

Climate-Conscious Monetary Policy

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Motivation¹

- Broad consensus on the need to decarbonize the global economy to mitigate climate change.
- Agreement also on the key role of carbon taxation.
- Less agreement on what role *central banks* should play in the green transition (Powell vs. Lagarde).
- Many reports arguing that climate change-mitigating policies will necessarily introduce important monetary policy trade-offs or “greenflation”
- What are the relevant trade-offs for central banks and how are they resolved under the optimal Ramsey policy?
- To address these questions, we use a canonical New Keynesian model and add to it climate externalities à la Golosov et al (ECMA, 2014).

¹The opinions expressed here are those of the authors only and do not reflect the views of the Bank of Spain, ECB, or the Eurosystem.

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 ≈ 25 years), departure from strict zero inflation targeting is tiny (barely 10 bp)
- Optimal green tilting of QE accelerates the green transition (optimal green/fossil energy mix reached 2 years earlier)
- 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 (investment grade) corporate bond spreads pre-QE

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), Airaudo, Pappa & Seoane (2023), Olovsson & Vestin (2023)
- Monetary policy (shocks) in DSGE models with climate externalities
 - ▶ Benmir & Roman (2020), Ferrari & Pagliari (2021), Diluio 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 τ^y per unit of sales
- Calvo (1983) pricing, θ : 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 τ_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,

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

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

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

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

ξ : 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

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

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* τ_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,

$$F(N_t, E_t) = N_t^{1-\alpha} E_t^\alpha$$

- Energy basket,

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

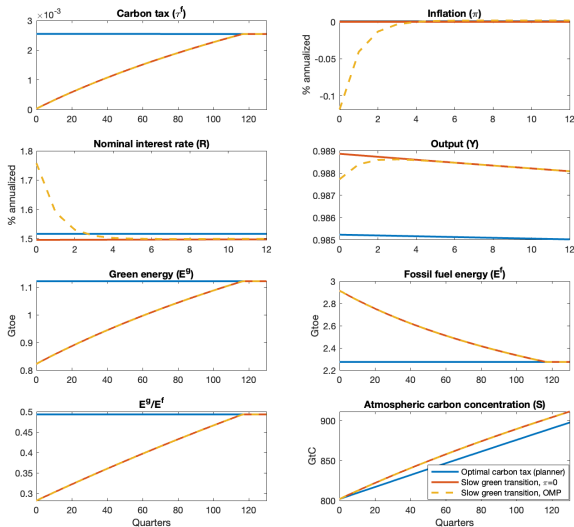
- Depreciation of atmospheric carbon concentration

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

Calibration

Description		Value	Target/Source
New Keynesian block			
β	Household discount factor	$0.985^{1/4}$	Golosov et al (2014)
θ	Calvo parameter	0.75	Price adj. freq. 1 yr
ϵ	Elasticity of substitution	7	Standard
φ	(inv) elasticity labor supply	1	Standard
Energy & climate change			
α	Energy share of output	0.04	Golosov et al (2014)
ρ	(1-inv) elast subst g vs f	0.65	Papageorgiou et al (2017)
γ	Elasticity damage function	0.000024	Golosov et al (2014)
ϕ_0, ϕ	carbon depreciation structure	0.51 0.00033	Golosov et al carbon structure
ω	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	84.2	
A^g	productivity green sector	155.9	
ξ	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



Green QE: Corporate bond supply

- Fraction ψ 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 (ζ_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 ζ_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 τ_t^f until reaching τ_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

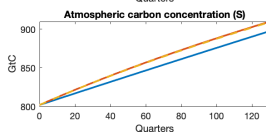
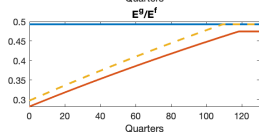
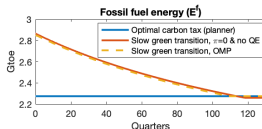
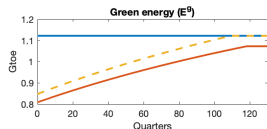
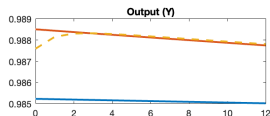
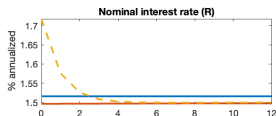
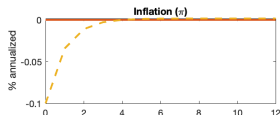
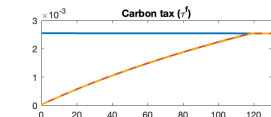
$$R_t^f - 1 = \min \left\{ \frac{1}{\psi} \frac{\tau_t^{f*} - \tau_t^f}{w_t/A_t^f}, \kappa_f (\psi w_t N_t^f - \bar{B}^f) \right\}.$$

- 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

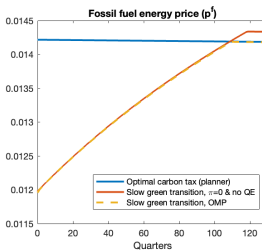
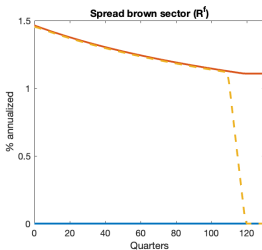
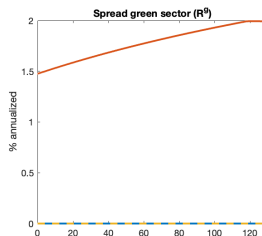
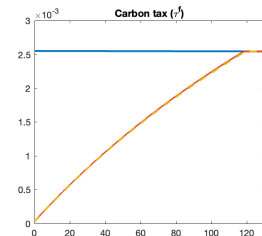
Calibration: QE parameters

- Bond intensity: $\psi_i = \frac{B^i}{wN^i} = 5, i = f, g$
 - ▶ Source: bond intensity of CSPP-eligible energy firms
- $(k_f, k_g) = (0.160, 0.024)$
 - ▶ Target: impact of CSPP announcement on eligible firms' bond yields $\simeq 50$ bp (Todorov 2020)
- $(\bar{B}^f, \bar{B}^g) = (0.017, 0.003)$
 - ▶ Target: pre-CSPP spreads (vs OIS) of eligible energy firms' bonds $\simeq 1.5\% = 4(R^i - 1), i = f, g$

Trade-offs along the transition



Green and brown spreads along the transition



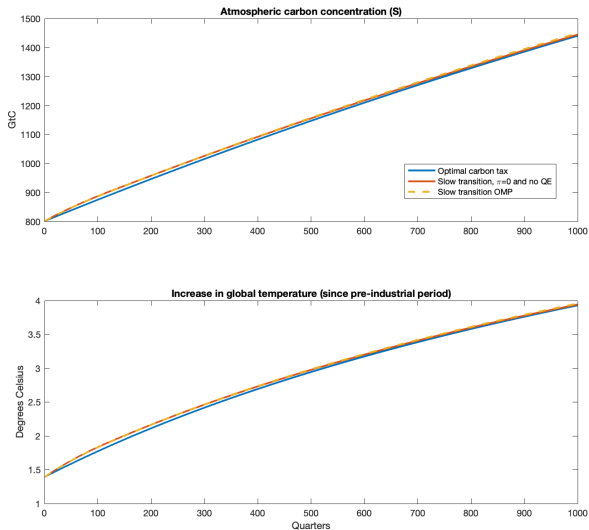
Carbon concentration and global warming in the long-run

- 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°C

Carbon concentration and global warming



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
- Ramsey plan to maximize utility, instead of Paris agreement goals
- World economy treated as single climate- and monetary-policy jurisdiction
- Exogenous production technologies
- No climate in the utility function