Climate Actions, Market Beliefs, and Monetary Policy

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*Advances in Macro and Finance Modelling of Climate Change*

Banque de France

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Background (i)

- Climate actions, transition and uncertainty
  - Achieving climate objectives requires ambitious policies
  - Carbon pricing essential: price v. quantity regulations
  - Uncertainty of the transition process

- Role of expectations
  - Bounded rationality and behavioral biases prevent agents from internalizing the impact of climate policies
  - Transition can be perturbed
  - Achievement of climate targets can be conditioned
  - Heterogeneity in the use of information
Background (ii)

Fig. 1- Cross-Sectional Dispersion of Growth and Inflation Expectations

Source: Data from the US Survey of Professional Forecasters for the period 1995Q1-2019Q4.
The role of Central Banks

- [...] In our strategic review, we will take up climate change [...] and see where and how we can participate in that particular endeavour (C. Lagarde Press Conference 12/12/2019)
- How climate policies can impact on the price stability mandate
- What role Central Banks can play in the fight against climate change (e.g. Carney 2015, Rudebusch et al., 2019, Schoenmaker 2019, Lagarde 2021, Villeroy de Galhau 2021)
This Paper
Research Questions

- A mitigation plan implemented through a quantity or a price regulation
  - What is the response of the economy to climate policies without the assumption of perfect rationality?
  - What is the role of market beliefs in driving or hindering the mitigation process?
  - Can monetary policy tame the irrational exuberance of the markets rendering the greening policy more effective, while maintaining price stability?
This Paper
The Way We Do

- Extend the canonical New Keynesian model
  - Environmental features
  - Behavioral agents
- Construct mitigation scenarios via price or quantity regulation
- Study the role of monetary policy and expectations
Related Literature (in short)

- Interactions between climate and monetary policy still in its infancy
  - Unconventional monetary policy: Dafermos et al. (2018), Diluiso et al. (2021), Ferrari and Nispi Landi (2021), Papoutsi et al. (2021)
  - Expectations on climate change: Dietrich et al. (2021)
- Behavioral macro (huge!): e.g. De Grauwe (2011, 2012), Kurz et al. (2013), Hommes et al. (2019), Jump and Levine (2019), Gabaix (2020)
The Model

Final-Good Producers
- perfect competition
- CES technology
The Model

Final-Good Producers
- perfect competition
- CES technology

Intermediate-Goods Producers
- monopolistic competition
- imperfect price adjustment
The Model

- **Households**
  - consumption/saving decisions
  - labor supply

- **Final-Good Producers**
  - perfect competition
  - CES technology

- **Intermediate-Goods Producers**
  - monopolistic competition
  - imperfect price adjustment

- **Consumption good**
- **Labor**
- **Wage & dividends**
- **Intermediate goods**
The Model

Households
- consumption/saving decisions
- labor supply

Final-Good Producers
- perfect competition
- CES technology

Central Bank
- interest rate rule

Intermediate-Goods Producers
- monopolistic competition
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Households
- consumption/saving decisions
- labor supply

Final-Good Producers
- perfect competition
- CES technology

Intermediate-Goods Producers
- monopolistic competition
- imperfect price adjustment
- CES technology in labor and polluting input

Central Bank
- interest rate rule

Government
- extracts the polluting input at no cost

Wage & dividends

Consumption good

Intermediate goods

Polluting input
The Model

Households
- consumption/saving decisions
- labor supply

Central Bank
- interest rate rule

Government
- extracts the polluting input at no cost
- price or quantity regulation

Final-Good Producers
- perfect competition
- CES technology

Intermediate-Goods Producers
- monopolistic competition
- imperfect price adjustment
- CES technology in labor and polluting input

Environmental Externality

Consumer
- consumption good

Wage & dividends

Labor

Intermediate goods

Polluting input

Emissions
The Model

Households
- consumption/saving decisions
- labor supply

Final-Good Producers
- perfect competition
- CES technology

Intermediate-Goods Producers
- monopolistic competition
- imperfect price adjustment
- CES technology in labor and polluting input

Central Bank
- interest rate rule

Government
- extracts the polluting input at no cost
- price or quantity regulation
- balanced budget

Environmental Externality
- transfers
- wage & dividends
- consequences
The Model

Households
- consumption/saving decisions
- labor supply
- behavioral expectations

Final-Good Producers
- perfect competition
- CES technology

Intermediate-Goods Producers
- monopolistic competition
- imperfect price adjustment
- CES technology in labor and polluting input
- behavioral expectations

Central Bank
- interest rate rule

Government
- extracts the polluting input at no cost
- price or quantity regulation
- balanced budget

Environmental Externality

Households
- consumption/saving decisions
- labor supply
- behavioral expectations

Final-Good Producers
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Intermediate-Goods Producers
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Central Bank
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- extracts the polluting input at no cost
- price or quantity regulation
- balanced budget

Environmental Externality
The Model

Uncertainty from Shocks
- productivity
- discount factor
- monetary policy

Households
- consumption/saving decisions
- labor supply
- behavioral expectations

Final-Good Producers
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- interest rate rule

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- extracts the polluting input at no cost
- price or quantity regulation
- balanced budget

Intermediate-Goods Producers
- monopolistic competition
- imperfect price adjustment
- CES technology in labor and polluting input
- behavioral expectations

Environmental Externality

Consumption Good

Wage & Dividends

Labor

Intermediate Goods

Polluting Input

Emissions
The Model - Environmental Features
Intermediate-Goods Producers

CES technology:

\[ Y_{i,t} = \Delta_t \left[ \zeta Z_{i,t}^{\frac{\kappa-1}{\kappa}} + (1 - \zeta) (A_t N_{i,t})^{\frac{\kappa-1}{\kappa}} \right]^{\frac{\kappa}{\kappa-1}}, \kappa \in (0,1) \]
The Model - Environmental Features
Intermediate-Goods Producers

CES technology:

\[ Y_{i,t} = \Delta_t \left[ \zeta \left( Z_{i,t}^{\frac{\kappa-1}{\kappa}} \right) + (1 - \zeta) (A_t N_{i,t})^{\frac{\kappa-1}{\kappa}} \right]^{\frac{\kappa}{\kappa-1}}, \quad \kappa \in (0, 1) \]
CES technology:

\[ Y_{i,t} = \Delta_t \left[ \zeta Z_{i,t}^{\frac{\kappa-1}{\kappa}} + (1 - \zeta) \underbrace{(A_t N_{i,t})^{\frac{\kappa-1}{\kappa}}}_{(i) \text{ source of shocks } \times \text{ labor}} \right]^{\frac{\kappa}{\kappa-1}}, \kappa \in (0, 1) \]
The Model - Environmental Features
Intermediate-Goods Producers

CES technology:

\[ Y_{i,t} = \Delta_t \left[ \zeta Z_{i,t}^{\frac{\kappa-1}{\kappa}} + (1 - \zeta) (A_t N_{i,t})^{\frac{\kappa-1}{\kappa}} \right]^\frac{\kappa}{\kappa-1}, \quad \kappa \in (0,1) \]

imperf. complementarity

Implications: (i) time varying cost shares; (ii) when the price of carbon goes up the cost share of the polluting input \( Z \) goes up; (iii) policy shock moves inflation through its effect on marginal costs

Marginal Cost and Price Setting  Final-Good Sector
The Model - Environmental Features
Intermediate-Goods Producers

CES technology:

$$Y_{i,t} = \Delta_t \left[ \zeta Z_{i,t}^{\frac{\kappa-1}{\kappa}} + (1 - \zeta) \left( A_t N_{i,t} \right)^{\frac{\kappa-1}{\kappa}} \right]^{\frac{\kappa}{\kappa-1}}, \kappa \in (0, 1)$$
The Model - Environmental Features

Environmental Externality

One-to-one relationship between emissions and use of factor input

aggregate emissions: \( Z_t = \int_0^1 Z_{i,t} \, di \)

As in Golosov et al. (2014) the stock of emissions in the atmosphere, \( M_t \), given by:

\[
M_t - \overline{M} \quad \text{pre-indust. concentr.} = \sum_{s=0}^{t+T} (1 - \delta_M)^s \left( Z_{t-s} + Z_{t.s}^{RoW} \right) \quad \text{rest of the world emissions}
\]

Damage function:

\[
\Delta_t = \exp \left( -\eta \left( M_t - \overline{M} \right) \right), \quad \eta > 0
\]
The Model - Households

The representative household of type $i$ has preferences

$$\tilde{E}_{i,0} \sum_{t=0}^{\infty} \left( \exp \mu_t \right) \beta^t \left[ \frac{(C_{i,t} - hC_{t-1})^{1-\gamma} - \chi N_{i,t}^{1+\phi} - \frac{q}{2} \left( \frac{B_{i,t}}{P_t} \right)^2}{1-\gamma} \right]$$

subjective expectation

(ii) shock

rule out excessive borrowing/lending

Flow budget constraint:

$$P_t C_{i,t} + B_{i,t} = W_t N_{i,t} + R_{t-1} B_{i,t-1} + D_{i,t}$$

risk-free rate

$D_{i,t}$ catch-all variable: dividends and lump-sum transfers
The Model - Public Sector

**Monetary policy**: log-linearized Taylor-type interest rate rule:

\[ r_t = \lambda_\pi \pi_t + \lambda_y (y_t - y_t^*) + u_t, \]

\( (iii) \text{ shock} \)

\( y_t^* \) natural level of output (flex price)

**Environmental policy**: 

- quantity restrictions on \( Z \) (cap-and-trade) or price control on \( p_Z \) (carbon tax)
- revenues distributed as lump-sum transfers
The Model - Behavioral Features

Forecasting Rules

Agents with “cognitive limitations” use two types of simple rules to forecast future income $y$ and inflation $\pi$

**Extrapolative rules:**

$$\tilde{E}_{e,t}(y_{t+1}) = y_{t-1}, \quad \tilde{E}_{e,t}(\pi_{t+1}) = \pi_{t-1},$$

**Fundamentalist rules:**

$$\tilde{E}_{f,t}(y_{t+1}) = E_t y_{t+1}^*, \quad \tilde{E}_{f,t}(\pi_{t+1}) = 0,$$

**Market expectations:**

**income:** $\tilde{E}_t(y_{t+1}) = \alpha_{y,t}^f \tilde{E}_{f,t}(y_{t+1}) + \alpha_{y,t}^e \tilde{E}_{e,t}(y_{t+1})$

**inflation:** $\tilde{E}_t(\pi_{t+1}) = \alpha_{\pi,t}^f \tilde{E}_{f,t}(\pi_{t+1}) + \alpha_{\pi,t}^e \tilde{E}_{e,t}(\pi_{t+1}).$
The Model - Behavioral Features
Forecasting Performance and Memory

Agents can switch between rules on the basis of forecasting performances (Brock and Hommes, 1997)
Fitness criterion based on squared forecasting errors:

\[ U_{x,t}^j = - \sum_{k=0}^{\infty} \gamma_k \left( x_{t-k-1} - \hat{E}_{t-k-2}^j x_{t-k-1} \right)^2, \ j \in \{f,e\}, \ x \in \{y,\pi\} \]

\( \gamma_k \) weight to past forecast errors, BUT agents tend to forget and attach more weight to recent errors: \( \gamma_k = (1 - \rho)\rho^k \), where \( 0 \leq \rho \leq 1 \) “agent memory” parameter: how much agents recall past mistakes

\[ U_{x,t}^j = \rho U_{x,t-1}^j - (1 - \rho) \left( x_{t-1} - \hat{E}_{t-2}^j x_{t-1} \right)^2, \ j \in \{f,e\}, \ x \in \{y,\pi\} \]
The Model - Behavioral Features

Willingness to Learn

Agents unpredictably affected by their state of mind when choosing between rules:

\[ \alpha_{x,t}^f = P[U_{x,t}^f + \epsilon_{x,t}^f > U_{x,t}^e + \epsilon_{x,t}^e], \quad x \in \{y, \pi\} \]

where \( \epsilon_{x,t}^f \) and \( \epsilon_{x,t}^e \) are logistically distributed random variables

The fraction of agents opting for rule \( j \in \{f, e\} \) for the variable \( x \in \{y, \pi\} \) given by:

\[ \alpha_{x,t}^j = \frac{e^{\theta U_{x,t}^j}}{\sum_j e^{\theta U_{x,t}^j}} \]

where \( \theta > 0 \), “learning” parameter: how fast agents tend to switch to the more successful forecasting rule

jump to Moments  jump to RQ1
Calibration (i)

Table 2a: Standard and Environment-Related Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.99</td>
<td>Discount rate</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>1</td>
<td>Risk aversion coefficient</td>
</tr>
<tr>
<td>$\phi$</td>
<td>1</td>
<td>Inverse Frisch elasticity</td>
</tr>
<tr>
<td>$h$</td>
<td>0.5</td>
<td>Habit parameter</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>0.1724</td>
<td>Energy quasi-share parameter</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>0.3</td>
<td>Elasticity of substitution between energy and labor inputs</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>0.5</td>
<td>Coefficient of price indexation</td>
</tr>
<tr>
<td>$\delta_M$</td>
<td>0.0021</td>
<td>Emissions decay rate</td>
</tr>
<tr>
<td>$\eta(M - \bar{M})$</td>
<td>0.0263</td>
<td>Impact damage coefficient</td>
</tr>
<tr>
<td>$\iota_r$</td>
<td>0</td>
<td>Smoothing parameter of the Taylor rule</td>
</tr>
<tr>
<td>$\iota_y$</td>
<td>0.125</td>
<td>Output gap coefficient of the Taylor rule</td>
</tr>
<tr>
<td>$\iota_\pi$</td>
<td>1.5</td>
<td>Inflation coefficient of the Taylor rule</td>
</tr>
</tbody>
</table>

Aggregate Model
## Calibration (ii)

### Table 2b: Behavioral and Shock Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>3050</td>
<td>Learning or intensity of choice parameter</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.4</td>
<td>Memory of agents</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>0.8</td>
<td>Technology shock persistence</td>
</tr>
<tr>
<td>$\rho_v$</td>
<td>0.8</td>
<td>Preference shock persistence</td>
</tr>
<tr>
<td>$\rho_u$</td>
<td>0.5</td>
<td>Monetary policy shock persistence</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>0.009</td>
<td>Standard deviation of the technology shock</td>
</tr>
<tr>
<td>$\sigma_v$</td>
<td>0.005</td>
<td>Standard deviation of the preference shock</td>
</tr>
<tr>
<td>$\sigma_u$</td>
<td>0.005</td>
<td>Standard deviation of the monetary policy shock</td>
</tr>
</tbody>
</table>
### Calibration (iii)

**Table 3: Moments for Output $y$ - Data and Model under the Baseline Calibration**

<table>
<thead>
<tr>
<th></th>
<th>Standard Deviation</th>
<th>Autocorrelation</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>0.0103</td>
<td>0.8565</td>
<td>3.3057</td>
</tr>
<tr>
<td>Model</td>
<td>0.0105</td>
<td>0.8863</td>
<td>3.3239</td>
</tr>
</tbody>
</table>

Note: the table reports moments generated by the model under the baseline calibration for 100 replications of shock sequences of size 1,000 and those of the US data over the period 1990Q1-2019Q4, retrieved from FRED, Federal Reserve Bank of St.Louis. Series used: Real Gross Domestic Product - GDPC1 (HP Filtered series).
The Role of Expectations

RQ1: What is the response of the economy to climate policies if we remove the assumption of perfect rationality?

- a permanent increase in the price of carbon to induce a 1% permanent reduction of emissions

Preview: Climate policies frustrated by the presence of agents lacking the cognitive abilities necessary to form rational expectations
A Simple Example
Fig. 2 - Increase in the Carbon Price under Rational and Behavioral Expectations
The Role of Expectations

• RQ2: What is the role of market beliefs in driving or hindering the mitigation process?
  • mitigation policy implemented through a cap or a commensurate carbon tax to gradually cut emissions by 20% in 5 years (in line with the emission reduction targets set by the US for 2030)
  • 3-step procedure:
    • design both scenarios in a RE setup where agents are surprised by the policy shock
    • use emissions or carbon tax path obtained above in a behavioral setup
    • consider an economy out of its steady state (shocks on technology, demand, and interest rate)

• Preview: the state of the economy and market beliefs shape the impact of the mitigation plan; more uncertainty on the time-path and the impact itself of climate policies
Mitigation Scenarios

Fig. 3 - Timely Mitigation under Behavioral Expectations - Carbon Tax

- Output, \( y \)
- Output Gap, \( y - y^* \)
- Emissions, \( z \)
- Marginal Cost, \( mc \)
- Inflation, \( \pi \)
- Real Interest Rate
- Output Extrapolation, \( \alpha_y^e \)
- Inflation Extrapolation, \( \alpha_\pi^e \)

Legend:
- Mean
- \( \pm 2SD \)
Mitigation Scenarios

Macroeconomic Volatility

- What’s the variability of emissions, output and inflation?
- What if same mitigation, but with one year delay?
- Behind the scenes: carbon tax v. cap and expectations
- What if the economy is highly pertubed?
## Mitigation Scenarios

### Table 4: Macroeconomic Volatility along the Mitigation Path

<table>
<thead>
<tr>
<th></th>
<th>Timely Mitigation</th>
<th>1 Year - Delayed Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tax</td>
<td>Cap</td>
</tr>
<tr>
<td>$\sigma_z$ s.d. emissions %</td>
<td>0.1584</td>
<td>0</td>
</tr>
<tr>
<td>$\sigma_{p_z}$ s.d. emission price %</td>
<td>0</td>
<td>0.4774</td>
</tr>
<tr>
<td>$\sigma_{y-y^*}$ s.d. output gap %</td>
<td>0.1001</td>
<td>0.0823</td>
</tr>
<tr>
<td>$\sigma_{\pi}$ s.d. inflation b.p.</td>
<td>2.7081</td>
<td>2.9812</td>
</tr>
<tr>
<td>$E(\pi)$ mean inflation b.p.</td>
<td>6.6437</td>
<td>7.7108</td>
</tr>
</tbody>
</table>

Note: the table reports the standard deviations for a selection of variables along with mean inflation and the its maximum observed value over the mitigation time path (20 quarters).
Mitigation Scenarios

Fig. 4: Behind the Scenes: Market Forecast Errors

Forecast Errors RE
Mitigation Scenarios

Fig. A-3: Highly Perturbed Economy - Carbon Tax

Note: Shocks’ SD 3 times larger
Mitigation Scenarios

Fig. A-4: Highly Perturbed Economy - Cap-and-Trade

Note: Shocks’ SD 3 times larger
RQ3: Can monetary policy tame the irrational exuberance of the markets rendering the greening policy more effective, while maintaining price stability?

- baseline results obtained with a standard rule - 
  \[ r_t = 1.5\pi_t + 0.125(y_t - y_t^*) \]
- change policy parameters; allow persistence
- different rules
- credibility issues on inflation targeting

Preview: Monetary policy can reduce transition uncertainty
# The Role of Monetary Policy

## Table 5a: Macroeconomic Volatility along the Mitigation Path: The Role of Monetary Policy - Tax

<table>
<thead>
<tr>
<th>( \lambda_y ) reactivity to output gap</th>
<th>( \sigma_z )</th>
<th>( \sigma_{y-y^*} )</th>
<th>( \sigma_\pi )</th>
<th>( E(\pi) )</th>
<th>( max(\pi) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.2097</td>
<td>0.1327</td>
<td>3.6079</td>
<td>7.8440</td>
<td>9.7411</td>
</tr>
<tr>
<td>0.125</td>
<td>0.1584</td>
<td>0.1001</td>
<td>2.7081</td>
<td>6.6437</td>
<td>8.1280</td>
</tr>
<tr>
<td>0.5</td>
<td>0.0778</td>
<td>0.0490</td>
<td>1.3043</td>
<td>4.5251</td>
<td>5.3703</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \lambda_\pi ) reactivity to inflation</th>
<th>( \sigma_z )</th>
<th>( \sigma_{y-y^*} )</th>
<th>( \sigma_\pi )</th>
<th>( E(\pi) )</th>
<th>( max(\pi) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>0.1998</td>
<td>0.1265</td>
<td>3.4545</td>
<td>7.6721</td>
<td>9.6154</td>
</tr>
<tr>
<td>1.5</td>
<td>0.1584</td>
<td>0.1001</td>
<td>2.7081</td>
<td>6.6437</td>
<td>8.1280</td>
</tr>
<tr>
<td>3</td>
<td>0.0776</td>
<td>0.0487</td>
<td>1.2679</td>
<td>4.3878</td>
<td>5.1074</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \lambda_r ) persistence</th>
<th>( \sigma_z )</th>
<th>( \sigma_{y-y^*} )</th>
<th>( \sigma_\pi )</th>
<th>( E(\pi) )</th>
<th>( max(\pi) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.1584</td>
<td>0.1001</td>
<td>2.7081</td>
<td>6.6437</td>
<td>8.1280</td>
</tr>
<tr>
<td>0.5</td>
<td>0.2150</td>
<td>0.1358</td>
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<td>7.4956</td>
<td>9.1287</td>
</tr>
<tr>
<td>0.9</td>
<td>0.9265</td>
<td>0.5900</td>
<td>16.5975</td>
<td>18.2039</td>
<td>24.3147</td>
</tr>
</tbody>
</table>

Note: \( \sigma_{p_z}, \sigma_z, \sigma_{y-y^*} \) expressed in percentages, \( \sigma_\pi, E(\pi) \) and \( max(\pi) \) in quarterly basis points.
The Role of Monetary Policy

Table 5b: Macroeconomic Volatility along the Mitigation Path: The Role of Monetary Policy - Cap

<table>
<thead>
<tr>
<th></th>
<th>$\sigma_{p_z}$</th>
<th>$\sigma_{y-y^*}$</th>
<th>$\sigma_{\pi}$</th>
<th>$E(\pi)$</th>
<th>$\max(\pi)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.6259</td>
<td>0.1080</td>
<td>3.9248</td>
<td>8.9555</td>
<td>11.1760</td>
</tr>
<tr>
<td>0.125</td>
<td>0.4775</td>
<td>0.0823</td>
<td>2.9812</td>
<td>7.7108</td>
<td>9.4923</td>
</tr>
<tr>
<td>0.5</td>
<td>0.2390</td>
<td>0.0410</td>
<td>1.4712</td>
<td>5.4329</td>
<td>6.4966</td>
</tr>
<tr>
<td>1.1</td>
<td>0.6395</td>
<td>0.1104</td>
<td>4.0471</td>
<td>9.1434</td>
<td>11.5907</td>
</tr>
<tr>
<td>1.5</td>
<td>0.4775</td>
<td>0.0823</td>
<td>2.9812</td>
<td>7.7108</td>
<td>9.4923</td>
</tr>
<tr>
<td>3</td>
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<td>1.1845</td>
<td>4.8382</td>
<td>5.5797</td>
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<td>0.4775</td>
<td>0.0823</td>
<td>2.9812</td>
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<td>9.4923</td>
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<td>0.5</td>
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<td>0.1134</td>
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<td>10.4960</td>
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<tr>
<td>0.9</td>
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<td>0.5507</td>
<td>20.3834</td>
<td>22.3629</td>
<td>30.1979</td>
</tr>
</tbody>
</table>

Note: $\sigma_{p_z}, \sigma_{z}, \sigma_{y-y^*}$ expressed in percentages, $\sigma_{\pi}, E(\pi)$ and $\max(\pi)$ in quarterly basis points
### The Role of Monetary Policy

**Table 6: Macroeconomic Volatility along the Mitigation Path - Alternative Monetary Rules**

<table>
<thead>
<tr>
<th>Tax</th>
<th>( \sigma_z )</th>
<th>( \sigma_{y-y^*} )</th>
<th>( \sigma_\pi )</th>
<th>( E(\pi) )</th>
<th>( \text{max}(\pi) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r_t = \iota_\pi \pi_t + \iota_y (y_t - y_t^*) )</td>
<td>0.1584</td>
<td>0.1001</td>
<td>2.7081</td>
<td>6.6437</td>
<td>8.1280</td>
</tr>
<tr>
<td>( r_t = \iota_\pi \pi_{t-1} + \iota_y (y_{t-1} - y_{t-1}^*) )</td>
<td>0.1885</td>
<td>0.1188</td>
<td>3.1408</td>
<td>7.1380</td>
<td>8.5656</td>
</tr>
<tr>
<td>( r_t = \iota_\pi \pi_{t+1} + \iota_y E_t (y_{t+1} - y_{t+1}^*) )</td>
<td>0.1577</td>
<td>0.0998</td>
<td>2.7323</td>
<td>6.8825</td>
<td>8.6229</td>
</tr>
<tr>
<td>( r_t = \iota_\pi \pi_{t+1} + \iota_y E_t (y_{t+1} - y_{t+1}^*) )</td>
<td>0.2978</td>
<td>0.1886</td>
<td>5.1800</td>
<td>9.9000</td>
<td>12.6396</td>
</tr>
<tr>
<td>( r_t = \iota_\pi \pi_t + \iota_y (y_t - y_{t-1}) )</td>
<td>0.2156</td>
<td>0.1365</td>
<td>3.7277</td>
<td>8.2961</td>
<td>10.3813</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cap</th>
<th>( \sigma_{p_z} )</th>
<th>( \sigma_{y-y^*} )</th>
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<td>( r_t = \iota_\pi \pi_t + \iota_y (y_t - y_t^*) )</td>
<td>0.4775</td>
<td>0.0823</td>
<td>2.9812</td>
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<td>9.4923</td>
</tr>
<tr>
<td>( r_t = \iota_\pi \pi_{t-1} + \iota_y (y_{t-1} - y_{t-1}^*) )</td>
<td>0.5853</td>
<td>0.1005</td>
<td>3.5268</td>
<td>8.3282</td>
<td>9.9898</td>
</tr>
<tr>
<td>( r_t = \iota_\pi \pi_{t+1} + \iota_y E_t (y_{t+1} - y_{t+1}^*) )</td>
<td>0.4720</td>
<td>0.0814</td>
<td>3.0077</td>
<td>8.0467</td>
<td>10.1408</td>
</tr>
<tr>
<td>( r_t = \iota_\pi \pi_{t+1} + \iota_y E_t (y_{t+1} - y_{t+1}^*) )</td>
<td>1.0218</td>
<td>0.1766</td>
<td>6.5035</td>
<td>12.1937</td>
<td>15.8057</td>
</tr>
<tr>
<td>( r_t = \iota_\pi \pi_t + \iota_y (y_t - y_{t-1}) )</td>
<td>0.6422</td>
<td>0.1108</td>
<td>4.0555</td>
<td>9.4710</td>
<td>11.8816</td>
</tr>
</tbody>
</table>

Note: \( \sigma_{p_z}, \sigma_z, \sigma_{y-y^*} \) expressed in percentages, \( \sigma_\pi, E(\pi) \) and \( \text{max}(\pi) \) in quarterly basis points
The Role of Monetary Policy

Table 6: Macroeconomic Volatility along the Mitigation Path - Alternative Monetary Rules

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<tr>
<th>Tax</th>
<th>$\sigma_z$</th>
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</thead>
<tbody>
<tr>
<td>$r_t = \iota_\pi \pi_t + \iota_y (y_t - y_t^*)$</td>
<td>0.1584</td>
<td>0.1001</td>
<td>2.7081</td>
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<td>$r_t = \iota_\pi \pi_{t-1} + \iota_y (y_{t-1} - y_{t-1}^*)$</td>
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<td>0.1188</td>
<td>3.1408</td>
<td>7.1380</td>
<td>8.5656</td>
</tr>
<tr>
<td>$r_t = \iota_\pi E_t \pi_{t+1} + \iota_y E_t (y_{t+1} - y_{t+1}^*)$</td>
<td>0.1577</td>
<td>0.0998</td>
<td>2.7323</td>
<td>6.8825</td>
<td>8.6229</td>
</tr>
<tr>
<td>$r_t = \iota_\pi \tilde{E}<em>t \pi</em>{t+1} + \iota_y \tilde{E}<em>t (y</em>{t+1} - y_{t+1}^*)$</td>
<td>0.2978</td>
<td>0.1886</td>
<td>5.1800</td>
<td>9.9000</td>
<td>12.6396</td>
</tr>
<tr>
<td>$r_t = \iota_\pi \pi_t + \iota_y (y_t - y_{t-1})$</td>
<td>0.2156</td>
<td>0.1365</td>
<td>3.7277</td>
<td>8.2961</td>
<td>10.3813</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Cap</th>
<th>$\sigma_{p_z}$</th>
<th>$\sigma_{y-y^*}$</th>
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<tbody>
<tr>
<td>$r_t = \iota_\pi \pi_t + \iota_y (y_t - y_t^*)$</td>
<td>0.4775</td>
<td>0.0823</td>
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<td>7.7108</td>
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<td>$r_t = \iota_\pi \pi_{t-1} + \iota_y (y_{t-1} - y_{t-1}^*)$</td>
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<td>0.1005</td>
<td>3.5268</td>
<td>8.3282</td>
<td>9.9898</td>
</tr>
<tr>
<td>$r_t = \iota_\pi E_t \pi_{t+1} + \iota_y E_t (y_{t+1} - y_{t+1}^*)$</td>
<td>0.4720</td>
<td>0.0814</td>
<td>3.0077</td>
<td>8.0467</td>
<td>10.1408</td>
</tr>
<tr>
<td>$r_t = \iota_\pi \tilde{E}<em>t \pi</em>{t+1} + \iota_y \tilde{E}<em>t (y</em>{t+1} - y_{t+1}^*)$</td>
<td>1.0218</td>
<td>0.1766</td>
<td>6.5035</td>
<td>12.1937</td>
<td>15.8057</td>
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</table>

Note: $\sigma_{p_z}$, $\sigma_z$, $\sigma_{y-y^*}$ expressed in percentages, $\sigma_\pi$, $E(\pi)$ and $\max(\pi)$ in quarterly basis points
## The Role of Monetary Policy

### Table 6: Macroeconomic Volatility along the Mitigation Path - Alternative Monetary Rules

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<tr>
<th>Tax</th>
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</tr>
</tbody>
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Note: $\sigma_{p_z}$, $\sigma_z$, $\sigma_{y-y^*}$ expressed in percentages, $\sigma_\pi$, $E(\pi)$ and $max(\pi)$ in quarterly basis points
The Role of Monetary Policy

Table 9a: Credibility Issues on Inflation Targeting - Tax

<table>
<thead>
<tr>
<th></th>
<th>( \sigma_z )</th>
<th>( \sigma_{y-y^*} )</th>
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<th>( E(\pi) )</th>
<th>( \text{max}(\pi) )</th>
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<td><strong>Baseline</strong></td>
<td>0.1584</td>
<td>0.1001</td>
<td>2.7081</td>
<td>6.6437</td>
<td>8.1280</td>
</tr>
<tr>
<td>Inflation targeting skepticism</td>
<td>0.1441</td>
<td>0.0910</td>
<td>6.1445</td>
<td>20.9906</td>
<td>38.2703</td>
</tr>
<tr>
<td>( \tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflation targeting credibility</td>
<td>0.1735</td>
<td>0.1098</td>
<td>1.7203</td>
<td>3.7914</td>
<td>4.3634</td>
</tr>
<tr>
<td>( \tilde{E}<em>t(\pi</em>{t+1}) = 0 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strong-trend following rule for inflation</td>
<td>0.2203</td>
<td>0.1397</td>
<td>28.1793</td>
<td>66.1670</td>
<td>107.1897</td>
</tr>
<tr>
<td>( \tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1} + 1.3(\pi_{t-1} - \pi_{t-2}) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weak-trend following rule for inflation</td>
<td>0.1360</td>
<td>0.0859</td>
<td>7.3463</td>
<td>25.6732</td>
<td>45.3238</td>
</tr>
<tr>
<td>( \tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1} + 0.4(\pi_{t-1} - \pi_{t-2}) )</td>
<td></td>
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<td></td>
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</tbody>
</table>

Note: \( \sigma_{p_z}, \sigma_z, \sigma_{y-y^*} \) expressed in percentages, \( \sigma_{\pi}, E(\pi) \) and \( \text{max}(\pi) \) in quarterly basis points.
## The Role of Monetary Policy

### Table 9a: Credibility Issues on Inflation Targeting - Tax

<table>
<thead>
<tr>
<th>Tax</th>
<th>$\sigma_z$</th>
<th>$\sigma_{y−y^*}$</th>
<th>$\sigma_\pi$</th>
<th>$E(\pi)$</th>
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<tr>
<td>Baseline</td>
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<td>38.2703</td>
</tr>
<tr>
<td>$\tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1}$</td>
<td>0.1735</td>
<td>0.1098</td>
<td>1.7203</td>
<td>3.7914</td>
<td>4.3634</td>
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<td>Inflation targeting credibility</td>
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<td>6.1445</td>
<td>20.9906</td>
<td>38.2703</td>
</tr>
<tr>
<td>$\tilde{E}<em>t(\pi</em>{t+1}) = 0$</td>
<td>0.2203</td>
<td>0.1397</td>
<td>28.1793</td>
<td>66.1670</td>
<td>107.1897</td>
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<tr>
<td>Strong-trend following rule for inflation</td>
<td>0.1360</td>
<td>0.0859</td>
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<td>45.3238</td>
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<td>107.1897</td>
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The Role of Monetary Policy

Table 9a: Credibility Issues on Inflation Targeting - Tax

<table>
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<td>107.1897</td>
</tr>
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<td></td>
<td></td>
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<tr>
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<td>0.0859</td>
<td>7.3463</td>
<td>25.6732</td>
<td>45.3238</td>
</tr>
<tr>
<td>$\tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1} + 0.4(\pi_{t-1} - \pi_{t-2})$</td>
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<td></td>
<td></td>
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</tr>
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</table>

Note: $\sigma_{p_z}, \sigma_z, \sigma_{y-y^*}$ expressed in percentages, $\sigma_{\pi}, E(\pi)$ and $\text{max}(\pi)$ in quarterly basis points
## The Role of Monetary Policy

**Table 9b: Credibility Issues on Inflation Targeting - Cap**

<table>
<thead>
<tr>
<th>Cap</th>
<th>( \sigma_{p_z} )</th>
<th>( \sigma_{y-y^*} )</th>
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<tr>
<td><strong>Baseline</strong></td>
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<td>0.0823</td>
<td>2.9812</td>
<td>7.7108</td>
<td>9.4923</td>
</tr>
<tr>
<td>Inflation targeting skepticism</td>
<td>0.4308</td>
<td>0.0742</td>
<td>6.2204</td>
<td>23.4153</td>
<td>41.5472</td>
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<td>( \tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1} )</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Inflation targeting credibility</td>
<td>0.5364</td>
<td>0.0926</td>
<td>1.8470</td>
<td>4.4050</td>
<td>5.1235</td>
</tr>
<tr>
<td>( \tilde{E}<em>t(\pi</em>{t+1}) = 0 )</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strong-trend following rule for inflation</td>
<td>0.6790</td>
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<td>26.1196</td>
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<td>108.5485</td>
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<td>( \tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1} + 1.3(\pi_{t-1} - \pi_{t-2}) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weak-trend following rule for inflation</td>
<td>0.4043</td>
<td>0.0695</td>
<td>7.3475</td>
<td>28.3265</td>
<td>48.2071</td>
</tr>
<tr>
<td>( \tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1} + 0.4(\pi_{t-1} - \pi_{t-2}) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: \( \sigma_{p_z}, \sigma_z, \sigma_{y-y^*} \) expressed in percentages, \( \sigma_\pi, E(\pi) \) and \( \text{max}(\pi) \) in quarterly basis points
## Table 9b: Credibility Issues on Inflation Targeting - Cap

<table>
<thead>
<tr>
<th>Cap</th>
<th>$\sigma_{p_z}$</th>
<th>$\sigma_{y-y^*}$</th>
<th>$\sigma_{\pi}$</th>
<th>$E(\pi)$</th>
<th>$\max(\pi)$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>0.4775</td>
<td>0.0823</td>
<td>2.9812</td>
<td>7.7108</td>
<td>9.4923</td>
</tr>
<tr>
<td>Inflation targeting skepticism</td>
<td>0.4308</td>
<td>0.0742</td>
<td>6.2204</td>
<td>23.4153</td>
<td>41.5472</td>
</tr>
<tr>
<td>$\tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflation targeting credibility</td>
<td>0.5364</td>
<td>0.0926</td>
<td>1.8470</td>
<td>4.4050</td>
<td>5.1235</td>
</tr>
<tr>
<td>$\tilde{E}<em>t(\pi</em>{t+1}) = 0$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Strong-trend following rule for inflation</strong></td>
<td>0.6790</td>
<td>0.1174</td>
<td>26.1196</td>
<td>66.6758</td>
<td>108.5485</td>
</tr>
<tr>
<td>$\tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1} + 1.3(\pi_{t-1} - \pi_{t-2})$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Weak-trend following rule for inflation</strong></td>
<td>0.4043</td>
<td>0.0695</td>
<td>7.3475</td>
<td>28.3265</td>
<td>48.2071</td>
</tr>
<tr>
<td>$\tilde{E}<em>t(\pi</em>{t+1}) = \pi_{t-1} + 0.4(\pi_{t-1} - \pi_{t-2})$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: $\sigma_{p_z}, \sigma_{z}, \sigma_{y-y^*}$ expressed in percentages, $\sigma_{\pi}, E(\pi)$ and $\max(\pi)$ in quarterly basis points
Conclusions

- Market beliefs and behavioral agents increase the trade-offs inherent to the chosen mitigation tool
  - carbon tax: more emissions uncertainty
  - cap-and-trade: more pronounced pressure on allowances prices and inflation
- A reactive monetary policy helps in reducing transition uncertainty and inflationary pressure
- Impact on price stability worsened by
  - delays in the implementation of climate policies
  - the adoption of monetary rules tied to market expectations
  - lack of confidence in the ability of central banks to keep inflation under control
- Central banks can also contribute to fight climate change acting in the perimeter of their mandate!
What’s Next

- Great uncertainty about the impact of climate change on the economy
- Beliefs about pollution policy and climate damages
- Optimal policy and hybrid environmental rules
Appendix
Perfectly competitive final good sector assembling differentiated intermediate goods to produce a single final good, $Y_t$, according to a constant elasticity of substitution (CES) technology:

$$Y_t = \left[ \int_0^1 (Y_{i,t})^{(\sigma-1)/\sigma} \, di \right]^{\sigma/(\sigma-1)}, \quad \sigma > 1$$

At the optimum: $Y_{i,t} = (P_{i,t}/P_t)^{-\sigma} Y_t$, where

$$P_t = \int_0^1 \left( p_{i,t}^{1-\sigma} \right)^{1/(1-\sigma)} \, di$$
The Model
Intermediate-Goods Producers - MC and Price Setting

Real marginal cost of production:

\[ MC_{i,t} = \Delta_t^{-1} \left[ \zeta^\kappa \left( \frac{P_{Z,t}}{P_t} \right)^{1-\kappa} + (1 - \zeta)^\kappa A_t^{\kappa-1} \left( \frac{W_t}{P_t} \right)^{1-\kappa} \right]^{\frac{1}{1-\kappa}}, \]

Calvo’s pricing: probability of price resetting \(1 - \varpi\)

Indexation rule for non re-optimizing firms:

\[ P_{i,t+s} = P_{i,t+s-1} \Pi_t^\kappa \Pi_{t+s-1}^\kappa, \quad s = 1, \ldots, n, \quad \kappa \in [0, 1] \]

where \( \Pi_{t+1} = P_{t+1}/P_t \)
Table 1: The Aggregate Log-Linearized Model

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_t (1 + h) = \tilde{E}<em>t y</em>{t+1} + hy_{t-1} - \frac{1-h}{\gamma} (r_t - \tilde{E}<em>t \pi</em>{t+1}) + v_t$</td>
<td>IS</td>
</tr>
<tr>
<td>$mc_t = mc_y y_t - mc_{\delta} \delta_t - mc_z z_t - mc_{\alpha} \alpha_t - mc_{y-1} y_{t-1}$</td>
<td>Marginal Cost</td>
</tr>
<tr>
<td>$z_t = \gamma mc_t + (\gamma - 1) \delta_t + y_t - \gamma p_{Z,t}$</td>
<td>Emissions</td>
</tr>
<tr>
<td>$\pi_t = \frac{1-\omega}{1+\beta} \frac{1-\alpha}{\alpha} mc_t + \frac{\beta}{1+\beta} \tilde{E}<em>t \pi</em>{t+1} + \frac{\kappa}{1+\beta} \pi_{t-1}$</td>
<td>New Keynesian Phillips Curve</td>
</tr>
<tr>
<td>$m_t = \delta M Z + Z_{RoW} Z_t + (1 - \delta_M) m_{t-1} + \delta_M Z_{RoW} Z_{RoW} Z_t$</td>
<td>Pollution Stock</td>
</tr>
<tr>
<td>$\delta_t = -\eta (\bar{M} - M) m_t$</td>
<td>Environmental Damage</td>
</tr>
<tr>
<td>$r_t = \iota_\pi \pi_t + \iota_y (y_t - y_t^*) + u_t$</td>
<td>Taylor Rule</td>
</tr>
</tbody>
</table>

Note: the model is log-linearized around zero steady-state inflation. In the second equation the coefficients are all positive and depend on a complex fashion on the deep parameters of the model. See Appendix. Variables $v_t, a_t$ and $u_t$ are exogenous stochastic processes driving economic fluctuations.

[back to Households] [back to Calibration]
Mitigation Scenarios

Fig. 3bis: Timely Mitigation under Behavioral Expectations - Cap
Mitigation Scenarios

Fig. A-1: Timely Mitigation under Behavioral and Rational Expectations - Carbon Tax

[Diagram showing graphs for Output, Emissions, Marginal Cost, Inflation, and Real Interest Rate with behavioral and rational expectations]

[Links to back to Figure 2 and back to Table 4]
Mitigation Scenarios

Fig. 3ter: Delayed Mitigation under Behavioral Expectations - Carbon Tax

- Output, $y$
- Output Gap, $y - y^*$
- Emissions, $z$
- Marginal Cost, $mc$
- Inflation, $\pi$
- Real Interest Rate
- Output Extrapolation, $\alpha_y$
- Inflation Extrapolation, $\alpha_\pi$

Mean
± 2SD

back to Table 4
Mitigation Scenarios

Fig. A-1bis: Delayed Mitigation under Behavioral and Rational Expectations - Carbon Tax

back to Table 4
Mitigation Scenarios

Fig. 4bis: Behind the Scenes: Forecast Errors under RE

Back to Figure 4
### Willingness to Learn and Memory

#### Table 7: Macroeconomic Volatility along the Mitigation Path: The Role of Willingness to Learn and Memory

<table>
<thead>
<tr>
<th>θ</th>
<th>$\sigma_z$</th>
<th>$\sigma_{y-y^*}$</th>
<th>$\sigma_\pi$</th>
<th>$E(\pi)$</th>
<th>$\max(\pi)$</th>
<th>$\sigma_{pz}$</th>
<th>$\sigma_{y-y^*}$</th>
<th>$\sigma_\pi$</th>
<th>$E(\pi)$</th>
<th>$\max(\pi)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>0.0260</td>
<td>0.0164</td>
<td>0.4440</td>
<td>4.6315</td>
<td>5.5010</td>
<td>0.0783</td>
<td>0.0135</td>
<td>0.4887</td>
<td>5.6256</td>
<td>6.6495</td>
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<tr>
<td>1000</td>
<td>0.0519</td>
<td>0.0328</td>
<td>0.8879</td>
<td>5.0261</td>
<td>6.0161</td>
<td>0.1565</td>
<td>0.0270</td>
<td>0.9774</td>
<td>6.0345</td>
<td>7.2069</td>
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<tr>
<td>2500</td>
<td>0.1299</td>
<td>0.0821</td>
<td>2.2198</td>
<td>6.2097</td>
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<td>0.0674</td>
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<td>8.8791</td>
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<tr>
<td>3050</td>
<td>0.1584</td>
<td>0.1001</td>
<td>2.7081</td>
<td>6.6437</td>
<td>8.1280</td>
<td>0.4775</td>
<td>0.0823</td>
<td>2.9812</td>
<td>7.7108</td>
<td>9.4923</td>
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<tr>
<td>3200</td>
<td>0.1662</td>
<td>0.1051</td>
<td>2.8413</td>
<td>6.7621</td>
<td>8.2826</td>
<td>0.5009</td>
<td>0.0863</td>
<td>3.1278</td>
<td>7.8334</td>
<td>9.6595</td>
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<tr>
<td>ρ</td>
<td>$\sigma_z$</td>
<td>$\sigma_{y-y^*}$</td>
<td>$\sigma_\pi$</td>
<td>$E(\pi)$</td>
<td>$\max(\pi)$</td>
<td>$\sigma_{pz}$</td>
<td>$\sigma_{y-y^*}$</td>
<td>$\sigma_\pi$</td>
<td>$E(\pi)$</td>
<td>$\max(\pi)$</td>
</tr>
<tr>
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<td>---</td>
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<tr>
<td>0</td>
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<td>0.0894</td>
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<tr>
<td>0.2</td>
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<td>8.1280</td>
<td>0.4775</td>
<td>0.0823</td>
<td>2.9812</td>
<td>7.7108</td>
<td>9.4923</td>
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<tr>
<td>0.6</td>
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<td>6.4746</td>
<td>7.9459</td>
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<tr>
<td>0.9</td>
<td>0.0744</td>
<td>0.0473</td>
<td>1.3450</td>
<td>5.8345</td>
<td>7.1174</td>
<td>0.2229</td>
<td>0.0387</td>
<td>1.4730</td>
<td>6.8288</td>
<td>8.2953</td>
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</table>

Note: $\sigma_{pz}, \sigma_z, \sigma_{y-y^*}$ expressed in percentages, $\sigma_\pi, E(\pi)$ and $\max(\pi)$ in quarterly basis points
## Asynchronous Updating

Table 8. Macroeconomic Volatility along the Mitigation Path: Asynchronous Updating of Expectations

<table>
<thead>
<tr>
<th>δ_i</th>
<th>σ_z</th>
<th>σ_y−y_*</th>
<th>σ_π</th>
<th>E(π)</th>
<th>max(π)</th>
<th>δ_i</th>
<th>σ_z</th>
<th>σ_y−y_*</th>
<th>σ_π</th>
<th>E(π)</th>
<th>max(π)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.1584</td>
<td>0.1001</td>
<td>2.7081</td>
<td>6.6437</td>
<td>8.1280</td>
<td>0.4775</td>
<td>0.0823</td>
<td>2.9812</td>
<td>7.7108</td>
<td>9.4923</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td>0.1536</td>
<td>0.0972</td>
<td>2.6413</td>
<td>6.5869</td>
<td>8.0726</td>
<td>0.4635</td>
<td>0.0800</td>
<td>2.9136</td>
<td>7.6531</td>
<td>9.4283</td>
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</tr>
<tr>
<td>0.4</td>
<td>0.1454</td>
<td>0.0921</td>
<td>2.5236</td>
<td>6.4960</td>
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<td>0.0760</td>
<td>2.7924</td>
<td>7.5583</td>
<td>9.3177</td>
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<tr>
<td>0.6</td>
<td>0.1307</td>
<td>0.0829</td>
<td>2.2970</td>
<td>6.3393</td>
<td>7.8002</td>
<td>0.3966</td>
<td>0.0686</td>
<td>2.5505</td>
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<td>0.8</td>
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<td>0.0636</td>
<td>1.7939</td>
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<td>7.4164</td>
<td>0.3033</td>
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<td>1</td>
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<td>5.2168</td>
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</tbody>
</table>

Note: \(σ_{pz}, σ_z, σ_{y−y^{*}}\) expressed in percentages, \(σ_π, E(π)\) and \(max(π)\) in quarterly basis points. 

[back to Table 4]