Consensus New Keynesian DSGE Model

Lawrence Christiano
Overview

• A consensus has emerged about the rough outlines of a model for the analysis of monetary policy.
  – Consensus influenced heavily by estimated impulse response functions from Structural Vector Autoregression (SVARs)

• Construct the consensus models based on SVAR results.
  – Christiano, Eichenbaum and Evans JPE (2005)
  – Smets and Wouters, AER (2007)
• Very brief review of SVARs.
Identifying Monetary Policy Shocks

• Rule that relates Fed’s actions to state of the economy.

\[ R_t = f(\Omega_t) + e_t^R \]

- \( f \) is a linear function

- \( \Omega_t \): set of variables that Fed looks at.

- \( e_t^R \): time t policy shock, orthogonal to \( \Omega_t \)
Response to a monetary policy shock

- Output
- M2M Growth (Q)
- Inflation
- Federal Funds Rate
- Capacity Utilization
- Average Hours
- Real Wage
- Consumption
- Investment
- Velocity
- Investment Good Price

Quarters
Interesting Properties of Monetary Policy Shocks

- Plenty of endogenous persistence:
  - money growth and interest rate over in 1 year, but other variables keep going....

- Inflation slow to get off the ground: peaks in roughly two years
  - It has been conjectured that explaining this is a major challenge for economics
  - Kills models in which movements in $P$ are key to monetary transmission mechanism (Lucas misperception model, pure sticky wage model)
  - Has been at the heart of the recent emphasis on sticky prices.

- Output, consumption, investment, hours worked and capacity utilization hump-shaped

- Velocity comoves with the interest rate
Identification of Technology Shocks

- Two technology shocks:
  - One perturbs price of investment goods
  - One perturbs total factor productivity

- Identification assumptions:
  - They are the only two shocks that affect labor productivity in the long run
  - Only the shock to investment good prices have an impact on investment good prices in the long run.
Response to a neutral technology shock

Graphs showing the response of various economic indicators over 15 quarters after a neutral technology shock:

- Output
- MZM Growth (Q)
- Inflation
- Federal Funds Rate
- Capacity Utilization
- Average Hours
- Real Wage
- Consumption
- Investment
- Velocity
- Investment Good Price

Each graph plots the percentage change over time.
Observations on Neutral Shock

• Generally, results are ‘noisy’, as one expects.
  – Interest, money growth, velocity responses not pinned down.

• Interestingly, inflation response is immediate and precisely estimated.

• Does this raise a question about the conventional interpretation of the response of inflation to a monetary shock?

• Alternative possibility: information confusion stories.
  – A variant of recent work by Rhys Mendes that builds on Guido Lorenzoni’s work.
Importance of Three Shocks

• According to VAR analysis, they account for a large part of economic fluctuations.
## Variance Decomposition

<table>
<thead>
<tr>
<th>Variable</th>
<th>BP(8,32)</th>
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<tbody>
<tr>
<td>Output</td>
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<td>Avg. Hours</td>
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<td>Real Wage</td>
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<td>Investment</td>
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<tr>
<td>Velocity</td>
<td>29</td>
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<tr>
<td>Price of investment goods</td>
<td>11</td>
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</tbody>
</table>
Next

- Use Impulse Responses to Estimate a DSGE Model
  - Motivate the Basic Model Features.
  - Model Estimation.

- Determine if there is a conflict regarding price behavior between micro and macro data.
  - Macro Evidence:
    - Inflation responds slowly to monetary shock
    - Single equation estimates of slope of Phillips curve produce small slope coefficients.
  - Micro Evidence:
    - Bils-Klenow, Nakamura-Steinsson report evidence on frequency of price change at micro level: 5-11 months.

- Finding: no micro macro puzzle, as long as we suppose that capital used by firms is ‘firm-specific’.
Outline

• Model

• Econometric Estimation of Model
  – Fitting Model to Impulse Response Functions

• Model Estimation Results (is there a micro/macro puzzle?)
Description of Model

- Timing Assumptions
- Firms
- Households
- Monetary Authority
- Goods Market Clearing and Equilibrium
Timing

• Technology Shocks Realized.

• Agents Make Price/Wage Setting, Consumption, Investment, Capital Utilization Decisions.

• Monetary Policy Shock Realized.

• Household Money Demand Decision Made.

• Production, Employment, Purchases Occur, and Markets Clear.

• Note: Wages, Prices and Output Predetermined Relative to Policy Shock.
Extension to small open economy (Christiano, Trabandt, Walentin (2009))

- Domestic homogeneous good
  - Final consumption goods
  - Final investment goods
  - Final export goods
  - Imported consumption goods
  - Imported investment goods
  - Imported goods for re-export
Firms

• Final good firms
  – Technology:
    \[ Y_t = \left[ \int_0^1 y_{it}^{\frac{1}{\lambda_f}} di \right]^{\lambda_f}, \quad 1 \leq \lambda_f < \infty \]

  – Objective:
    \[ \max_{y_t, \{y_{it}, 0 \leq i \leq 1\}} P_t Y_t - \int_0^1 P_{it} y_{it} di \]

  – Foncs and prices:
    \[ \left( \frac{P_t}{P_{it}} \right)^{\frac{\lambda_f}{\lambda_f - 1}} = \frac{y_{it}}{Y_t}, \quad P_t = \left[ \int_0^1 P_{it}^{\frac{1}{1-\lambda_f}} \right]^{1-\lambda_f} \]
Firms, cont’d

- Intermediate good firms
  - Each $y_{it}$ produced by a monopolist with demand curve:
    $$y_{it} = \left( \frac{P_t}{P_{it}} \right)^{\frac{\lambda_f}{\lambda_f - 1}} Y_t$$
  - Technology:
    $$y_{it} = K_{it}^\alpha (z_t L_{it})^{1-\alpha}, \ 0 < \alpha < 1$$
  - Law of motion of technology shock:
    $$\mu_{z,t} \equiv \log z_t - \log z_{t-1}, \ \hat{\mu}_{z,t} \equiv \frac{\mu_{z,t} - \mu_z}{\mu_z}, \ \mu_z = E\mu_{z,t}$$
    $$\hat{\mu}_{z,t} = \rho_{\mu_z} \hat{\mu}_{z,t-1} + \epsilon_{\mu_z,t}$$
  - consistent with identifying assumption on technology.
Firms, cnt’d

- Intermediate good firm marginal cost

\[ MC^\$ = [\psi + (1 - \psi)R_t]\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{P_t r_t^k}{\alpha}\right)^\alpha \frac{1}{z_t^{1-\alpha}} \]

Fraction of wage and capital rental bill that must be borrowed in advance at gross nominal rate of interest, \( R \)

\( \psi < 1 \) creates ‘working capital channel’ for the interest rate, \( R \), on the supply side of the economy.

Helps keep prices from rising after monetary injection (actually, may Even help explain the ‘price puzzle’).
Firms, cnt’d

• Intermediate good firm marginal cost

\[ MC = [\psi + (1 - \psi)R_t] \left( \frac{W_t}{1-\alpha} \right)^{1-\alpha} \left( \frac{P_t r^k_t}{\alpha} \right)^\alpha \frac{1}{z_t^{1-\alpha}} \]

• Marginal cost divided by final good price:

\[ s_t \equiv \frac{MC}{P_t} = [\psi + (1 - \psi)R_t] \left( \frac{W_t/P_t}{1-\alpha} \right)^{1-\alpha} \left( \frac{r^k_t}{\alpha} \right)^\alpha \frac{1}{z_t^{1-\alpha}} \]
Calvo price frictions in intermediate good firms

- With probability, $1 - \xi_p$, firms may optimize price:
  \[ P_{it} = \tilde{P}_t \]

- With probability, $\xi_p$,
  \[ P_{it} = \bar{\pi}^\nu \pi_{t-1}^{1-\nu} P_{i,t-1}, \quad 0 < \nu < 1 \]

- Alternative is that with probability $\xi_p$,
  \[ P_{it} = P_{i,t-1} \]
Evidence from Midrigan, ‘Menu Costs, Multi-Product Firms, and Aggregate Fluctuations’

Figure 1: Distribution of price changes conditional on adjustment

Histograms of $\log(P_t/P_{t-1})$, conditional on price adjustment, for two data sets pooled across all goods/stores/months in sample.
Combining Optimal Price and Aggregate Price Relation:

\[
\Delta \hat{\pi}_t = \beta E_t \Delta \hat{\pi}_{t+1} + \frac{(1 - \beta \xi_p)(1 - \xi_p)}{\xi_p} E_t \hat{s}_t, \quad v = 0
\]

\[
\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \frac{(1 - \beta \xi_p)(1 - \xi_p)}{\xi_p} E_t \hat{s}_t. \quad v = 1
\]
Households: Sequence of Events

• Technology shock realized.

• Decisions: Consumption, Capital accumulation, Capital Utilization.

• Wage rate set.

• Monetary policy shock realized.

• Household allocates beginning of period cash between deposits at financial intermediary and cash to be used in consumption transactions.
Households

• Each household is identical

• Each household supplies each of many different varieties of labor, \( j \in (0, 1) \)
  – Quantity of \( j \)-type labor: \( h_{j,t} \)

• Quantity of consumption: \( C_t \)

• Household preferences:

\[
E_0 \sum_{t=0}^{\infty} \beta^t \left[ \log(C_t - bC_{t-1}) - \frac{\psi_L}{1+\sigma} \int_0^1 h_{j,t}^{1+\sigma} \, dj \right]
\]
Household and Labor Market
Erceg-Henderson-Levin Model

• Each type of labor, \( j \), in the household joins a union of all \( j \)-type labor from all other households.

• The union for \( j \)-type labor behaves as a monopolist on behalf of its members, setting the wage \( W_{j,t} \) subject to a demand curve for \( j \)-type labor.

• With probability \( \xi_w \) the union may not reoptimize the wage, and with probability \( 1 - \xi_w \) it may reoptimize.
Labor market, cnt’d

• Given the specified wage, $j$-type workers supply whatever quantity of labor is demanded.

• Labor is demanded by competitive ‘labor contractors’, who aggregate different labor services into a homogeneous labor input that they rent to intermediate good producers.

• Labor contractors use the following technology:

$$l_t = \left[ \int_0^1 (h_{t,j}) \frac{1}{\lambda_w} dj \right]^{\lambda_w}, \ 1 \leq \lambda_w < \infty.$$
\[ l_t = \left[ \int_0^1 (h_{t,j})^{1/\lambda_w}dj \right]^\lambda_w \]
What’s the point of the wage setting frictions?

• They help the model account for the response of inflation and output to a monetary policy shock.

  – Sticky wage in effect makes labor supply highly elastic.

  – Positive monetary policy shock leads to:
    • Big increase in employment and output.
    • Small increase in cost and, hence, inflation.
Firms use a lot of labor because it’s ‘cheap’.
Households must supply that labor.
Extensions of Labor Market

• Jordi Gali (2009) shows how to derive a theory of unemployment from the EHL model.

• Christiano-Trabandt-Walentin (2010) extend the model to obtain ‘involuntary’ unemployment.

• Gertler-Trigari, Gertler-Sala-Trigari show how to introduce Mortensen-Pissarides-style search and matching approach
  – see Christiano-Illut-Motto-Rostagno and Christiano-Trabandt-Walentin for empirical applications to closed and small open economies.
Why Habit Persistence in Preferences?

• They help resolve the ‘consumption puzzle’ in monetary economics…..

• With standard preferences, hard to understand the way consumption responds to monetary policy shock.
Consumption ‘Puzzle’

• In Estimated Impulse Responses:
  – Real Interest Rate Falls
    \[ R_t / \pi_{t+1} \]
  – Consumption Rises in Hump-Shape Pattern:

• Standard preferences inconsistent with above
Consumption ‘Puzzle’

- Intertemporal First Order Condition:

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

‘Standard’ Preferences imply:

- Data!
A Solution to the Consumption Puzzle

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

- 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, \( b > 0 \)
Households...

- Asset Evolution Equation:

\[ M_{t+1} = R_t[M_t - Q_t + (x_t - 1)M_t^a] + Q_t + \int_0^1 W_{j,t}h_{j,t}dj \]

\[ + P_t r^k_t u_t \bar{K}_t + D_t - P_t \left[ (1 + \eta(V_t)) C_t + \frac{1}{\gamma_t} (I_t + a(u_t) \bar{K}_t) \right] \]

- \( M_t \): Beginning of Period Base Money; \( Q_t \): Transactions Balances
- \( x_t \): Growth Rate of Base; \( u_t \): Utilization Rate of Capital
  * \( u_t = 1 \) in steady state, \( a(1) = 0, a'(1) > 0, \sigma_a = a''(1)/a'(1) \).
- \( \gamma_t^{-1} \): (Real) Price of investment goods, \( \mu_{\gamma,t} = \gamma_t/\gamma_{t-1} \),

\[ \hat{\mu}_{\gamma,t} = \rho_{\mu,\gamma} \hat{\mu}_{\gamma,t-1} + \varepsilon_{\mu,\gamma,t} \]

- Velocity:

\[ V_t = \frac{P_tC_t}{Q_t} \]
Money Demand

- Asset Evolution Equation:

\[ M_{t+1} = R_t[M_t - Q_t + (x_t - 1)M_t^a] + Q_t + \int_0^1 W_{j,t}h_{j,t}dj \]

\[ + P_t r_t^k u_t \bar{K}_t + D_t - P_t \left[ (1 + \eta(V_t))C_t + \frac{1}{Y_t} (I_t + a(u_t)\bar{K}_t) \right] \]

- Increase in \( Q_t \):
  - Marginal Cost of Interest Foregone: \( R_t \)
  - Marginal Benefit:

\[ 1 - P_t \eta'(V_t) C_t \frac{dV_t}{dQ_t} \]

\[ = 1 + \underbrace{\eta'(\frac{P_t C_t}{Q_t}) \left( \frac{P_t C_t}{Q_t} \right)^2} \]

additional cash available at end of period

reduction in transactions costs due to extra cash
Money Demand ...

- Money Demand: Equate Marginal Benefits and Costs of $Q_t$ —

$$R_t = 1 + \eta' \left( \frac{P_t C_t}{Q_t} \right) \left( \frac{P_t C_t}{Q_t} \right)^2.$$

- Properties of Money Demand:
  - Unit Consumption Elasticity of Money Demand
    * Increase $C_t$ 1 percent and Hold $R_t$, $P_t$ Fixed $\Rightarrow$ Desired $Q_t$ increases 1 percent
  - $R_t \uparrow$ Implies $Q_t \downarrow$
    * To Induce Households to Hold Additional $Q$, Must Have Lower $R$
    * Money Demand Elasticity is Bigger, the Bigger is $\eta''$
Money Demand ...

- Quantitative Analysis of Money Demand
  
  - Consider the Following Parametric Function for $\eta$

  $$\eta = AV_t + \frac{B}{V_t} - 2\sqrt{AB}$$

  $$\Rightarrow$$

  $$R = 1 + \eta'(V) \times V^2 = 1 + \left[ A - BV^{-2} \right] V^2 = 1 - B + AV^2$$

- Data:
  * Money - St. Louis Fed's MZM, 1974-2004
  * Consumption - NIPA Consumption of Services and Nondurables
  * Interest Rate - One Year T-Bills.
  * OLS Regression of $V^2$ on $R \Rightarrow A = 0.0174$ and $B = 0.0187$
Money Demand ...

- Top Graph: Velocity of Money
- Bottom Graph: Actual and Predicted Interest Rate

- Findings: Static Money Demand Equation Fits the Data Well!
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

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

\( P_{k',t} \sim \) consumption price of installed capital

\( MP_t^k \sim \) marginal product of capital

\( \delta \in (0, 1) \sim \) 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!
Investment Puzzle: a failed approach

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

\[ k' = (1 - \delta)k + F\left(\frac{I}{k}\right)I. \]

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

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

\[ \text{Optimal Under Standard Specification} \]

\[ \text{Data!} \]
A Solution to the 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, Sherwin Rosen
  – Theoretical: Matsuyama, David Lucca
Monetary and Fiscal Policy

\[ x_t = M_t/M_{t-1} \]

\[ \hat{x}_{M,t} = \rho_M \hat{x}_{M,t-1} + \varepsilon_{M,t} \]
\[ \hat{x}_{z,t} = \rho_{xz} \hat{x}_{z,t-1} + c_z \varepsilon_{z,t} + c_{z}\varepsilon_{z,t-1} \]
\[ \hat{x}_{\gamma,t} = \rho_{x\gamma} \hat{x}_{\gamma,t-1} + c_{\gamma} \varepsilon_{\gamma,t} + c_{\gamma}\varepsilon_{\gamma,t-1} \]

- \( \hat{x}_{M,t} \): response of monetary policy to a monetary policy shock, \( \varepsilon_{M,t} \)
- \( \hat{x}_{z,t} \): response of monetary policy to an innovation in neutral technology, \( \varepsilon_{z,t} \).
- \( \hat{x}_{\gamma,t} \): response of monetary policy to an innovation in capital embodied technology, \( \varepsilon_{\gamma,t} \).
- Government has access to lump sum taxes, pursues a Ricardian fiscal policy.
Loan Market and Final Good Market Clearing Conditions, Equilibrium

- Financial intermediaries receive $M_t - Q_t + (x_t - 1) M_t$ from the household.
  - Lend all of their money to intermediate good firms, which use the funds to pay for $H_t$.
- Loan market clearing
  $$W_t H_t = x_t M_t - Q_t.$$
- The aggregate resource constraint is
  $$(1 + \eta(V_t)) C_t + \Upsilon_t^{-1} [I_t + a(u_t) \bar{K}_t] \leq Y_t.$$  
- We adopt a standard sequence-of-markets equilibrium concept.
Econometric Methodology

• Variant of limited information strategy used in CEE (2004).
  – Impose a subset of assumptions made in equilibrium model to estimate impulse response functions of ten key macroeconomic variables to the three shocks in our model.
  – Neutral technology shocks, capital embodied technology shocks and monetary policy shocks.

• Choose values for key parameters of structural model to minimize difference between estimated impulse response functions and analogous objects in model.
Estimating Parameters in the Model

- Partition Parameters into Three Groups.
  - Parameters set a priori (e.g., $\beta$, $\delta$, ...)
  - $\zeta_1$: remaining parameters pertaining to the nonstochastic part of model
    
    $$\zeta_1 = [\xi_w, \gamma, \sigma_a, b, S''', \epsilon]$$

  - $\zeta_2$: parameters pertaining to stochastic part of the model
- Number of parameters, $\zeta = (\zeta_1, \zeta_2)$, to be estimated - 18
- Estimation Criterion
  - $\Psi(\zeta)$: mapping from $\zeta$ to model impulse responses
  - $\hat{\Psi}$: 592 impulse responses estimated using VAR
  - Estimation Strategy:
    $$\hat{\zeta} = \underset{\zeta}{\arg \min} \left( \hat{\Psi} - \Psi(\zeta) \right)' V^{-1} \left( \hat{\Psi} - \Psi(\zeta) \right).$$
  - $V$: diagonal matrix with sample variances of $\hat{\Psi}$ along the diagonal.

We estimate $\gamma$, the slope of the Phillips curve, rather than $\xi_p$. 
Classical Perspective

• Impulse response functions have the following asymptotic distribution:
  \[ \sqrt{T} \left( \hat{\Psi} - \Psi^0 \right) \overset{a}{\sim} N(0, \tilde{V}) \]
  – or,
  \[ \hat{\Psi} \overset{a}{\sim} N(\Psi^0, \tilde{V}/T) = \left( \frac{1}{2\pi} \right)^{\frac{n}{2}} \left| \frac{\tilde{V}}{T} \right|^{-\frac{1}{2}} \exp \left[ -\frac{1}{2} \left( \hat{\Psi} - \Psi^0 \right)' \left( \frac{\tilde{V}}{T} \right)^{-1} \left( \hat{\Psi} - \Psi^0 \right) \right] \]

• Estimation criterion:
  \[ L(\zeta, \hat{\Psi}) \equiv (\hat{\Psi} - \Psi(\zeta))' V^{-1} (\hat{\Psi} - \Psi(\zeta)) \]

• Estimator: \[ L_1(\zeta, \hat{\Psi}) = 0 \rightarrow \hat{\zeta} = f(\hat{\Psi}) \]

• Asymptotic distribution (delta function method):
  \[ \sqrt{T} \left( \hat{\zeta} - \zeta^0 \right) \overset{a}{\sim} N\left( 0, f'(\Psi^0) \tilde{V} f'(\Psi^0)^{\text{transpose}} \right) \]
Bayesian Perspective

• Suppose that the estimation criterion used the actual asymptotic variance-covariance of $\hat{\Psi}$, $\tilde{V}/T$:

$$L(\zeta, \hat{\Psi}) = -\frac{1}{2} (\hat{\Psi} - \Psi(\zeta))^\prime \left( \frac{\tilde{V}}{T} \right)^{-1} (\hat{\Psi} - \Psi(\zeta))$$

• Suppose that the model is true, with parameter values, $\zeta$.

• Then, the likelihood of the observed impulse response functions, conditional on $\zeta$ is (for large $T$):

$$\text{likelihood}(\hat{\Psi}|\zeta) \propto e^{L(\zeta, \hat{\Psi})}$$

• Bayesian posterior of model parameters

$$\text{posterior}(\zeta|\hat{\Psi}) \propto e^{L(\zeta, \hat{\Psi})} \times \text{prior}(\zeta)$$

Chernozhukov and Hong, 2003, JME, vol. 115, pp. 293-346
• Parameter estimates

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<th>$\gamma$</th>
<th>$\sigma_a$</th>
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Markup parameter goes to unity in estimation, and estimation criterion is very flat.
• Parameter estimates

Estimated Parameter Values, $\zeta_1$

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Calvo parameter on wage ‘reasonable’

Mean time between wage reoptimization $= \frac{1}{1 - \xi_w} = (2.63, 4.55, 16.7)$

Point estimate plus/minus 2 standard deviations
- Parameter estimates

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A big number, implying capital utilization hardly varies
• Parameter estimates

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Habit parameter value similar to others reported in the literature
• Parameter estimates

\begin{center}
\begin{tabular}{ccccccc}
Model & $\lambda_f$ & $\xi_w$ & $\gamma$ & $\sigma_a$ & $b$ & $S''$\\
Benchmark & 1.01 & 0.78 & 0.014 & 11.42 & 0.76 & 1.50 \\
& (0.08) & (0.007) & (6.86) & (0.08) & (0.83) &
\end{tabular}
\end{center}

• Slope of Phillips curve very small.

\[ \gamma = \frac{(1 - \xi_p)(1 - \beta \xi_p)}{\xi_p} = 0.014 \rightarrow \xi_p = 0.89 \]

average amount of time a price remains unchanged = \[ \frac{1}{1 - \xi_p} = 9 \text{ quarters!} \]

• Apparently, a major failure!
Not a Failure…

• The standard model assumes capital is homogeneous
  – traded freely in homogeneous markets.
  – assumption made for simplicity, not realism.
  – hope: it does not matter.
  – in fact: it matters a lot!

• In reality, much capital is firm-specific
  – once in place, cannot easily be converted to another use.
Homogeneous versus firm-specific capital

• Homogeneous capital:
  – Marginal cost is independent of firm output.
    \[ Y_{it} = (u_t \bar{K}_{it})^\alpha (z_t L_{it})^{1-\alpha} \]

• Firm-specific capital:
  – Marginal cost is increasing in firm output.
    • Requires that capital utilization not be variable.
  – As firm expands output, cannot simultaneously increase capital so incur diminishing returns in labor.
Homogeneous versus firm-specific capital, cnt’d…

• When firms have rising marginal cost, a given shock to marginal cost has smaller impact on price.
More Intuition: Rising Marginal Cost and Incentive to Raise Price

• A Firm Contemplates Raising Price

  – This Implies Output Falls
  – Marginal Cost Falls
  – Incentive to Raise Price Falls

• Effect Quantitatively Important When:

  – Marginal Cost Steep (capital firm-specific; no variable utilization, $\sigma_a$ large)

  – Demand Elastic (elasticity of demand, $\frac{\lambda_f}{\lambda_f - 1}$)
Observational Equivalence
Property of Model

• Firm-Specificity of Capital Irrelevant for All Aggregate Equilibrium Conditions, Except One

• Aggregate Inflation Dynamics:

\[ \pi_t = \beta E_t \pi_{t+1} + \gamma s_t, \ s_t = \text{marginal cost} \]

\[ \gamma = \frac{(1-\xi_p)(1-\beta \xi_p)}{\xi_p} \chi \]

\[ \chi = \begin{cases} 
1 & \text{standard, homogeneous capital model} \\
\frac{1}{f(\text{slope of marginal cost and demand})} & \text{firm-specific capital model}
\end{cases} \]
Plausible degree of price stickiness with assumption that capital is firm-specific consistent with the flat slope of the Phillips curve.

Full assessment requires an estimate of firm-level demand elasticity.

But, is the model consistent with evidence that inflation doesn’t respond much to a monetary policy shock?
Figure 1: Response to a monetary policy shock (o - Model, - VAR, grey area - 95% Confidence Interval)
Figure 2: Response to a neutral technology shock (o - Model, - VAR, grey area - 95% Confidence Interval)
Figure 3: Response to an embodied technology shock (o - Model, - VAR, grey area - 95 % Confidence Interval)
Conclusion of Analysis of Standard Model

- Simple model with various frictions is capable of accounting well for key features of economic responses to monetary and technology shocks.

- But, model is missing financial frictions, and so cannot be used to address many of the policy questions arising from the financial crisis.