

# Climate-Conscious Monetary Policy

Anton Nakov   Carlos Thomas

European Central Bank · Banco de España<sup>1</sup>

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<sup>1</sup>The opinions expressed here are those of the authors only and do not necessarily reflect the views of the Banco de España, the ECB, or the Eurosystem.

# Motivation

- Broad consensus on the need to decarbonize the global economy to mitigate climate change.
- Agreement also on the key role of carbon taxation/pricing.
- Less agreement on what role *central banks* should play in the green transition
  - ▶ Transatlantic “divide”: Lagarde (2021) vs Powell (2023)
- Even if central banks assume climate goals, key normative questions remain unanswered:
  - ▶ Trade-offs between climate and core goals (price stability)?
  - ▶ How do these trade-offs depend on what climate authorities are doing?
  - ▶ How are these trade-offs optimally resolved?
- To address these questions, we use a canonical New Keynesian model and add to it climate externalities as in Golosov et al (ECMA, 2014).

# Preview of results

- If carbon taxes are set optimally, then the central bank faces no policy trade-offs: strict inflation targeting delivers the first-best equilibrium
- Under sub-optimal carbon taxes, there is a trade-off between price stability and climate goals, but it is resolved overwhelmingly in favor of price stability
  - ▶ Under “slow” green transition (optimal fossil tax reached after  $\approx 30$  years), departure from strict zero inflation targeting is tiny (barely 15 bp)
- Optimal green tilting of QE accelerates the green transition (faster reduction in fossil energy use)
- But the impact on carbon concentration in the atmosphere and on global temperatures is small
  - ▶ The effectiveness of green tilting is limited by the (small) size of spreads on eligible (i.e. investment grade) corporate bonds

# Related literature

- Standard environmental policies (taxes, subsidies, caps) in RBC models
  - ▶ Fischer & Springborn (2011), Heutel (2012), Angelopoulos et al (2013)
  - ▶ Optimal carbon taxation: **Golosov-Hassler-Krusell-Tsyvinski (ECMA, 2014)**
- Climate mitigating policies in New Keynesian DSGE and “greenflation”
  - ▶ Annicchiarico & Di Dio (2015), Ferrari & Nispi Landi (2022), Airaud, Pappa & Seoane (2023), Del Negro et al (2023), Olovsson & Vestin (2023)
- Monetary policy (shocks) in DSGE models with climate externalities
  - ▶ Benmir & Roman (2020), Ferrari & Pagliari (2021), Diluiso et al (2020), Ferrari & Nispi Landi (2021, 2022)
- Welfare-maximizing green QE in a real (non-monetary) model:
  - ▶ Papoutsis, Piazzesi & Schneider (2023)

# Model structure

- World economy as a single climate- and monetary-policy jurisdiction
- New Keynesian model...
  - ▶ Households consume differentiated consumption varieties and supply labor
  - ▶ Monopolistic competition in goods markets and staggered price setting
- ... extended with energy sector...
  - ▶ Goods production uses labor and combination of green and fossil energy
- ... and climate change externalities along Nordhaus' DICE model (we follow closely Golosov et al's 2014 specification)
  - ▶ Fossil energy produces carbon emissions
  - ▶ adding to atmospheric carbon concentration and global warming,
  - ▶ which damages the economy's productive capacity
- Tax on carbon emissions phased in gradually from zero to optimal

# Model: Households

Representative household maximizes

$$\sum_{t=0}^{\infty} \beta^t \left[ \log(C_t) - \frac{\chi}{1+\varphi} N_t^{1+\varphi} \right],$$

where  $C_t = \left( \int_0^1 c_{z,t}^{(\epsilon-1)/\epsilon} dz \right)^{\epsilon/(\epsilon-1)}$ , subject to

$$\int_0^1 P_{z,t} c_{z,t} dz + B_t = R_{t-1} B_{t-1} + W_t N_t + \Pi_t + T_t.$$

# Households (cont'd)

FOCs,

$$\chi N_t^\varphi C_t = \frac{W_t}{P_t} \equiv w_t,$$

$$\frac{1}{C_t} = \beta R_t E_t \left( \frac{P_t}{P_{t+1} C_{t+1}} \right),$$

$$c_{z,t} = \left( \frac{P_{z,t}}{P_t} \right)^{-\epsilon} C_t, \quad \forall z \in [0, 1].$$

Nominal consumption:  $\int_0^1 P_{z,t} c_{z,t} dz = P_t C_t$ , where

$$P_t = \left( \int_0^1 P_{z,t}^{1-\epsilon} dz \right)^{1/(1-\epsilon)}.$$

# Final goods producers: technology

- Production function of variety- $z$  producer,

$$y_{z,t} = [1 - D(S_t)] A_t F(N_{z,t}, E_{z,t}),$$

- $D(S_t)$ : *damage function*,  $D' > 0$ .  $S_t$ : stock of carbon concentration in the atmosphere
- Producers combine green ( $g$ ) and fossil-fuel ( $f$ ) energy inputs,

$$E_{z,t} = \mathbf{E}(E_{z,t}^g, E_{z,t}^f).$$

- Both  $F$  and  $\mathbf{E}$  have constant returns to scale



# Final goods producers: cost minimization

- $p_t^i$ : real price of type- $i$  energy,  $i = f, g$
- Cost minimization implies

$$w_t = \frac{MC_t}{P_t} [1 - D(\cdot)] A_t \frac{\partial F(\cdot)}{\partial N_{z,t}}$$

$$p_t^i = \frac{MC_t}{P_t} [1 - D(\cdot)] A_t \frac{\partial F(\cdot)}{\partial E_{z,t}^i}, \quad i = f, g,$$

where  $MC_t$  is nominal marginal cost

# Final goods producers: pricing

- Each producer faces demand  $y_{z,t} = (P_{z,t}/P_t)^{-\epsilon} C_t$ .
- Subsidy  $\tau^y$  per unit of sales
- Calvo (1983) pricing,  $\theta$ : probability of non-adjustment.
- Optimal price decision,

$$\sum_{t=0}^{\infty} E_t \left\{ \Lambda_{t,t+s} \theta^s \left( (1 + \tau^y) P_t^* - \frac{\epsilon}{\epsilon - 1} MC_{t+s} \right) \left( \frac{P_t^*}{P_{t+s}} \right)^{-\epsilon} C_{t+s} \right\} = 0,$$

- Aggregate price level follows

$$P_t^{1-\epsilon} = (1 - \theta) (P_t^*)^{1-\epsilon} + \theta P_{t-1}^{1-\epsilon}.$$

# Energy sectors

- Technology of energy sector  $i = f, g$ :

$$E_t^i = A_t^i N_t^i.$$

- Fossil-fuel energy production subject to a per-unit tax  $\tau_t^f$
- Representative firm in energy sector  $i = g, f$  maximizes

$$(p_t^i - \mathbf{1}_{i=f}\tau_t^i) A_t^i N_t^i - w_t N_t^i.$$

- FOCs

$$p_t^g = \frac{w_t}{A_t^g},$$

$$p_t^f = \frac{w_t}{A_t^f} + \tau_t^f.$$

# Climate externalities

- Following Golosov et al (2014)
- Damage function,

$$1 - D(S_t) = e^{-\gamma_t(S_t - \bar{S})},$$

$\gamma_t$  exogenous elasticity,  $\bar{S}$  pre-industrial atmospheric carbon concentration.

- Law of motion of atmospheric carbon concentration (measured in GtC),

$$S_t - \bar{S} = \sum_{s=0}^{t+T} (1 - d_s) \xi E_{t-s}^f.$$

$\xi$ : GtC/Gtoe conversion factor

# Market clearing

- For each  $z$ ,  $y_{z,t} = c_{z,t}$
- Aggregate output:  $Y_t \equiv \left( \int_0^1 y_{z,t}^{\frac{\epsilon}{\epsilon-1}} dz \right)^{\frac{\epsilon-1}{\epsilon}} \Rightarrow Y_t = C_t$
- Labor market clearing:  $N_t = \sum_{i=g,f} N_t^i + N_t^y$ , where  $N_t^y \equiv \int_0^1 N_{z,t} dz$ .
- From CRS and energy-labor ratio equalization,

$$[1 - D(\cdot)] A_t F(N_t^y, E_t) = \Delta_t Y_t,$$

where

$$\Delta_t \equiv \int_0^1 (P_{z,t}/P_t)^{-\epsilon} dz$$

are relative price distortions, with law of motion

$$\Delta_t = \theta \pi_t^\epsilon \Delta_{t-1} + (1 - \theta) \left( \frac{P_t^*}{P_t} \right)^{-\epsilon}.$$

# Characterization of the first-best equilibrium

- Social planner maximizes

$$\sum_{t=0}^{\infty} \beta^t E_0 \left\{ \log(C_t) - \frac{\chi}{1+\varphi} \left( N_t^y + \sum_{i=g,f} N_t^i \right)^{1+\varphi} \right\}$$

subject to

$$C_t = [1 - D(S_t)] A_t F(N_t^y, \mathbf{E}(E_t^g, E_t^f)),$$

$$E_t^i = A_t^i N_t^i, \quad i = f, g,$$

$$S_t - \bar{S} = \sum_{s=0}^{t+T} (1 - d_s) \xi E_{t-s}^f.$$

# The first-best equilibrium (cont'd)

- Social efficiency conditions,

$$[1 - D(S_t)] A_t \frac{\partial F(\cdot)}{\partial N_t^y} = \chi N_t^\varphi C_t,$$

$$[1 - D(S_t)] A_t \frac{\partial F(\cdot)}{\partial E_t^i} = \frac{\chi N_t^\varphi C_t}{A_t^i} + 1_{i=f} \tau_t^{f*},$$

where *climate externality*  $\tau_t^{f*}$  is as in Golosov et al (2014),

$$\tau_t^{f*} \equiv Y_t E_t \left\{ \sum_{s=0}^{\infty} \beta^s (1 - d_s) \xi \gamma_{t+s} \right\}.$$

# Optimal monetary policy: the case of optimal carbon tax

- Under strict inflation targeting ( $\Pi_t = 1$ ), the decentralized equilibrium replicates the *flexible-price equilibrium*
- All firms have the same price (no relative price distortions:  $\Delta_t = 1$ ),

$$P_{z,t} = P_t = (1 + \tau^y)^{-1} \underbrace{\frac{\epsilon}{\epsilon - 1}}_{\text{monopolistic markup}} MC_t.$$

- Since  $MC_t/P_t = (1 + \tau^y) \frac{\epsilon - 1}{\epsilon}$ ,

$$(1 + \tau^y) \frac{\epsilon - 1}{\epsilon} [1 - D(S_t)] A_t \frac{\partial F(\cdot)}{\partial N_t^y} = \chi N_t^\varphi C_t,$$

$$(1 + \tau^y) \frac{\epsilon - 1}{\epsilon} [1 - D(S_t)] A_t \frac{\partial F(\cdot)}{\partial E_t^i} = \frac{\chi N_t^\varphi C_t}{A_t^i} + 1_{i=f} \tau_t^f.$$

- Provided  $1 + \tau^y = \frac{\epsilon}{\epsilon - 1}$  and  $\tau_t^f = \tau_t^{f*}$ , the flex-price equilibrium replicates the *first-best equilibrium*



# Optimal monetary policy: the case of optimal carbon tax

## Theorem

Let  $\tau^y = \frac{\epsilon}{\epsilon-1} - 1$ , such that monopolistic distortions are offset. Provided carbon taxes are set at their socially optimal level,  $\tau_t^f = \tau_t^{f*}$ , it is optimal to fully stabilize prices:  $\Pi_t = 1$ .

- Intuition:

- ▶ If  $\tau_t^f = \tau_t^{f*}$ , climate change externalities are perfectly internalized by fossil-fuel energy producers
- ▶ If in addition  $\tau^y = \frac{\epsilon}{\epsilon-1} - 1$ , the only distortions left are those caused by nominal rigidities, which are fully offset by strict price stability

- In sum: as long as they are set at their socially optimal level, carbon taxes *create no trade-offs for MP*: strict price stability is optimal

# Calibration: functional forms

- Goods production technology,

$$F(N_t, E_t) = [\alpha(E_t)^\delta + (1 - \alpha)(N_t)^\delta]^{1/\delta}$$

- Energy basket,

$$E_t = [\omega(E_t^g)^\rho + (1 - \omega)(E_t^f)^\rho]^{1/\rho}$$

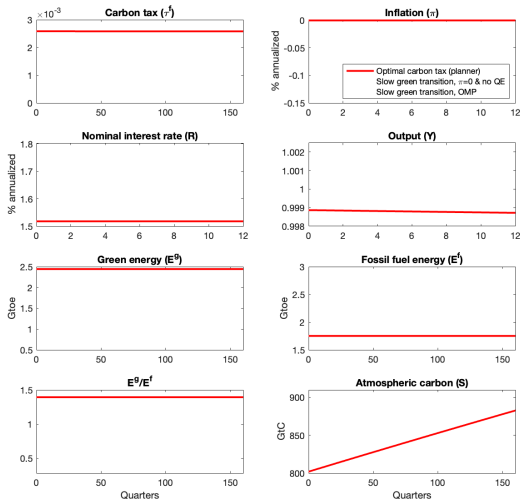
- Depreciation of atmospheric carbon concentration

$$(1 - d_s) = \phi_0 (1 - \phi)^s$$

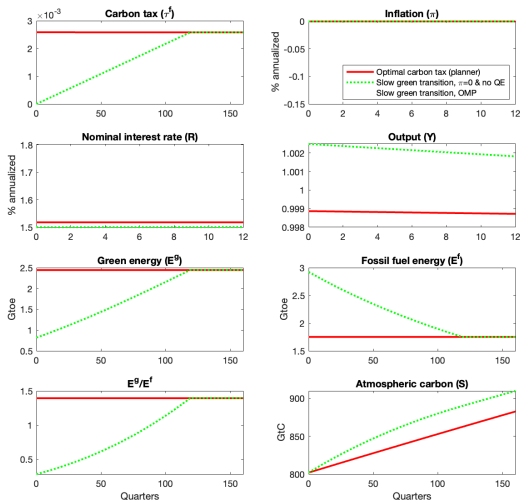
# Calibration

Description		Value	Target/Source
New Keynesian block			
$\beta$	Household discount factor	$0.985^{1/4}$	Golosov et al (2014)
$\theta$	Calvo parameter	0.75	Price adj. freq. 1 yr
$\epsilon$	Elasticity of substitution	7	Standard
$\varphi$	(inv) elasticity labor supply	1	Standard
Energy & climate change			
$\alpha$	Energy share of output	0.04	Golosov et al (2014)
$\rho$	(1-inv) elast subst $g$ vs $f$	$1 - 1/2.86$	Papageorgiou et al (2017)
$\delta$	(1-inv) elast subst $L$ vs $E$	$1 - 1/0.4$	Böringer and Rivers (2021)
$\gamma$	Elasticity damage function	0.000024	Golosov et al (2014)
$\phi_0, \phi$	carbon depreciation structure	0.51 0.00033	Golosov et al carbon structure
$\omega$	weight of green energy	0.2571	$\begin{cases} p^g/p^f = 0.54 \\ E^f = 11.7 \text{ Gtoe} \\ E^g = 3.3 \text{ Gtoe} \end{cases}$
$A^f$	productivity fossil sector	290.33	
$A^g$	productivity green sector	537.65	
$\xi$	carbon content fossil energy	0.879	IPCC (2006) tables
$\bar{S}, S_0$	Atmosph. carbon concentr.	581, 802	Golosov et al (2014)

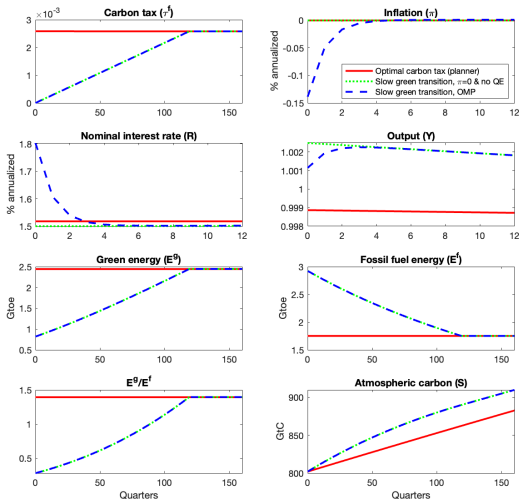
# Inflation-climate trade-off along the transition: planner



# Inflation-climate trade-off along the transition: $\pi = 0$



# Inflation-climate trade-off along the transition: OMP



## Green QE: Corporate bond supply

- Fraction  $\psi$  of energy firms' operating costs financed with short-term (within period) bonds
- Bonds are issued at a price  $1/R_t^i, i = f, g$ . Face value = 1
- # of bonds issued:  $\frac{\psi w_t N_t^i}{1/R_t^i} = \psi R_t^i w_t N_t^i$
- Sector  $i$  firm now maximizes

$$(p_t^i - 1_{i=f} \tau_t^i) A_t^i N_t^i - [1 + \psi (R_t^i - 1)] w_t N_t^i.$$

- FOC now reads

$$p_t^i = \underbrace{[1 + \psi (R_t^i - 1)]}_{\text{financial wedge}} \frac{w_t}{A_t^i} + 1_{i=f} \tau_t^f, \quad i = f, g$$

# Household demand and financial friction

- Households can purchase corporate bonds ( $B_t^i, i = f, g$ ),
- subject to transaction costs from adjusting corporate bond portfolio ( $\zeta_t^i$ )
- Budget constraint is now

$$P_t C_t + B_t + \sum_{i=g,f} B_t^i (1 + \zeta_t^i) = R_{t-1} B_{t-1} + \sum_{i=g,f} R_t^i B_t^i + W_t N_t + \dots,$$

where  $\zeta_t^i$  is as in Gertler and Karadi (2013),

$$\zeta_t^i = \frac{\kappa_i}{2} \frac{(B_t^i - \bar{B}^i)^2}{B_t^i}, \quad B_t^i \geq \bar{B}^i.$$

- FOC wrt  $\{B_t^i\}_{i=g,f}$ ,

$$R_t^i - 1 = \kappa_i (B_t^i - \bar{B}^i), \quad B_t^i \geq \bar{B}^i.$$

- The larger the amount of bonds to be absorbed by private sector ( $B_t^i$ ), the larger the spread  $R_t^i - 1$



# Central bank purchases and market clearing

- Central bank purchases of corporate bonds:  $B_t^{i,cb}$ ,  $i = f, g$
- Market clearing for sector- $i$  bonds,

$$\psi w_t N_t^i = B_t^i + B_t^{i,cb}.$$

- Using this in the spread equation,

$$R_t^i - 1 = \kappa_i \left( \psi w_t N_t^i - B_t^{i,cb} - \bar{B}^i \right) \quad (1)$$

- Central bank bond purchases ease sector- $i$  financing conditions and lower the price of type- $i$  energy
- From now on, treat spread  $R_t^i - 1$  as the policy variable:  $B_t^{i,cb}$  can then be backed out from eq (1)

# Optimal corporate QE: the case of optimal carbon taxes

- If  $\tau_t^f = \tau_t^{f*}$  and under strict inflation targeting ( $\pi_t = 1$ ), the only friction left is the corporate financial wedge
- It is optimal for the CB to eliminate the spreads  $\{R_t^i - 1\}_{i=f,g}$  by absorbing all corporate (both green *and* brown) bonds supply in excess of  $\bar{B}^i$ .
- Generalize our previous (no QE) result:

## Theorem

Let  $\tau^y = \frac{\epsilon}{\epsilon-1} - 1$ . Provided  $\tau_t^f = \tau_t^{f*}$ , it is optimal to fully stabilize inflation,  $\pi_t = 1$ , and to fully eliminate corporate spreads,  $R_t^g = R_t^f = 1$ , by setting  $B_t^{i,cb} = \psi w_t N_t^i - \bar{B}^i, i = f, g$ .

# Optimal corporate QE under suboptimal carbon taxation

- Let  $\tau_0^f = 0$ , assume rising path for  $\tau_t^f$  until reaching  $\tau_t^{f*}$  at some time  $t^* > 0$
- It is optimal for CB to eliminate green bond spread:  $R_t^g = 1$  at all  $t$
- CB can use brown spread to (try to) compensate for suboptimal carbon taxes...

$$\underbrace{\tau_t^f + [1 + \psi(R_t^f - 1)] \frac{w_t}{A_t^f}}_{\text{decentralized } p_t^f} = \underbrace{\tau_t^{f*} + \frac{w_t}{A_t^f}}_{\text{socially optimal } p_t^f} \Leftrightarrow R_t^f - 1 = \frac{\tau_t^{f*} - \tau_t^f}{\psi w_t / A_t^f}$$

- ... but brown spread cannot exceed  $R_t^f - 1 \leq \kappa_f(\psi w_t N_t^f - \bar{B}^f)$ : no CB purchases, all brown bonds absorbed by private sector

# Optimal corporate QE under suboptimal carbon taxation

- Therefore, optimal rule for brown spread is

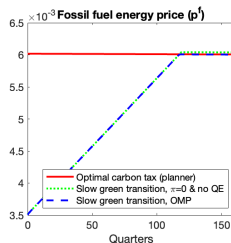
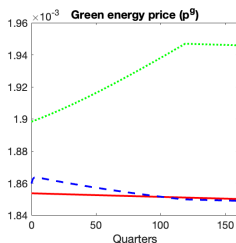
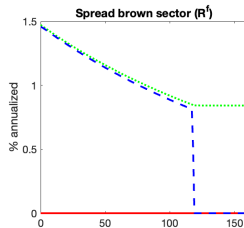
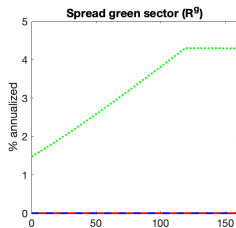
$$R_t^f - 1 = \min \left\{ \frac{1}{\psi} \frac{\tau_t^{f*} - \tau_t^f}{w_t/A_t^f}, \kappa_f (\psi w_t N_t^f - \bar{B}^f) \right\}.$$

- At the beginning of green transition,  $\tau_t^{f*} - \tau_t^f$  is too large: the best the CB can do is *not* to hold any brown bonds at all (100% green tilting)
- Once  $\tau_t^{f*} - \tau_t^f$  becomes sufficiently small, CB maintains brown spreads just enough to compensate for suboptimal carbon taxation

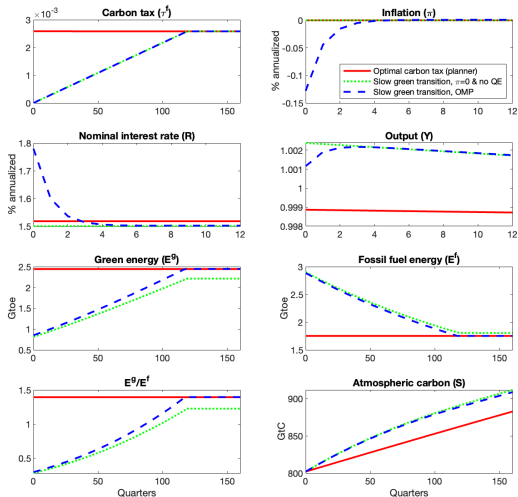
# Calibration: QE parameters

- Bond intensity:  $\psi_i = \frac{B^i}{wN^i} = 5, i = f, g$ 
  - ▶ Source: bond intensity of CSPP-eligible energy firms
- $(k_f, k_g) = (0.0813, 0.5373)$ 
  - ▶ Target: impact of CSPP announcement on eligible firms' bond yields  $\simeq 50$  bp (Todorov 2020)
- $(\bar{B}^f, \bar{B}^g) = (0.00512, 0.00076)$ 
  - ▶ Target: pre-CSPP spreads (vs OIS) of eligible energy firms' bonds  $\simeq 1.5\% = 4(R^i - 1), i = f, g$

# Green and brown spreads along the transition



# Trade-offs along the transition



# Carbon concentration and global warming in the long-run

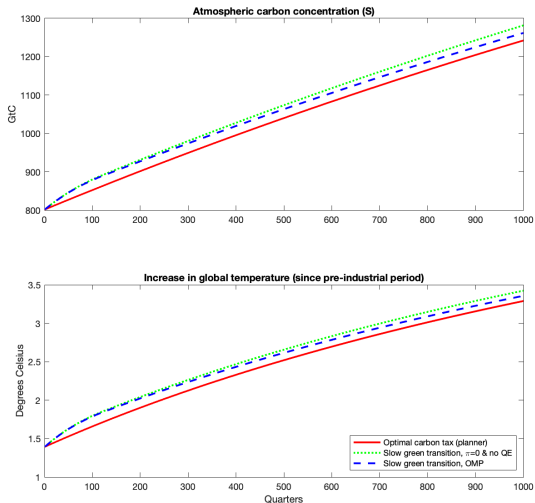
- How does all this translate into global temperatures?
- Standard mapping from atmospheric carbon concentration to global warming (vs pre-industrial temperatures),

$$T_t = \lambda \log \left( \frac{S_t}{\bar{S}} \right) / \log(2)$$

- Standard value  $\lambda = 3 \Rightarrow$  doubling of carbon concentration (vs pre-industrial) raises temperature by  $3^\circ\text{C}$



# Carbon concentration and global warming



# Robustness

Three key parameters:

- Elasticity of substitution (ES) between L and E:  $(1/(1 - \delta))$ ; baseline 0.4). Consider higher (1, i.e. Cobb-Douglas) and lower (0.2) values
- Elasticity of damage function ( $\gamma$ ): what if 3 times higher?
- Discount factor ( $\beta$ ): set it such that net emissions (under OMP) in 2050  $\simeq 0$  (discount rate = 0.4% annual; baseline 1.5%)

Calibration	Tax rev % GDP	Max infl dev (pp)	Max y- gap (%)	Net em's in 2050	$S(t)$ reduct in 2050	Welfare gain %C
Baseline	0.7570	-0.1280	-0.1219	0.4885	-2.0885	0.0023
Cobb-Douglas	0.7570	-0.1154	-0.1067	0.7168	-0.7591	0.0011
ES = 0.2	0.7570	-0.1342	-0.1248	-0.1935	-6.7913	0.0097
Higher $\gamma$ (x3)	2.5737	-0.4415	-0.4152	-0.0114	-4.2923	0.0187
Higher $\beta$	2.5655	-0.4394	-0.4154	-0.0094	-4.2971	0.0120

# Key takeaways

- Normative analysis of monetary policy in a simple NK model with climate change externalities
- If carbon tax is optimal: no trade offs, strict inflation targeting gives first best
- Slow transition to optimal carbon tax: policy trade-off optimally resolved overwhelmingly in favor of price stability
- Optimal green GE accelerates reduction in fossil energy consumption, but limited impact on atmospheric carbon concentration
  - ▶ Effectiveness limited by size of (high-quality) corporate bond spreads
- Hard to escape conclusion that carbon taxes (and similar direct interventions, e.g. emissions trading schemes) are the most effective “game in town”

# Caveats and directions for future research

- The model is canonical NK with externalities a la Golosov et al (2014)
- No tipping point effects of carbon concentration
- Exogenous production technologies
- World economy treated as single climate- and monetary-policy jurisdiction