Monetary Economics: Empirical, Theoretical and Policy Issues

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Questions

• Why Did Inflation Take Off in Many Countries in the 1970s?
• Does Low Inflation Monetary Target Expose Economy to Collapse?
  – Claim -
    * Combination: Low Inflation Target and Zero Lower Bound
    * ⇒ Risk: Fall into a Downward Spiral of Deflation and Low Output
  – Does Claim Hold Water In Reasonably Constructed Models of Economy?
• Japan’s ‘Lost Decade’ of 1990s: Why?
• What is the Appropriate Monetary Policy in the Wake of a Financial Crisis?
• How Much Price Stability is Desirable? What is the ‘Optimal’ Nominal Interest Rate?
• Stock Market...
  – Why Did the Recent Stock Market Boom/Bust Cycle Occur?
  – Should (Could?) Monetary Policy Have Done Something to Prevent The Cycle?
  – Did Monetary Policy Inadvertently Contribute to the Amplitude of the Cycle?
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.
Objective

• Provide Exposure to Key Aspects of Formulation, Estimation and Analysis of Equilibrium Models

• Provide Tutorials and MATLAB Software for Analysis of a Range of Models, Which You May Find Useful as Templates for Future Research

• Target Audience:
  – People with Little Exposure to this Material
  – People Currently Already Actively Applying the Material in their Research.
Outline

• Formulating and Estimating a DSGE Model For Monetary Policy Analysis (2.0 lectures)

• Policy Analysis
  – Optimal Policy (1.5 lectures)
  – Evaluation of Alternative Policy Rules (1.5 lectures)

• Materials are on the Course Website,
VAR Analysis: General Background Comments

• My Focus Will Be On The Use of VARs to Learn About Construction and Parameterization of Dynamic, General Equilibrium Models of Money.

• A ‘Shock-Based Approach to Estimating Models’.

• Basic Idea:
  – Use Minimal Restrictions From Class of Economic Models Under Consideration to Estimate the Dynamic Impact of Economic Shocks on Economic Variables of Interest
  – Choose Parameters and Functional Forms for a Dynamic General Equilibrium Model to Match These Effects as Closely As Possible.

• Lucas Program for Model Selection:

  ‘Neet to test them (models) as useful imitations of reality by subjecting them to shocks for which we are fairly certain how actual economies would react. The more dimensions on which the model mimics the answers actual economies give to simple questions, the more we trust its answers to harder questions.’
VAR Analysis: General Background Comments

• Alternative Strategy:
  – Maximum Likelihood
  – Must Have *all* the Shocks in and Without Specification Error.
VAR Analysis: General Background Comments

- Advantages of Shock-Based Approach
  - Focus of Analysis is on Objects of Specific Economic Interest:
    * What Accounts for Inertia in Response of Inflation to Policy Shocks (Mankiw, Chari-Kehoe-McGrattan)?
      · Need a Measure of That Inertia
    * What Fraction of Variance of Output is Due to Different Kinds of Technology Shocks?
      · Need a Measure of Different Shocks
  - May Only Want a Small Number of Shocks in Model - Capturing All the Smaller Shocks May Only Generate Specification Error
    * Models are Abstractions: Small Number of Shocks May Be Enough to Account for 75-80% of Variation in Data
  - Modelers Who Want All the Shocks Can Use VARs for Diagnostic Purposes
Outline of VAR Discussion

• The Identification Problem

• Long Run Restrictions as a Way to Solve the Problem:
  – Bivariate Blanchard-Quah Example
  – The Multivariate Case

• Short Run Restrictions: Identification of Monetary Policy Shocks

• Results

• Historical Decompositions of Data
Identification

- Vector Autoregression (VAR):

\[ Y_t = B_1 Y_{t-1} + \ldots + B_p Y_{t-p} + u_t, \quad E u_t u_t' = V, \]

\( B_l \)'s, \( u_t \)'s and \( V \) Obtained by OLS Regressions.

- Fundamental Economic Shocks, \( e_t \):

\[ u_t = C e_t, \quad E e_t e_t' = D, \quad D \sim \text{Diagonal}, \quad C C' = V. \]

- Impulse Responses (\( p = 2 \)):

\[ Y_t - E_{t-1} Y_t = C e_t, \quad E_t Y_{t+1} - E_{t-1} Y_{t+1} = B_1 C e_t \]
\[ E_t Y_{t+2} - E_{t-1} Y_{t+2} = B_1^2 C e_t + B_2 C e_t \]
Identification ...

- For Impulse Responses: Need $B_i$’s and Columns of $C$.
- Problem: $N^2$ Unknown Elements in $C$,
  a. Only $N(N + 1)/2$ Equations in:

$$CC' = V$$

b. Need to Make (Identifying) Assumptions!
Bivariate Blanchard and Quah Example

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

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

  (sign restriction) \( f' > 0 \)

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

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

- Bivariate VAR:

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

\[ u_t = C e_t \]

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

\[ e_{zt} \sim \text{Technology Shock.} \]

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

\[ B, \quad V \]

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

- Result: Assumption that \( e_{2t} \) Has No Long Run Impact on \( y_t \) Supplies the Extra Required Equation
Bivariate Blanchard and Quah Example ...

- Easy to Verify:

\[
E_t[\Delta y_{t+1} + \Delta y_t] - E_{t-1}[\Delta y_{t+1} + \Delta y_t] \\
E_t[y_{t+1}] - E_{t-1}[y_{t+1}] = (1, 0) \left[ B + I \right] Ce_t
\]

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

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

as \( j \to \infty \):

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

\[
= (1, 0) \left[ I - B \right]^{-1} Ce_t
\]
Bivariate Blanchard and Quah Example ...

• As $j \to \infty$:

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

• 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

(exclusion restriction) 1, 2 element of $[I - B]^{-1} C$ is zero

(sign restriction) 1, 1 element of $[I - B]^{-1} C$ is positive

$$CC'' = V$$

• Conclude: Long-Run Restriction Supplies Extra Equation Needed to Achieve Identification.
Arbitrary Variables, Arbitrary Lags

- More General Case of Arbitrary Number \((N)\) of Variables and Lags:

\[
X_t = B_1 X_{t-1} + B_2 X_{t-2} + \ldots + B_p X_{t-p} + u_t
\]

- To Compute Impulse Response to Technology Shock,
  - Require: \(B_1, \ldots, B_p\) and \(C_1\), First Column of \(C\) in \(CC' = V\)
  - Can Obtain by OLS: \(B_1, \ldots, B_p\) and \(V\)
  - Identification Problem: Find \(C_1\)

- Solution: Use Restriction, as \(j \to \infty\):

\[
\lim_{j \to \infty} E_t[y_{t+j}] - E_{t-1}[y_{t+j}] = (1, 0, \ldots, 0) [I - B(1)]^{-1} Ce_t
\]

\[
B(1) \equiv B_1 + B_2 + \ldots + B_p.
\]
Arbitrary Variables, Arbitrary Lags ...

- **VAR:**

\[ X_t = B_1X_{t-1} + B_2X_{t-2} + \ldots + B_pX_{t-p} + u_t \]

- **Long-Run Restriction:**

(exclusion restriction) \( [I - B(1)]^{-1} C = \begin{bmatrix} \text{number} & 0, \ldots, 0 \\ \text{numbers} & \text{numbers} \end{bmatrix} \)

(sign restriction) \((1, 1)\) element of \([I - B(1)]^{-1} C\) is positive

\[ CC'' = V \]

- **There Are Many** \( C \) **That Satisfy These Constraints. All Have the Same** \( C_1 \).
Arbitrary Variables, Arbitrary Lags ...

- Using the Restrictions to Uniquely Pin Down $C_1$
- Let
  
  $$D \equiv [I - B(1)]^{-1} C$$

  so, $DD' = [I - B(1)]^{-1} V [I - B(1)']^{-1} \equiv S_0$ (Since $CC' = V$)

- Exclusion Restriction Requires:
  $$D = \begin{bmatrix} d_{11} & 0, ..., 0 \\ D_{21} & D_{22} \end{bmatrix}$$

- So
  
  $$DD' = \begin{bmatrix} d_{11}^2 & d_{11}D'_{21} \\ D_{21}d_{11} & D_{21}D'_{21} + D_{22}D'_{22} \end{bmatrix} = \begin{bmatrix} S_{011} & S_{021}' \\ S_{021} & S_{022} \end{bmatrix}.$$

- Sign Restriction:
  $$d_{11} > 0.$$  

- Then, First Column of $D$ Uniquely Pinned Down:
  $$d_{11} = \sqrt{S_{011}}, \ D_{21} = S_{021}' / d_{11}$$

- First Column of $C$ Uniquely Pinned Down:
  $$C_1 = [I - B(1)] D_1.$$
Arbitrary Variables, Arbitrary Lags ... 

- In the Application We Will Review Here, More Convenient to Follow Variant of Shapiro-Watson Approach.
Arbitrary Variables, Arbitrary Lags ...

- Data:

\[
Y_t = \begin{pmatrix}
\Delta \ln \text{(relative price of investment}_t

\Delta \ln \left( \frac{GDP_t}{\text{Hours}_t} \right)

\Delta \ln \left( \frac{GDP \text{ deflator}_t}{\text{capacity utilization}_t} \right)

\ln \left( \text{Hours}_t \right)

\ln \left( \frac{GDP_t}{\text{Hours}_t} \right) - \ln \left( \frac{W_t}{P_t} \right)

\ln \left( \frac{C_t}{GDP_t} \right)

\ln \left( \frac{I_t}{GDP_t} \right)

\text{Federal Funds Rate}_t

\ln \left( \frac{GDP \text{ deflator}_t}{GDP_t} \right) + \ln \left( GDP_t \right) - \ln \left( MZM_t \right)
\end{pmatrix}
\]
Figure 1: data used in the analysis
Three Identified Shocks:
  – Two Technology Shocks: *Only* Shocks that Have a Long Run Impact on Labor Productivity
    * Neutral Shock to Technology.
    * Embodied Shock to Technology
      · only shock with long-run effect on investment good prices (J. Fisher)
  – Monetary Policy Shock
    * Disturbance in OLS Regression:

\[
R_t = f(\Omega_t) + \omega e_{Rt},
\]

\[e_{Rt} \perp \Omega_t\]

* ⇒ Monetary Policy Has No Contemporaneous Impact on Prices and Aggregate Allocations.
* ⇒ Interest Rate Not Significantly Contemporaneously Affected by Money Demand Shocks, Other than Via \(\Omega_t\).
Arbitrary Variables, Arbitrary Lags ...

What Is A Monetary Policy Shock?

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

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

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 $\beta_0 \neq 0$, $u_t = 0$. 
Arbitrary Variables, Arbitrary Lags ...

What Is a Monetary Policy Rule?

- Combination of Structural Policy Rule and Other Stuff
  - Example (Clarida-Gertler):

  ‘True’ Policy Rule:

  \[ S_t = \alpha E_t x_{t+1} + \epsilon_t \]

  \[ = f(\text{all time } t \text{ data used in } E_t x_{t+1}) + \epsilon_t \]
Results for Impulse Response Functions

- Show Data, VAR Lag Length: 4, Sample Period 1959Q1-2001Q3.
- Responses to Monetary Policy Shock
  - Impact on Money Growth and Interest Rate Over in 1 Year, Other Variables Keep Going
  - Significant Liquidity Effect
  - Inflation Peaks in Roughly Two Years
  - Output, consumption, investment, hours worked and capacity utilization are hump-shaped.
  - Velocity comoves with the interest rate
- Responses to a Positive, Neutral Technology Shock
  - Output, hours, investment, consumption display strong, positive, significant responses.
  - Strong, immediate drop in inflation
- Responses to a Negative, Embodied Shock to Technology
  - Rise in Output, Hours Worked, Interest Rate, Strong Rise in Investment.
Figure 3: Benchmark model – dynamic response to a monetary policy shock
Figure 4: Benchmark model – dynamic response to a neutral technology shock
Figure 5: Benchmark model – dynamic response to an embodied technology shock
Historical Decompositions

• With the Identified Shocks in Hand, we Can Ask:

  – What Would have Happened if Only Monetary Policy Shocks Had Driven the Data?

  – We Can Ask This About the Other Shocks, or About a Combination of Shocks

  – We Find that The Three Shocks Together Account for A Large Part (Perhaps as much as 50%) Of Fluctuations

  * Money Has More to Do With Business Cycles

  * Neutral Technology Has More to Do With Lower-Frequency Component of the Data
Figure 6: Historical decomposition – monetary policy shocks only

Output, MZM Growth, Inflation, Fed Funds, Capacity Util, Avg Hours, Real Wage, Consumption, Investment, Velocity, Price of Inv.
Figure 7: Historical decomposition – neutral technology shocks only
Figure 8: Historical decomposition – embodied technology shocks only
Figure 9: Historical decomposition – monetary policy and technology shocks
Conclusion from VAR Analysis

- Our Estimates Suggest that the Three Identified Shocks Account for A Substantial Fraction (Around 50%) of Business Cycle Variation.
- We have a set of Estimates of How Economy Responds to Three Types of Shocks
- Will use these to Estimate a DSGE Model.