Monetary Economics: Empirical, Theoretical and Policy Issues
Questions

- Why Did Inflation Take Off in Many Countries in the 1970s?
- How to Prevent it From Happening Again?
  - Adopt Monetary Policy Institutions that Embody More ‘Commitment’?
  - Adopt a Better Monetary Policy Rule?
- How Much Price Stability is Desirable?
- Should Monetary Authorities be Worry About the Stock Market?
- What is the Appropriate Response of Monetary Policy to a Financial Crisis?
- Would Certain Regions of the World Benefit From ‘Dollarization’ or ‘Euroization’?
- Do Low Interest Rates Inhibit a Central Bank From Pursuing Its Job?
Ways to Answer Questions Like These:
- Look at Historical Episodes (limited use)
- Experiment (not an option!)
- Experiment in Model Economies.

Issues to Confront in Analysis of Model Economies
a. Empirical: Formulate and Estimate a Model
b. Analytic
  * Appropriate Equilibrium Concepts for the Issue Studied
  * Relevant Computational Strategies
  * Other Issues.
Outline

1. Selection and Construction of a Monetary Model

2. Analysis of Models
   a. What Monetary Policy is Optimal?
      * The Friedman-Phelps Debate Over the Appropriate Interest Rate Target
      * Ramsey Equilibrium
      * Lucas-Stokey Cash-Credit Good Model
   b. Monetary Policy When The Monetary Authority Cannot Commit to Its Future Actions
      * Kydland-Prescott/Barro-Gordon Time Consistency Problem.
      * Putting Kydland-Prescott/Barro-Gordon into Modern Models
      * Can Time-Consistency Problems Account for Episodes of High and Low Inflation?
      * Markov Equilibrium.
      * Interaction Between Asymmetric Information and Lack of Commitment in Monetary Policy.
c. The Operating Characteristics of Simple Monetary Policy Rules.
   * The Operating Characteristics of a Taylor Rule.
     · Is the Surge of Inflation in the 1970s the Result of a Bad Taylor Rule?
     · Taylor Rule Pathologies and ‘Escape Clauses’
   * Should a Central Bank Raise or Lower the Interest Rate in the Wake of a Financial Crisis?
     · Analysis of Small, Open Economy
     · The Impact of Collateral Constraints on the Monetary Transmission Mechanism.
3. Formulation of a More ‘Serious’ Model for Policy Analysis

– Incorporation of a Banking Sector With Currency, Demand Deposits, Time Deposits, Bank Reserves.
  i. Can Model Shocks Originating in Financial Sector
  ii. Should Policy Accommodate an Increase in Demand for Bank Reserves and Demand for Currency by Public? (US Fed said ‘no’ in US Great Depression, Friedman and Schwartz said this was a big mistake).

– Incorporation of Net Worth (Balance Sheet) Constraints Into Analysis.
  i. What is Economic Effect of ‘Evaporation’ of Net Worth after Stock Market Crash?
  ii. Should Monetary Policy do something about it?
Formulation and Estimation of a Standard General Equilibrium Macro Model: A Shock-Based Approach

1. Identify the Dynamic Impact of Various Shocks: Monetary Policy, Technology
2. Fit Dynamic General Equilibrium Model to Estimated Dynamic Responses.
   a. Nominal Part of Economy Important
      * Sticky Prices, Sticky Wages, etc.
   b. Real Part of Economy Important
      * Adjustment Costs in Investment, Variable Capital Utilization, Habit Persistence.
   c. What Nominal Frictions and Real Features are Necessary for a Model to Conform Well with the Facts?
   d. Various ‘Puzzles’ Addressed
Shock-Based Strategy for Estimating a Dynamic GE Model

- Vector Autoregression (VAR):
  \[ Y_t = B_1 Y_{t-1} + \ldots + B_p Y_{t-p} + u_t, \quad E u_t u_t' = V \]
  \( B_i \)'s, \( u_t \)'s and \( V \) Easily Obtained by OLS Regressions.

- Fundamental Economic Shocks, \( e_t \):
  \[ u_t = C e_t, \quad E e_t e_t' = I, \quad C C' = V. \]
Shock-Based Strategy...

- Impulse Responses ($p = 2$):
  \[
  Y_t - E_{t-1}Y_t = Ce_t \\
  E_tY_{t+1} - E_{t-1}Y_{t+1} = B_1Ce_t \\
  E_tY_{t+2} - E_{t-1}Y_{t+2} = B_1^2Ce_t + B_2Ce_t \\
  E_tY_{t+3} - E_{t-1}Y_{t+3} = [B_1(B_1^2 + B_2) + B_1B_2 + B_2B_1]Ce_t
  \]

- Suppose Want Dynamic Response of $Y_t$ to $i^{th}$ Element of $e_t$.
  Need $B_l$'s and $i^{th}$ Column of $C'$. 


Shock-Based Strategy...

- Problem:
  \( N^2 \) Unknown Elements in \( C \),
  
  a. Only \( N(N + 1)/2 \) Equations in:
  
  \[ CC'' = V \]
  
  b. Need to Make (Identifying) Assumptions!
Shock-Based Strategy...

- Moving Average Representation:
  \[ Y_t = c_1(L)e_{1t} + c_2(L)e_{2t} + \ldots + c_p(L)e_{pt} \]
  \[ c_i(L) = c^0_i + c^1_i L + c^2_i L^2 \ldots \]

- A Dynamic GE Model Implies:
  \[ c_i(L; \gamma), \text{ each } i. \]

- Estimate \( \gamma \) by making
  \[ c_i(L; \gamma) - c_i(L) \]
  small, \( i = 1, 2, 3\ldots \)

- With Enough Shocks, Have a Model that Fits the Data As Well as a VAR.
Alternative (More Traditional) Strategy for Estimating A Model:

- Compute Unconditional Moments of Data
- Estimate Model Based on All Moments (Maximum Likelihood)
- Disadvantage of This Approach:
  - Need to Determine All Shocks in the Model

Advantages of Shock-Based Strategy

- Avoid Need to Specify All the Shocks Right Away
- The Economics of a Model Lie in its Impulse Responses to Shocks.
  - Analysis and Diagnosis of Models Made Transparent.
Advantages, cont’d...

- Sometimes, Interesting Puzzles and Questions Posed Directly in Terms of Shocks.
     * Why So Much Inflation Inertia, Output Persistence?
     * Price ‘Puzzle’
  b. Technology Shock.
     * How Important In Business Cycle?
     * Response of Employment and Other Variables to Technology?
     * What is Role of Monetary Policy in Propagation of Technology Shocks?
Outline of Remainder of Analysis

1. The Vector Autoregression Used in the Analysis.
2. Estimated Impulse Responses to:
   b. Persistent Shock to Technology.
3. Our GE Model.
4. Fitting the GE Model to VAR Impulse Responses.
Vector Autoregression

- **VAR:**

\[ Y_t = B(L)Y_{t-1} + C e_t, \]
\[ e_t \sim \text{fundamental shocks} \]

- **Vector,** \( Y_t, \) **Set Up to Satisfy Integration and Co-Integration Properties of Model.**

\[
Y_t = \begin{pmatrix}
\Delta \ln(GDP_t/\text{Hours}_t) \\
\Delta \ln(GDP \text{ deflator}_t) \\
\text{capacity utilization}_t \\
\ln(GDP_t/\text{Hours}_t) - \ln(W_t/P_t) \\
\ln(\text{Hours}_t) \\
\ln(C_t/GDP_t) \\
\ln(I_t/GDP_t) \\
\text{Federal Funds Rate}_t \\
\ln(\text{GDP deflator}_t) + \ln(GDP_t) - \ln(M2_t)
\end{pmatrix}
\]

- **Estimation Period:** 1960Q1 - 2001QIV
Figure 1

Data Used In VAR

[Graphs showing various economic indicators from 1960 to 2000]
Identification Assumptions for Monetary Policy Shock

- Monetary Policy Rule:
  \[ R_t = f(\Omega_t) + \varepsilon_t \]
  \[ \varepsilon_t \sim \text{Monetary Policy Shock} \]

- Identification Assumptions:
  - \( \Omega_t = \{ \text{aggregate activity}_t, \text{aggregate prices and wages}_t, \text{lagged variables} \} \)
  - \( \varepsilon_t \) orthogonal with \( \Omega_t \)

- Our GE Model is Consistent with These Assumptions.
What Is A Monetary Policy Shock?

- Shocks to Preferences of Monetary Authority
- Technical Factors Like Measurement Error (Bernanke-Mihov):

\[
x_t(0) = x_t + v_t, \quad x_t(1) = x_t + u_t
\]
\[
S_t = \beta_0 S_{t-1} + \beta_1 x_t(0) + \beta_2 x_{t-1}(1)
\]

or

\[
S_t = \beta_0 S_{t-1} + \beta_1 x_t + \beta_2 x_{t-1} + \epsilon_t
\]
\[
\epsilon_t = \beta_1 v_t + \beta_2 u_{t-1}.
\]

Recursiveness Assumption: \( \beta_0 = 0 \), or \( \beta_0 \neq 0, u_t = 0 \).
What Is a Monetary Policy Rule?


○ Combination of Structural Policy Rule and Other Stuff
  – Example (Clarida-Gertler):
    ‘True’ Policy Rule : \[ S_t = \alpha E_t x_{t+1} + \varepsilon_t \]
    \[ = f(\text{all time } t \text{ data used in } E_t x_{t+1}) + \varepsilon_t \]
Dynamic Effects of a Monetary Policy Shock

- After a Positive Monetary Shock:
  a. hump-shaped response of output, consumption, investment, labor with peak effect after roughly 1 year.
  b. hump-shaped response inflation, with peak response after about 2 years (‘Inflation Inertia’)
  c. interest rate down for one year.
  d. money growth up for 2-3 quarters.
  e. real wage up slightly.

- Lots of Internal Propagation
- Strong Liquidity Effect
Figure: Impulse Responses to a Monetary Policy Shock
Identification Assumptions for Technology Shock

• Identification Assumption:
  Technology Shock is *Only* Shock that Has Long-Run Impact on (Forecast of) Level of Labor Productivity:

\[
\lim_{j \to \infty} [E_t y_{t+j} - E_{t-1} y_{t+j}] = f(\text{technology shock only})
\]

\[
y_t = \frac{\text{output}}{\text{hour}}
\]

• Blanchard-Quah/Jordi Gali:
  This Assumption Makes it Possible to Estimate Technology Shock, Even Without Direct Observations on Technology

• Our GE Model is Consistent with This Assumption.
Technology Identification

• Simple VAR:

\[ Y_t = B Y_{t-1} + u_t, \quad E u_t u_t' = V \]

\[ u_t = C e_t \]

\[ Y_t = \begin{pmatrix} \Delta y_t \\ x_t \end{pmatrix}, \quad C = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix}, \quad e_t = \begin{pmatrix} e_{1t} \\ e_{2t} \end{pmatrix}, \quad e_{1t} \sim \text{Technology Shock.} \]

• From Applying OLS To Both Equations in VAR, We Know:

\[ B, V \]

• Problem: \( CC'' = V \) Provides only Three Equations in Four Unknowns in \( C \).

• Result: Assumption that \( e_{2t} \) Has No Long Run Impact on \( y_t \) Can Be Used to Identify All of \( C \)
Technology Identification

• Note #1:
\[ E_t [\Delta y_{t+1} + \Delta y_t] - E_{t-1} [\Delta y_{t+1} + \Delta y_t] = E_t[y_{t+1}] - E_{t-1}[y_{t+1}] \]

• Note #2:
\[ (1, 0)E_t [Y_{t+1} + Y_t] - (1, 0)E_{t-1} [Y_{t+1} + Y_t] = E_t [\Delta y_{t+1} + \Delta y_t] - E_{t-1} [\Delta y_{t+1} + \Delta y_t] \]

• Note #3:
\[ (1, 0)E_t [Y_{t+1} + Y_t] - (1, 0)E_{t-1} [Y_{t+1} + Y_t] = (1, 0) [BCE_t + Ce_t] \]

• Conclude:
\[ E_t[y_{t+1}] - E_{t-1}[y_{t+1}] = (1, 0) [B + I] Ce_t \]
... Technology Identification

• Result for Two Period-Ahead Forecast of \( y_t \):

\[
E_t[y_{t+2}] - E_{t-1}[y_{t+2}] = (1, 0) \left[ B^2 + B + I \right] C e_t
\]

• Result for \( j \) Period-Ahead Forecast of \( y_t \):

\[
E_t[y_{t+j}] - E_{t-1}[y_{t+j}] = (1, 0) \left[ B^j + B^{j-1} + ... + B^2 + B + I \right] C e_t
\]

• As \( j \to \infty \):

\[
\lim_{j \to \infty} E_t[y_{t+j}] - E_{t-1}[y_{t+j}] = (1, 0) \left[ ... + B^j + B^{j-1} + ... + B^2 + B + I \right] C e_t
\]

\[
= (1, 0) \left[ I - B \right]^{-1} C e_t
\]
Technology Identification

• As $j \to \infty$:
  \[
  \lim_{j \to \infty} E_t[y_{t+j}] - E_{t-1}[y_{t+j}] = (1, 0) [I - B]^{-1} C e_t
  \]

• Identification Assumption About Technology:
  \[
  [I - B]^{-1} C = \begin{bmatrix}
  \text{number} & 0 \\
  \text{number} & \text{number}
  \end{bmatrix}
  \]

• Final Result (?!)
  Solve for $C$ Using
  \[
  1, 2 \text{ element of } [I - B]^{-1} C \text{ is zero}
  \]
  \[
  CC' = V
  \]
Conclusion of Technology Identification With Long-Run Restrictions

- Example (Taken from Blanchard-Quah) Gives Flavor of Identification When There are Long-Run Restrictions
- In Practice, An Alternative Computational Strategy, Based on Instrumental Variables Estimation, Also Useful.
- Other Applications of Long-Run Restrictions:
  - Labor Supply Shock Has Long-Run Impact on Hours Worked, No Long Run Impact on Productivity
  - Money Supply Shock Has No Impact on Real Variables in Long Run, Money Demand Shock Affects Real Balances in Long Run
Results for Technology Identification

  - b. Inflation Low.
Figure: Impulse Responses to an Innovation in Technology
Relation to the Literature:

• Our Finding That Employment Rises Persistently After Technology Shock Contrasts with Results in Literature

• Literature: Employment *Falls* Persistently After Technology Shock (Gali, Francis-Ramey, Basu).

• We Use Same Long-Run Identifying Restrictions Used in Literature.
Our Analysis Suggests Results in Literature Reflect Two Forms of Specification
Error:
– Working With VAR’s With Too Few Variables.
– Overdifferencing the Hours Data.
Variance Decomposition Results

- Monetary Policy Shocks Account for Very Little Variance, Even in Money.
- Technology Shocks Account for Over 50 Percent of Overall Variance of Output Horizon.
- Technology Shocks Account for Only a Small Part of Business Cycle Fluctuations.
Percent of Overall Variance At Various Horizons, Due to Monetary Policy Shocks

Table 1: Contribution of Policy Shocks to Variance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Forecast Variance at Indicated Horizons</th>
<th>B. C. Freq’s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Output</td>
<td>0.0</td>
<td>3.1</td>
</tr>
<tr>
<td>M2 Growth</td>
<td>6.2</td>
<td>6.5</td>
</tr>
<tr>
<td>Inflation</td>
<td>0.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Fed Funds</td>
<td>65.2</td>
<td>21.0</td>
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<tr>
<td>Capacity Util</td>
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<td>2.6</td>
</tr>
<tr>
<td>Average Hours</td>
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<td>1.9</td>
</tr>
<tr>
<td>Real Wage</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Consumption</td>
<td>0.0</td>
<td>3.3</td>
</tr>
<tr>
<td>Investment</td>
<td>0.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Velocity</td>
<td>2.3</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Percent of Overall Variance At Various Horizons, Due to Technology Shocks

Table 2: Contribution of Tech. Shocks to Variance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Forecast Variance</th>
<th>B. C.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>at Indicated Horizon</td>
<td>Freq’s</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Output</td>
<td>48.4</td>
<td>48.8</td>
</tr>
<tr>
<td>M2 Growth</td>
<td>2.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Inflation</td>
<td>41.1</td>
<td>32.1</td>
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<tr>
<td>Fed Funds</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Capacity Util</td>
<td>1.4</td>
<td>9.7</td>
</tr>
<tr>
<td>Average Hours</td>
<td>4.1</td>
<td>15.6</td>
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<tr>
<td>Real Wage</td>
<td>27.7</td>
<td>32.1</td>
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<tr>
<td>Consumption</td>
<td>61.0</td>
<td>67.4</td>
</tr>
<tr>
<td>Investment</td>
<td>9.8</td>
<td>14.5</td>
</tr>
<tr>
<td>Velocity</td>
<td>11.4</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Role of Technology Shocks: Big in Low Frequencies, Small in Business Cycles

Thick Line - Actual Historical Data, Thin Line - Technology Only
Next Step:

- Construct a Model that is Consistent With Identifying Assumptions in VAR
- Estimate the Combination of Frictions Needed for Model Responses to Resemble Estimated Responses.
Key Features of the Model

- Consistent with Identifying Assumptions Used in Estimating Response of Economy to Shocks.
- Two Forms of Nominal Rigidities: Calvo-style Nominal Price and Wage Contracts.
- Real Side of Model - Three Departures from Standard Textbook Growth Model
  - Habit Persistence in Consumption
  - Adjustment Costs in Investment
  - Variable Capacity Utilization
- Model Will Do Well Empirically, with Reasonable Degree Price and Wage Stickiness.
Model

- Timing Assumptions.
- Firms.
- Households.
- Monetary Authority.
Timing

1. Technology Shock Realized.
4. Household Money Demand Decision Made.
5. Production, Employment, Purchases Occur, and Markets Clear.

- Note: Wages, Prices and Output Predetermined Relative to Policy Shock.
Firm Sector

Final Good, Competitive Firms

Intermediate Good Producer 1

Intermediate Good Producer 2

Intermediate Good Producer infinity

Competitive Market For Homogeneous Capital

Competitive Market for Homogeneous Labor Input

Household 1

Household 2

Household infinity
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:

\[ \max P_t Y_t - \int_0^1 P_{it} Y_{it} di \]

• Firms and Prices:

\[ \left( \frac{P_t}{P_{it}} \right)^{\frac{\lambda_f}{\lambda_f - 1}} = \frac{Y_{it}}{Y_t}, \quad P_t = \left[ \int_0^1 P_{it}^{\frac{1}{1-\lambda_f}} di \right]^{(1-\lambda_f)}. \]
Intermediate Good Firms -

- Each $Y_{it}$ Produced by a Monopolist, With Demand Curve:
  \[
  \left( \frac{P_t}{P_{it}} \right)^{\frac{\lambda_f}{\lambda_f - 1}} = \frac{Y_{it}}{Y_t}.
  \]

- Technology:
  \[
  Y_{it} = \begin{cases} 
  k_{it}^\alpha (z_t L_{it})^{1-\alpha} - \phi z_t & \text{if } k_{it}^\alpha (z_t L_{it})^{1-\alpha} \geq \phi z_t \\
  0, & \text{otherwise}
  \end{cases}
  \]

- Here, $z_t$ is a Technology Shock:
  \[
  x_t = \log z_t - \log z_{t-1}, \quad x_t = (1 - \rho_x)x + \rho_x x_{t-1} + \epsilon_{xt}.
  \]

- $\phi > 0$:
  - Ensures Zero Profits in Steady State
Calvo Price Setting:
- With Probability $1 - \xi_p$, $i^{th}$ Firm Sets Price, $P_{it}$, Optimally, to $\tilde{P}_t$.
- With Probability $\xi_p$, Do Not Optimize Current Price. Instead:

$$P_{it} = \pi_{t-1} P_{i,t-1}, \quad \pi_t = \frac{P_t}{P_{t-1}}.$$
• Firms Setting Prices Optimally at $t$ Choose $\tilde{P}_t$ to max:

$$v_t \left[ \tilde{P}_t Y_{it} - MC_t Y_{it} \right]$$

$$+ \beta \xi_p v_{t+1} \left[ \tilde{P}_t \pi_{t} Y_{i,t+1} - MC_{t+1} Y_{i,t+1} \right]$$

$$+ \left( \beta \xi_p \right)^2 v_{t+2} \left[ \tilde{P}_t \pi_{t} \pi_{t+1} Y_{i,t+2} - MC_{t+2} Y_{i,t+2} \right]$$

$$+ \ldots$$

subject to:

$$\left( \frac{P_t}{\tilde{P}_t} \right)^{\lambda_f} = \frac{Y_{it}}{Y_t}.$$  

$v_t \sim$ value of a dividend at $t$  

$MC_t \sim$ given
• Scaling:

\[
\tilde{p}_t = \frac{\tilde{P}_t}{P_t}, \quad w_t = \frac{W_t}{P_t}
\]

\[
r_t^k = \frac{\text{rental rate on capital}}{P_t}
\]

\[
s_t = \frac{MC_t}{P_t}.
\]

• Real Marginal Cost:

\[
s_t = \left(\frac{1}{1 - \alpha}\right)^{(1-\alpha)} \left(\frac{1}{\alpha}\right)^\alpha (r_t^k)^\alpha (w_t R_t)^{1-\alpha} \frac{1}{z_t}
\]

• Linear approximation:

\[
\hat{x}_t \equiv \frac{x_t - x}{x}.
\]
• Approximate (Linearized) Solution:

\[ \hat{p}_t = \hat{s}_t + \sum_{l=1}^{\infty} (\beta \xi_p)^l (\hat{s}_{t+l} - \hat{s}_{t+l-1}) \]

\[ + \sum_{l=1}^{\infty} (\beta \xi_p)^l (\hat{\pi}_{t+l} - \hat{\pi}_{t+l-1}) \]

• Front-Loading:

\[ -\hat{p}_t > \hat{s}_t \text{ if } \hat{s}_{t+l} > \hat{s}_t \text{ and/or } \hat{\pi}_{t+l} > \hat{\pi}_t. \]
• Aggregate Price Level:

\[ P_t = \left[ \int_0^1 P_{it}^{\frac{1}{1-\lambda_f}} \, dt \right]^{(1-\lambda_f)} \]

\[ = \left[ (1 - \xi_p) \tilde{P}_t^{\frac{1}{1-\lambda_f}} + \xi_p (\pi_{t-1} P_{t-1})^{\frac{1}{1-\lambda_f}} \right]^{1-\lambda_f} \]

• Scale:

\[ 1 = \left[ (1 - \xi_p) \tilde{P}_t^{\frac{1}{1-\lambda_f}} + \xi_p \left( \frac{\pi_{t-1}}{\pi_t} \right)^{\frac{1}{1-\lambda_f}} \right]^{1-\lambda_f} \]

• Approximately

\[ \hat{P}_t = \frac{\xi_p}{1 - \xi_p} [\hat{\pi}_t - \hat{\pi}_{t-1}] . \]
Combining:

\[ \hat{\pi}_t = \frac{1}{1 + \beta} \hat{\pi}_{t-1} + \frac{\beta}{1 + \beta} E_{t-1} \hat{\pi}_{t+1} + \frac{(1 - \beta \xi_p)(1 - \xi_p)}{(1 + \beta) \xi_p} E_{t-1} \hat{s}_t, \]

Or:

\[ \hat{\pi}_t = \hat{\pi}_{t-1} + \frac{(1 - \beta \xi_p)(1 - \xi_p)}{\xi_p} E_{t-1} \sum_{j=0}^{\infty} \beta^j \hat{s}_{t+j} \]

Damped Inflation Response Requires Damped Marginal Cost Response.

Econometric Estimates Likely to Emphasize Model Features That Mute Response of Marginal Cost to Shocks.
• Under Standard Price-Updating Scheme:

\[ P_{it} = \bar{\pi}P_{i,t-1}. \]

Associated Reduced Form:

\[ \hat{\pi}_t = \beta E_{t-1}\hat{\pi}_{t+1} + \frac{(1 - \beta \xi_p)(1 - \xi_p)}{\xi_p} E_{t-1}\hat{s}_t. \]

  – Standard Approach Fits Data Badly.
  – Need Lagged Inflation.

• For Any Process Describing \( \hat{s}_t \), Inflation Will Be More Inertial with Dynamic Price-Updating.
Households

- Wage Decision.
- Consumption Decision.
- Investment Decision.
- Capital Utilization Decision.
- Portfolio Decision.
• State Contingent Securities
  – Allow Household to Insulate Consumption, Asset Holdings from Realization of Idiosyncratic Calvo Uncertainty.
  – This Simplifies Computation of Equilibrium.
  – Ignore State Contingent Securities in the Presentation.
  – Households Are Different With Respect to Wages and Employment.
Preferences:

\[ E^h_{t-1} \sum_{l=0}^{\infty} \beta^{l-t} [u(c_{t+l} - b c_{t+l-1}) - z(h_{j,t+l}) + v(q_{t+l})] . \]

\[ b \sim \text{habit parameter} \]

\[ q = \frac{Q}{P} \]

\[ u(\cdot) = \log(\cdot) \]

\[ z(\cdot) = \frac{\psi_0}{2} (\cdot)^2 \]

\[ v(\cdot) = \psi_q \frac{(\cdot)^{1-\sigma_q}}{1 - \sigma_q} \]
Habit Persistence and Response of Consumption

- Recall that after an expansionary monetary policy shock, we see:
  - Hump-shaped rise in consumption
  - Decline in real interest rate.

- Euler equation in standard model:
  \[ \frac{u_{c,t}}{\beta u_{c,t+1}} \approx \frac{c_{t+1}}{\beta c_t} = \frac{g_{t+1}}{R_t} = \frac{\pi_{t+1}}{\pi_{t+1}} = \frac{\pi_{t+1}}{\pi_{t+1}} = \frac{P_{t+1}}{P_t}. \]

- Problem: Can’t have \( g_t \) high and \( R_t \) high simultaneously!
• Habit Persistence in Preferences (example):
  \[ u(c_t - b\bar{c}_{t-1}), \quad \bar{c}_{t-1} \sim \text{aggregate consumption} \]

• Euler Equation:
  \[
  \frac{u_{c,t}}{\beta u_{c,t+1}} \approx \frac{c_{t+1} - bc_t}{\beta (c_t - b\bar{c}_{t-1})} = \frac{g_{t+1} - b}{\beta \left( 1 - \frac{b}{g_t} \right)}
  \approx \frac{g_{t+1} - bg_t}{\beta (1 - b)}
  \]

• Result:
  – \( g_{t+1} \) and \( g_t \) Can Both be High, as Long as \( g_{t+1} < bg_t \).
  – Consistent with Simultaneous Hump-Shape \( c \) Response and Low Real Rate.

• Habit Persistence Also Helpful for Understanding Asset Prices
Flow Budget Constraint of $j^{th}$ Household (Ignoring Insurance Considerations):

$$M_{t+1} = R_t [M_t - Q_t + (\mu_t - 1)M^a_t]$$

$$\quad + Q_t + W_{jt}h_{jt} + P_t r^k_t u_t \bar{k}_t + D_t$$

$$- P_t (c_t + i_t + a(u_t)\bar{k}_t)$$

$$\bar{k}_t = u_t \bar{k}_t, \text{ capital services}$$

$$\bar{k}_{t+1} = (1 - \delta)\bar{k}_t + F(i_t, i_{t-1})$$
Variables:

$Q_t \sim$ cash balances
$M_t \sim$ beginning-of-period $t$ Household Money
$M_t^a \sim$ beginning-of-period $t$ Aggregate Money
$D_t \sim$ profits

$\mu_t \sim$ gross money growth rate

$M_t - Q_t + (\mu_t - 1)M_t^a \sim$ deposits at financial intermediary

$a(\cdot) \sim$ costs of utilizing capital more intensively

$u_t \sim$ utilization rate of capital

$F(i_t, i_{t-1}) \sim$ cost of adjusting investment

$k_t \sim$ capital services

$\bar{k}_t \sim$ physical capital.
Structure of the Labor Market

• Intermediate Good Firms Use Labor Aggregate:

\[ L_t = \left[ \int_0^1 h_{j,t}^{\frac{1}{\lambda_w}} dj \right]^{\lambda_w} \]

• Price of \( L_t \):

\[ W_t = \left[ \int_0^1 W_{it}^{\frac{1}{1-\lambda_w}} di \right]^{1-\lambda_w} \]

• Demand for Household Labor Service, \( h_{j,t} \):

\[ h_{j,t} = \left( \frac{W_t}{W_{jt}} \right)^{\frac{\lambda_w}{\lambda_w-1}} L_t, \ 1 \leq \lambda_w < \infty. \]

\( W_{jt} \sim \) wage set by household

\( L_t \sim \) homogeneous aggregate labor

\( W_t \sim \) wage rate of aggregate labor
Calvo-style Wage Setting:

- With Probability $1 - \xi_w$, $i^{th}$ Household Sets Wage, $W_{it}$, Optimally, to $\tilde{W}_t$.
- With Probability $\xi_w$,

$$W_{it} = \pi_{t-1}W_{i,t-1}, \quad \pi_t = \frac{P_t}{P_{t-1}}.$$

- First Order Condition:

$$E_t \left[ \sum_{l=0}^{\infty} (\xi_w \beta)^l h_{jt+l} \left[ \psi_{t+l} \frac{\tilde{W}_t X_{t,l}}{P_{t+l}} - \lambda_w z_{h,t+l} \right] \right] = 0.$$

$\frac{\psi_t}{P_t}$ value of one dollar (Multiplier on Budget Constraint)
Cash Balance Decision, $Q_t$

- Households Set $Q_t$ To Maximize Utility
  \[ v' \left( \frac{Q_t}{P_t} \right) \frac{1}{P_t} + \frac{\psi_t}{P_t} = \frac{\psi_t}{P_t} R_t, \]

- $Q_t/P_t$ Decreasing in $R_t$.

- Liquidity Effect Lives In This Equation.
  - $c_t, i_t, Y_t, L_t, P_t, W_t$ Predetermined Relative to Monetary Shock
  - Loan Market Clearing:
    \[ W_t L_t = \mu_t M_t - Q_t \]
    - $Q_t$ Must Absorb all Money Injections.
    - Can Only Happen With Fall in $R_t$.

- This is a ‘Limited Participation Story’
  - But With A Different Twist
Consumption Decision

\[ E_{t-1} \frac{u_{c,t}}{P_t} = \beta E_{t-1} \frac{u_{c,t+1}}{P_{t+1}} R_{t+1}. \]
Capital Utilization Decision

\[ E_{t-1} u_{c,t} \left[ r_t^k - a'(u_t) \right] = 0 \]

- Reduces Upward Pressure On Rental Rate of Capital and, hence, on Marginal Costs After Expansionary Monetary Policy Shock.
- Helps Account for Rise in \( Y/L \) After Expansionary Monetary Policy Shock.
  - Suppose Fixed Cost, \( \phi \), is Zero.
  - Standard Model: \( L \uparrow \Rightarrow \frac{Y}{L} = \left( \frac{k}{\bar{L}} \right)^\alpha \downarrow \).
  - Our Model: \( L \uparrow \Rightarrow \frac{Y}{L} = \left( \frac{u\bar{k}}{\bar{L}} \right)^\alpha \uparrow \).
Investment and Adjustment Costs

• Rate of Return on Capital:

\[ R^k_t = \frac{r^k_{t+1} + P_{k',t+1}(1 - \delta)}{P_{k',t}}, \]

\[ P_{k',t} \sim \text{consumption price of installed capital} \]

\[ \delta \in (0, 1) \sim \text{depreciation rate.} \]

\[ r^k_{t+1} = s_{t+1} MP^k_{t+1}, \text{ rental rate on capital} \]

\[ MP^k_{t} \sim \text{marginal product of capital} \]

\[ s_{t+1} = \frac{MC_t}{P_t} = \frac{1}{\text{markup}} \]
Almost Any Model,
\[
\frac{R_t}{\pi_{t+1}} \approx R_t^k = \frac{r_{t+1}^k + P_{k',t+1}(1 - \delta)}{P_{k',t}}.
\]

So, If a Positive Money Shock Drives Down Real Rate, Then \(R_t^k \downarrow\)

This is Trouble For Standard Models (\(P_{k',t} = 1, \ s_t = 1\)): \(R_t^k\) down requires \(MP_t^k\) down

Problem:
\(MP_t^k\) down Requires Surge in Investment, especially with employment up.
With Adjustment Costs, No Surge in Investment

Cost-of-Change Adjustment Costs:

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

Good for ‘Hump-shaped Investment Response’

Other Reasons for Interest in Adjustment Costs:
- Important for Understanding Asset Prices
- Necessary for Movements in Price of Capital
Investment Decision

- Household Owns the Capital Stock and Carries Out Capital Accumulation.
- Technology for Capital Accumulation:
  \[ \bar{k}_{t+1} = (1 - \delta) \bar{k}_t + F(i_t, i_{t-1}), \]
  \[ F(i_t, i_{t-1}) = (1 - S \left( \frac{i_t}{i_{t-1}} \right)) i_t. \]
- Euler Equation for \( \bar{k}_{t+1} \):
  \[
  E_{t-1} \psi_t = \beta E_{t-1} \psi_{t+1} \frac{u_{t+1} r_{i+1}^k - a(u_{t+1}) + P_{k',t+1}(1 - \delta)}{P_{k',t}}.
  \]
  \( P_{k',t} \) ~ marginal cost, in units of consumption goods, of installed, physical capital
- Euler Equation for \( i_t \):
  \[
  E_{t-1} \psi_t = E_{t-1} [\psi_t P_{k',t} F_{1,t} + \beta \psi_{t+1} P_{k',t+1} F_{2,t+1}].
  \]
- After linearization:
  \[
  \hat{i}_t = \hat{i}_{t-1} + \frac{1}{\mathcal{S}''} \sum_{j=0}^{\infty} \beta^j E_{t-1} \hat{P}_{k',t+j}.
  \]
• Monetary Growth, $\mu_t$:

$$\mu_t = \mu + \mu_{p,t} + \mu_{x,t},$$

‘Exogenous Component’ $\mu_{p,t} = \rho_{\mu_p}\mu_{p,t-1} + \varepsilon_{\mu_p,t}$

‘Endogenous Component’ $\mu_{x,t} = \rho_{\mu_x}\mu_{x,t-1} + c_{\mu_x}\varepsilon_{x,t}$
Econometric Estimation

- Two Types of Parameters:
  - a. Parameters Set Without Reference to VAR Data.
  - b. Parameters Estimated by Making Model Impulse Responses Look Like The Estimated Impulse Responses.
<table>
<thead>
<tr>
<th>Parameter Set 1: Parameters that Don’t Enter Formal Estimation Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>discount factor</td>
</tr>
<tr>
<td>capital’s share</td>
</tr>
<tr>
<td>capital depreciation rate</td>
</tr>
<tr>
<td>markup, labor suppliers</td>
</tr>
<tr>
<td>mean, money growth</td>
</tr>
<tr>
<td>labor utility parameter</td>
</tr>
<tr>
<td>real balance utility parameter</td>
</tr>
<tr>
<td>fixed cost of production</td>
</tr>
</tbody>
</table>
• $\gamma \sim 13$ free parameters to be estimated:
  \[
  \gamma \equiv (\lambda_f, \xi_w, \xi_p, \sigma_q, S''', b, \sigma_a, \ldots)
  \]
  6 parameters governing exogenous shocks.
  \[
  \begin{align*}
  \lambda_f & \quad \text{Steady State Markup of Firms} \\
  \xi_w & \quad \text{Degree of Stickiness in Wages} \\
  \xi_p & \quad \text{Degree of Stickiness in Prices} \\
  b & \quad \text{Habit Persistence Parameter}
  \end{align*}
  \]

• Estimation Criterion:
  \[
  J = \min_{\gamma} (\hat{\psi} - \psi(\gamma))^T V^{-1} (\hat{\psi} - \psi(\gamma)),
  \]

• $\psi(\gamma) \sim 353$ model impulse responses

• $\hat{\psi} \sim 353$ estimated VAR impulse responses
Estimation Results:

**Table: Economic Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Policy and Technology</th>
<th>Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shocks Simultaneously</td>
<td>Shocks Only</td>
</tr>
<tr>
<td>$\lambda_f$</td>
<td>1.14 (0.10)</td>
<td>1.15 (0.13)</td>
</tr>
<tr>
<td>$\xi_w$</td>
<td>0.78 (0.04)</td>
<td>0.73 (0.04)</td>
</tr>
<tr>
<td>$\xi_p$</td>
<td>0.42 (0.30)</td>
<td>0.45 (0.19)</td>
</tr>
<tr>
<td>$\sigma_q$</td>
<td>14.13 (4.25)</td>
<td>12.33 (3.19)</td>
</tr>
<tr>
<td>$S''$</td>
<td>7.69 (3.04)</td>
<td>9.97 (3.90)</td>
</tr>
<tr>
<td>$b$</td>
<td>0.73 (0.07)</td>
<td>0.77 (0.05)</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>0.05 (0.007)</td>
<td>0.03 (0.005)</td>
</tr>
</tbody>
</table>

Parameters that Match Money Impulse Responses Work Well With Technology Too.
### Table: Exogenous Shock Processes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Policy and Technology</th>
<th>Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shocks Simultaneously</td>
<td>Shocks Only</td>
</tr>
<tr>
<td>$\rho_x$</td>
<td>0.80 (0.05)</td>
<td>na</td>
</tr>
<tr>
<td>$\sigma_{\epsilon_x}$</td>
<td>0.12 (0.03)</td>
<td>na</td>
</tr>
<tr>
<td>$\rho_{\mu_x}$</td>
<td>0.47 (0.15)</td>
<td>na</td>
</tr>
<tr>
<td>$c_{\mu_x}$</td>
<td>2.07 (0.63)</td>
<td>na</td>
</tr>
<tr>
<td>$\rho_{\mu_p}$</td>
<td>0.27 (0.04)</td>
<td>0.27 (0.06)</td>
</tr>
<tr>
<td>$\sigma_{\epsilon_{\mu_p}}$</td>
<td>0.11 (0.04)</td>
<td>0.13 (0.04)</td>
</tr>
</tbody>
</table>
Figure 1: Model and Data Impulse Response Functions to a Policy Shock

- Output
- Money growth
- Inflation (APR)
- Interest rate (APR)
- Capital utilization
- Labor
- Real wage
- Consumption
- Investment
- Velocity
...
Model Diagnostics

- Employment Rises in Response to Technology Because Monetary Policy is Accommodative.
- Sticky Prices Not Important for Transmission of Monetary Policy or Technology Shocks.
Diagnostics: Monetary Accommodation Important for Transmission of Technology Shocks
Diagnostics: Sticky Prices *Not* Important for Trans. of Tech Shocks
Conclusion

• We Presented Empirical Estimates of the Dynamic Effects of Monetary Policy and Technology Shocks.
  – A Model Was Found that Can Roughly Reproduce These Effects.

• Finding: Technology Shocks Seem to Have Little to do with Business Cycles
  – Need to Bring Other Technology Shocks Into the Analysis.
  – Stationary Investment-Specific Shocks.
  – These Shocks May Account for Business Cycle Fluctuations.
  – Paper Describes a ‘Model-Based’ Identification Strategy For Doing This.

• Hope: Model with Additional Shocks Capable of Accounting for Details of Quarterly Data.

• Such a Model is Ready for Policy Analysis!