sensitivity Analysis

	Baseline	Flat QE	CO2 Bias	Pos. Corr.	Low SE	WAPR	CO2 Re.
T in 2100	3.505	3.503	3.505	3.408	3.539	3.190	2.566
ΔT-τ	-0.167	-0.167	-0.167	-0.170	-0.155	-0.149	-0.107
ΔT-QE	-0.039	-0.011	-0.056	-0.032	-0.005	-0.036	-0.029
ΔT-$\tau/\Delta T$-QE	4.3	15.2	3	5.3	31	4.1	3.7

Summary

$\downarrow$ - Lower CO2 emissions $\uparrow$ - Higher CO2 emissions

- Carbon tax leads to ...
  1. $\downarrow$ Final sector: **Lower demand** for dirty interm. good
  2. $\downarrow$ Interm. sector: **Lower demand** for dirty energy
- Green QE leads to ...
  1. $\downarrow$ Final sector: **Lower demand** for dirty interm. good
  2. $\uparrow$ Interm. sector: **Higher demand** for dirty energy
  3. $\uparrow$ Partial crowding out of private capital
- Carbon tax stronger ($-0.167C^\circ$ vs. $-0.039C^\circ$ for green QE) ...
  - Green QE equivalent to carbon tax ≈ 3 USD/tCO2
- ... but green QE complementary to carbon tax

End

Thank you for your attention!

Households

Households choose $k_{t,i,cl}, k_{t,i,di}$ and c_{ti} facing **idiosyncratic risks in returns** $r_{t,i,cl}$ and $r_{t,i,di}$

Households **Epstein-Zin preferences**:

$$u_{ti} = \left[c_{ti}^{1-\upsilon} + \beta \cdot \left(\mathbb{E}[u_{t+1i}^{1-\theta}] \right)^{\frac{1-\upsilon}{1-\theta}} \right]^{\frac{1}{1-\upsilon}},$$

Households' **budget**:

$$k_{t+1,cl,i} + k_{t+1,cl,i}^{D} + (1+\tau_t^c)c_{ti} = (1+r_{t,cl,i})k_{t,cl,i} + (1+r_{t,di,i})k_{t,di,i} + r_t^l L$$

Energy production

Clean and **dirty** energy production, $s \in \{cl, di\}$ through labor only

$$E_{ts} = \Upsilon^e_{ts} L^e_{ts}.$$

Profit maximization, given energy prices p^e_{ts}, energy taxes τ^e_{ts} and wages r^l_t,

$$\max_{L^e_t} \; p^e_{ts} \left(1 - \tau^e_{ts}\right) \Upsilon^e_{ts} L^e_{ts} - r^l_t L^e_{ts},$$

yields **energy prices**

$$p^e_{ts} = \frac{r^l_t}{\left(1 - \tau^e_{ts}\right) \Upsilon^e_{ts}}.$$

Intermediate good production

Every household runs **two intermediate good firms**, **clean** and **dirty**, $s \in \{cl, di\}$ using **own capital** k_{tsi}, and purchasing labor ℓ_{tsi} and energy e_{tsi}

$$y_{tis} = \psi_s \left[(k_{tis})^{\alpha} (\ell_{tis})^{1-\alpha} \right]^{\gamma} \cdot e_{tis}^{1-\gamma} + \zeta_{tis} k_{tis},$$

where $(\zeta_{t,cl,i}, \zeta^{X}_{t,di,i}) \sim D(\cdot, \mathbf{\Sigma})$.

Profit maximization, given **intermediate good prices** p_{ts}, wages r_t^l, energy prices p_{ts}^e and depreciation rate δ_s

$$\max_{\ell_{tis}, e_{tis}} \quad p_{ts} \cdot y_{tis} - r_t^l \ell_{tis} - p_{ts}^e e_{tis} - \delta_s k_{tis},$$

... yields **capital returns**

$$r_{tis} = coeff \cdot p_{ts} \left(\frac{r_t^l}{p_{ts}} \right)^{-\frac{1-\alpha}{\alpha}} \cdot \left(\frac{p_{ts}^e}{p_{ts}} \right)^{-\frac{1-\gamma}{\alpha\gamma}} - \delta_s + p_{ts} \zeta_{tis}$$

Final Good Production

$$Y_t = (1 - D_t) \cdot \Upsilon_t \cdot \left(\kappa_{cl} (Y_{t,cl})^{\frac{\varepsilon - 1}{\varepsilon}} + \kappa_{di} (Y_{t,di})^{\frac{\varepsilon - 1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon - 1}},$$

with **damage** D_t.

Climate Module (Golosov et al., 2014)

Carbon stock

$$S_t = S_{1t} + S_{2t},$$

... accumulates according to

$$S_{1t} = \phi_1 \xi E_t^D + \rho_1 S_{1,t-1}$$
$$S_{2t} = (1 - \phi_1) \xi E_t^D + \rho_2 S_{2,t-1},$$

... determines **temperature**

$$T_t = \lambda \frac{\log(S_t / S)}{\log(2)},$$

... which determines **damage**

$$D_t = 1 - \frac{1}{1 + \nu T_t^2}.$$

- **Fiscal**
  - Levies **carbon taxes** $\tau^e_{t,di}$ and **consumption taxes** τ^c_t
  - Receives central bank's profits π^m_t
  - No government debt ($\rightarrow$ OLG/perpetual youth needed)

$$\tau^e_t E_{t,di} + \tau^c_t C_t + \pi^m_t = 0$$

- **Monetary**
  - Holds **clean** $K^m_{t,cl}$ and **dirty** $K^m_{t,di}$ **capital**
  - Proportional portfolio size: $K^m_{t,cl} + K^m_{t,di} = \bar{k}^{QE} \cdot \left(K^{HH}_{t,cl} + K^{HH}_{t,di} \right)$
  - **Central bank's profits** are

$$\pi = \mathbb{E}[r_{t,cl}]K^m_{t,cl} + \mathbb{E}[r_{t,di}]K^m_{t,di} - \Delta K^m_{t+1,cl} - \Delta K^m_{t+1,di}$$

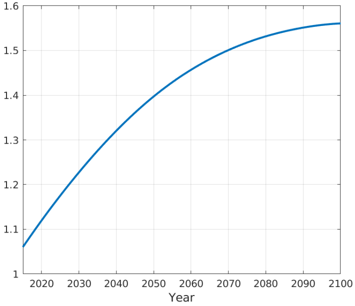
- Climate Module (a la Golosov et al., 2014):

$$S_{1t} = 0.5 \cdot 0.4 E_t^D + 0.999 \cdot S_{1,t-1}$$
$$S_{2t} = (1 - 0.5) \cdot 0.4 \cdot E_t^D + 0.995 \cdot S_{2,t-1}$$

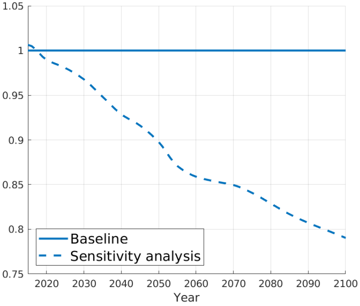
$$T_t = 3 \cdot \frac{\log(S_t/581)}{\log(2)}$$

$$D_t = 1 - \frac{1}{1 + 0.0028388\, T_t^2}$$

Population Dynamics



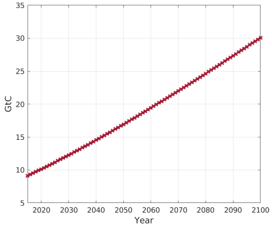
(a) Population size



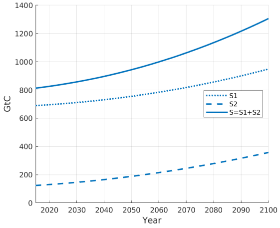
(b) WAPR

Results - Baseline

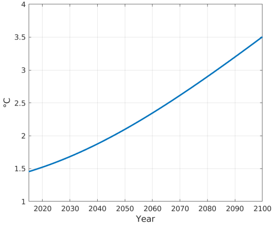
Climate Variables



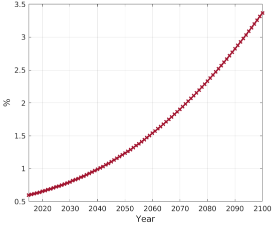
(a) CO2 emissions



(b) Carbon stock



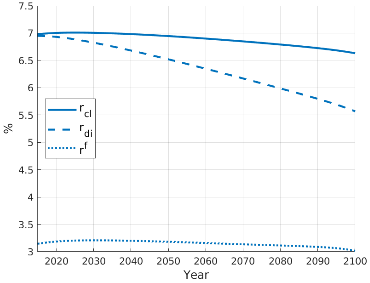
(c) Temperature



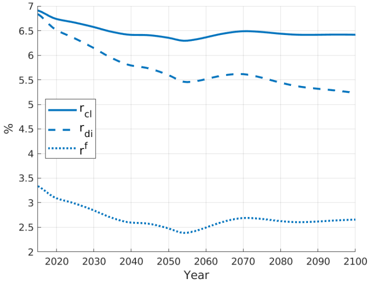
(d) Damage

Results - Baseline

Interest Rates



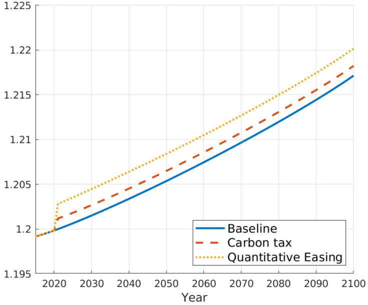
(a) Fixed WAPR - Main setup



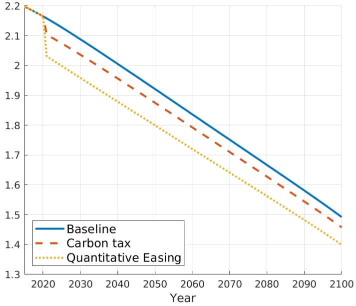
(b) Time-varying WAPR - Sensitivity setup

Results - Scenarios

Dirty Intermediate Good Price and Demand



(a) Relative price dirty to clean $\left(\frac{p_{di}}{p_{cl}}\right)$



(b) Relative good use dirty/clean $\left(\frac{Y_{di}}{Y_{cl}}\right)$

Calibration
First Stage Parameters

Parameter	Value	Target (Source)
Population and labour supply		
Initial population size N_0	1	Data moment (United Nations)
Initial population growth rate n_0	0.0121	Data moment (United Nations)
Initial working age population ratio ω_0	1	Constant (baseline)
Final good technology		
Elast. of subst. ε	26	Elasticity of energy subst. 2
Intermediate good technology		
Non-energy share: γ	0.96	Kotlikoff et al. (2019)
Capital share: α	0.33	Standard value
Climate Module		
Initial carbon stock: S_0	802 GtC	
Pre-industrial carbon stock: S_{pre}	581 GtC	
Stock 1 share: ϕ_s	[0.5,0.5]	a la
Emission share in atmosphere: ξ	0.4	Golosov et al. (2014)
Carbon stock persistence: ρ_c	$\rho_c = [0.996, 0.999], c \in \{ra, sl\}$	
Temp. increase with S: λ	3	
Temperature to damage: ν	0.0028388	
Preferences		
Elasticity inter-temp. substit., $1/\upsilon$	0.5	Standard value

Notes: Calibration in the baseline model. First stage parameters calibrated with reference to other studies or without using the model. Steady state year is year 2010.

Calibration

Second Stage Parameters

Parameter	Value	Moment
Final good technology		
Interm. good weight $\kappa_s, s \in \{cl, di\}$	$0.45, 0.55$	$E_{0s=di}/E_{0s=cl} = 4$
Growth rate final good TFP, g	0.0098	$(\frac{Y_{2100}}{L_{2100}} / \frac{Y_{2020}}{L_{2020}})^{\frac{1}{80}} - 1 = 1.50\%$
Intermediate good technology		
Iterm. productivity factor: $\psi_{s=cl} = \psi_{s=di}$	4811	$E_{0s=di} = 30$ GtCO2
Expected depreciation rate: $\delta_s, s \in \{cl, di\}$	$0.015, 0.087$	$\mathbb{E}[r_{0s}] = 6.94\%, , s \in \{cl, di\}$
Std. of depreciation shock: $\sigma_s^{\zeta}, s \in \{cl, di\}$	$0.030, 0.021$	$\sigma^{r_{0s}} = 8.4\%, s \in \{cl, di\}$ (std. of capital returns)
Energy production technology		
Clean productivity factor, $\Upsilon^e_{0s=cl}$	128	$p^e_{0s=cl} = 810$ USD/tC
Dirty productivity factor, $\Upsilon^e_{0s=di}$	192	$p^e_{0s=di} = 540$ USD/tCe
Growth rate clean prod. fact., $g^e_{s=cl}$	0.020	$(p^e_{2100s=cl}/p^e_{2020s=cl})^{\frac{1}{70}} - 1 = -0.50\%$
Growth rate dirty prod. fact., $g^e_{s=di}$	0.011	$(\frac{E_{2035s=di}}{Y_{2035}} / \frac{E_{2020s=di}}{Y_{2020}})^{\frac{1}{15}} - 1 = -0.50\%$
Preferences		
Time discount factor: β	0.997	$K/Y = 2.5$
Relative risk aversion: θ	63.9	$r^f = 2.9\%$
Central bank portfolio		
Capital holdings $K^m_{0s}, s \in \{cl, di\}$	$[6244, 8930]$	$K^m_{0s}/K_{0s} = 4\%, s \in \{cl, di\}$

Notes: Calibration in the baseline model. Second stage parameters calibrated endogenously by matching of moments. Steady state year is year 2010.