Networks, Phillips curves, and Monetary Policy

Elisa Rubbo

Harvard University

May 22, 2020
New Keynesian framework

- Textbook model:
  - stabilize output and prices
  - “divine coincidence” → optimal policy via inflation targeting

- With many sectors:
  - relevant measure of aggregate inflation for monetary policy
    (CPI? PPI? Other?)
  - how to trade off inflation in different sectors?
Key objects

1. Phillips curve:

\[ \overline{\pi}_t = \rho \mathbb{E}\overline{\pi}_{t+1} + \kappa \tilde{y}_t + u_t \]

- inflation
- output gap

- many inflation measures
- slope and residual
Key objects

1. Phillips curve:

\[
\bar{\pi}_t = \rho \bar{\pi}_{t+1} + \kappa \tilde{y}_t + u_t
\]

- many inflation measures
- slope and residual

2. Loss function:

\[
W = \frac{1}{2} \left[ \zeta \tilde{y}^2 + \epsilon \pi^2 \right] \quad \rightarrow \quad W = \frac{1}{2} \left[ \zeta \tilde{y}^2 + \pi^T D \pi \right]
\]

- full distribution of sectoral inflation rates
Theoretical results

1. Phillips curve(s):

\[
\bar{\pi}_t = \rho \bar{\pi}_{t+1} + \kappa \tilde{y}_t + u_t
\]

- intermediate inputs → flattening
- endogenous cost-push shocks
- “divine coincidence” inflation index
  - sufficient statistic for aggregate output gap
  - preserves the “positive” properties of inflation in the baseline model
Theoretical results

2. Loss function:

\[
W = \frac{1}{2} \left[ \zeta \tilde{y}^2 + \pi^T D \pi \right]
\]

- aggregate vs relative output
- inflation target for optimal policy
  - "divine coincidence" index only captures aggregate output
Quantitative results

3. Phillips curve(s)
   - calibrated model predicts coefficients correctly
   - R-squared 2 to 4 times larger with “divine coincidence” index
   - flattening of the CPI Phillips curve over time (NOT wage)
Quantitative results

4. Welfare loss from business cycles

- 1.12% of per-period GDP if target consumer inflation
- reduced to 0.28% with optimal policy
- closing output gap ~ optimal policy
- benchmark: Lucas’ estimate (0.05% per-period GDP)
Related literature

- **Markup distortions and aggregate productivity** Baqae and Farhi (2018), Hsieh and Klenow (2009), Edmond, Midrigan and Xu (2018)


- **Networks and optimal policy** La’O and Tahbaz-Salehi (2019)

Roadmap

1. Key elements of network model

2. Phillips curve(s)
   - sketch of derivation
   - “divine coincidence” index

3. Optimal policy
   - loss function
   - optimal inflation target
Outline

Setup

Sectoral inflation and Phillips curve(s)

Calibration: slope & monetary non-neutrality

“Divine coincidence” index

Optimal policy

Calibration: welfare loss from business cycles

Conclusion
Consumption

- Utility from consumption \((C)\), homothetic preferences over bundle of all goods produced in the economy
- Disutility from labor supply \((L)\)

\[
U = \frac{C^{1-\gamma}}{1-\gamma} - \frac{L^{1+\varphi}}{1+\varphi}
\]

- Nominal expenditure \((PC)\) cannot exceed money supply \((M)\):

\[
PC \leq M
\]
Production

- $N$ sectors

- continuum of firms within sectors, CES bundle
- CRS production function $F_i$

\[ \begin{align*}
Y_i &= \underbrace{A_i} \overbrace{F_i(L_i, \{x_{ij}\})} \\
\text{Hicks-neutral shifter}
\end{align*} \]

- fraction $\delta_i$ of producers adjust price after seeing $A$

- Sticky wages: add labor sector with sticky price
- Undistorted steady state (optimal subsidies)
Log-linearized model

Parameters:

- Labor, input, consumption shares: $\alpha, \Omega, \beta$
- adjustment probabilities: $\Delta = \text{diag}(\delta_1 \ldots \delta_N)$
- elasticities of substitution in production and consumption

Variables:

- Aggregate output gap
  \[ \tilde{y} = y - y_{nat} \]
- Sectoral inflation rates
  \[ \pi = \left( \pi_1, \ldots, \pi_N \right)^T \]
Outline

Setup

Sectoral inflation and Phillips curve(s)

   Calibration: slope & monetary non-neutrality

“Divine coincidence” index

Optimal policy

   Calibration: welfare loss from business cycles

Conclusion
Sectoral vs aggregate

- Sectoral Phillips curves:
  \[
  \pi \equiv B\bar{y} + \mathcal{V}d\log A
  \]

- Aggregate Phillips curve (weights \(\phi\)):
  \[
  \pi^{AGG} \equiv \phi^T\pi = \phi^TB\bar{y} + \phi^T\mathcal{V}d\log A
  \]
  - slope
  - residual
Phillips curve: \( \pi^C = \kappa^C \tilde{y} + u^C \)

\[ \begin{aligned} \tilde{y} \uparrow & \implies \text{labor demand} \uparrow \implies rw \uparrow: \\
\kappa^C &= \frac{\delta_w}{1 - \delta_w} \left( \gamma + \varphi \right) \\
&= \frac{d \log P}{d \log rw} \frac{d \log rw}{d \log y} \\
\end{aligned} \]
Phillips curve: $\pi^C = \kappa^C \tilde{y} + u^C$

- $\tilde{y} \uparrow \Rightarrow \text{labor demand} \uparrow \Rightarrow rw \uparrow$:

$$\kappa^C = \frac{\bar{\delta}_w}{1 - \bar{\delta}_w} \left( \frac{\gamma + \varphi}{\frac{d \log P}{d \log rw}} \frac{d \log rw}{d \log y} \right)$$

- Pass-through of nominal wages into consumer prices:

$$\bar{\delta}_w = \beta^T \Delta \left( I - \Omega \Delta \right)^{-1} \alpha < \mathbb{E}_{\beta} \left( \Delta \right)$$

- No input-output: $\bar{\delta}_w = \mathbb{E}_{\beta} \left( \delta \right)$
- Dampened with IO linkages
Outline

**Setup**

**Sectoral inflation and Phillips curve(s)**

- Calibration: slope & monetary non-neutrality

- “Divine coincidence” index

**Optimal policy**

- Calibration: welfare loss from business cycles

**Conclusion**
Slope (calibration)

- Input-output data from the BEA
- Sector-level price adjustment frequencies from Pasten, Schoenle and Weber (2016)

<table>
<thead>
<tr>
<th></th>
<th>full model</th>
<th>no IO, flex w</th>
<th>no IO</th>
</tr>
</thead>
<tbody>
<tr>
<td>slope</td>
<td>0.09</td>
<td>1.16</td>
<td>0.22</td>
</tr>
<tr>
<td>full/alt calibration</td>
<td>1.00</td>
<td>0.07</td>
<td>0.38</td>
</tr>
</tbody>
</table>

**Table:** Slope in the full calibration and alternative calibrations
Slope over time
Phillips curve:  
\[ \pi^C = \kappa^C \tilde{y} + u^C \]

- Productivity pass-through:

  \[ \bar{\delta}_A (d \log A) \equiv \beta^T \Delta \frac{(I - \Omega \Delta)^{-1}}{\lambda^T d \log A} \]

- Wage response (efficient equilibrium):

  \[ d \log rw = \lambda^T d \log A \]

- Consumer inflation:

  \[ u^C = \frac{\bar{\delta}_w - \bar{\delta}_A}{1 - \lambda^T d \log A} \]
Calibration

**Figure:** Residual constructed from sector-level TFP shocks (BEA-KLEMS data), 1988-2016

- Standard deviation: 25 bp
Outline

Setup

Sectoral inflation and Phillips curve(s)

Calibration: slope & monetary non-neutrality

“Divine coincidence” index

Optimal policy

Calibration: welfare loss from business cycles

Conclusion
“Divine coincidence” inflation index

\[ DC \equiv \lambda^T_{\text{sales}} \underbrace{(I - \Delta)\Delta^{-1}}_{\text{discount flex sectors}} \pi \]

Proposition

\[ DC = \underbrace{(\gamma + \varphi)}_{\text{indep of network}} \tilde{y} \]

- Sales shares: full role in production chain
- Flexible price \(\Rightarrow\) smaller markup response given cost shock
SW and consumer prices

SW and core PCE

AGRICULTURE, FORESTRY, FISHING, AND HUNTING
UTILITIES
CONSTRUCTION
RETAIL TRADE
MINING
OTHER SERVICES
EDUCATION SERVICES
ART AND ENTERTAINMENT
WHOLESALE TRADE
ACCOMMODATION AND FOOD SERVICES
GOVERNMENT
HEALTH CARE
MANAGEMENT OF COMPANIES
RE AND RENTAL/LEASING
TRANSPORTATION AND WAREHOUSING
NONDURABLE GOODS
ADMINISTRATIVE AND WASTE SERVICES
INFORMATION
DURABLE GOODS
FINANCE AND INSURANCE
PROFESSIONAL SERVICES
LABOR

Healthcare
Housing
Non-durables
Professional services
Finance
Labor

SW over time

<table>
<thead>
<tr>
<th>$\kappa$</th>
<th>SW</th>
<th>consumer prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.00</td>
<td>-0.09</td>
<td></td>
</tr>
</tbody>
</table>

**Table:** Calibrated slope of the Phillips curve ($\gamma = 1$, $\varphi = 2$)

<table>
<thead>
<tr>
<th>gap</th>
<th>DC</th>
<th>CPI</th>
<th>core CPI</th>
<th>PCE</th>
<th>core PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-3.8814**</td>
<td>-0.2832**</td>
<td>-0.1839**</td>
<td>-0.1667**</td>
<td>-0.1007*</td>
</tr>
<tr>
<td></td>
<td>(0.6329)</td>
<td>(0.0729)</td>
<td>(0.0642)</td>
<td>(0.0628)</td>
<td>(0.0565)</td>
</tr>
<tr>
<td>intercept</td>
<td>1.9842**</td>
<td>2.9052**</td>
<td>2.9021**</td>
<td>2.3978**</td>
<td>2.372**</td>
</tr>
<tr>
<td></td>
<td>(0.0475)</td>
<td>(0.1196)</td>
<td>(0.1052)</td>
<td>(0.103)</td>
<td>(0.0926)</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.2154</td>
<td>0.0991</td>
<td>0.0566</td>
<td>0.0489</td>
<td>0.0227</td>
</tr>
</tbody>
</table>

**Table:** Regression results for the CBO unemployment gap

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>consumer prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\kappa$</td>
<td>-3.00</td>
<td>-0.09</td>
</tr>
</tbody>
</table>

Table: Calibrated slope of the Phillips curve ($\gamma = 1$, $\varphi = 2$)

<table>
<thead>
<tr>
<th>Gap</th>
<th>DC</th>
<th>CPI</th>
<th>core CPI</th>
<th>PCE</th>
<th>core PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-3.8814**</td>
<td>-0.2832**</td>
<td>-0.1839**</td>
<td>-0.1667**</td>
<td>-0.1007*</td>
</tr>
<tr>
<td></td>
<td>(0.6329)</td>
<td>(0.0729)</td>
<td>(0.0642)</td>
<td>(0.0628)</td>
<td>(0.0565)</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.9842**</td>
<td>2.9052**</td>
<td>2.9021**</td>
<td>2.3978**</td>
<td>2.372**</td>
</tr>
<tr>
<td></td>
<td>(0.0475)</td>
<td>(0.1196)</td>
<td>(0.1052)</td>
<td>(0.103)</td>
<td>(0.0926)</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.2154</td>
<td>0.0991</td>
<td>0.0566</td>
<td>0.0489</td>
<td>0.0227</td>
</tr>
</tbody>
</table>

Table: Regression results for the CBO unemployment gap
20y rolling regressions

CBO unemployment

Coefficients

R-squareds
20y rolling regressions

CBO unemployment

Coefficients

R-squareds
20y rolling regressions

CBO unemployment

Coefficients

R-squareds
20y rolling regressions

CBO unemployment

Coefficients

R-squareds
20y rolling regressions

CBO unemployment

Coefficients

R-squareds

- Coefficients for various economic indicators such as DC, CPI, core CPI, PCE, and core PCE are plotted over time from 1996 to 2008.
- R-squared values are shown for each indicator, with bars indicating the explained variance.
Outline

Setup

Sectoral inflation and Phillips curve(s)
  Calibration: slope & monetary non-neutrality

“Divine coincidence” index

Optimal policy
  Calibration: welfare loss from business cycles

Conclusion
Welfare function

▶ Second order approximation around the flex price outcome:

\[
\frac{U - U^*}{U_c C} \simeq -\frac{1}{2} \left[ (\gamma + \varphi) \tilde{y}^2 + \pi^T D \pi \right]
\]

aggregate demand

welfare cost of inflation

▶ Price distortions \implies substitution \implies productivity loss

\[ D = D_1 + D_2 \]

within sectors

across sectors

▶ higher ES \implies more substitution
▶ IO linkages \implies propagation
Central bank’s problem

\[ \min \ W = \frac{1}{2} \left[ (\gamma + \varphi) \tilde{y}^2 + \pi^T D \pi \right] \]

s.t. \[ \pi = B \tilde{y} + V d \log A \]

full vector
Central bank’s problem

\[
\min \ W = \frac{1}{2} \left[ (\gamma + \varphi) \tilde{y}^2 + \pi^T D \pi \right]
\]

s.t. \[ \pi = B\tilde{y} + V d \log A \]

Marginal gain from raising \( \tilde{y} \) given current inflation \( \pi \):

\[
(\gamma + \varphi) \tilde{y}^* + B^T D \pi^* = 0
\]
Central bank’s problem

\[ \min \ W = \frac{1}{2} \left[ (\gamma + \varphi) \tilde{y}^2 + \pi^T D\pi \right] \]

s.t. \[ \pi = B\tilde{y} + Vd \log A \]

Marginal cost of raising \( \tilde{y} \):

\[ (\gamma + \varphi) \tilde{y}^* + B^T D\pi^* = 0 \]
A new inflation target

- Optimal tradeoff:

\[
(\gamma + \varphi) \tilde{y}^* + B^T D \pi^* = 0
\]

marginal cost          marginal benefit

- Optimal target:

\[
\pi_T \equiv \left[ \lambda^T (I - \Delta) \Delta^{-1} + B^T D \right] \pi
\]
A new inflation target

- Optimal tradeoff:

\[
(\gamma + \varphi) \tilde{y}^* + \begin{bmatrix} B^T \\ D \end{bmatrix} \pi^* = 0
\]

marginal cost          marginal benefit

- Optimal target:

\[
\pi_T \equiv \begin{bmatrix} \lambda^T (I - \Delta) \Delta^{-1} + B^T D \end{bmatrix} \pi
\]

\[
(\gamma + \varphi) \tilde{y}
\]
A new inflation target

▶ Optimal tradeoff:

\[
\left(\gamma + \varphi\right) \tilde{y}^* + \begin{bmatrix} B^T \end{bmatrix} \Delta \pi^* = 0
\]

▶ Optimal target:

\[
\pi_T \equiv \left[ \lambda^T (I - \Delta) \Delta^{-1} + B^T \Delta \right] \pi
\]

Proposition

\[
\pi_T > 0 \iff \tilde{y} > \tilde{y}^*
\]
Outline

Setup

Sectoral inflation and Phillips curve(s)

Calibration: slope & monetary non-neutrality

“Divine coincidence” index

Optimal policy

Calibration: welfare loss from business cycles

Conclusion
Calibration: welfare loss from business cycles

- Consumer prices poor target
  - also with aggregate shocks only
Model with no IO linkages

- Loss entirely from idiosyncratic component
- Consumer inflation good target
Outline

Setup

Sectoral inflation and Phillips curve(s)

Calibration: slope & monetary non-neutrality

“Divine coincidence” index

Optimal policy

Calibration: welfare loss from business cycles

Conclusion
Conclusion

Framework for monetary policy in disaggregated economy

1. Phillips curve(s)
   - intermediate inputs $\rightarrow$ flattening
   - endogenous cost-push shocks
   - “divine coincidence” index

2. Welfare
   - new inflation target
   - output gap good target, not consumer inflation
Extensions

- No rep consumer: segmented labor markets in currency union
  - local vs aggregate Phillips curve
  - local vs aggregate fiscal multipliers

- Open economy: add exchange rates and independent CBs
  - monetary policy spillovers, competitive devaluations...under intermediate goods trade/global production chains
Thank you!
Timing

One-period model. Same results in dynamic setting

- Period 0: prices are pre-set
- Period 1: unanticipated shock
  - only a fraction of producers can adjust prices
  - production and consumption take place
  - the world ends
Policy instruments

Money supply

► Equivalent to interest rates in dynamic setting
► Cash-in-advance constraint

\[ PC \leq M \]

► Map into output gap for given productivity (in the background)

\[
d \log M = \pi^C + \tilde{y} + \frac{1+\varphi}{\gamma+\varphi} \lambda^T d \log A = \\
= \left(1 + \kappa^C\right) \tilde{y} + u^C + \frac{1+\varphi}{\gamma+\varphi} \lambda^T d \log A
\]
Decomposition

\[
\delta_w = \beta^T \Delta (I - \Omega \Delta)^{-1} \alpha
\]

![Graph of change in consumption shares vs pass-through](image1)

![Graph of change in pass-through vs consumption shares](image2)
\[ \bar{\delta}_w = \beta^T (I - \Omega \Delta)^{-1} \alpha \]

21% pass-through

79% consumption shares

Change in consumption shares vs pass-through

Change in pass-through vs consumption shares
Markups, output gap and inflation

- Markups $\uparrow \implies$ labor share $\downarrow \implies$ labor supply $\downarrow$:

\[(\gamma + \varphi) \dot{y} = -\lambda^T d \log \mu\]

- Markups and inflation:

\[
d \log \mu = - (I - \Delta) \Delta^{-1} \pi
\]
Dynamics

- Dynamic system:

\[
\begin{align*}
\pi_t &= B\tilde{y}_t + \mathcal{V}\log \mu_{t-1} + \rho \mathcal{M}\mathbb{E}\pi_{t+1} \\
-(I - \Delta)^{-1} \Delta \log \mu_t &= B(\tilde{y}_t - \tilde{y}_{t-1}) + \mathcal{V}[(\log A_t - \log A_{t-1}) + \\
&+ (I - \Omega) \rho \mathbb{E}\pi_{t+1}] - \mathcal{M}(I - \Delta)^{-1} \Delta \log \mu_{t-1}
\end{align*}
\]

- Past markups are state variable
- \(\mathcal{M}\): propagation
Propagation

\[ M \equiv \left( \frac{B \gamma^T}{\gamma + \varphi} - \mathcal{V} \right) (I - \Delta) \Delta^{-1} \]

- Impact response:

\[ \pi^C_t = \sum_{s \geq 0} \rho^s \left[ \beta^T M^s B \tilde{E}_t \tilde{y}_{t+s} + \beta^T M^s \mathcal{V} \tilde{E}_t \log \mu_{t+s-1} \right] \]
Full impulse-response
TFP vs labor augmenting shocks

- Labor augmenting shock $\implies$ “divine coincidence”
  - wage $\downarrow = \text{productivity} \downarrow$ for every sector

- Aggregate TFP shock ($-1\%$): $\pi^C \uparrow$ by 0.26%
  - wage pass-through vs productivity pass-through
Oil shocks - a simple model

- vertical chain + horizontal economy

\[ \pi C = - \frac{\text{Cov}_\beta(\delta, \omega_{oil}) + (1 - \delta_L) \mathbb{E}_\beta(\delta) \mathbb{E}_\beta(\omega_{oil})}{1 - \delta_L \mathbb{E}_\beta(\delta)} d \log A_{oil} \]

- Flex oil prices, sticky wages \(\Rightarrow\) “downstream” shock
- \(\text{Cov}_\beta(\delta, \omega_{oil}) > 0\)
Oil shocks: calibration

<table>
<thead>
<tr>
<th></th>
<th>$\delta = \text{actual}$</th>
<th>$\delta \equiv \delta_{\text{mean}}, \delta_{\text{oil}} = 1$</th>
<th>$\delta \equiv \delta_{\text{mean}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>sticky wages</td>
<td>0.22</td>
<td>0.07</td>
<td>-0.00</td>
</tr>
<tr>
<td>flexible wages</td>
<td>0.18</td>
<td>0.01</td>
<td>-0.06</td>
</tr>
</tbody>
</table>

Table: Consumer inflation after a 10% negative shock to the oil sector (full model)

- Both wage rigidity and correlation matter
- Opposite prediction if ignore that oil price is flexible
Match observed path of inflation and oil prices with shocks to:

- oil productivity
- rational expectations

Oil prices explain too little of early inflation, more later.
Substitution within sectors

- Customers buy too much of the varieties with lower price

\[ \pi^T D_1 \pi = \sum_i \lambda_i \left( \frac{1 - \delta_i}{\delta_i} \right) \]

- Same intuition as one-sector model
- Aggregation
Substitution across inputs

- High demand for inputs with relative price < efficient outcome
- Depends on ES across inputs and relative price distortions
- Distortion across inputs \( \simeq \) negative productivity shock

\[ \pi_i \Rightarrow \text{price distortion between } k \text{ and } h \Rightarrow \text{substitution in } t \]

\[
\text{(distortion)}_{k,h} = \left( \frac{(I - \Omega)_{ki}^{-1} - (I - \Omega)_{hi}^{-1}}{\delta_i} \right) \pi_i
\]

- relative exposure
- discount flex sectors
Substitution across inputs

- Loss $\Phi_t \simeq$ covariance between distortions from $\pi_i, \pi_j$

$$\Phi_t(i, j) = \frac{1}{2} \sum_k \sum_h \omega_{tk} \omega_{th} \theta_{kh}^t \text{ (distortion from } i)_{kh} \text{ (distortion from } j)_{kh}$$

- Aggregate with sales shares:

$$\pi^T D_2 \pi \equiv \sum_t \lambda_t \sum_{i,j} \Phi_t(i, j) \text{ (productivity loss in } t)$$
Cost-push shocks

- SW Phillips curve:
  \[ SW = (\gamma + \varphi) \ddot{y} + \lambda^T d\log \mu^D \]

- CPI Phillips curve:
  \[ CPI = \kappa^C \ddot{y} + u + v \]

where

\[ v = \frac{\bar{\delta}_\mu}{1 - \bar{\delta}_w} \lambda^T d\log \mu^D \]

\[ \delta_\mu = \beta^T \Delta (I - \Omega \Delta)^{-1} d\log \mu^D \]

\[ \lambda^T d\log \mu^D \]
Optimal policy

- Optimal output gap:

\[
\bar{y}_{CP} = \frac{B^T \left( D \left( \frac{B \lambda^T}{\gamma + \varphi} - \mathcal{V} \right) - D_2 \Delta (I - \Delta)^{-1} \right) - B^T DB \log \mu^D}{(\gamma + \varphi) + B^T DB}
\]

Proposition

\[
y > y^* \iff \pi_T > \left( \lambda^T - B^T D_2 \Delta (I - \Delta)^{-1} \right) d\log \mu^D
\]
Dynamics

- SW Phillips curve

\[ SW_t = (\gamma + \varphi) \tilde{y}_t + \rho \mathbb{E}(SW_{t+1}) \]

\[ \hat{\delta}_i = \frac{\delta_i (1 - \rho(1 - \delta_i))}{1 - \rho \delta_i (1 - \delta_i)} \]
Dynamics

- CPI Phillips curve:

\[ CPI_t = \kappa_t \tilde{y}_t + u_t + \tilde{\nu}_t \]

where

\[
\tilde{\nu}_t = \nu_t - \frac{\bar{\delta}_\mu - \bar{\delta}_w}{1 - \bar{\delta}_w} \lambda^T d\log \mu_{t-1} - \frac{\bar{\delta}_\pi - \bar{\delta}_w}{1 - \bar{\delta}_w} \rho \mathbb{E} CPI_{t+1}
\]

\[
\bar{\delta}_\pi = \frac{\beta^T \Delta (I - \Omega \hat{\Delta})^{-1} \mathbb{E} \pi_{t+1}}{\mathbb{E} CPI_{t+1}}
\]
Optimal policy and implementation

- **Interest rate rule (for \( \zeta > 1 \))**

\[
i_t = r^n_t + \gamma \left[ E\tilde{y}^*_{t+1} - \tilde{y}^*_t \right] + \beta^T E\pi^*_{t+1} + \zeta \left( \phi_t \pi_t + \phi_{t+1} \rho E\pi_{t+1} \right)
\]

- **Inflation target:**

\[
\phi_t = \frac{\lambda^T (I - \hat{\Delta}) \hat{\Delta}^{-1}}{\gamma + \varphi} + \frac{B^T \mathcal{D}}{\gamma + \varphi + B^T \mathcal{D} B}
\]

\[
\phi_{t+1} = \left( \lambda^T \left( I - \hat{\Delta} \right) \hat{\Delta}^{-1} - B^T \mathcal{D}_2 \right)
\]

inflation response to cp shock under optimal policy
Within- and cross-sector misallocation

Figure: Main calibration: \( \epsilon = 8, \sigma = 0.9, \theta_L = 0.5, \theta = 0.001 \); uniform elasticities: \( \epsilon = \sigma = \theta_L = \theta = 2 \)
With oil prices

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>CPI</th>
<th>core CPI</th>
<th>PCE</th>
<th>core PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>gap</td>
<td>-3.6385**</td>
<td>-0.2198**</td>
<td>-0.2038**</td>
<td>-0.1194**</td>
<td>-0.1066*</td>
</tr>
<tr>
<td></td>
<td>(0.6294)</td>
<td>(0.0655)</td>
<td>(0.0643)</td>
<td>(0.0584)</td>
<td>(0.0573)</td>
</tr>
<tr>
<td>intercept</td>
<td>1.9532**</td>
<td>2.7286**</td>
<td>2.9576**</td>
<td>2.266**</td>
<td>2.3883**</td>
</tr>
<tr>
<td></td>
<td>(0.0483)</td>
<td>(0.1099)</td>
<td>(0.1078)</td>
<td>(0.0979)</td>
<td>(0.0961)</td>
</tr>
<tr>
<td>oil prices</td>
<td>0.0032**</td>
<td>0.0185**</td>
<td>-0.0058*</td>
<td>0.0138**</td>
<td>-0.0017</td>
</tr>
<tr>
<td></td>
<td>(0.0013)</td>
<td>(0.003)</td>
<td>(0.0029)</td>
<td>(0.0027)</td>
<td>(0.0026)</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.2488</td>
<td>0.2959</td>
<td>0.0829</td>
<td>0.2049</td>
<td>0.0257</td>
</tr>
</tbody>
</table>

Table: Regression results for the CBO unemployment gap, with oil prices
With endogenous cost-push

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>CPI</th>
<th>core CPI</th>
<th>PCE</th>
<th>core PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>cost-push</td>
<td>0.5627**</td>
<td>2.5545**</td>
<td>0.4886</td>
<td>2.3948**</td>
<td>1.1224**</td>
</tr>
<tr>
<td></td>
<td>(0.2345)</td>
<td>(0.565)</td>
<td>(0.4768)</td>
<td>(0.4745)</td>
<td>(0.4102)</td>
</tr>
<tr>
<td>gap</td>
<td>-3.7586**</td>
<td>-0.1906**</td>
<td>-0.2175**</td>
<td>-0.0783</td>
<td>-0.0886</td>
</tr>
<tr>
<td></td>
<td>(0.6872)</td>
<td>(0.0758)</td>
<td>(0.064)</td>
<td>(0.0637)</td>
<td>(0.0551)</td>
</tr>
<tr>
<td>intercept</td>
<td>2.0842**</td>
<td>3.2239**</td>
<td>2.8559**</td>
<td>2.6509**</td>
<td>2.397**</td>
</tr>
<tr>
<td></td>
<td>(0.058)</td>
<td>(0.1398)</td>
<td>(0.118)</td>
<td>(0.1174)</td>
<td>(0.1015)</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.3317</td>
<td>0.2782</td>
<td>0.142</td>
<td>0.2558</td>
<td>0.1275</td>
</tr>
</tbody>
</table>

Table: Regression results for the CBO unemployment gap, with CP shock
With oil prices and cost-push

Table: Regression results for the CBO unemployment gap (CP shock and oil prices)

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>CPI</th>
<th>core CPI</th>
<th>PCE</th>
<th>core PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>cost-push</td>
<td>0.2874</td>
<td>1.1895**</td>
<td>0.99*</td>
<td>1.4128**</td>
<td>1.3585**</td>
</tr>
<tr>
<td></td>
<td>(0.265)</td>
<td>(0.5943)</td>
<td>(0.5409)</td>
<td>(0.5123)</td>
<td>(0.4707)</td>
</tr>
<tr>
<td>gap</td>
<td>-3.8932**</td>
<td>-0.2211**</td>
<td>-0.2062**</td>
<td>-0.1003*</td>
<td>-0.0833</td>
</tr>
<tr>
<td></td>
<td>(0.6795)</td>
<td>(0.0698)</td>
<td>(0.0635)</td>
<td>(0.0602)</td>
<td>(0.0553)</td>
</tr>
<tr>
<td>intercept</td>
<td>2.0185**</td>
<td>2.8983**</td>
<td>2.9754**</td>
<td>2.4167**</td>
<td>2.4533**</td>
</tr>
<tr>
<td></td>
<td>(0.065)</td>
<td>(0.1458)</td>
<td>(0.1327)</td>
<td>(0.1257)</td>
<td>(0.1155)</td>
</tr>
<tr>
<td>oil prices</td>
<td>0.0034**</td>
<td>0.0167**</td>
<td>-0.0062*</td>
<td>0.012**</td>
<td>-0.0029</td>
</tr>
<tr>
<td></td>
<td>(0.0016)</td>
<td>(0.0036)</td>
<td>(0.0033)</td>
<td>(0.0031)</td>
<td>(0.0028)</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.3581</td>
<td>0.399</td>
<td>0.1692</td>
<td>0.3472</td>
<td>0.1358</td>
</tr>
</tbody>
</table>
With expectations

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>CPI</th>
<th>core CPI</th>
<th>PCE</th>
<th>core PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>gap</td>
<td>-1.1054**</td>
<td>-0.1613**</td>
<td>-0.0344</td>
<td>-0.062</td>
<td>0.0047</td>
</tr>
<tr>
<td></td>
<td>(0.3275)</td>
<td>(0.0809)</td>
<td>(0.052)</td>
<td>(0.0487)</td>
<td>(0.0368)</td>
</tr>
<tr>
<td>inflation expcections</td>
<td>0.8287**</td>
<td>0.4846**</td>
<td>0.5446**</td>
<td>0.6364**</td>
<td>0.6406**</td>
</tr>
<tr>
<td></td>
<td>(0.0383)</td>
<td>(0.1557)</td>
<td>(0.0559)</td>
<td>(0.0621)</td>
<td>(0.045)</td>
</tr>
<tr>
<td>intercept</td>
<td>0.3484**</td>
<td>1.3851**</td>
<td>1.3193**</td>
<td>0.5522**</td>
<td>0.8388**</td>
</tr>
<tr>
<td></td>
<td>(0.0789)</td>
<td>(0.5021)</td>
<td>(0.1818)</td>
<td>(0.196)</td>
<td>(0.1228)</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.8234</td>
<td>0.159</td>
<td>0.4425</td>
<td>0.4635</td>
<td>0.6072</td>
</tr>
</tbody>
</table>

Table: CBO unemployment gap
## Other gaps

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>CPI</th>
<th>core CPI</th>
<th>PCE</th>
<th>core PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>gap</td>
<td>1.0861**</td>
<td>0.1881**</td>
<td>0.0412</td>
<td>0.0881**</td>
<td>0.0084</td>
</tr>
<tr>
<td></td>
<td>(0.2714)</td>
<td>(0.0678)</td>
<td>(0.0449)</td>
<td>(0.0417)</td>
<td>(0.032)</td>
</tr>
<tr>
<td>inflation expectations</td>
<td>0.8297**</td>
<td>0.4412**</td>
<td>0.5398**</td>
<td>0.6231**</td>
<td>0.6365**</td>
</tr>
<tr>
<td></td>
<td>(0.0368)</td>
<td>(0.1515)</td>
<td>(0.0561)</td>
<td>(0.0617)</td>
<td>(0.0455)</td>
</tr>
<tr>
<td>intercept</td>
<td>0.3668**</td>
<td>1.6124**</td>
<td>1.3548**</td>
<td>0.6459**</td>
<td>0.8614**</td>
</tr>
<tr>
<td></td>
<td>(0.0772)</td>
<td>(0.4987)</td>
<td>(0.1892)</td>
<td>(0.2005)</td>
<td>(0.1291)</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.8288</td>
<td>0.1808</td>
<td>0.4442</td>
<td>0.4744</td>
<td>0.6073</td>
</tr>
</tbody>
</table>

**Table: CBO output gap**
### Other gaps

<table>
<thead>
<tr>
<th></th>
<th>SW</th>
<th>CPI</th>
<th>core CPI</th>
<th>PCE</th>
<th>core PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>gap</td>
<td>-0.9404**</td>
<td>-0.0049</td>
<td>0.0781</td>
<td>-0.0505</td>
<td>0.0757**</td>
</tr>
<tr>
<td></td>
<td>(0.3185)</td>
<td>(0.0788)</td>
<td>(0.0499)</td>
<td>(0.0477)</td>
<td>(0.0355)</td>
</tr>
<tr>
<td>inflation expectations</td>
<td>0.8468**</td>
<td>0.6312**</td>
<td>0.5668**</td>
<td>0.6549**</td>
<td>0.6432**</td>
</tr>
<tr>
<td></td>
<td>(0.0372)</td>
<td>(0.1518)</td>
<td>(0.0537)</td>
<td>(0.0608)</td>
<td>(0.0434)</td>
</tr>
<tr>
<td>intercept</td>
<td>0.3108**</td>
<td>0.8344*</td>
<td>1.1705**</td>
<td>0.4941**</td>
<td>0.7757**</td>
</tr>
<tr>
<td></td>
<td>(0.0762)</td>
<td>(0.4879)</td>
<td>(0.1711)</td>
<td>(0.1851)</td>
<td>(0.1155)</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.8202</td>
<td>0.1344</td>
<td>0.4507</td>
<td>0.4616</td>
<td>0.6198</td>
</tr>
</tbody>
</table>

**Table:** unemployment rate
Other gaps

CBO output

Coefficients

R-squareds
Other gaps

CBO output

Coefficients

R-squareds
Other gaps

CBO output

Coefficients

R-squareds
Other gaps

CBO output

Coefficients

R-squareds
Other gaps

CBO output

Coefficients

R-squareds
Other gaps

unemployment rate

Coefficients

R-squareds

DC
CPI
core CPI
PCE
core PCE


1 2 3 4 5
Other gaps

unemployment rate

Coefficients

R-squareds
Other gaps

unemployment rate

Coefficients

R-squareds
Other gaps

unemployment rate

Coefficients

R-squareds

(back)
Other gaps

Unemployment rate

Coefficients

R-squareds
Residuals

Plot of residuals vs. fitted values

Plot of residuals vs. fitted values

Plot of residuals vs. fitted values

Plot of residuals vs. fitted values
Distribution of price adjustment frequencies

- mean
- median
SW and consumer prices

[Graphs showing SW and CPI, SW and PCE, SW and PPI from 1990 to 2010]
Model comparison

- Mis-measurement:
  \[ \pi_{mis}^c = SW - \pi^c \]

- Model 1:
  \[ \tilde{y} = \alpha_0 + \alpha_1 \pi^c + u \]

- Model 2:
  \[ \tilde{y} = \beta_0 + \beta_1 \pi^c + \beta_2 \pi_{mis}^c + \nu \]
## Model comparison

<table>
<thead>
<tr>
<th></th>
<th>CPI</th>
<th>core CPI</th>
<th>PCE</th>
<th>core PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(nested)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha_1$</td>
<td>$-0.35$</td>
<td>$-0.30$</td>
<td>$-0.29$</td>
<td>$-0.22$</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.10</td>
<td>0.05</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(full)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>$-1.21$</td>
<td>$-1.22$</td>
<td>$-1.28$</td>
<td>$-1.19$</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>$-1.22$</td>
<td>$-1.16$</td>
<td>$-1.48$</td>
<td>$-1.33$</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.22</td>
<td>0.22</td>
<td>0.23</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>F-stat</strong></td>
<td>20.20</td>
<td>28.30</td>
<td>31.80</td>
<td>34.90</td>
</tr>
<tr>
<td><strong>p-value</strong></td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
Vertical chain, $A_D \downarrow$

- **Inflation upstream?**

\[ \pi_U = \delta_U d \log w < 0 \]

- **Consumer inflation?**

\[ \bar{\delta}_w = \delta_D \left( \alpha_D \delta_U + (1 - \alpha_D) \delta_U \right) < \delta_D = \bar{\delta}_A \]

\[ \Rightarrow \pi^C = \pi_D > 0 \]
Horizontal economy

- Wages:
  \[ d \log rw = \mathbb{E}_\beta [d \log A] \]

- Prices respond more in flexible sectors:
  \[ \pi^C > 0 \iff \text{Cov}_\beta (\delta, d \log A) < 0 \]