The Distributional Implications of Climate Policies Under Uncertainty

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June 18, 2021

Motivation I

- Market-based climate polices are important instruments to promote a timely decarbonization
- Under uncertainty climate policies have far reaching macroeconomic implications:
  - Volatility/cyclicality (Fischer and Springborn, 2011) and (Heutel, 2012)
  - Sectoral heterogeneity (Dissou and Siddiqui, 2014)
- Effects of climate policy driven by adjustment frictions, market structures and spillovers:
  - Nominal rigidities (Annicchiarico and Di Dio, 2015)
  - Transmission of shocks (Annicchiarico and Diluiso, 2019)

Motivation Con't

- Ambiguous evidence regarding distributional effects of climate policies:
  - Context-specific effects (Ohlendorf et al., 2020)
- Climate policy induces additional uncertainty:
  - Scientific uncertainty about carbon budget (Fujimori et al., 2019)
  - Technological uncertainty about abatement and capture (Ng et al., 2020)
- **The present study:**
  - Macroeconomic assessment of policies: volatility and welfare
  - Focus on distributional effects (credit constraint households)
  - Gauging the role of adjustment frictions (labor market rigidities)
  - Uncertainty about carbon budget and emission intensity

Nutshell

- **Approach:**
  - New-Keynesian Dynamic Stochastic General Equilibrium (DSGE)
  - Ricardian and non-Ricardian households (TANK)
  - Wage rigidities, price rigidities, and investment frictions
  - Quantitative assessment German economy
- **Summary Results:**
  - Policies differ w.r.t. volatility, welfare and distributional effects
  - Price instruments rather neutral and favorable in terms of welfare
  - Dist. effects driven by frictions and revenue recycling
  - Uncertainty about budget/technology has aggregate effects

Structure

- **Households:**
  - Supply labor to unions (wage rigidity)
  - Ricardian households: consume $c_{R,t}$, invest x_t in capital k_t and hold gov. bonds b_t
  - Non-Ricardian households: no assets, consume $c_{N,t}$ their net income ($MPC = 1$)
- **Production:**
  - Final goods y_t are CES composite of intermediate goods $y_{i,t}$ (monopolistic competition)
  - Intermediate goods producing firms are subject to Calvo pricing, demand union labor $h_{d,t}$, employ capital, and use polluting inputs (m_t) (Fischer and Springborn, 2011)
- **Public Sector:**
  - Standard government sector and monetary policy
  - Set of climate policies: tax, cap-and-trade, intensity target, flexible price

Households

- Continuum of households $l \in [0,1]$ where a fraction $1-\lambda$ has positive net worth (Ricardian) and a fraction λ has no net worth (non-Ricardian)
- Ricardian households solve:

$$E_0 \sum_{t=0}^{\infty} d_t \beta^t \left[\frac{c_{R,t}^{1-\rho}}{1-\rho} - \nu_t \psi \frac{h_{R,t}^{1+\chi}}{1+\chi} \right], \beta \in (0,1), \chi > 0,$$

s.t.

$$c_{R,t} + x_t + b_t = \mathcal{W}_t h_{R,t} + R_{t-1} \frac{b_{t-1}}{\Pi_t} + F_{u,t} + F_{F,t} + R_{k,t} k_t - T_t$$

$$k_{t+1} = \left[1 - \frac{\kappa}{2} \left(\frac{x_t}{x_{t-1}} - 1 \right)^2 \right] z_t x_t + (1-\delta) k_t$$

- Demand shocks (d_t), labor supply shocks (ν_t) and investment shocks (z_t) are i.i.d.

Households con't

- Non-Ricardian households have no access to financial markets:

$$c_{N,t} = \mathcal{W}_t h_{N,t} - T_t + F_{u,t}$$
$$\nu_t \psi h_{N,t}^{\chi} = c_{N,t}^{-\rho} \mathcal{W}_t$$

- Unions aggregate differentiated labor inputs $h_{u,t} = \left(\frac{w_{u,t}}{w_t}\right)^{-\eta_w} h_{d,t}$ with labor remuneration ($\mathcal{W}_t$) and set wages:

$$w_t^* = \frac{\eta_w}{\eta_w - 1} \frac{E_t \sum_{k=0}^{\infty} \theta_w^k \Lambda_{t,t+k}}{E_t \sum_{k=0}^{\infty} \theta_w^k \Lambda_{t,t+k} w_{t+k}^{\eta_w} p_{t+k}^{-1} h_{d,t+k}}$$

- Wage-setting frictions lead to wage inertia:

$$w_t^{1-\eta_w} = (1-\theta_w) w_t^{*1-\eta_w} + \theta_w \Pi_t^{\eta_w - 1} w_{t-1}^{1-\eta_w}.$$

FOCs Unions

Firms

- Final goods are CES composite of intermediate goods
- Intermediate goods produced under monopolistic competition

$$y_{j,t} = A_t (k_{j,t}^{\alpha} h_{d,j,t}^{1-\alpha})^{1-\gamma} m_{j,t}^{\gamma}, \qquad 0 < \alpha < 1, \qquad 0 < \gamma < 1$$

- A_t denotes stochastic TFP and $m_{j,t}$ denotes polluting input factor
- Emissions evolve as $e_{j,t} = \phi_{e,t} m_{j,t}$ and emissions intensity is stochastic:

$$\phi_{e,t} = (1 - \rho_{\phi_e})\bar{\phi_e} + \rho_{\phi_e} \phi_{e,t-1} + \epsilon_{\phi_e,t}$$

- Cost minimization yields:

$$\begin{aligned} R_{k,t} &= \lambda_{j,t}(1-\gamma)\alpha A_t (k_{j,t}^{\alpha} h_{d,j,t}^{1-\alpha})^{1-\gamma} m_{j,t}^{\gamma} k_{j,t}^{-1} \\ w_t &= \lambda_{j,t}(1-\gamma)(1-\alpha) A_t (k_{j,t}^{\alpha} h_{d,j,t}^{1-\alpha})^{1-\gamma} m_{j,t}^{\gamma} h_{d,j,t}^{-1} \\ p_{m,t} &= \lambda_{j,t}\gamma A_t (k_{j,t}^{\alpha} h_{d,j,t}^{1-\alpha})^{1-\gamma} m_{j,t}^{\gamma-1} \end{aligned}$$

Firms con't

- Price-setting is subject to Calvo rigidity yields:

$$p_t^* = p_{j,t} = \frac{\varepsilon}{(\varepsilon - 1)} \frac{E_t \sum_{i=0}^{\infty} \theta_p^i \Lambda_{t,t+i} p_{t+i}^{\varepsilon} y_{t+i} mc_{t+i}}{E_t \sum_{i=0}^{\infty} \theta_p^i \Lambda_{t,t+i} p_{t+i}^{\varepsilon-1} y_{t+i}}$$

- Firms take wages as given and face identical marginal costs

$$mc_t = \left(\frac{1}{(1-\alpha)(1-\gamma)} \right)^{1-\gamma} \left(\frac{(1-\alpha)}{\alpha} \right)^{\alpha(1-\gamma)} \left(\frac{1}{\gamma} \right)^{\gamma} \frac{w_t^{(1-\alpha)(1-\gamma)} R_{k,t}^{\alpha(1-\gamma)} \hat{p}_{m,t}^{\gamma}}{A_t}$$

- Climate policies affect marginal costs via $\hat{p}_{m,t} = \hat{p}_{m,t} + \phi_{e,t} p_{e,t}$ where $p_{e,t}$ differs across policy instruments

Policy Instruments

- Climate policies affect relative prices of inputs:

Instrument	Functional form	Price of intermediate inputs
Price	$g(e_t) = \mu$	$\hat{p}_{m,t} = \phi_{e,t}\mu$
Flex Price	$g(e_t) = \mu + \eta_e(e_t - \bar{e})$	$\hat{p}_{m,t} = \phi_{e,t}(\mu + \eta_e(e_t - \bar{e}))$
Cap-and-Trade	$g(e_t) = e_t \leq \bar{e}$	$\hat{p}_{m,t} = \phi_{e,t}\omega_t$
Intensity Target	$g(y_t, e_t) = e_t \leq \xi y_t$	$\hat{p}_{m,t} = \phi_{e,t}\omega_t$

Table: Climate policy instruments and intermediate input prices.

- Carbon budget uncertainty:

$$\bar{e}_t = (1 - \rho_e)\bar{e} + \rho_e \bar{e}_{t-1} + \epsilon_{e,t}$$

Public sector

- Taylor rule:

$$\frac{R_t}{\bar{R}} = \left(\left(\frac{R_{t-1}}{\bar{R}} \right)^{\gamma_R} \left(\frac{\Pi_t}{\bar{\Pi}} \right)^{\gamma_\Pi} \right)^{1-\gamma_R} exp(\epsilon_{R,t})$$

- Government budget and fiscal rule:

$$g_t = b_t + T_t + T_{E,t} - R_{t-1} b_{t-1} / \Pi_t$$
$$T_t = \bar{T} + \phi_T (b_t - \bar{b})$$
$$g_t = (1 - \rho_g)\bar{g} + \rho_g g_{t-1} + \epsilon_{g,t}$$

- Stochastic innovations in monetary policy ($\epsilon_{R,t}$) and government spending ($\epsilon_{g,t}$)

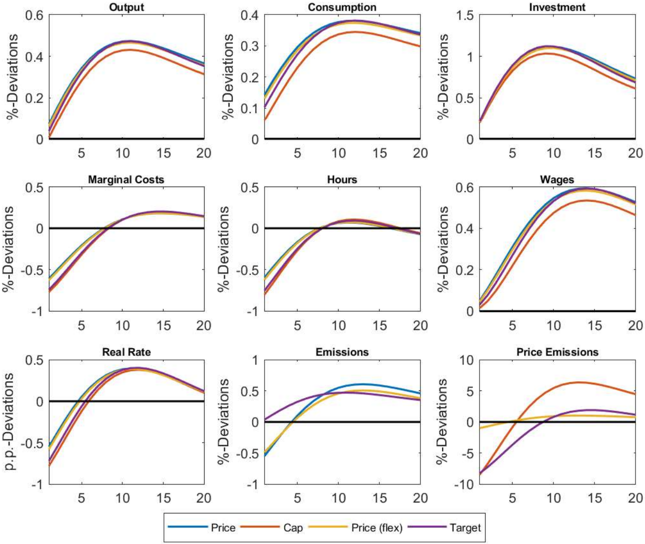
Calibration and Solution

- Stochastic model (42 equations) solved numerically via 2nd order approximation
- Calibrated to match German data (1991–2015, Destatis) Overview
- Structural parameters taken from (Hristov, 2016), (Grabka and Halbmeier, 2019), ...
- Climate policy uncertainty
  - Emission intensity shocks (quarterly data on CO_2 emissions in Germany) Emissions
  - Carbon budget uncertainty (Fujimori et al., 2019) and IPCC 1.5℃ report (2018) $\rightarrow$ 5 - 10% deviations

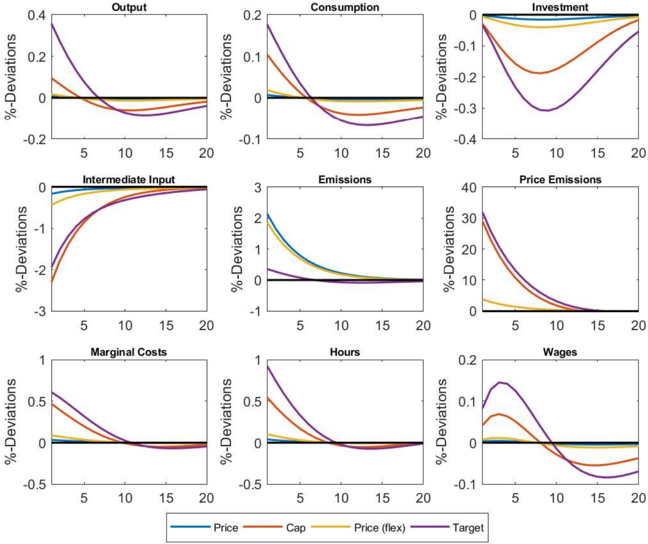
Scenario Overview

- Instrument comparison with 10% emissions reduction relative to no-policy
- Benchmark scenario – full absorption of revenues
  - Dynamics (impulse responses)
  - Volatility (unconditional 2nd moments)
  - Welfare (consumption equivalent variations)
- Inequality, frictions and policy design (sensitivity)
- Carbon budget uncertainty
  - Permanent effects (transitory dynamics)
  - Stochastic effects (unconditional moments)

Dynamics: TFP shock



Dynamics: Emission intensity shock



Comparison 2nd Moments

Scenario	σ_y	σ_c	$\frac{\sigma_c}{\sigma_y}$	σ_x	$\frac{\sigma_x}{\sigma_y}$	σ_e	$\frac{\sigma_e}{\sigma_y}$
Data	0.0160	0.0075	0.47	0.0367	2.29	0.0151	0.94
No-Policy	0.0162	0.0095	0.58	0.0414	2.55	0.0463	2.86
Price	0.0162	0.0095	0.58	0.0414	2.55	0.0452	2.79
Price (flex)	0.0163	0.0096	0.59	0.0410	2.52	0.0395	2.43
Cap-and-Trade	0.0170	0.0106	0.62	0.0387	2.28	0	0
Intensity Target	0.0166	0.0100	0.60	0.0401	2.41	0.0166	1

Table: Standard deviations and relative standard deviations of macroeconomic variables. Based on a second-order approximation of the HP-filtered theoretical moments of the model.

- Volatility ranking: price $<$ price (flex) $<$ intensity target $<$ cap-and-trade

Welfare Effects

Scenario	Overall Welfare	Ricardian	Non-Ricardian
Price	-1.06%	-1.06%	-1.05%
Price (flex)	-1.09%	-1.09%	-1.09%
Cap-and-Trade	-1.62%	-1.57%	-1.73%
Intensity Target	-1.55%	-1.52%	-1.64%

Table: Welfare changes of a 10% emissions reduction, reported in terms of consumption equivalent compensations (in %) relative to the no-policy scenario. Based on a second-order approximation of the theoretical moments of the model.

- Welfare ranking: price $>$ price (flex) $>$ intensity target $>$ cap-and-trade
- Quantity instruments exert regressive effects

Inequality: Income shares and consumption

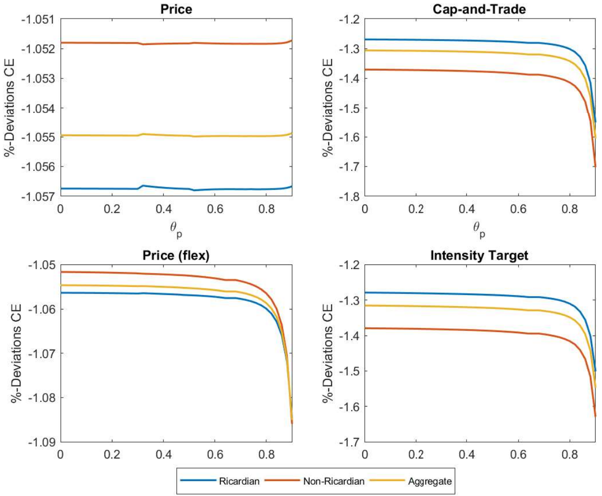
- Distributional effects emerge on the "sources-side" (relative factor incomes)

Scenario	Capital share	Labor share	c_t	$c_{R,t}$	$c_{N,t}$
Price	0.0051	0.0141	0.0096	0.0051	0.0368
(% change)	0.2%	0.2%	0.1%	0.1%	0
Price (flex)	0.0054	0.0148	0.0097	0.0050	0.0381
(% change)	5.9%	5.6%	1.1%	0.1%	3.7%
Cap-and-Trade	0.0074	0.0199	0.0106	0.0049	0.0469
(% change)	44.7%	41.9%	10.6%	-3.9%	27.6%
Intensity Target	0.0065	0.0175	0.0100	0.0051	0.0424
(% change)	26.7%	24.9%	4.7%	0.4%	15.5%

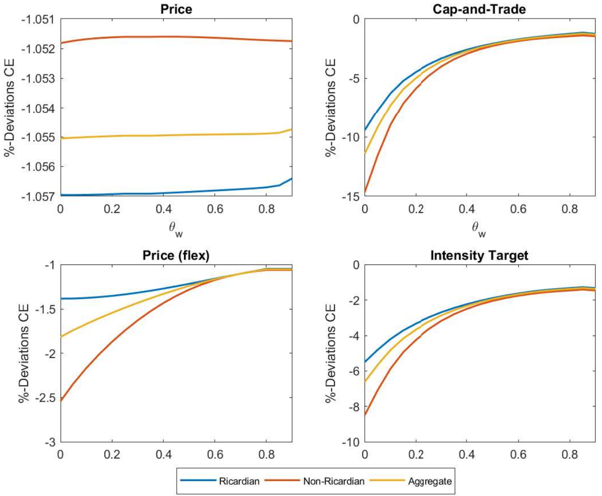
Table: S.D. and S.D. relative to no-policy scenario (HP-Filtered variables).

- Effects particularly driven by:
  - Degree of nominal rigidities (wages and prices)
  - Revenue recycling from emission policies

Inequality: Welfare and price rigidity



Inequality: Welfare and wage rigidity

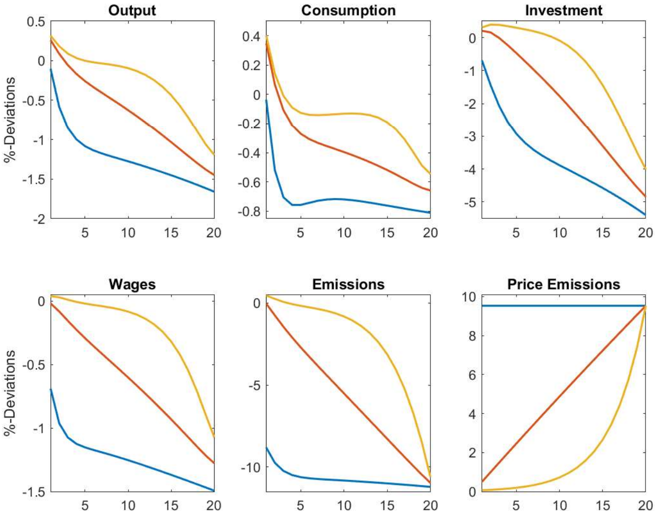


Inequality: Revenue schemes

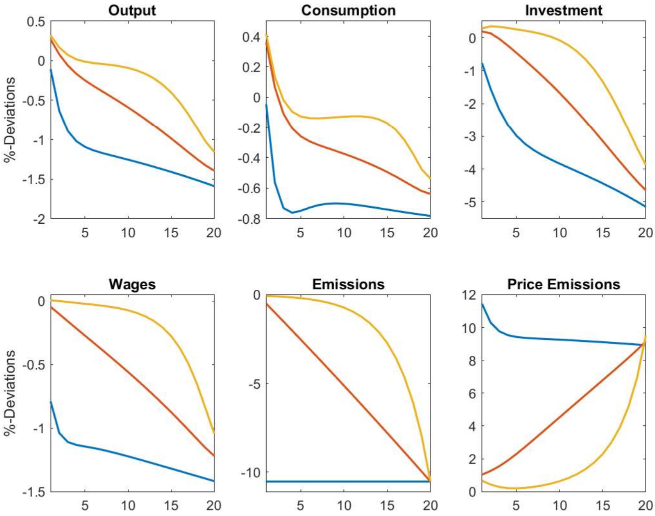
Scenario	Overall Welfare	Ricardian	Non-Ricardian
Full Absorption			
Price	-1.04%	-1.04%	-1.04%
Price (flex)	-1.05%	-1.04%	-1.05%
Cap-and-Trade	-1.32%	-1.27%	-1.46%
Intensity Target	-1.32%	-1.28%	-1.43%
Tax cut and Spending			
Price	-0.65%	-0.69%	-0.54%
Price (flex)	-0.67%	-0.70%	-0.58%
Cap-and-Trade	-1.04%	-0.96%	-1.25%
Intensity Target	-1.00%	-0.97%	-1.07%
Full Transfer			
Price	-0.22%	-0.33%	0.01%
Price (flex)	-0.23%	-0.31%	0.00%
Cap-and-Trade	-0.51%	-0.55%	-0.43%
Intensity Target	-0.50%	-0.55%	-0.39%

- Transfers and tax cuts alleviate regressive effects

Uncertainty: 10% shock (Price)



Uncertainty: 10% shock (Cap)



Uncertainty: Aggregates and welfare

- Volatility and welfare effects with carbon budget shocks (price vs. cap-and-trade)

Scenario	y_t	c_t	x_t	Agg.	Ric.	Non-Ric.
$\rho_e = 0$						
Price	0.5%	0.8%	0.0%	-0.59%	-0.58%	-0.61%
Cap-and-Trade	7.0%	12.4%	0.2%	-0.93%	-0.78%	-1.32%
$\rho_e = 0.4$						
Price	0.6%	0.9%	0.1%	-0.59%	-0.58%	-0.62%
Cap-and-Trade	8.8%	15.1%	1.5%	-1.22%	-1.05%	-1.65%
$\rho_e = 0.8$						
Price	3.1%	3.4%	4.6%	-0.63%	-0.62%	-0.65%
Cap-and-Trade	30.1%	36.4%	44.5%	-3.17%	-2.97%	-3.67%

- Price fluctuations exert small effects relative to regulatory fluctuations

Concluding Remarks

- Climate policies alter short-run dynamics and instruments differ w.r.t. aggregate and distributional implications
  - Price instrument favorable in terms of volatility and welfare, flexibility mitigates distributional effects
  - Quantity instruments require larger adjustments, which leads to regressive welfare effects and larger volatility
- Labor market (goods market) frictions affect the dynamics of factor income and amplify distributional effects
- Regressive effects can be alleviated through revenue recycling schemes (transfers)
- Fluctuations in emission intensity require additional (costly) adjustments on the supply side
- Uncertainty about carbon budget reduces welfare and policy adjustments can induce substantial aggregate effects

Fin

Thank you.

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FOC households

$$\lambda_{R,t} = d_t c_{R,t}^{-\rho}$$

$$\lambda_{R,t} = \nu_t \psi h_{R,t}^{\chi} \mathcal{W}_t^{-1}$$

$$\lambda_{R,t} = \beta R_t E_t \lambda_{R,t+1} \Pi_{t+1}^{-1}$$

$$1 = q_t \left(1 - \frac{\kappa}{2}\left(\frac{x_t}{x_{t+1}} - 1\right)^2 - \kappa\left(\frac{x_t}{x_{t-1}} - 1\right)\frac{x_t}{x_{t-1}}\right) \ldots$$

$$\ldots + \beta E_t \frac{\lambda_{R,t+1}}{\lambda_{R,t}} q_{t+1} \kappa \left(\frac{x_{t+1}}{x_t} - 1\right)\left(\frac{x_{t+1}}{x_t}\right)^2$$

$$q_t = \beta E_t \frac{\lambda_{R,t+1}}{\lambda_{R,t}} \frac{z_t}{z_{t+1}} ((1-\delta) q_{t+1} + z_{t+1} R_{K,t+1})$$

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Union Framework

- Sims and Wu, 2019: Continuum of labor types $u \in [0, 1]$
- Unions sell labor at $w_{u,t}$ to labor packer $h_{d,t} = (\int_0^1 h_{u,t}^{(\eta_w - 1)/1} \, du)^{\eta_w/(\eta_w - 1)}$
- Given aggregate labor demand $h_{d,t}$, we get:

$$h_{u,t} = \left(\frac{w_{u,t}}{w_t} \right)^{-\eta_w} h_{d,t}$$

- Calvo rigidity:

$$w_t^* = \frac{\eta_w}{\eta_w - 1} \frac{E_t \sum_{k=0}^{\infty} \theta_w^k \Lambda_{t,t+k}}{E_t \sum_{k=0}^{\infty} \theta_w^k \Lambda_{t,t+k} w_{t+k}^{\eta_w} p_{t+k}^{-1} h_{d,t+k}}.$$

- Real wage: $w_t^{1-\eta_w} = \int_0^1 w_{u,t}^{1-\eta_w} du$

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Calibration Table

Parameter	Value	Description
Households:		
β	0.998	Subjective discount factor
χ	1.5	Inverse Frisch elasticity
ρ	2	Inverse elasticity of intertemporal substitution
ψ	45	Labor disutility
λ	0.28	Share of non-Ricardian households
θ_w	0.83	Wage adjustment frictions (unions)
η_w	4	Elasticity of substitution labor types
Firms:		
δ	0.025	Depreciation rate
γ	0.1	Output elasticity polluting goods
α	0.30	Output elasticity capital
κ	3.9	Investment adjustment costs
θ_p	0.86	Price stickiness
ε	6	Elasticity of substitution intermediate goods

Parameter	Value	Description
Polices:		
γ_Π	1.47	Interest rate rule inflation coefficient
γ_R	0.91	Interest rate rule smoothing coefficient
$\bar{\Pi}$	1.01	Target inflation
ϕ_T	0.38	Reaction of taxation
b/y	0.6	Debt-GDP-ratio
g/y	0.19	Government consumption to GDP ratio
Stochastic processes:		
ρ_a, σ_a	0.95 , 0.0049	TFP shock
ρ_g, σ_g	0.86 , 0.0039	Government spending
ρ_d, σ_d	0.82 , 0.0044	Preference shock
ρ_ν, σ_ν	0.88 , 0.0118	Labor supply shock
ρ_z, σ_z	0.77 , 0.0183	Investment shock
ρ_ϕ, σ_ϕ	0.78 , 0.023	Emission intensity shock
σ_R	0.0004	Monetary shock

Table: Calibrated Parameters – Baseline Scenario

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Quarterly Emissions

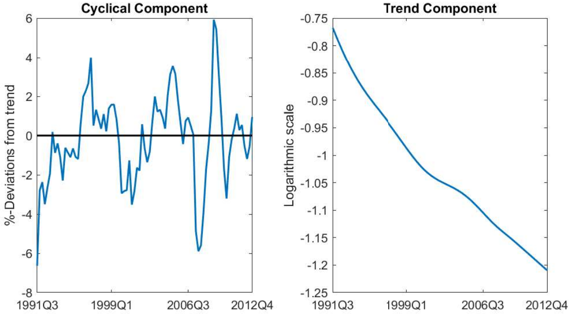

Figure: Emission intensity in Germany 1991Q3–2012Q4.

Variable	Mean	AR(1)	S.D.
e_t/y_t	0.36	0.78	0.023