Optimal Monetary Policy in a Two-Sector Environmental DSGE Model

Oliver Holtemöller and Alessandro Sardone

Halle Institute for Economic Research (IWH)

Oliver.Holtemoeller@iwh-halle.de

EEA-ESEM Congress 2022

Introduction

"There is no single panacea for climate change, and combating it requires rapid progress along several dimensions. Relying on just one solution, or on one party, will not be enough to avoid a climate catastrophe."

Christine Lagarde, January 25, 2021

- Paris Agreement (2015): climate change becomes central to the global economic policy agenda
- ECB Strategy Review 2021: Climate change action plan
- But conventional macroeconomic models employed to design macroeconomic policies, often neglect the natural environment
- Research Question: What is the role of monetary policy in combating climate change?

The Role of Monetary Policy in Combating Climate Change

- Standard RBC model: no role for economic policy
- In a RBC model with environmental production externality (Heutel 2012)
  - optimal carbon tax to offset negative externality
  - quantity policy (cap-and-trade) is tightened in recessions because output loss is lower due to lower productivity
- In a RBC model with environmental externality and nominal frictions
  - optimal carbon tax offsets environmental externality
  - optimal monetary policy offsets nominal friction
- What if optimal carbon tax is not feasible? ▸ CO_2 projections and carbon tax

Literature

- IAM – Integrated Assessment Model (Nordhaus 1977,2013; Hassler and Krussel 2018) merging neoclassical economic growth model with climate features
- E-DSGE – environmental dynamic stochastic general equilibrium model (Heutel 2012; Golosov et al. 2014)
- New Keynesian E-DSGE (Annicchiarico and Di Dio 2015, 2017); how monetary policy can contribute to achieving environmental goals while maintaining the price stability objective:
  - Environmental-augmented Taylor rule (Chan 2020; Chen et al. 2020)
  - Green QE bonds policy (Ferrari and Nispi-Landi 2020)
  - Macroprudential and climate policies in the contest of transition risk (Carattini et al. 2021)

Contribution

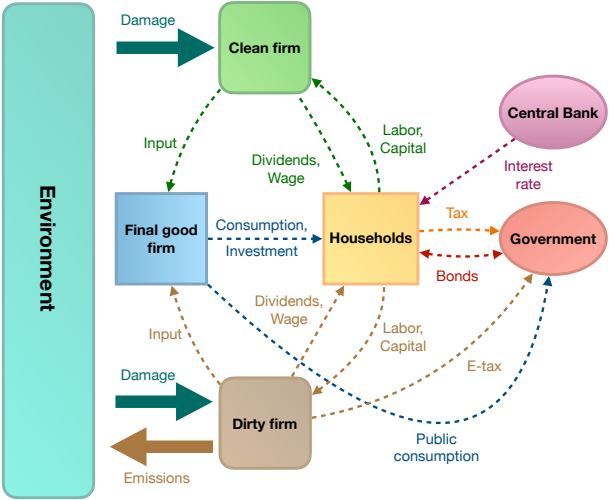
Research gap

- In a world with sub-optimal environmental fiscal policy, what role can monetary policy play?
- Should monetary policy stabilize aggregate inflation or should it differentiate between bad (clean) and good (dirty) inflation when setting its policy rate?

Preview

- The optimal monetary policy rule is asymmetric
- Reaction coefficients to clean and dirty inflation are different
- Optimal rule depends on nature of the macroeconomic shock

Two-Sector E-DSGE: Model Overview



Households

Utility maximization problem: maximize w.r.t consumption and labor, s.t. budget balance and law of motion of capital:

$$U = \sum_{t=0}^{\infty} \beta^t u(C_t, L_t) \tag{1}$$

$$u(C_t, L_t) = \frac{C^{1-\varphi_c} - 1}{1-\varphi_c} - \psi \frac{L_t^{1+\varphi_l}}{1+\varphi_l} \tag{2}$$

$$\begin{aligned} \text{s.t.} \quad & b_t + c_t + i_t = \\ & b_{t-1}\frac{r_{t-1}}{\pi_t} + r_t^k k_{t-1} + w_t^C l_t^C + w_t^D l_t^D - t_t + \mathcal{T}_t \end{aligned} \tag{3}$$

$$K_t = (1-\delta)K_{t-1} + I_t \left[1 - \frac{\Phi_i}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] \tag{4}$$

Firms

Final good y_t^E is a CES aggregator combining clean and dirty intermediate goods:

$$y_t^E = \left[(1-\Delta)^{\frac{1}{\epsilon}} \left(y_t^C\right)^{\frac{\epsilon-1}{\epsilon}} + \Delta^{\frac{1}{\epsilon}} \left(y_t^D\right)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}} \tag{5}$$

$$y_t^j = \left(\int_0^1 \left(y_{i,t}^j\right)^{\frac{\xi-1}{\xi}} di\right)^{\frac{\xi}{\xi-1}}, \quad \text{where} \quad j = \{C, D\} \tag{6}$$

Demand functions for the two sectors:

$$y_{i,t}^C = \left(\frac{p_{i,t}^C}{p_t^C}\right)^{-\xi} y_t^E (1-\Delta) \left(\frac{p_t^C}{p_t^E}\right)^{-\epsilon}, \qquad y_{i,t}^D = \left(\frac{p_{i,t}^D}{p_t^D}\right)^{-\xi} y_t^E \Delta \left(\frac{p_t^D}{p_t^E}\right)^{-\epsilon}$$

Intermediaries

- Intermediate firms employ sector-specific resources (labor and capital)
- Intermediaries are affected by environmental degradation, which reduces total factor productivity
- Only dirty firms pollute

Dirty Intermediaries

Dirty production:

$$y_{i,t}^{D} = A_{i,t}^{D}\left(k_{i,t-1}^{D}\right)^{\alpha}\left(l_{i,t}^{D}\right)^{1-\alpha}, \tag{7}$$

$$\Pi_{i,t}^{D} = p_{i,t}^{D}y_{i,t}^{D} - \tau_{i,t}^{E}e_{i,t} - z_{t} - w_{i,t}^{D}L_{i,t}^{D} - r_{k,i,t}^{D}k_{i,t-1}^{D} \tag{8}$$

Dirty firms face a trade-off between paying an environmental tax on their polluting emissions or sacrifice a share of their output to abate emissions.

Dirty firms

Clean Intermediaries

Clean production:

$$y_{i,t}^{C} = A_{i,t}^{C}\left(k_{i,t-1}^{C}\right)^{\alpha}\left(l_{i,t}^{C}\right)^{1-\alpha}, \tag{9}$$

$$\Pi_{i,t}^{C} = p_{i,t}^{C}y_{i,t}^{C} - w_{i,t}^{C}L_{i,t}^{C} - r_{k,i,t}^{C}k_{i,t-1}^{C} \tag{10}$$

TFP:

$$A_t^j = (1 - D_t(x_t))\, a_t^j \tag{11}$$

Technology a_t^j follows an autoregressive AR(1) process:

$$\log\left(a_t^j\right) = (1-\rho_a)\log(\bar{a}) + \rho_a \log\left(a_{t-1}^j\right) + e_a^j \tag{12}$$

Clean firms

Price Setting

- Nominal rigidities are modeled by introducing quadratic adjustment costs $\left(AC_t^j\right)$ à la Rotemberg (1983):

$$AC_{i,t}^j = \frac{\Phi_p}{2}\left(\frac{p_{i,t}^j}{p_{i,t-1}^j} - \bar{\pi}\right)^2 y_t^j, \quad \Phi_p > 0 \tag{13}$$

Climate Module

- The climate module describes the interconnection between
  - Dirty production y_t^D
  - Emissions e_t and pollution stock x_t
  - Abatement effort $g(\mu_t)$ as a function of abatement spending z_t

$$x_t = \eta x_{t-1} + e_t + e_t^{\text{ROW}} \tag{14}$$

$$e_t = (1 - \mu_t)\,\gamma_1 \left(y_t^D\right)^{1-\gamma_2}, \quad 0 < \gamma_1, \gamma_2 < 1 \tag{15}$$

$$g(\mu_t) = \frac{z_t}{y_t^D}, \quad \mu_t \in [0, 1] \tag{16}$$

- Environmental degradation reduces output via the damage function D_t

$$D_t(x_t) = d_0 + d_1 x_t + d_2 x_t^2 \tag{17}$$

Environmental Policy: 4 Regimes

1. *No environmental policy*

$$\tau_t = \mu_t = 0$$

2. *Tax policy*: Fixed emission tax rate

$$\tau_t = \bar{\tau}$$

3. *Target policy:* Emission intensity target linked to output

$$e_t = T_e y_t$$

4. *Cap policy:* Limit on emissions based on a fixed amount of pollution stock

$$e_t = \bar{x}(1 - \eta) - e^{\text{ROW}}$$

IRF Env. policies

Monetary Policy

- The central bank employs a non-standard Taylor Rule to set its policy rate: it takes into account the change of p_t^C and p_t^D instead of the general level of price p_t

$$\frac{r_t}{\bar{r}} = \left(\frac{r_{t-1}}{\bar{r}}\right)^{\rho_m} \left[\left(\frac{\pi_t^C}{\bar{\pi}}\right)^{\phi_\pi^C} \left(\frac{\pi_t^D}{\bar{\pi}}\right)^{\phi_\pi^D} \left(\frac{y_t}{\bar{y}}\right)^{\phi_y}\right]^{1-\rho_m} exp(e_m) \tag{18}$$

Monetary Rules Comparison: 4 Scenarios

1. Standard Taylor Rule

$$\phi = 1.5$$

2. Clean Rule: the central bank targets only clean inflation

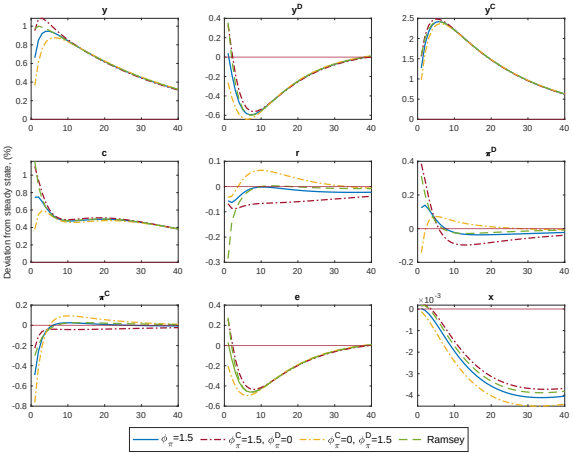
$$\phi_\pi^C = 1.5, \quad \phi_\pi^D = 0$$

3. Dirty Rule: the central bank targets only dirty inflation

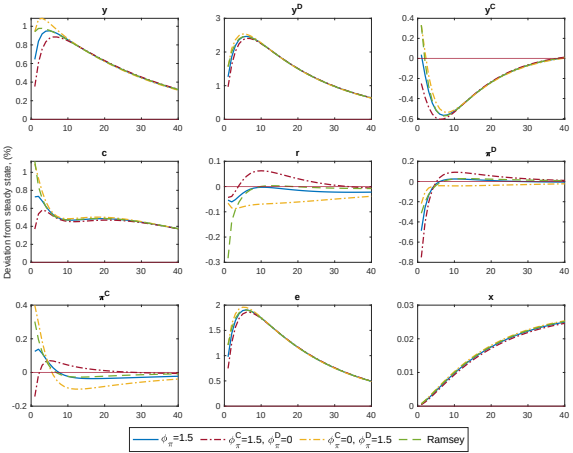
$$\phi_\pi^C = 0, \quad \phi_\pi^D = 1.5$$

4. Ramsey policy: a Ramsey planner maximizes total welfare by optimally choosing the monetary policy instrument

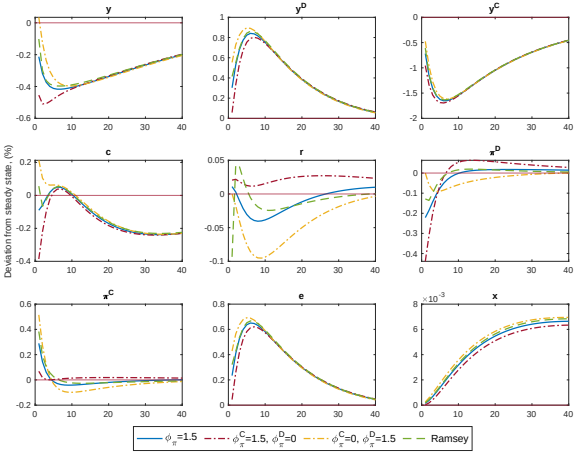
Clean TFP Shock (Tax policy)



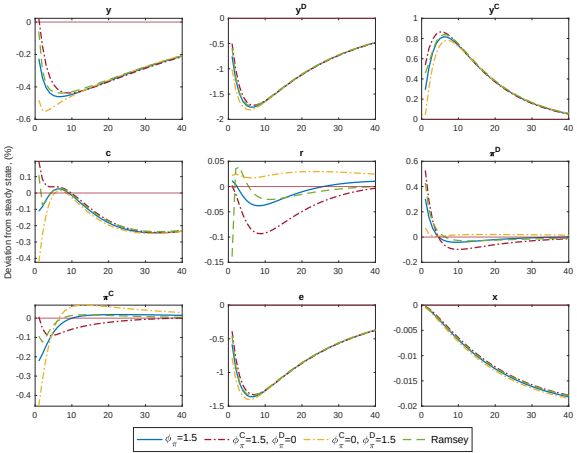
Dirty TFP Shock (Tax policy)



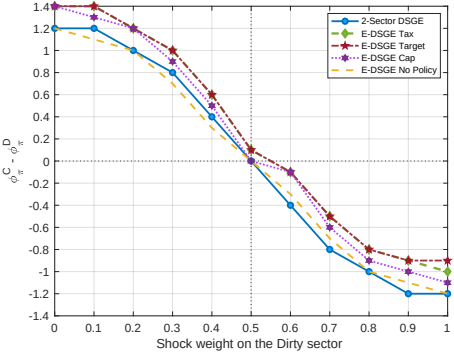
Clean Cost-push Shock (Tax policy)



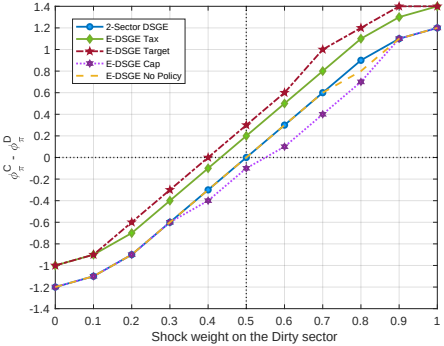
Dirty Cost-push Shock (Tax policy)



Welfare – Optimal monetary policy: Two-Sector vs. E-DSGE



(a) TFP shock



(b) Cost-push shock

Welfare

Simple Rules Comparison: Welfare Maximization

Env. Policy	Shock	ϕ_π^C	ϕ_π^D	ϕ_π	Welfare variation	Emission variation
No policy	C-TFP	5.0	3.8	5.0	-0.0193	0.0041
–	D-TFP	3.8	5.0	5.0	-0.0191	0.0046
–	C-Markup	1.7	2.9	3.3	-0.0153	-0.0059
–	D-Markup	3.1	1.9	3.3	-0.0129	0.0065
Tax policy	C-TFP	5.0	3.6	5.0	-0.0231	0.0054
–	D-TFP	4.0	5.0	5.0	-0.0173	0.0061
–	C-Markup	2.0	3.0	3.5	-0.0100	-0.0058
–	D-Markup	2.9	1.5	3.1	-0.0241	0.0130

Welfare (emission) variation measures the cost of implementing the two-sectors inflation targeting Taylor rule vs a standard Taylor rule. A negative value indicates that welfare (emission) for the asymmetric Taylor Rule is higher (lower).

Simple Rules Comparison: Emissions Minimization

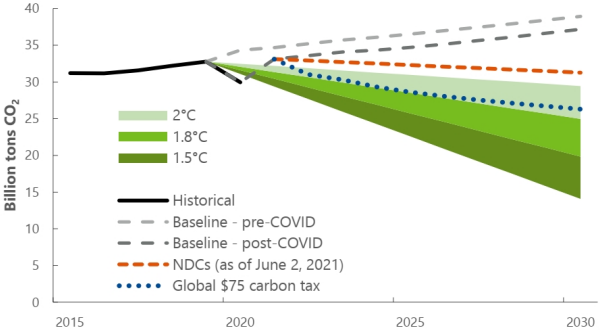
Env. Policy	Shock	ϕ_π^C	ϕ_π^D	ϕ_π	Welfare variation	Emission variation
No policy	C-TFP	0.0	1.8	1.1	0.3053	-0.0231
–	D-TFP	1.7	0.0	1.1	0.2992	-0.0250
–	C-Markup	1.1	0.0	1.1	0.3490	-0.1692
–	D-Markup	0.0	1.1	1.1	0.3071	-0.2402
Tax policy	C-TFP	0.0	1.8	1.1	0.3265	-0.0307
–	D-TFP	1.7	0.0	1.1	0.2921	-0.0319
–	C-Markup	1.1	0.0	1.1	0.3398	-0.2181
–	D-Markup	0.0	1.1	1.1	0.4103	-0.2767

Conslusion

- Monetary policy rule parameters sensitive to the introduction of environmental externalities
- Value of policy parameters varies across shocks and climate policies
- Weaker (stronger) reaction to positive (negative) inflation in the dirty sector – when asymmetric shocks hit the economy – is welfare optimal: it pushes up the demand for clean goods, reduces the relative amount of emissions and increases the households' welfare level

Global CO_2 Projections and Pathways for Warming Trends

(Black et al. 2021, Figure 1) back



Source: IMF staff estimates using UN Environment Programme (2020) and International Energy Agency (2020).
Note: Carbon tax starts at $15 per ton, rising steadily thereafter from 2022 to 2030. Warming pathways assume CO_2 emissions are reduced in proportion to total greenhouse gas emissions. COVD = coronavirus disease; NDCs = nationally determined contributions.

Dirty firms:

FOC w.r.t. abatement μ_t:

$$\tau_t^E \gamma_1 \left[y_t^E \Delta \left(\frac{p_t^D}{p_t^E} \right)^{-\epsilon} \right]^{-\gamma_2} = \theta_1 \theta_2 \mu_t^{\theta_2 - 1} \tag{19}$$

Dirty Phillips Curve:

$$\pi_t^D \left(\pi_t^D - \bar{\pi} \right) = \beta \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{y_{t+1}^D}{y_t^D} \pi_{t+1}^D \left(\pi_{t+1}^D - \bar{\pi} \right) \right] + \\ + \frac{\xi}{\phi_p} \left[mc_t^D - \frac{\xi - 1}{\xi} + \tau_t^E (1 - \mu_t) \gamma_1 (1 - \gamma_2) \left[y_t^E \Delta \left(\frac{p_t^D}{p_t^E} \right)^{-\epsilon} \right]^{-\gamma_2} + \theta_1 \mu_t^{\theta_2} \right] \tag{20}$$

back

Clean firms:

Clean Phillips Curve:

$$\pi_t^C \left(\pi_t^C - \bar{\pi}\right) = \beta \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{y_{t+1}^C}{y_t^C} \pi_{t+1}^C \left(\pi_{t+1}^C - \bar{\pi}\right)\right] + \frac{\xi}{\phi_p}\left[mc_t^C - \frac{\xi - 1}{\xi}\right] \tag{21}$$

back

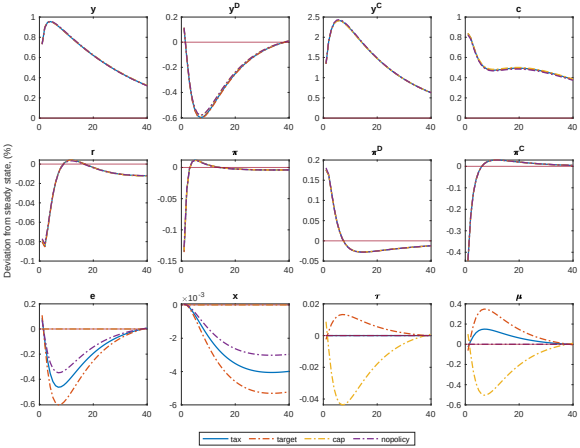
Welfare:

$$W_t^o - W_t^b = E_t \sum_{t=0}^{\infty} \beta^t \left[U((1-\Omega)c_t, l_t) - U(c_t, l_t) \right]$$

$$\text{where} \quad U = \sum_{t=0}^{\infty} \beta^t \left[\frac{c_t^{1-\varphi_c} - 1}{1-\varphi_c} - \psi \frac{l_t^{1+\varphi_l}}{1+\varphi_l} \right]$$

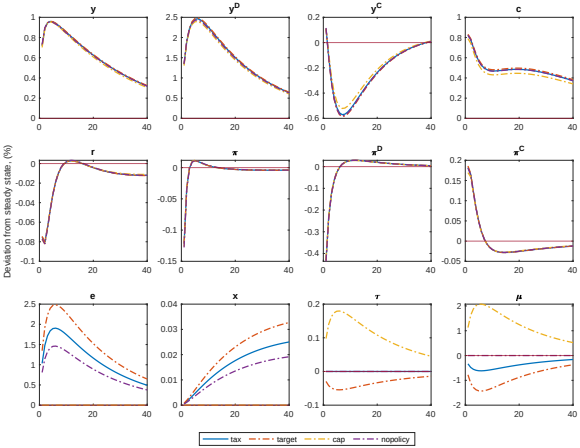
Ω: welfare gain/cost of implementing a specific policy rule *optimal* (o) vs the *baseline* (b) policy, in terms of % of steady state consumption variation, or consumption equivalent (CE). back

Clean TFP Shock: Environmental Policies Comparison

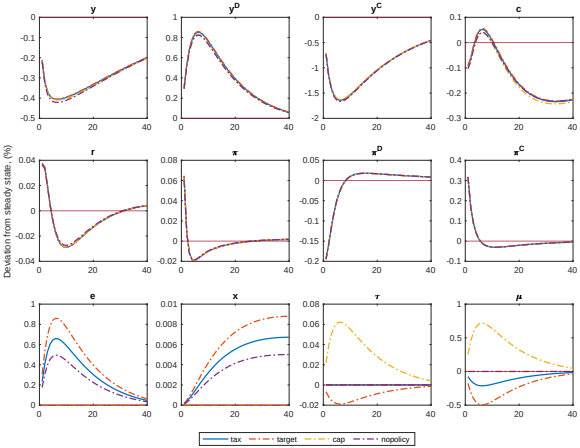


back

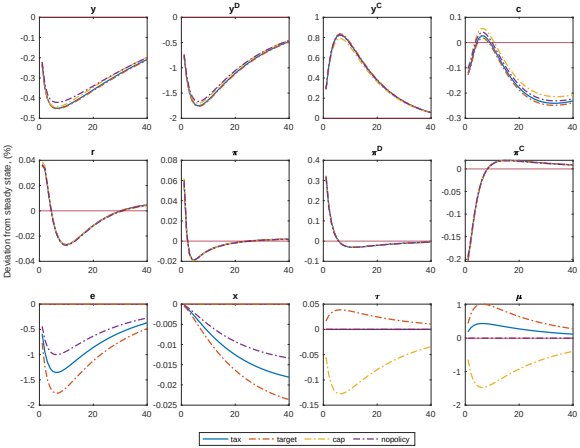
Dirty TFP Shock: Environmental Policies Comparison



Clean Cost-push Shock: Environmental Policies Comparison



Dirty Cost-push Shock: Environmental Policies Comparison



Taylor Rule vs Ramsey Optimal Policy

Env. Policy	Shock	Welfare cost (%)
No policy	C-TFP	-0.1574
–	D-TFP	-0.1549
–	C-Markup	0.3554
–	D-Markup	0.3469
Target policy	C-TFP	-0.1607
–	D-TFP	-0.1680
–	C-Markup	0.3912
–	D-Markup	0.4126