Optimal Monetary Policy in a Two-Sector Environmental DSGE Model

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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


- 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**
  - Clean firm
  - Dirty firm
  - Final good firm

- **Clean firm**
  - Consumption, Investment
  - Labor, Capital
  - Dividends, Wage

- **Dirty firm**
  - Emissions
  - Labor, Capital
  - Dividends, Wage

- **Government**
  - Tax
  - Bonds
  - Interest rate

- **Central Bank**
  - Interest rate

- **Environment**
  - Damage
  - Input

- **E-DSGE Monetary Policy**
  - Holtemöller, Sardone (IWH)
Households

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

\[
U = \sum_{t=0}^{\infty} \beta^t u(C_t, L_t)
\]

\[
u(C_t, L_t) = \frac{C^{1-\varphi_c} - 1}{1 - \varphi_c} - \psi \frac{L^{1+\varphi_l}}{1 + \varphi_l}
\]

s.t. \[b_t + c_t + i_t = \]

\[
b_{t-1} \frac{r_{t-1}}{\pi_t} + r_t^k K_{t-1} + w_t^C l_t^C + w_t^D l_t^D - t_t + T_t
\]

\[
K_t = (1 - \delta)K_{t-1} + l_t \left[ 1 - \frac{\Phi_i}{2} \left( \frac{l_t}{l_{t-1}} - 1 \right)^2 \right]
\]
Firms

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

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

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

Demand functions for the two sectors:

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

\[ y_{i,t}^D = A_{i,t}^D \left( k_{i,t-1}^D \right)^\alpha \left( I_{t,t}^D \right)^{1-\alpha} , \]  
\[ \Pi_{i,t}^D = p_{i,t}^D y_{i,t}^D - \tau_{i,t}^E e_{i,t} - z_t - w_{i,t}^D L_{i,t}^D - r_{k,i,t}^D k_{i,t-1}^D \]  

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.
Clean Intermediaries

Clean production:

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

(9)

\[ \Pi_{i,t}^C = p_{i,t}^C y_{i,t}^C - w_{i,t}^C L_{i,t}^C - r_{k,i,t}^C k_{i,t-1}^C. \]  

(10)

TFP:

\[ A_t^j = (1 - D_t(x_t)) a_t^j \]  

(11)

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

\[ \log \left( a_t^j \right) = (1 - \rho_a) \log(\bar{a}) + \rho_a \log \left( a_{t-1}^j \right) + e_t^j \]  

(12)
Price Setting

Nominal rigidities are modeled by introducing quadratic adjustment costs \( AC_i^j \) à la Rotemberg (1983):

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

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

\[
x_t = \eta x_{t-1} + e_t + e^{ROW}_t
\]

\[
e_t = (1 - \mu_t) \gamma_1 (y^D_t)^{1-\gamma_2}, \quad 0 < \gamma_1, \gamma_2 < 1
\]

\[
g(\mu_t) = \frac{z_t}{y^D_t}, \quad \mu_t \in [0, 1]
\]

- Environmental degradation reduces output via the damage function $D_t$

\[
D_t(x_t) = d_0 + d_1 x_t + d_2 x_t^2
\]
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
   \[ e_t = \bar{x}(1 - \eta) - e^{ROW} \]
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 $p_t$

\[
\frac{r_t}{\bar{r}} = \left( \frac{r_{t-1}}{\bar{r}} \right)^{\rho_m} \left[ \frac{\pi_t^C}{\bar{\pi}} \phi_{\pi}^C \left( \frac{\pi_t^D}{\bar{\pi}} \phi_{\pi}^D \left( \frac{y_t}{\bar{y}} \phi_y \right) \right]^{1-\rho_m} \exp(e_m) \tag{18}
\]
Monetary Rules Comparison: 4 Scenarios

1. Standard Taylor Rule

\[ \phi = 1.5 \]

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

\[ \phi^C = 1.5, \quad \phi^D = 0 \]

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

\[ \phi^C = 0, \quad \phi^D = 1.5 \]

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

Holtemöller, Sardone (IWH)
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
# Simple Rules Comparison: Welfare Maximization

<table>
<thead>
<tr>
<th>Env. Policy</th>
<th>Shock</th>
<th>$\phi^C_\pi$</th>
<th>$\phi^D_\pi$</th>
<th>$\phi_\pi$</th>
<th>Welfare variation</th>
<th>Emission variation</th>
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<td>C-TFP</td>
<td>5.0</td>
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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

<table>
<thead>
<tr>
<th>Env. Policy</th>
<th>Shock</th>
<th>$\phi_C^\pi$</th>
<th>$\phi_D^\pi$</th>
<th>$\phi_\pi$</th>
<th>Welfare variation</th>
<th>Emission variation</th>
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<td>C-TFP</td>
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<td>1.1</td>
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<td>D-TFP</td>
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<td>1.1</td>
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Conclusion

- 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 CO₂ Projections and Pathways for Warming Trends
(Black et al. 2021, Figure 1)

Note: Carbon tax starts at $15 per ton, rising steadily thereafter from 2022 to 2030. Warming pathways assume CO₂ emissions are reduced in proportion to total greenhouse gas emissions. COVD = coronavirus disease; NDCs = nationally determined contributions.
Dirty firms:

FOC w.r.t. abatement $\mu_t$:

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

Dirty Phillips Curve:

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

Clean Phillips Curve:

\[
\pi_t^C \left( \pi_t^C - \bar{\pi} \right) = \beta \left[ \frac{\lambda_{t+1}}{\lambda_t} \frac{\nu_{t+1}^C}{\nu_t^C} \pi_{t+1}^C \left( \pi_{t+1}^C - \bar{\pi} \right) \right] + \xi \frac{\phi}{p} \left[ m_{t+1}^C - \frac{\xi - 1}{\xi} \right] \tag{21}
\]
Welfare:

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

where \( U = \sum_{t=0}^{\infty} \beta^t \left[ \frac{c_t^{1-\varphi_c} - 1}{1 - \varphi_c} - \psi \frac{l_{t+1}^{1+\varphi_l}}{1 + \varphi_l} \right] \)

\( \Omega \): welfare gain/cost of implementing a specific policy rule \textit{optimal} (o) vs the \textit{baseline} (b) policy, in terms of % of steady state consumption variation, or consumption equivalent (CE).
Clean TFP Shock: Environmental Policies Comparison
Dirty TFP Shock: Environmental Policies Comparison

[Graph showing deviations from steady state for various policies]
Clean Cost-push Shock: Environmental Policies Comparison
Dirty Cost-push Shock: Environmental Policies Comparison

![Graphs showing the deviation from steady state for different variables under various policies.](image-url)
## Taylor Rule vs Ramsey Optimal Policy

<table>
<thead>
<tr>
<th>Env. Policy</th>
<th>Shock</th>
<th>Welfare cost (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No policy</td>
<td>C-TFP</td>
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<tr>
<td>–</td>
<td>D-TFP</td>
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<tr>
<td>–</td>
<td>C-Markup</td>
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<tr>
<td>–</td>
<td>D-Markup</td>
<td>0.3469</td>
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<td>Target policy</td>
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<tr>
<td>–</td>
<td>C-Markup</td>
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<tr>
<td>–</td>
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