# An Empirical New Keynesian Model

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# Overview

- Presentation based on Justinano, Primiceri, and Tambalotti (2010,2011).
  - which builds on Christiano, Eichenbaim and Evans (2005) and Smets and Wouters (2007).
- Add features to baseline NK model to capture the data (up to 2007)
  - (Add financial frictions later).
- Estimate the modeld using Bayesian methods.
- Identify the key exogenous driving forces.
- Key point: Some type of disturbance to investment is the key driving force.

# Key Challenges

Accounting for:

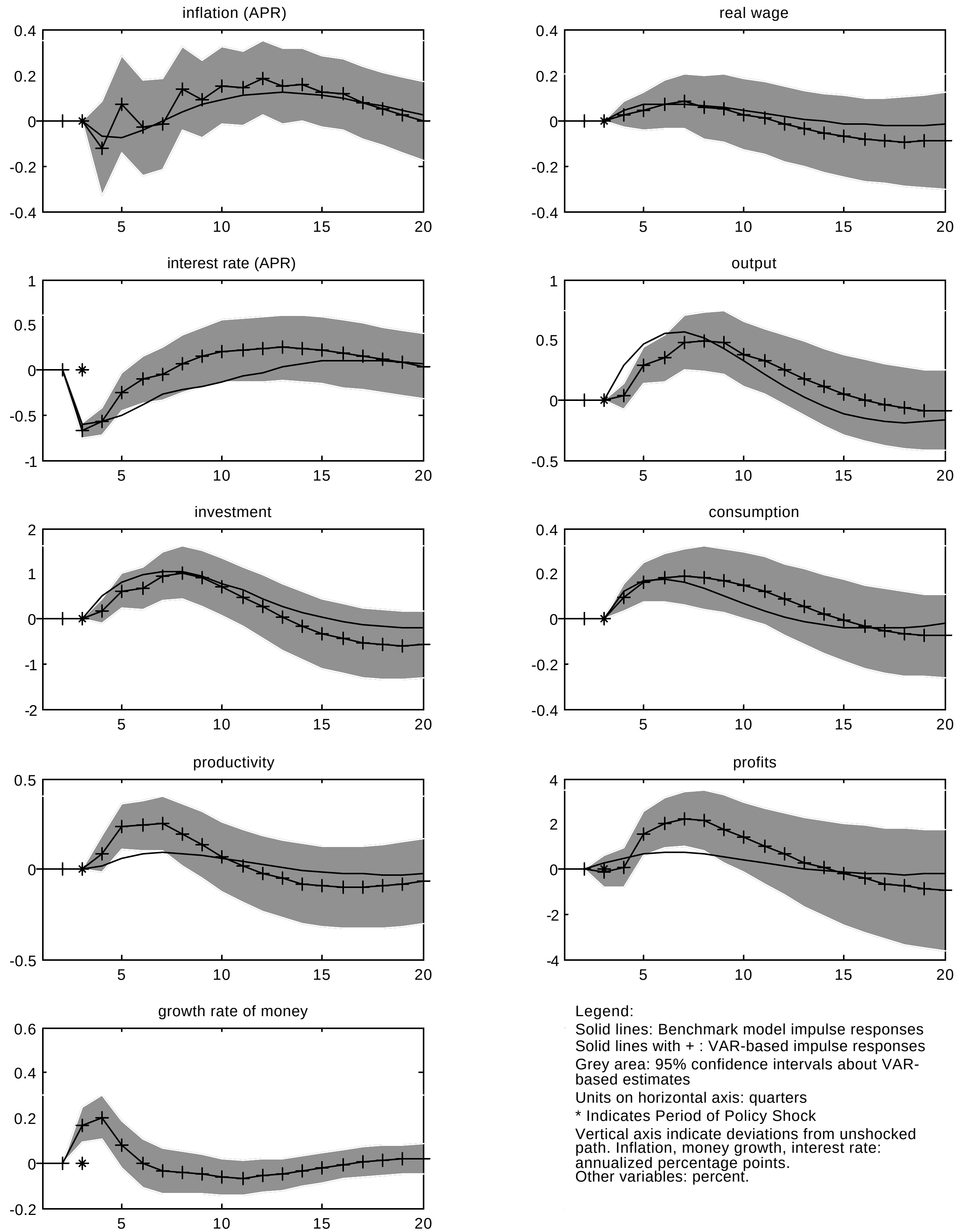
- Humped shaped dynamics in output and other quantity variables

- The volatile behavior of output and smooth behavior of inflation

- The positive short run co-movement between output and inflation

- The effect of monetary policy on output

Figure 1: Model- and VAR-Based Impulse Responses



# Key Additions to Baseline Model

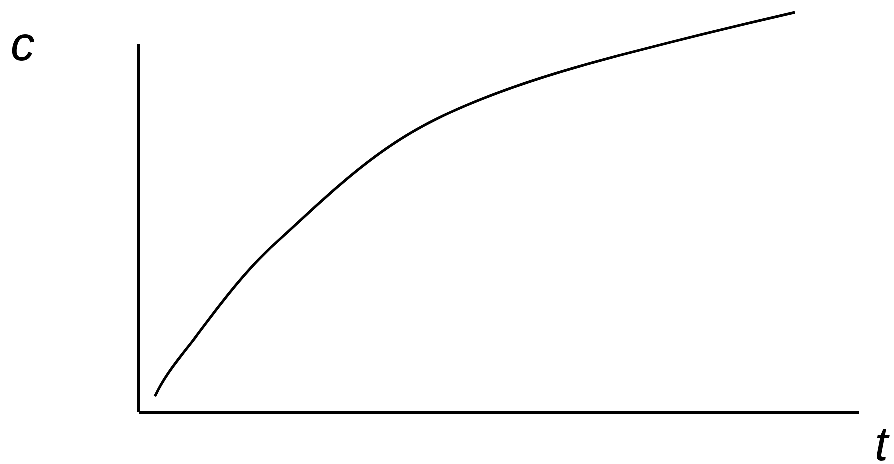
- Habit formation in consumption
- Flow investment adjustment costs
- Variable capitail utilization
- Nominal wage rigidity

# Dynamic Response of Consumption to Monetary Policy Shock

- In Estimated Impulse Responses:
  - Real Interest Rate Falls

$$R_t/\pi_{t+1}$$

  - Consumption Rises in Hump-Shape Pattern:



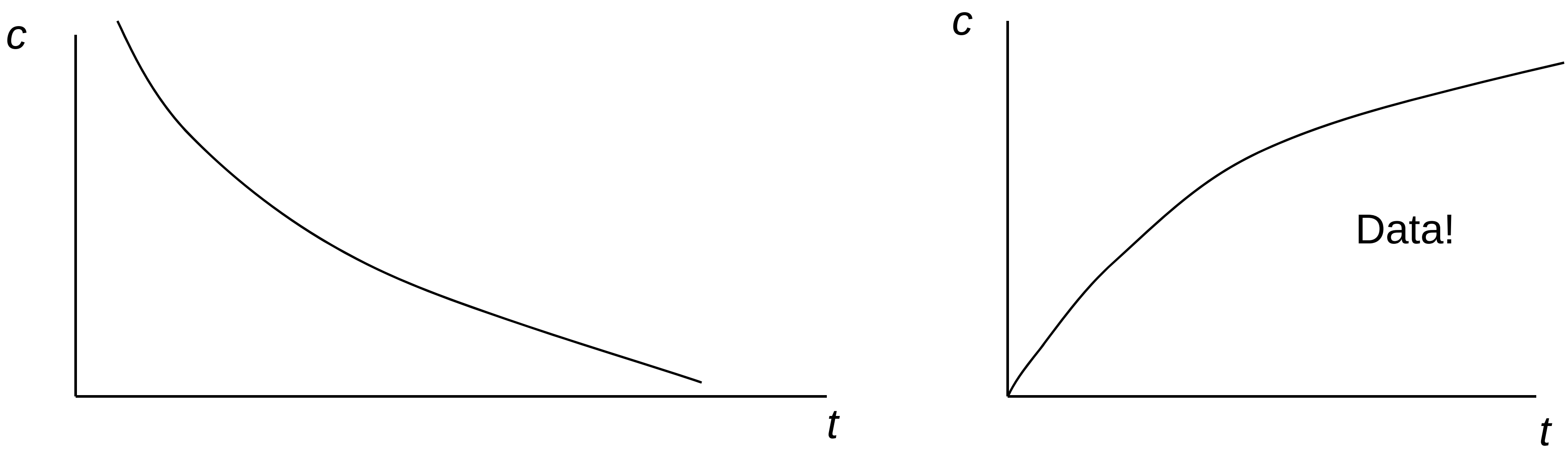
# Consumption 'Puzzle'

- Intertemporal First Order Condition:

'Standard' Preferences →

$$\frac{c_{t+1}}{\beta c_t} = \frac{MU_{c,t}}{\beta MU_{c,t+1}} \approx R_t/\pi_{t+1}$$

- With Standard Preferences:



# One Resolution to Consumption Puzzle

- Concave Consumption Response Displays:
  - Rising Consumption (problem)
  - Falling Slope of Consumption

Habit parameter

- Habit Persistence in Consumption

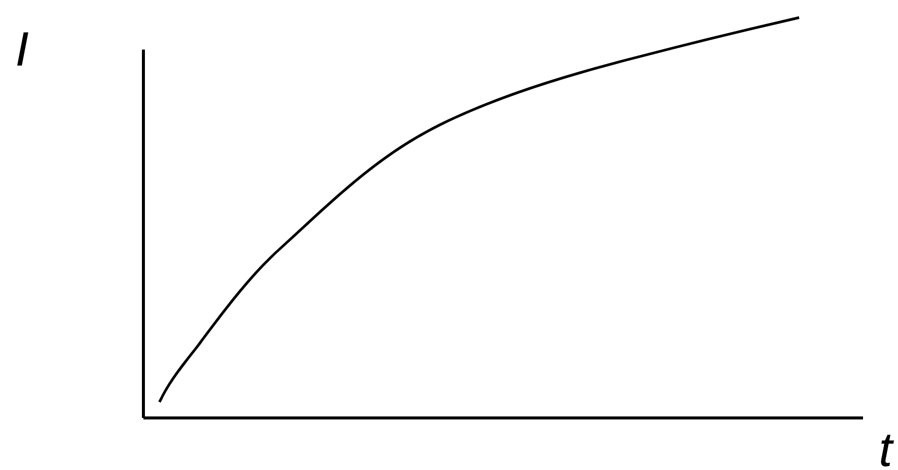
$$U(c) = \log(c - b \times c_{-1})$$

  - Marginal Utility Function of *Slope* of Consumption
  - Hump-Shape Consumption Response Not a Puzzle

- Econometric Estimation Strategy Given the Option, *b>0*

# Dynamic Response of Investment to Monetary Policy Shock

- In Estimated Impulse Responses:
  - Investment Rises in Hump-Shaped Pattern:



# Investment 'Puzzle'

- Rate of Return on Capital

$$R_t^k = \frac{MP_{t+1}^k + P_{k',t+1}(1-\delta)}{P_{k',t}},$$

$P_{k',t}$ ~ consumption price of installed capital

$MP_t^k$ ~marginal product of capital

$\delta \in (0,1)$ ~depreciation rate.

- Rough 'Arbitrage' Condition:

$$\frac{R_t}{\pi_{t+1}} \approx R_t^k.$$

- Positive Money Shock Drives Real Rate:

$$R_t^k \downarrow$$

- Problem: Burst of Investment!

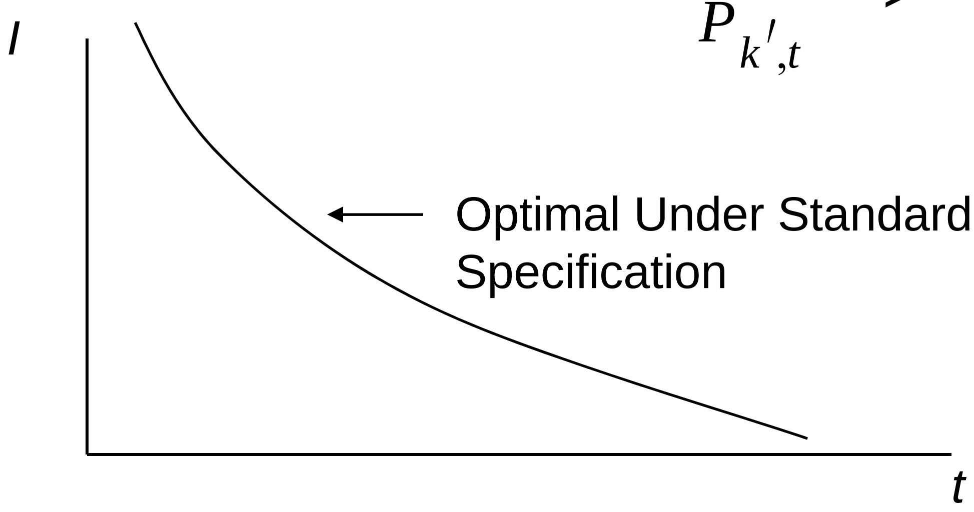
# One Solution to Investment Puzzle

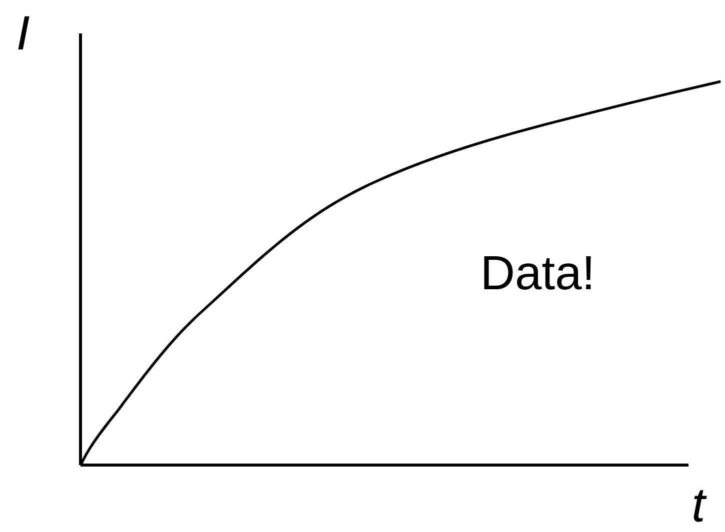
- Adjustment Costs in Investment
  - Standard Model (Lucas-Prescott)

$$k' = (1-\delta)k + F(\frac{I}{k})I.$$

  - Problem:
    - Hump-Shape Response Creates Anticipated Capital Gains

$$\frac{P_{k',t+1}}{P_{k',t}} > 1$$



# One Solution to Investment Puzzle…

- Cost-of-Change Adjustment Costs:

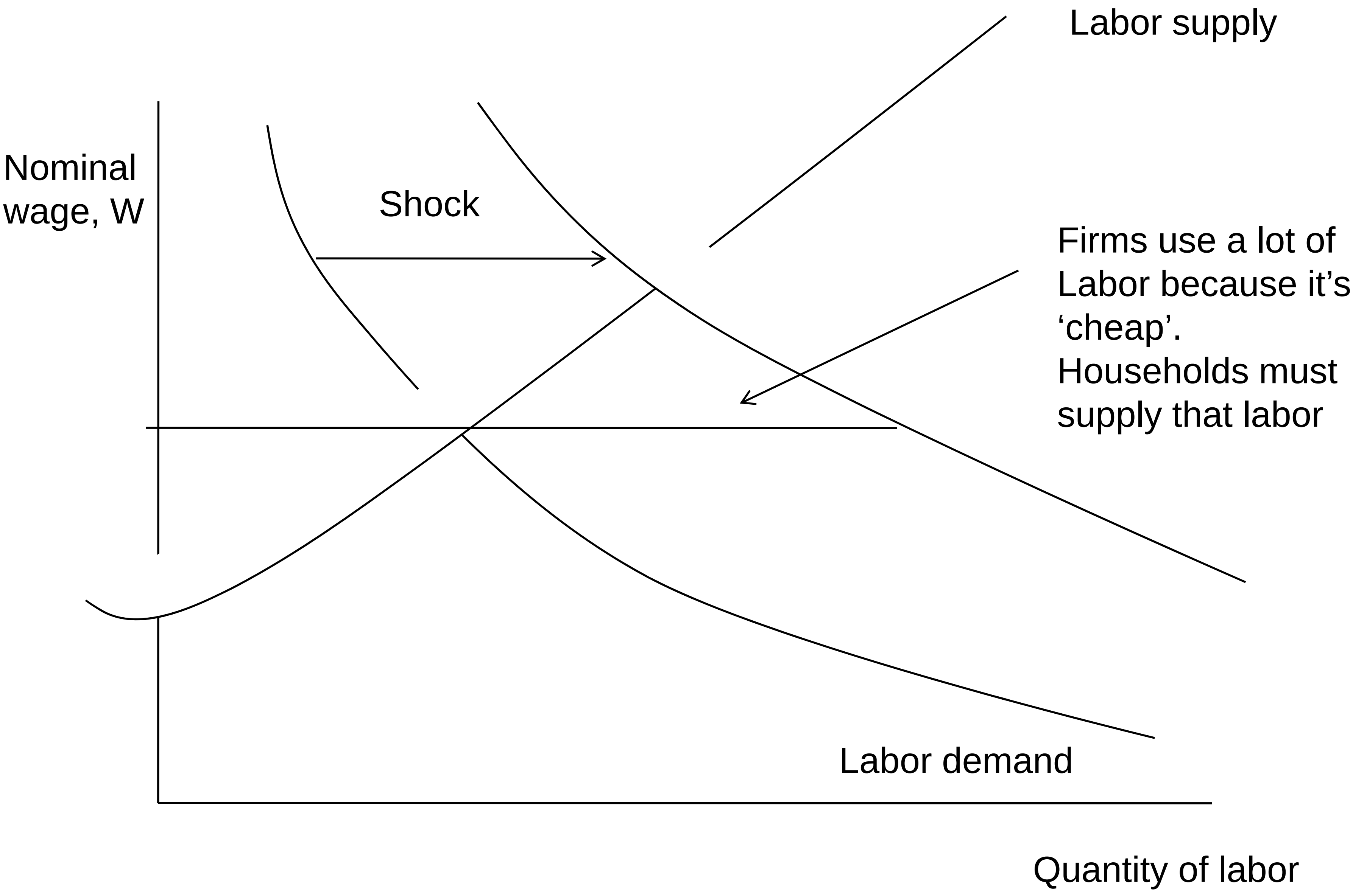
$$k' = (1 - \delta)k + F\left(\frac{I}{I_{-1}}\right)I$$

- This Does Produce a Hump-Shape Investment Response
  - Other Evidence Favors This Specification
  - Empirical: Matsuyama, Smets-Wouters.
  - Theoretical: Matsuyama, David Lucca

# Wage Decisions

- Each household is a monopoly supplier of a specialized, differentiated labor service.
  - Sets wages subject to Calvo frictions.
  - Given specified wage, household must supply whatever quantity of labor is demanded.
- Household differentiated labor service is aggregated into homogeneous labor by a competitive labor 'contractor'.

$$l_t = \left[ \int_0^1 (h_{t,j})^{\frac{1}{\lambda_w}} dj \right]^{\lambda_w},\ 1 \leq \lambda_w < \infty.$$



Labor supply
Nominal
wage, W
Shock
Firms use a lot of
Labor because it's
'cheap'.
Households must
supply that labor
Labor demand
Quantity of labor

# ‘Barro critique’

- Most worker-firm relationships are long-term, and unlikely to be strongly affected by details of the timing of wage-setting.

- Standard sticky wage model implausible.

- Recent results in search-matching literature:

  – Must distinguish between intensive (hours) and extensive (employment) margin.

  – Barro critique applies to idea that wage frictions matter in the intensive margin.

  – Does not apply to idea that wage frictions matter for extensive margin.

# Modification of labor market

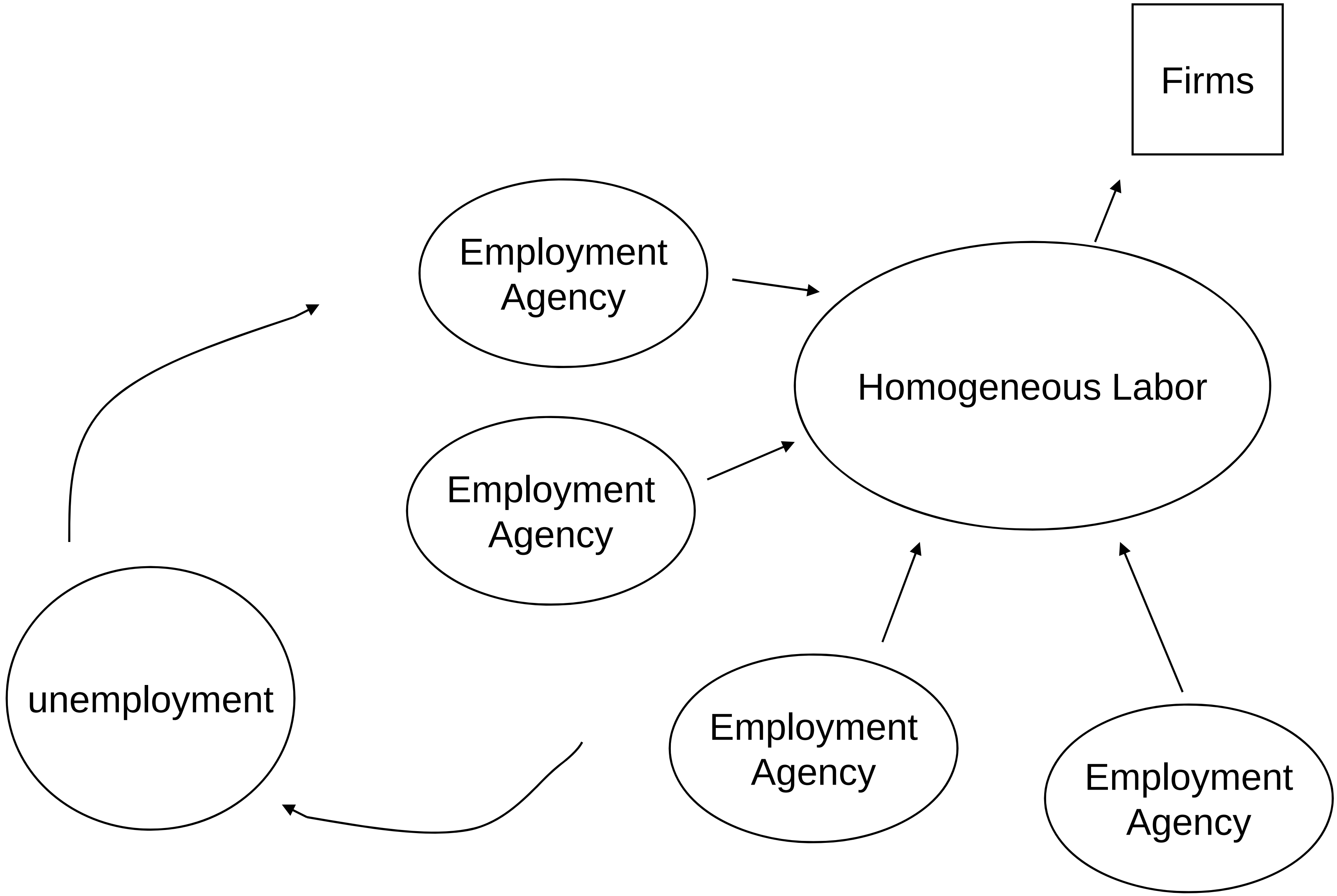
- Mortensen-Pissarides search and matching frictions recently introduced into DSGE models (Gertler-Sala-Trigari, Blanchard-Gali, Christiano-Ilut-Motto-Rostagno)

- Draw a distinction between hours (‘intensive margin’) and number of workers (‘extensive margin’)

- Intensive and extensive margins exhibit very different dynamics over business cycle

- Wage frictions thought to matter for extensive margin, not intensive margin.

- Extension to open economy (Christiano, Trabandt, Walentin)


Firms
Employment Agency
Homogeneous Labor
Employment Agency
unemployment
Employment Agency
Employment Agency

# Model Outline

- Households
- Final Goods Producers
- Intermediate Goods Producer
- Government that conducts monetary and fiscal ponlicy.

# Final good producers (competitive)

- Produce final good $Y_t$ combining intermediate goods $\{Y_t(i)\}_i$, $i \in [0,1]$:

$$Y_t = \left[ \int_0^1 Y_t(i)^{\frac{1}{1+\lambda_{p,t}}} di \right]^{1+\lambda_{p,t}}. \tag{1}$$

with

$$\log\left(1+\lambda_{p,t}\right) = (1-\rho_p)\log(1+\lambda_p) + \rho_p \log\left(1+\lambda_{p,t-1}\right) + \varepsilon_{p,t} - \theta_p \varepsilon_{p,t-1}, \tag{2}$$

where $\varepsilon_{p,t}$ is $i.i.d.N(0,\sigma_p^2)$ (shock to price markup).'

# Final good producers (con't)

- Cost minimization:

$$Y_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{-\frac{1+\lambda_{p,t}}{\lambda_{p,t}}} Y_t. \tag{3}$$

with

$$P_t = \left[ \int_0^1 P_t(i)^{-\frac{1}{\lambda_{p,t}}} di \right]^{-\lambda_{p,t}}, \tag{4}$$

# Intermediate goods producers (monop. comp.)

- Production

$$Y_t(i) = A_t^{1-\alpha} K_t(i)^\alpha L_t(i)^{1-\alpha} \tag{5}$$

with $z_t \equiv \Delta \log A_t$ given by

$$z_t = \rho_z z_{t-1} + \varepsilon_{z,t}, \tag{6}$$

with $\varepsilon_{z,t}$ $i.i.d.N(0, \sigma_z^2)$.

# Intermediate goods producers (con't)

- Calvo pricing with indexing:
  - each period a fraction $\xi_p$ of ifirms cannot choose its price optimally, but resets it according to the indexation rule

$$P_t(i) = P_{t-1}(i)\pi_{t-1}^{\iota_p}\pi^{1-\iota_p}, \tag{7}$$

where $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is gross inflation and $\pi$ is its steady state.

  - The remaining fraction of firms chooses its price $P_t(i)$ optimally, by maximizing: the present discounted value of future profits

$$E_t \sum_{s=0}^{\infty} \xi_p^s \frac{\beta^s \Lambda_{t,s}}{\Lambda_t} \left[ P_t(i) \left( \prod_{k=1}^{s} \pi_{t+k-1}^{\iota_p} \pi^{1-\iota_p} \right) Y_{t+s}(i) - W_{t+s} L_{t+s}(i) - r_{t+s}^k K_{t+s} \tag{8}$$

subject to the demand function 3 and to cost minimization.

# Employment agencies

- Firms are owned by a continuum of households, indexed by $j \in [0, 1]$.
- Each household is a monopolistic supplier of specialized labor, $L_t(j)$.
- A large number of competitive "employment agencies" combine this specialized labor into a homogenous labor input sold to intermediate firms, according to

$$L_t = \left[ \int_0^1 L_t(j)^{\frac{1}{1+\lambda_{w,t}}} dj \right]^{1+\lambda_{w,t}} . \tag{9}$$

- $\lambda_{w,t}$, follows the exogenous stochastic process

$$\log \left(1 + \lambda_{w,t}\right) = (1-\rho_w) \log (1 + \lambda_w) + \rho_w \log \left(1 + \lambda_{w,t-1}\right) + \varepsilon_{w,t} - \theta_w \varepsilon_{w,t-1}, \tag{10}$$

with $\varepsilon_{w,t}$ $i.i.d.N(0, \sigma_w^2)$. This is the wage markup shock.

# Employment agencies (con't)

- Profit maximization by the perfectly competitive employment agencies:

$$L_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\frac{1+\lambda_{w,t}}{\lambda_{w,t}}} L_t, \tag{11}$$

with

$$W_t = \left[\int_0^1 W_t(j)^{-\frac{1}{\lambda_{w,t}}} dj\right]^{-\lambda_{w,t}}. \tag{12}$$

# Households

- Each household maximizes

$$E_t \left\{ \sum_{s=0}^{\infty} \beta^s b_{t+s} \left[ \log \left( C_{t+s} - hC_{t+s-1} \right) - \varphi \frac{L_{t+s}(j)^{1+\nu}}{1+\nu} \right] \right\}, \qquad (13)$$

where $C_t$ is consumption, $h$ is the degree of habit formation and $b_t$ is a shock to the discount factor:

$$\log b_t = \rho_b \log b_{t-1} + \varepsilon_{b,t}, \qquad (14)$$

with $\varepsilon_{b,t} \sim i.i.d.N(0, \sigma_b^2)$.

# Households (con't)

- The household's flow budget constraint is

$$P_tC_t + P_tI_t + T_t + B_t \;\; \leq$$

$$R_{t-1}B_{t-1} + Q_t(j) + \Pi_t + W_t(j)L_t(j) + [r_t^k u_t - P_t a$$

where $I_t$ is investment, $T_t$ is lump-sum taxes, $B_t$ is holdings of government bonds,

$R_t$ is the gross nominal interest rate, $Q_t(j)$ is the net cash flow from household's $j$ portfolio of state contingent securities, $u_t$ is the capital utilization rate, and $\Pi_t$ is the per-capita profit from ownership of the firms.

# Households (con't)

- Households own capital and choose the capital utilization rate, $u_t$, which transforms physical capital into effective capital according to

$$K_t = u_t \bar{K}_{t-1}.$$

- Effective capital is then rented to firms at the rate $r_t^k$.

- The cost of capital utilization is $a(u_t)$ per unit of physical capital. In steady state, $u = 1$, $a(1) = 0$ and $\chi \equiv \frac{a''(1)}{a'(1)}$.

# Households (con't)

- The physical capital accumulation equation is

$$\bar{K}_t = (1-\delta)\bar{K}_{t-1} + \mu_t \left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) I_t, \tag{17}$$

where $\delta$ is the depreciation rate. In steady state, $S = S' = 0$ and $S'' > 0$.

- The investment shock follows the stochastic process

$$\log \mu_t = \rho_\mu \log \mu_{t-1} + \varepsilon_{\mu,t}, \tag{18}$$

where $\varepsilon_{\mu,t}$ is $i.i.d.N(0, \sigma_\mu^2)$.

# Wage Setting

- "Calvo" wage setting:
  - Each period a fraction $\xi_w$ of households cannot freely set its wage, but follows the indexation rule

$$W_t(j) = W_{t-1}(j)\left(\pi_{t-1}\right)^{\iota_w}(\pi)^{1-\iota_w}. \tag{19}$$

  - The remaining fraction of households choose an optimal wage $W_t(j)$ by maximizing

$$E_t\left\{\sum_{s=0}^{\infty}\xi_w^s\beta^s\left[-b_{t+s}\varphi\frac{L_{t+s}(j)^{1+\nu}}{1+\nu}+\Lambda_{t+s}W_t(j)\,L_{t+s}(j)\right]\right\}$$

,

subject to the labor demand function and the indexing rule.

- Gertler, Sala, and Trigari (2009): search and matching with stagggered Nash wage bargaining a la Calvo.

# The Government

- Monetary policy:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{Y_t}{Y_t^*}\right)^{\phi_X}\right]^{1-\rho_R} \left[\frac{Y_t/Y_{t-1}}{Y_t^*/Y_{t-1}^*}\right]^{\phi_{dX}} \eta_{mp,t}, \qquad (20)$$

with,

$$\log \eta_{mp,t} = \rho_{mp} \log \eta_{mp,t-1} + \varepsilon_{mp,t}, \qquad (21)$$

where $\varepsilon_{mp,t}$ is $i.i.d.N(0, \sigma_{mp}^2)$.

# The government (con't)

- Fiscal policy:

$$G_t = \left(1 - \frac{1}{g_t}\right) Y_t, \tag{22}$$

where

$$\log g_t = (1 - \rho_g) \log g + \rho_g \log g_{t-1} + \varepsilon_{g,t}, \tag{23}$$

with $\varepsilon_{g,t} \sim i.i.d.N(0, \sigma_g^2)$.

- Government budget constraint:

$$G_t = T_t$$

# Market clearing

- The aggregate resource constraint:

$$C_t + I_t + G_t + a(u_t)\bar{K}_{t-1} = Y_t, \tag{24}$$

# Loglinear model

- Aggregate Demand

$$\hat{y}_t = \frac{cg}{y}\hat{c}_t + \frac{ig}{y}\hat{\imath}_t + \frac{\rho kg}{y}\hat{u}_t + \hat{g}_t$$

$$\hat{\lambda}_t = \hat{R}_t - E_t\hat{\pi}_{t+1} + E_t\hat{\lambda}_{t+1}$$

$$\hat{\lambda}_t = \frac{h\beta}{(1-h\beta)(1-h)}E_t\hat{c}_{t+1} - \frac{1+h^2\beta}{(1-h\beta)(e^{\gamma}-h)}\hat{c}_t + \frac{h}{(1-h\beta)(1-h)}\hat{c}_{t-1} + \frac{1-h\beta\rho_b}{1-h\beta}$$

$$\widehat{q}_t = S''(\hat{\imath}_t - \hat{\imath}_{t-1}) - \beta S''(E_t\hat{\imath}_{t+1} - \hat{\imath}_t) - \hat{\mu}_t$$

$$\widehat{q}_t = (1-\delta)\beta E_t[\hat{\lambda}_{t+1} - \hat{\lambda}_t + \widehat{q}_{t+1} + (1-(1-\delta)\beta)\, E_t\left[\hat{\lambda}_{t+1} - \hat{\lambda}_t + \hat{\rho}_{t+1}\right]$$

# Loglinear model (con't)

- Aggregate Supply

$$\hat{y}_t = \alpha \hat{k}_t + (1-\alpha)\hat{L}_t$$

$$\hat{y}_t - \hat{k}_t = -\widehat{mc}_t + \hat{\rho}_t$$

$$\hat{y}_t - \hat{L}_t = -\widehat{mc}_t + \hat{w}_t$$

$$\hat{k}_t = \hat{u}_t + \hat{\bar{k}}_{t-1}$$

$$\hat{\rho}_t = \chi \hat{u}_t$$

$$\hat{\bar{k}}_t = (1-\delta)\hat{\bar{k}}_{t-1} + (1-(1-\delta))\left(\hat{\mu}_t + \hat{\imath}_t\right)$$

# Loglinear model (con't)

$$\hat{\pi}_t = \frac{\beta}{1+\iota_p\beta} E_t \hat{\pi}_{t+1} + \frac{\iota_p}{1+\iota_p\beta}\hat{\pi}_{t-1} + \kappa \widehat{mc}_t + \kappa \hat{\lambda}_{p,t}$$

$$\hat{w}_t = \frac{1}{1+\beta}\hat{w}_{t-1} + \frac{\beta}{1+\beta}E_t\hat{w}_{t+1} + \kappa_w \hat{g}_{w,t} + \frac{\iota_w}{1+\beta}\hat{\pi}_{t-1} - \frac{1+\beta\iota_w}{1+\beta}\pi_t + \frac{\beta}{1+\beta}E_t\hat{\pi}_{t+1}$$

$$\hat{g}_{w,t} = \left(\nu \hat{L}_t + \hat{b}_t - \hat{\lambda}_t\right) - \hat{w}_t$$

# Loglinear model (con't)

- Policy:

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1-\rho_R)\left[\phi_\pi \hat{\pi}_t + \phi_Y\left(\hat{x}_t - \hat{x}_t^*\right)\right] + \phi_{dY}\left[\left(\widehat{y}_t - \widehat{y}_{t-1}\right) - \left(\widehat{y}_t^* - \widehat{y}_{t-1}^*\right)\right]$$

# Loglinear model (con't)

- The following 15 equations form a linear system of rational expectations equations, together with the 14 equations describing the evolution of the economy with flexible prices, flexible wages and no markup shocks, whose allocation we denote with a "$*$" superscript. We solve this system of equations for the 29 endogenous variables

$$\left[\begin{array}{c} \hat{y}_t, \hat{k}_t, \hat{L}_t, \hat{\rho}_t, \hat{w}_t, \widehat{mc}_t, \hat{\pi}_t, \hat{c}_t, \hat{\lambda}_t, \hat{R}_t, \hat{u}_t, \hat{\phi}_t, \hat{\imath}_t, \hat{\bar{k}}_t, , \hat{g}_{w,t}, \\ \hat{y}_t^*, \hat{k}_t^*, \hat{L}_t^*, \hat{\rho}_t^*, \hat{w}_t^*, \widehat{mc}_t^*, \hat{c}_t^*, \hat{\lambda}_t^*, \hat{R}_t^*, \hat{u}_t^*, \hat{\phi}_t^*, \hat{\imath}_t^*, \hat{\bar{k}}_t^*, \hat{g}_{w,t}^* \end{array}\right],$$

conditional on the evolution of the exogenous shocks

# Estimation

- Use Bayesian methods to characterize the posterior distribution of the structural parameters (see An and Schorfheide, 2007)
  - The posterior distribution combines the likelihood function with prior information.

- The likelihood is based on the following vector of observable variables

$$[\Delta \log X_t, \Delta \log C_t, \Delta \log I_t, \log L_t, \Delta \log \frac{W_t}{P_t}, \pi_t, \log R_t], \tag{25}$$

  where $\Delta$ denotes the temporal difference operator.

- The data are quarterly and span the period from 1954QIII to 2004QIV.

- Two parameters are fixed: the quarterly depreciation rate of capital ($\delta$) to 0.025 and the steady state ratio of government spending to GDP ($1 - 1/g$) to 0.

- The priors on the other coefficients are fairly diffuse and in line with other work

## Inspecting the Mechanism: How Investment Shocks Become Important

- Real Business Cycle Model:
  - Absent productivity shocks, positive co-movement between C and $L$ not possible
  - Result comes from labor market condition
  - $$MRS\left(\underset{+}{C},\underset{+}{L}\right)=MPL\left(\underset{-}{L}\right). \tag{26}$$
- NK Model
  - Countercyclical co-movement makes positive co-movement possible.

$$\omega\left(\underset{-}{L}\right)MRS\left(\underset{+}{C},\underset{+}{L}\right)=MPL\left(\underset{-}{L}\right)$$

## Table 1: Prior densities and posterior estimates for the baseline model

| Coefficient | Description | Prior: Prior Density [1] | Prior: Mean | Prior: Std | Posterior [2]: Median | Posterior [2]: Std | Posterior [2]: [ 5 , 95 ] |
|---|---|---|---|---|---|---|---|
| $\alpha$ | Capital share | N | 0.30 | 0.05 | 0.17 | 0.01 | [ 0.16 , 0.18 ] |
| $\iota_p$ | Price indexation | B | 0.50 | 0.15 | 0.24 | 0.08 | [ 0.12 , 0.38 ] |
| $\iota_w$ | Wage indexation | B | 0.50 | 0.15 | 0.11 | 0.03 | [ 0.06 , 0.16 ] |
| $100\gamma$ | SS technology growth rate | N | 0.50 | 0.03 | 0.48 | 0.02 | [ 0.44 , 0.52 ] |
| $h$ | Consumption habit | B | 0.50 | 0.10 | 0.78 | 0.04 | [ 0.72 , 0.84 ] |
| $\lambda_p$ | SS price markup | N | 0.15 | 0.05 | 0.23 | 0.04 | [ 0.17 , 0.29 ] |
| $\lambda_w$ | SS wage markup | N | 0.15 | 0.05 | 0.15 | 0.04 | [ 0.08 , 0.22 ] |
| $logL^{ss}$ | SS log-hours | N | 0.00 | 0.50 | 0.38 | 0.47 | [ -0.39 , 1.15 ] |
| $100(\pi\text{-}1)$ | SS quarterly inflation | N | 0.50 | 0.10 | 0.71 | 0.07 | [ 0.58 , 0.82 ] |
| $100(\beta^{-1}\text{-}1)$ | Discount factor | G | 0.25 | 0.10 | 0.13 | 0.04 | [ 0.07 0.21 ] |
| $\nu$ | Inverse Frisch elasticity | G | 2.00 | 0.75 | 3.79 | 0.76 | [ 2.70 , 5.19 ] |
| $\xi_p$ | Calvo prices | B | 0.66 | 0.10 | 0.84 | 0.02 | [ 0.80 , 0.87 ] |
| $\xi_w$ | Calvo wages | B | 0.66 | 0.10 | 0.70 | 0.05 | [ 0.60 , 0.78 ] |
| $\chi$ | Elasticity capital utilization costs | G | 5.00 | 1.00 | 5.30 | 1.01 | [ 3.84 , 7.13 ] |
| $S''$ | Investment adjustment costs | G | 4.00 | 1.00 | 2.85 | 0.54 | [ 2.09 , 3.88 ] |
| $\phi_\pi$ | Taylor rule inflation | N | 1.70 | 0.30 | 2.09 | 0.17 | [ 1.84 , 2.39 ] |
| $\phi_X$ | Taylor rule output | N | 0.13 | 0.05 | 0.07 | 0.02 | [ 0.04 , 0.10 ] |
| $\phi_{dX}$ | Taylor rule output growth | N | 0.13 | 0.05 | 0.24 | 0.02 | [ 0.20 , 0.28 ] |
| $\rho_R$ | Taylor rule smoothing | B | 0.60 | 0.20 | 0.82 | 0.02 | [ 0.79 , 0.86 ] |

*( Continued on the next page )*

**Table 1: Prior densities and posterior estimates for the baseline model**

| | | Prior | | | Posterior [2] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coefficient | Description | Prior Density [1] | Mean | Std | Median | Std | [ | 5 | , | 95 | ] |
| $\rho_{mp}$ | Monetary policy | B | 0.40 | 0.20 | 0.14 | 0.06 | [ | 0.05 | , | 0.25 | ] |
| $\rho_z$ | Neutral technology growth | B | 0.60 | 0.20 | 0.23 | 0.06 | [ | 0.14 | , | 0.32 | ] |
| $\rho_g$ | Government spending | B | 0.60 | 0.20 | 0.99 | 0.00 | [ | 0.99 | , | 0.99 | ] |
| $\rho_\mu$ | Investment | B | 0.60 | 0.20 | 0.72 | 0.04 | [ | 0.65 | , | 0.79 | ] |
| $\rho_p$ | Price markup | B | 0.60 | 0.20 | 0.94 | 0.02 | [ | 0.90 | , | 0.97 | ] |
| $\rho_w$ | Wage markup | B | 0.60 | 0.20 | 0.97 | 0.01 | [ | 0.95 | , | 0.99 | ] |
| $\rho_b$ | Intertemporal preference | B | 0.60 | 0.20 | 0.67 | 0.04 | [ | 0.60 | , | 0.73 | ] |
| $\theta_p$ | Price markup MA | B | 0.50 | 0.20 | 0.77 | 0.07 | [ | 0.61 | , | 0.85 | ] |
| $\theta_w$ | Wage markup MA | B | 0.50 | 0.20 | 0.91 | 0.02 | [ | 0.88 | , | 0.94 | ] |
| $100\sigma_{mp}$ | Monetary policy | I | 0.10 | 1.00 | 0.22 | 0.01 | [ | 0.20 | , | 0.25 | ] |
| $100\sigma_z$ | Neutral technology growth | I | 0.50 | 1.00 | 0.88 | 0.05 | [ | 0.81 | , | 0.96 | ] |
| $100\sigma_g$ | Government spending | I | 0.50 | 1.00 | 0.35 | 0.02 | [ | 0.33 | , | 0.38 | ] |
| $100\sigma_\mu$ | Investment | I | 0.50 | 1.00 | 6.03 | 0.96 | [ | 4.71 | , | 7.86 | ] |
| $100\sigma_p$ | Price markup | I | 0.10 | 1.00 | 0.14 | 0.01 | [ | 0.12 | , | 0.17 | ] |
| $100\sigma_w$ | Wage markup | I | 0.10 | 1.00 | 0.20 | 0.02 | [ | 0.18 | , | 0.24 | ] |
| $100\sigma_b$ | Intertemporal preference | I | 0.10 | 1.00 | 0.04 | 0.00 | [ | 0.03 | , | 0.04 | ] |

[1] N stands for Normal, B Beta, G Gamma and I Inverted-Gamma1 distribution

[2] Median and posterior percentiles from 3 chains of 120,000 draws generated using a Random walk Metropolis algorithm. We discard the initial 20,000 and retain one every 10 subsequent draws.

## Table 1: Posterior variance decomposition at business cycle frequencies in the baseline model[1]

*Medians and [5th,95th] percentiles*

| ***Series \ Shock*** | **Policy** | **Neutral** | **Government** | **Investment** | **Price mark-up** | **Wage mark-up** | **Preference** |
|---|---|---|---|---|---|---|---|
| Output | 0.05 | 0.25 | 0.02 | 0.50 | 0.05 | 0.05 | 0.07 |
| | [ 0.03, 0.08] | [ 0.19, 0.33] | [ 0.01, 0.02] | [ 0.42, 0.59] | [ 0.03, 0.07] | [ 0.03, 0.08] | [ 0.05, 0.10] |
| Consumption | 0.02 | 0.26 | 0.02 | 0.09 | 0.01 | 0.07 | 0.52 |
| | [ 0.01, 0.04] | [ 0.20, 0.32] | [ 0.02, 0.03] | [ 0.04, 0.16] | [ 0.00, 0.01] | [ 0.04, 0.12] | [ 0.42, 0.61] |
| Investment | 0.03 | 0.06 | 0.00 | 0.83 | 0.04 | 0.01 | 0.02 |
| | [ 0.02, 0.04] | [ 0.04, 0.10] | [ 0.00, 0.00] | [ 0.76, 0.89] | [ 0.02, 0.06] | [ 0.01, 0.02] | [ 0.01, 0.04] |
| Hours | 0.07 | 0.1 | 0.02 | 0.59 | 0.06 | 0.07 | 0.08 |
| | [ 0.04, 0.10] | [ 0.08, 0.13] | [ 0.02, 0.03] | [ 0.52, 0.66] | [ 0.04, 0.09] | [ 0.04, 0.11] | [ 0.06, 0.12] |
| Wages | 0.00 | 0.4 | 0.00 | 0.04 | 0.31 | 0.23 | 0.00 |
| | [ 0.00, 0.01] | [ 0.30, 0.52] | [ 0.00, 0.00] | [ 0.02, 0.07] | [ 0.23, 0.41] | [ 0.16, 0.32] | [ 0.00, 0.01] |
| Inflation | 0.03 | 0.14 | 0.00 | 0.06 | 0.39 | 0.34 | 0.02 |
| | [ 0.02, 0.06] | [ 0.09, 0.21] | [ 0.00, 0.00] | [ 0.02, 0.13] | [ 0.29, 0.50] | [ 0.26, 0.42] | [ 0.01, 0.04] |
| Interest Rates | 0.17 | 0.09 | 0.01 | 0.47 | 0.05 | 0.04 | 0.16 |
| | [ 0.13, 0.22] | [ 0.06, 0.12] | [ 0.00, 0.01] | [ 0.37, 0.56] | [ 0.03, 0.07] | [ 0.03, 0.07] | [ 0.11, 0.23] |

[1] Business cycle frequencies correspond to periodic components with cycles between 6 and 32 quarters. The decomposition is obtained using the spectrum of the DSGE model and an inverse first difference filter for output, consumption, investment and wages to reconstruct the levels. The spectral density is computed from the state space representation of the model with 500 bins for frequencies covering that range of periodicities. Medians need not add up to one.

## Table 2: Variance share of output and hours at business cycles frequencies[1] due to investment shocks, comparison with Smets and Wouters

| ***Model*** | **Smets and Wouters** | **Ours** | | | **Durables in Home Production** |
|---|---|---|---|---|---|
| ***Definition of observables*** | **Smets and Wouters** | **Smets and Wouters** | **Investment includes consumer durables but not inventories** | **Baseline** | **Baseline with consumption of durable goods observable** |
| ***Series*** | | | | | |
| Output | 0.23 | 0.19 | 0.42 | 0.50 | 0.65 |
| Hours | 0.26 | 0.22 | 0.47 | 0.59 | 0.74 |

[1] Business cycle frequencies correspond to periodic components with cycles between 6 and 32 quarters. Variance decompositions are performed at the mode of each specification.

**Table 3: Variance share of output and hours at business cycle frequencies[1] due to investment shocks, restricted models**

| *Series* | Baseline | No habits[2] | No investment costs and variable capital utilization[3] | Perfectly competitive goods and labor markets[4] | Perfectly competitive goods markets[5] | Perfectly competitive labor market[6] | No frictions[7] |
|---|---|---|---|---|---|---|---|
| Output | 0.50 | 0.39 | 0.23 | 0.04 | 0.30 | 0.31 | 0.02 |
| Hours | 0.59 | 0.51 | 0.30 | 0.08 | 0.51 | 0.42 | 0.03 |
| log Marginal Likelihood | -1176.3 | -1302.6 | -1283.3 | -1457.1 | -1415.1 | -1274.7 | -1512.0 |

[1] Business cycle frequencies correspond to periodic components with cycles between 6 and 32 quarters. Variance decompositions are performed at the mode of each specification.

[2] $h$ calibrated at 0.01

[3] $S''$ calibrated at 0.01, $1/\chi$ calibrated at 0.001

[4] $\lambda_{w}$, $\xi_{w}$, $\iota_{w}$, $\lambda_{p}$, $\xi_{p}$ *and* $\iota_{p}$ calibrated at 0.01

[5] $\lambda_{w}$, $\xi_{w}$ and $\iota_{w}$ calibrated at 0.01

[6] $\lambda_{p}$, $\xi_{p}$ and $\iota_{p}$ calibrated at 0.01

[7] Combines the calibration for all specifications above, except baseline

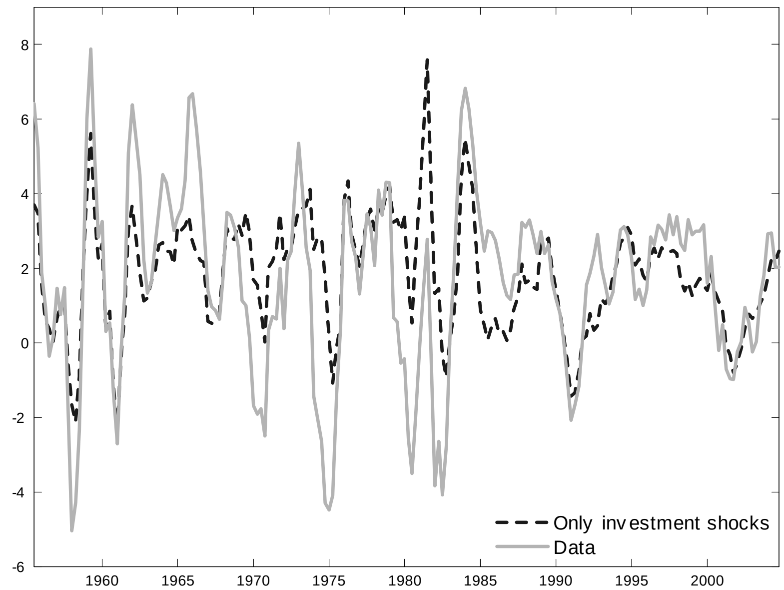



Figure 1: Year-over-year output growth in the data and in the model with only investment shocks.

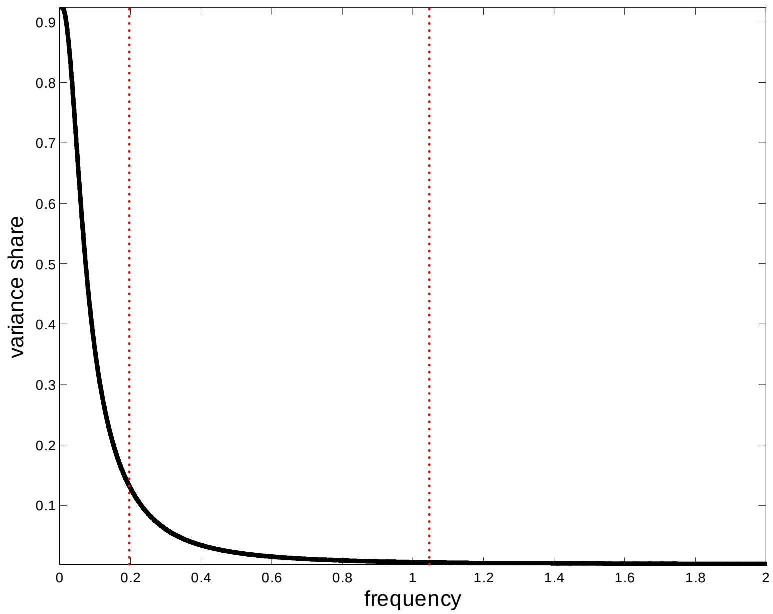



Figure 2: Variance share of hours due to wage markup shocks as a function of the spectrum frequencies. The vertical dashed lines mark the frequency band associated with business cycles, which includes frequencies between $2\pi/32 = 0.19$ and $2\pi/6 = 1.05$.

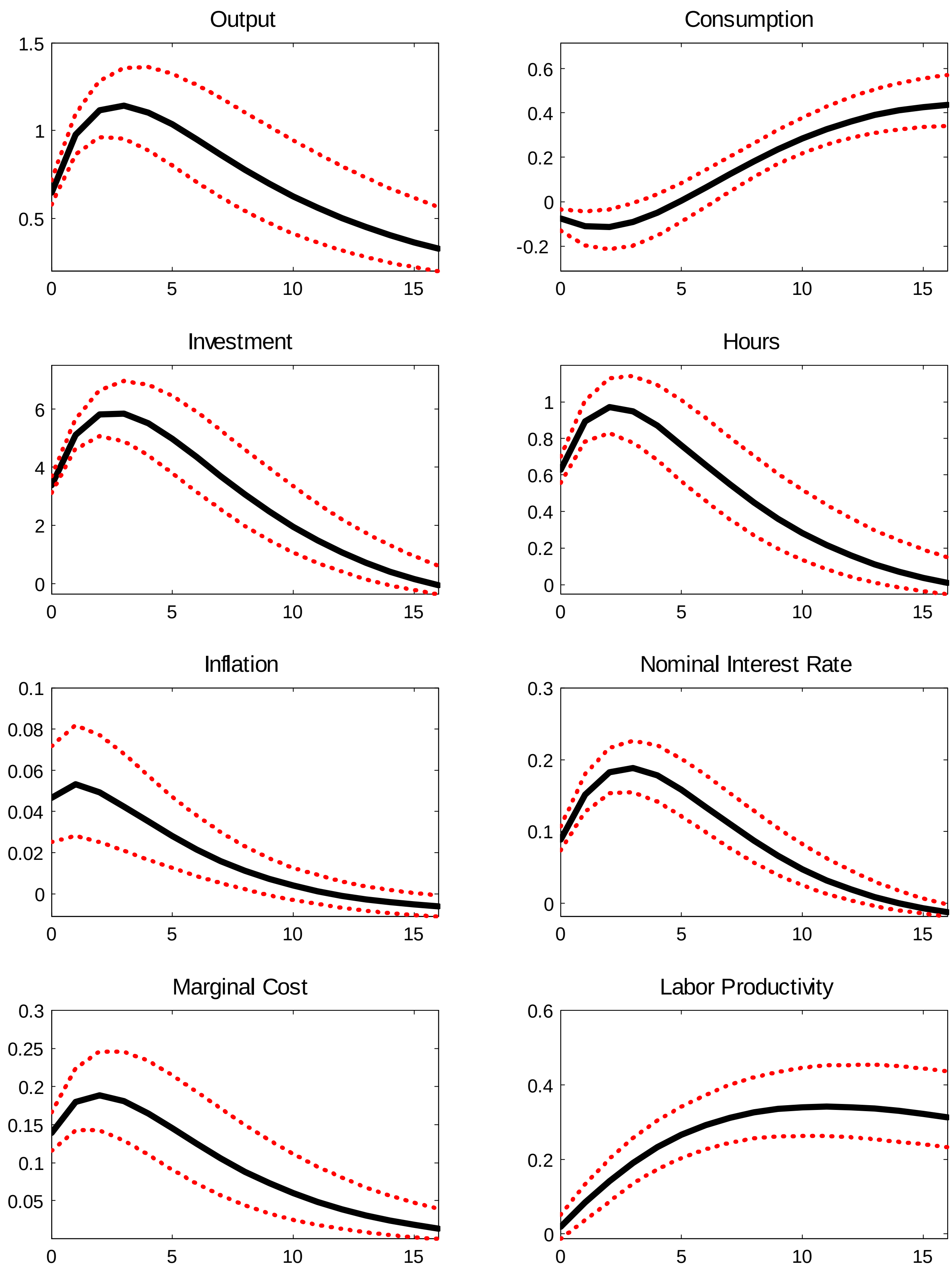



Figure 3: Impulse responses to a one standard deviation investment shock. The dashed lines represent 90 percent posterior probability bands around the posterior median.