VARs, the Current Consensus Model and Extensions

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Overview

• A new 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)

• Describe empirical SVAR results.

• Construction of the consensus models based on results from SVARs.
  – Christiano, Eichenbaum and Evans JPE (2005)
  – Smets and Wouters, AER (2007)

• Further developments of the consensus model
  – Labor market
  – Financial frictions
  – Open economy

• Monetary policy analysis: how policy should respond to interest rate spreads, relationship between monetary policy asset market volatility.
Vector Autoregressions

- Proposed by Chris Sims in 1970s, 1980s

- Major subsequent contributions by others (Bernanke, Blanchard-Watson, Blanchard-Quah)

- Useful Way to Organize Data
  - VARs serve as a ‘Battleground’ between alternative economic theories
  - VARs can be used to quantitatively construct a particular model

- Question that can (in principle) be addressed by VAR:
  - ‘How does the economy respond to a particular shock?’
  - Current consensus model heavily guided by answers to this question

- VARs can’t actually address such a question
  - Identification problem
  - Need extra assumptions….Structural VAR (SVAR).
Outline of SVAR discussion

• What is a VAR?

• The Identification Problem

• Identification restrictions

• Results

• Historical Decompositions of Data
Estimating the Effects of Shocks to the Economy

- Vector Autoregression for a $N \times 1$ vector of observed variables:

$$Y_t = B_1 Y_{t-1} + ... + B_p Y_{t-p} + u_t,$$

$$E u_t u_t' = V$$

- $B_1$s, $u'$s and $V$ are Easily Obtained by OLS.
- Problem: $u'$s are statistical innovations.
  - We want impulse response functions to fundamental economic shocks, $e_t$.

$$u_t = C e_t,$$

$$E e_t e_t' = I,$$

$$CC' = V$$
Estimating the Effects of a Shock to the Economy ...

VAR: \[ Y_t = B_1 Y_{t-1} + \ldots + B_p Y_{t-p} + C e_t \]

- Impulse Response to \( i^{th} \) Shock:

\[ Y_t - E_{t-1} Y_t = C_i e_{it}, \]

\[ E_t Y_{t+1} - E_{t-1} Y_{t+1} = B_1 C_i e_{it} \]

\[ \ldots \]

- To Compute Dynamic Response of \( Y_t \) to \( i^{th} \) Element of \( e_t \) We Need

\[ B_1, \ldots, B_p \text{ and } C_i. \]
Identification Problem

\[ Y_t = B_1 Y_{t-1} + \ldots + B_p Y_{t-p} + u_t \]

\[ u_t = C e_t, \ E u_t u'_t = CC' = V \]

- We know \( B' s \) and \( V \), we need \( C \).
- Problem
  - \( N^2 \) Unknown Elements in \( C \),
  - Only \( N(N+1)/2 \) Equations in

\[ CC' = V \]

- Identification Problem: Not Enough Restrictions to Pin Down \( C \)
- Need More Identifying Restrictions!
Shocks and Identification Assumptions

- Monetary Policy Shock
- Neutral Technology Shock
- Capital-Embodied Shock to Technology
Identifying Monetary Policy Shocks

• One strategy: estimate parameters of Fed’s feedback rule
  – Rule that relates Fed’s actions to state of the economy:
    \[ R_t = f(\Omega_t) + e_t^R \]
    - \( f \) linear
    - \( e_t^R \) orthogonal to Fed information, \( \Omega_t \)
    - \( \Omega_t \) contains current prices and wages, aggregate quantities, lagged stuff
    - \( e_t^R \) estimated by OLS regression
    - Regress \( X_t \) on \( e_t^R, e_{t-1}^R, e_{t-2}^R, \ldots \)
Identification of Technology Shocks (Blanchard-Quah, Fisher, JPE 2007)

- There are two types of technology shocks: neutral and capital embodied

\[ X_t = Z_t F(K_t, L_t) \]

\[ K_{t+1} = (1 - \delta)K_t + V_t I_t \]

- These are only shocks that can affect labor productivity in the long run.

- The only shock which also has a long run effect on the relative price of capital is a capital embodied technology shock \((V_t)\).
VAR estimation with the following data:

\[
\begin{pmatrix}
\Delta \ln (\text{relative price of investment}_t) \\
\Delta \ln \left(\frac{GDP_t}{\text{Hours}_t}\right) \\
\Delta \ln (GDP \text{ deflator}_t) \\
\text{capacity utilization}_t \\
\ln (\text{Hours}_t) \\
\ln \left(\frac{GDP_t}{\text{Hours}_t}\right) - \ln \left(\frac{W_t}{P_t}\right) \\
\ln \left(\frac{C_t}{GDP_t}\right) \\
\ln \left(\frac{I_t}{GDP_t}\right) \\
\text{Federal Funds Rate}_t \\
\ln (GDP \text{ deflator}_t) + \ln (GDP_t) - \ln (MZM_t)
\end{pmatrix}
\]

The data have been transformed to ensure stationarity
Sample period: 1959Q1-2007Q1
data used in the analysis

- Inflation
- Capacity Util
- Hours
- APL / Real Wage
- C / Y
- I / Y
- Fed Funds
- MZM velocity

Q2-59, Q4-67, Q2-76, Q4-84, Q2-93, Q4-01
Whether per capita hours are stationary has stimulated much debate.
Inflation a little non-stationary
US trade Balance issue

Sort of stationary

data used in the analysis

- P1 growth
- Inflation
- Capacity Util
- APL / Real Wage
- C / Y
- I / Y
- Fed Funds
- MZM velocity
Note how high rates tend to precede recessions.
data used in the analysis

Moves with Interest rate
• Results.....
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

Quarters
Lots of persistence!

Response to a monetary policy shock
Inflation very slow to respond!

Response to a monetary policy shock
Response to a monetary policy shock

Lots of hump-shapes
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
Response to a neutral technology shock

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

Quarters
Confidence intervals are wide, as you’d expect given the nature of the question being asked.
Response to a neutral technology shock

Output shows random walk response
Hours responds positively
Inflation exhibits a quick response. Raises a potential challenge, and draws attention to alternative approaches.
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.
Response to an embodied technology shock
Response to an embodied technology shock

Warning: confidence intervals are wide! Econometric model estimation will take this into account.
Historical Decomposition of Data into Shocks

• We can ask:

  – What would have happened if only monetary policy shocks had driven the data?

  – We can ask this about other identified shocks, or about combinations of shocks

  – We find that the three shocks together account for a large part of fluctuations
Historical decomposition of US GDP

Technology shocks specific to capital goods

Dark line: detrended actual GDP

Thin line: what GDP would have been if there had only been one type of technology shock, the type that affects only the capital goods industry

These shocks have some effect, but not terribly important
Type of technology shock that affects all industries

This has very large impact on broad trends in the data, and a smaller impact on business cycles.

Has big impact on trend in data, and 2000 boom-bust
Monetary policy shocks have a big impact on 1980 'Volcker recession'.
All three shocks together account for large part of business cycle
## Variance Decomposition

<table>
<thead>
<tr>
<th>Variable</th>
<th>BP(8,32)</th>
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<tbody>
<tr>
<td>Output</td>
<td>86</td>
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<tr>
<td>Money Growth</td>
<td>23</td>
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<tr>
<td>Inflation</td>
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<td>Fed Funds</td>
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<td>Avg. Hours</td>
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<td>Real Wage</td>
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<td>69</td>
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<td>Velocity</td>
<td>29</td>
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<tr>
<td>Price of investment goods</td>
<td>11</td>
</tr>
</tbody>
</table>
Figure 4: Historical decomposition - monetary policy and technology shocks

- Output
- MZM Growth
- Inflation
- Fed Funds
- Capacity Util
- Avg Hours
- Real Wage
- Consumption
- Investment
- Velocity
- Price of Inv.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Embodied Technology</th>
<th>Neutral Technology</th>
<th>Monetary Policy</th>
<th>All Three Shocks</th>
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<td>Capacity Util.</td>
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<td>Avg. Hours</td>
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<td>Price of Inv.</td>
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<td>[20]</td>
<td>[7]</td>
<td>[10]</td>
</tr>
</tbody>
</table>

Notes: Numbers are point estimates, number in square brackets are standard deviation of point estimates across bootstrap simulations. In the case of the forecast error decomposition row sums fail to add only because of rounding error. In the case of BP(8,32) row sums fail to add due to in-sample correlation between shocks.
Now, to the construction of a monetary equilibrium model, based on the previous impulse response functions.

Based on
- Christiano-Eichenbaum-Evans JPE(2005)
- Altig-Christiano-Eichenbaum-Linde
Objectives

• Constructing a standard (‘consensus’) DSGE Model
  – Model features.
  – Estimation of model using impulse responses from SVAR’s.

• Determine if there is a conflict regarding price behavior between micro and macro data.
  – Macro Evidence:
    • Inflation appears sluggish
    • Inflation responds slowly to monetary shock
  – Micro Evidence:
    • Bils-Klenow, Nakamura-Steinsson report evidence on frequency of price change at micro level: 5-11 months.
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.
Firm Sector

Final Good, Competitive Firms

Intermediate Good Producer 1

Intermediate Good Producer 2

Intermediate Good Producer infinity

Competitive Market for Homogeneous Labor Input

Competitive Market For Homogeneous Capital

Household 1

Household 2

Household infinity

Erceg-Henderson-Levin labor market.
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:

$$\max P_i Y_t - \int_0^1 P_i Y_{it} di$$

- 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:

\[
Y_{it} = K_{it}^\alpha \left( z_t L_{it}^{1-\alpha} \right), \quad 0 < \alpha < 1,
\]

- Here, $z_t$ is a technology shock:

\[
\mu_{z,t} = \log z_t - \log z_{t-1}, \quad \hat{\mu}_{z,t} = \rho_{\mu_z} \hat{\mu}_{z,t-1} + \varepsilon_{\mu_z,t}
\]
- Calvo Price Setting:
  
  - With Probability $1 - \xi_p$, $i^{th}$ Firm Sets Price, $P_{it}$, Optimally, to $\tilde{P}_t$.
  
  - With Probability $\xi_p$,
    
    $$P_{it} = \pi_{t-1} P_{i,t-1}, \quad \pi_t = \frac{P_t}{P_{t-1}}.$$  
  
  - Standard Approach in Literature:
    
    $$P_{it} = \bar{\pi} P_{i,t-1}, \text{ or } P_{it} = P_{i,t-1}.$$  
  
  - Stand on Indexing Matters
    
    Determines Extent of ‘Front-Loading’
What Price Optimizers Do

• What they do *not* do:
  – Firms with the opportunity to set price today, do *not* do the usual thing of setting price as a markup of today’s marginal cost.
  
  – This is because they understand there is a chance that they will be stuck in the future with the price they pick today.
What Price Optimizers Do, cont’d

• Optimizers set price today based on expected current and future marginal costs.

\[
\text{marginal cost} = \frac{1}{z_t} \left( \frac{R_t W_t}{1 - \alpha} \right)^{1-\alpha} \left( \frac{P_t r^k_t}{\alpha} \right)^\alpha
\]

• Note:
  – marginal cost involves interest rate, because firms are assumed to have to borrow to pay the wage bill.
  – High supply elasticities limit rise in factor prices in an expansion and so limit the rise in marginal costs and, hence, prices.
Is Calvo a Good Reduced Form Model of Sticky Prices?

- Evidence on relative frequency of large and small price changes suggests ‘yes’

- Evidence of probability of price change conditional on time since last change suggests ‘yes’
Evidence from Midrigan, ‘Menu Costs, Multi-Product Firms, and Aggregate Fluctuations’

Lot’s of small changes

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:

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

• Under Standard Price-Updating Scheme:

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

Associated Reduced Form:

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

- Technology shock realized.

- Decisions: Consumption, Capital accumulation, Capital Utilization.

- Insurance markets on wage-setting open.

- 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...

- Monopoly supplier of differentiated labor
  - Sets wage subject to Calvo style frictions like firms
- Preferences of $j^{th}$ household

$$E_t^j \sum_{i=0}^{\infty} \beta^{i-l} \left[ \log (C_{t+l} - bC_{t+l-1}) - \psi_L \frac{h_{j,t}^2}{2} \right]$$

- $E_t^j$ : expectation operator, conditional on aggregate and household $j$ idiosyncratic information.
- $C_t$ : consumption
- $h_{j,t}$ : hours worked.
Households...

- Asset Evolution Equation:

\[ M_{t+1} = R_t [M_t - Q_t + (x_t - 1)M_t^g] + A_{j,t} + Q_t + W_{j,t}h_{j,t} + Pr_t^k u_t \tilde{K}_t + D_t - P_t [(1 + \eta (V_t)) C_t + \gamma_t^{-1} (I_t + a(u_t) \tilde{K}_t)] \]

- \( M_t \) : Beginning of Period Base Money; \( Q_t \) : Transactions Balances

- Velocity:

\[ V_t = \frac{P_t C_t}{Q_t}, \]
Households...

- Asset Evolution Equation:

\[
M_{t+1} = R_t [M_t - Q_t + (x_t - 1)M_t^g] + A_{j,t} + Q_t + W_{j,t}h_{j,t} + P_t r_t^k u_t \tilde{K}_t + D_t - P_t \left[ (1 + \eta(V_t)) C_t + \gamma_t^{-1} (I_t + a(u_t)\bar{K}_t) \right]
\]

- \(M_t\) : 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, \(a(1) = 0\), \(a'(1) > 0\), \(\sigma_a = a''(1)/a'(1)\).
Households...

- Asset Evolution Equation:

\[ M_{t+1} = R_t [M_t - Q_t + (x_t - 1)M_t^o] + A_{j,t} + Q_t + W_{j,t}h_{j,t} + P_t r_t^k u_t \tilde{K}_t + D_t - P_t [(1 + \eta(V_t)) C_t + \gamma_t^{-1} (I_t + a(u_t) \tilde{K}_t)] \]

- \( M_t \): 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, \( \mu_{\gamma,t} = \gamma_t/\gamma_{t-1} \),

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

...
Dynamic Response of Consumption to Monetary Policy Shock

- In Estimated Impulse Responses:
  - Real Interest Rate Falls
    \[ \frac{R_t}{\pi_{t+1}} \]
  - Consumption Rises in Hump-Shape Pattern:
Consumption ‘Puzzle’

- Intertemporal First Order Condition:

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

- With Standard Preferences:

\[
\frac{c_{t+1}}{\beta c_t} = \frac{MU_{c,t}}{\beta MU_{c,t+1}} \approx \frac{R_t}{\pi_{t+1}}
\]
One Resolution to 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, \( b > 0 \)
Dynamic Response of Investment to Monetary Policy Shock

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

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

Final Good, Competitive Firms

Intermediate Good Producer 1

Intermediate Good Producer 2

Intermediate Good Producer infinity

Competitive Market for Homogeneous Labor Input

Competitive Market For Homogeneous Capital

Household 1

Household 2

Household infinity
Firms use a lot of Labor because it’s ‘cheap’. Households must supply that labor.
Monetary and Fiscal Policy

$$x_t = M_t / M_{t-1}$$

$$\hat{x}_{M,t} = \rho_M \hat{x}_{M,t-1} + \varepsilon_{M,t}$$

$$\hat{x}_{z,t} = \rho_{xz} \hat{x}_{z,t-1} + c_z \varepsilon_{z,t} + c_z^\varphi \varepsilon_{z,t-1}$$

$$\hat{x}_{\gamma,t} = \rho_{x\gamma} \hat{x}_{\gamma,t-1} + c_{\gamma} \varepsilon_{\gamma,t} + c_{\gamma}^\varphi \varepsilon_{\gamma,t-1}$$

- $\hat{x}_{M,t}$: 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
  \[ (1 + \eta(V_t)) C_t + \gamma_t^{-1} \left[ I_t + a(u_t) \bar{K}_t \right] \leq Y_t. \]
- We adopt a standard sequence-of-markets equilibrium concept.
Econometric Methodology

• Choose parameters of economic model, so that the dynamic response to shocks resembles as closely as possible the impulse responses estimated from SVARs.

• Make sure that identifying assumptions used in the SVAR are satisfied in the 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

\[
\zeta_2 = [\xi_w, \gamma, \sigma_a, b, S'', \epsilon]
\]

- $\zeta_2$: 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:

\[
\hat{\zeta} = \text{arg min}_{\zeta} \left( \hat{\Psi} - \Psi(\zeta) \right) V^{-1} \left( \hat{\Psi} - \Psi(\zeta) \right)
\]

- $V$: diagonal matrix with sample variances of $\hat{\Psi}$ along the diagonal.
- Parameter estimates

<table>
<thead>
<tr>
<th>Model</th>
<th>$\lambda_f$</th>
<th>$\xi_w$</th>
<th>$\gamma$</th>
<th>$\sigma_a$</th>
<th>$b$</th>
<th>$S''$</th>
<th>$\epsilon$</th>
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<tr>
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<td>1.35</td>
<td>.75</td>
<td>.32</td>
<td>0.06</td>
<td>0.80</td>
<td>4.85</td>
<td>0.77</td>
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<tr>
<td></td>
<td>(0.17)</td>
<td>(0.06)</td>
<td>(0.32)</td>
<td>(0.18)</td>
<td>(0.04)</td>
<td>(2.15)</td>
<td>(0.27)</td>
</tr>
</tbody>
</table>

- Parameters are surprisingly consistent with estimates reported in JPE (2005) based on studying only monetary policy shocks

- Point estimates imply prices relatively flexible at micro level
  - At point estimates: $\xi_p = 0.58, \frac{1}{1 - \xi_p} = 2.38$ quarters

- Other parameters ‘reasonable’: estimation results really want sticky wages!
• Combining Optimal Price and Aggregate Price Relation:

\[ \Delta \hat{\pi}_t = \beta E_t \Delta \hat{\pi}_{t+1} + \frac{(1 - \beta \xi_p)(1 - \xi_p)}{\xi_p} E_t \hat{s}_t, \]
• Parameters of exogenous shocks:

<table>
<thead>
<tr>
<th>TABLE 3: ESTIMATED PARAMETER VALUES $\zeta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho_M$</td>
</tr>
<tr>
<td>Benchmark Model</td>
</tr>
</tbody>
</table>
| $\begin{array}{cccccccc}
-0.10 & 0.31 & 0.91 & 0.05 & 0.36 & 3.68 & 2.49 & -0.24 & 0.17 & 0.91 & -0.10 & 0.63 \\
(0.12) & (0.10) & (0.03) & (0.02) & (1.55) & (1.22) & (0.52) & (0.06) & (0.07) & (0.57) & (0.65)
\end{array}$ |

• Neutral technology shock, $\rho_{\mu z}$, is highly persistent.
Figure 1: Response to a monetary policy shock (o - Model, - VAR, grey area - 95% Confidence Interval)
Monetary Policy Shock

- Key findings:
  - Can account for sluggish aggregate response to monetary policy shock without a lot of price stickiness
  - Can account for the observed effects of monetary policy on consumption, investment, output, etc.
Figure 2: Response to a neutral technology shock (o - Model, - VAR, grey area - 95% Confidence Interval)

troublesome
Figure 3: Response to an embodied technology shock (o - Model, - VAR, grey area - 95 % Confidence Interval)
Further work with this model

• Policy questions:
  – role of monetary policy in transmission of technology shocks
  – Role of monetary policy in asset price volatility

• Can construct ‘micro panel data sets’ implied by model:
  – Gain power to test model by developing its micro implications.
  – What are cross-sectional implications of model for prices and quantities at the firm level?
Implications for Panel Data

• ‘Demand shocks’ for intermediate good firms:

\[ Y_t = \left[ \int_0^1 (\theta_{it} Y_{it})^{\frac{1}{\lambda_f}} \right]^\lambda_f \]

\[ \int_0^1 \theta_{it} di = 1, \theta_{it} \sim iid \text{ across } i \]

• ‘Supply shocks’ for intermediate good firms:

\[ Y_{it} = \eta_{it} K_{it}^\alpha (z_i L_{it})^{1-\alpha} \]

\[ \eta_{it} \sim iid \text{ across } i \]
Conclusion of ‘Consensus’ Model Construction and Estimation

• Identified features of a model (variable capital utilization, habit persistence, adjustment costs in the change of investment) that allow it to account for estimated SVAR impulse responses.

• The estimation strategy focused on a subset of model implications.

• Full information methods have been used to estimate version of the model with a full set of shocks on the raw data (Smets and Wouters).

• A future phase of empirical work will draw out the implications of macro models for panel data sets.
Additional model development

• Labor market
  – Model has no implications for unemployment, vacancies, hours worked, people employed, separations, on-the-job search, etc.
  – Sticky wages in model subject to ‘Barro critique of sticky wages’

• Financial markets
  – Financial markets are not a source of shocks or propagation.
  – Cannot ask: ‘what should monetary authority do in response to increase in interest rate spreads?’
‘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.
Papers

• Mortensen and Pissarides
• Shimer
• Gertler-Trigari, Gertler-Sala-Trigari
• Hall
• Den Haan, Ramey and Watson
• Christiano, Ilut, Motto, Rostagno
• Christiano, Trabandt, Walentin
Firm Sector

Final Good, Competitive Firms

Intermediate Good Producer 1

Intermediate Good Producer 2

Intermediate Good Producer infinity

Competitive Market for Homogeneous Labor Input

Competitive Market For Homogeneous Capital

Household 1

Household 2

Household infinity
Adding Labor Market Frictions

- Employment agency
- Firms
- Labor Market
- Households
- Employment agency
- Employment agency
- Unemployment

Undirected search endogenous vacancies
Endogenous and exogenous separation
More on the Labor Market

• Household Preferences

\[
E_t \sum_{l=0}^{\infty} \beta^{l-t} \{ \zeta^c_{t+l} \log(C_{t+l} - bC_{t+l-1}) - \zeta^h_{t+l}A_L \left[ \sum_{i=0}^{N-1} \frac{(\zeta_{i,t+l})^{1+\sigma_L}}{1 + \sigma_L} L_{i,t+l} \right] \},
\]

• Worker finances

\[
(1 - L_t)P_t^c b^u z_t^+ + \sum_{i=0}^{N-1} W_t^i L_t^i \zeta_{i,t}^i,
\]
Timeline – labor market

Stock of employees in each agency reduced by exogenous separations increased by new arrivals

Each worker experiences idiosyncratic, iid productivity shock. Least efficient are cut:
• Unilateral firm decision
• Cut determined by total surplus criterion

Vacancies posted

Agency employees sent to work

Wages set
• If it’s a time to bargain, choose wage to solve
  \[
  \max_{w_t} (V^0(w_t) - U_t)^{\eta_t} J(w_t)^{(1-\eta_t)}
  \]
• Otherwise, do simple updating

Hours worked set according to an efficiency criterion:
Marginal value of worker to agency = marginal cost of labor for worker
Each worker experiences idiosyncratic, iid productivity shock. Least efficient are cut:

- Unilateral firm decision
- Cut determined by total surplus criterion

Wages set

- If it’s a time to bargain, choose wage to solve
  \[
  \max_{w_t} (V^0(w_t) - U_t)^{\eta_t} J(w_t)^{(1-\eta_t)}
  \]
  
  - Otherwise, do simple updating

Hours worked set according to an efficiency criterion:

Marginal value of worker to agency = marginal cost of labor for worker
Extension to Incorporate Financial Frictions

• General idea:
  – Standard model assumes borrowers and lenders are the same people..no conflict of interest
  
  – Financial friction models suppose borrowers and lenders are different people, with conflicting interests
  
  – Financial frictions: features of the relationship between borrowers and lenders adopted to mitigate conflict of interest.
Standard Model

Firms

Supply labor

Investment goods

Rent capital

Households

Backyard capital accumulation: $K_{t+1} = (1 - \delta)K_t + G(I_t, I_{t-1})$

$u_{c,t} = \beta E_t u_{c,t+1} \frac{r_{k,t+1} + (1 - \delta)P_{k',t+1}}{P_{k',t}}$

Savers and investors are the same: NO FRICTIONS!
Frictions in Financing of Physical Capital

Savers
Have money, but no ideas

Investors ('entrepreneurs')
Have ideas, but not enough money.
Frictions in Financing of Physical Capital

Savers
Have money, but no ideas

Investors (‘entrepreneurs’)
Problem: ‘stuff’ happens.

Money

Incentive of entrepreneurs to under-report earnings
Entrepreneurs (BGG)

- Own and Rent the Stock of Capital
- Period $t$:
  - Go to bank with own net worth and obtain loan
  - Purchase new capital from capital producers: $\bar{K}_{t+1}$
  - Experience an idiosyncratic productivity shock: $\omega \bar{K}_{t+1}$, $\omega \sim F(\omega; \sigma_t)$
- Periot $t + 1$:
  - Choose capital utilization rate and rent out capital services: $u_{t+1} \omega \bar{K}_{t+1}$
  - Cost of utilization: $\tau_{t+1}^{oil} a(u_{t+1}) \Upsilon^{-(t+1)} \omega \bar{K}_{t+1}$

$$V_{t+1} = \text{real earnings on capital (rent plus capital gains)}$$

$$\text{nominal rate of interest}^{t-1}_{\pi_t} \text{real debt to banks}^{t-1}_{t-1}$$

$$\text{Net Worth}_{t+1} = \gamma (V_{t+1} + W^e_{t+1}) + (1 - \gamma) W^e_{t+1}$$
Prediction of financial friction model:

• Shocks that drive output and price in the same direction (‘demand’) accelerated by financial frictions.
  – Fisher and earnings effects reinforce each other.

• Shocks that drive output and price in opposite directions (‘supply’) not much affected by financial frictions.
  – Fisher and earnings effects cancel each other.
Model with Financial Frictions

- Firms
- Labor market
- Capital Producers
- Entrepreneurs
- Household

Flows:
- $L$ from Labor market to Firms
- $I$ from Capital Producers to Firms
- $C$ from Household to Firms
- $K$ from Entrepreneurs to Firms
Model with Financial Frictions

- Firms
- Labor market
- Household
- Capital Producers
- Entrepreneurs
- Banks

- $K'$
- Loans
The equations of the financial friction model

• Net addition of two equations to consensus model:
  
  – Subtract the household intertemporal equation for capital.

  – Add three equations pertaining to the entrepreneurs
Three equations pertaining to entrepreneur

- Law of motion of net worth

- Zero-profit conditions of banks
  
  \[
  \text{revenues from non-bankrupt entrepreneurs} \times \text{quantity of non-bankrupt entrepreneurs} + \text{receipts from bankrupt entrepreneurs net of bankruptcy costs} = \text{payment obligations on bank debt to households}
  \]

- Optimality condition associated with entrepreneur’s choice of contract.
Empirical Analysis of Financial Friction Model

Risk Shock and News

• Assume

\[ \hat{\sigma}_t = \rho_1 \hat{\sigma}_{t-1} + u_t \]

iid, univariate innovation to \( \hat{\sigma}_t \)

• Agents have advance information about pieces of \( u_t \)

\[ u_t = \xi^0_t + \xi^1_{t-1} + \ldots + \xi^8_{t-8} \]

\[ \xi^i_{t-i} \sim \text{iid}, \ E(\xi^i_{t-i})^2 = \sigma_i^2 \]

\[ \xi^i_{t-i} \sim \text{piece of } u_t \text{ observed at time } t - i \]
Estimation

- EA and US data covering 1985Q1-2007Q2

\[ X_t = \left\{ \begin{array}{l}
\Delta \log \left( \frac{N_{t+1}}{P_t} \right) \\
\pi_t \\
\log (\text{per capita hours}_t) \\
\Delta \log \left( \frac{\text{per capita credit}_t}{P_t} \right) \\
\Delta \log (\text{per capita GDP}_t) \\
\Delta \log \left( \frac{W_t}{P_t} \right) \\
\Delta \log (\text{per capita } I_t) \\
\Delta \log \left( \frac{\text{per capita } M_{1t}}{P_t} \right) \\
\Delta \log \left( \frac{\text{per capita } M_{3t}}{P_t} \right) \\
\Delta \log (\text{per capita consumption}_t) \\
\text{External Finance Premium}_t \\
R_{t}^{long} - R^{e}_t \\
R^{e}_t \\
\Delta \log P_{1,t} \\
\Delta \log \text{real oil price}_t \\
\Delta \log \left( \frac{\text{per capita Bank Reserves}}{P_t} \right)
\end{array} \right. \]

- Standard Bayesian methods
- We remove sample means from data and set steady state of X to zero in estimation.
Summary of Empirical Results With Financial Frictions

• Risk shocks:
  – important source of fluctuations.
  – news on the risk shock important

• The Fisher debt-deflation channel has a substantial impact on propagation.

• Money demand and mechanism of producing inside money:
  – relatively unimportant as a source of shocks
  – modest contribution to forecast ability

• Model accounts or substantial fraction of fluctuations in term structure.

• Out-of-Sample RMSEs of the model perform well compared with BVAR and simpler models.
Risk Shocks are Important

Actual data versus what actual data would have been if there were only risk Shocks:

Note:
(1) as suggested by the picture, risk shocks are relatively important at the lower frequencies
(2) We find that they are the single most important source of low frequency fluctuation in the EA, and a close second (after permanent tech shocks) in the US
<table>
<thead>
<tr>
<th>Shock</th>
<th>Output</th>
<th>Consumption</th>
<th>Investment</th>
<th>Hours</th>
<th>Inflation</th>
<th>Labor Productivity</th>
<th>Interest Rate</th>
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<td>Markup</td>
<td>15.02</td>
<td>23.05</td>
<td>2.63</td>
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<td>0.72</td>
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<td>5.40</td>
<td>0.10</td>
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<td>Risk, contemp</td>
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<td>0.19</td>
<td>5.11</td>
<td>6.57</td>
<td>0.88</td>
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<td>Marginal eff of I</td>
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<td>30.69</td>
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<td>Price of oil</td>
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<td>All shocks</td>
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<tr>
<td>Shock</td>
<td>Output</td>
<td>Consumption</td>
<td>Investment</td>
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<td>Labor Productivity</td>
<td>Interest Rate</td>
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<td>$\alpha_{11}$</td>
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<td>100.00</td>
<td>100.00</td>
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It’s the signals!
Table: Variance Decomposition, HP filtered data, EA

<table>
<thead>
<tr>
<th>Shock</th>
<th>stock market</th>
<th>credit spread</th>
<th>term structure</th>
<th>real M1</th>
<th>real M3</th>
</tr>
</thead>
<tbody>
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<td>13.15</td>
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<td>Banking tech</td>
<td>$\sigma_{x^{b}}$</td>
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<td>0.07</td>
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<td>Money demand</td>
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<td>0.00</td>
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<tr>
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<td>0.07</td>
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<td>Permanent tech</td>
<td>$\sigma_{\mu_{z}}$</td>
<td>0.17</td>
<td>0.07</td>
<td>0.05</td>
<td>0.14</td>
</tr>
<tr>
<td>Gamma shock</td>
<td>$\sigma_{\gamma}$</td>
<td>5.37</td>
<td>25.82</td>
<td>1.86</td>
<td>0.33</td>
</tr>
<tr>
<td>Temporary tech</td>
<td>$\sigma_{\epsilon}$</td>
<td>0.10</td>
<td>4.06</td>
<td>0.00</td>
<td>3.40</td>
</tr>
<tr>
<td>Monetary policy</td>
<td>$\sigma_{\epsilon_{policy}}$</td>
<td>4.89</td>
<td>1.81</td>
<td>0.99</td>
<td>25.76</td>
</tr>
<tr>
<td>Risk, contemp</td>
<td>$\sigma_{\sigma}$</td>
<td>13.94</td>
<td>5.07</td>
<td>20.58</td>
<td>0.97</td>
</tr>
<tr>
<td>Signals on risk</td>
<td>$\sigma_{\sigma_{signal}}$</td>
<td>68.29</td>
<td>44.23</td>
<td>75.90</td>
<td>6.79</td>
</tr>
<tr>
<td>Risk and signals</td>
<td>$\sigma_{\sigma}$ and $\sigma_{\sigma_{signal}}$</td>
<td>82.22</td>
<td>49.30</td>
<td>96.48</td>
<td>7.76</td>
</tr>
<tr>
<td>Discount rate</td>
<td>$\sigma_{\xi_{c}}$</td>
<td>0.02</td>
<td>1.72</td>
<td>0.02</td>
<td>3.99</td>
</tr>
<tr>
<td>Marginal eff of I</td>
<td>$\sigma_{\xi_{i}}$</td>
<td>1.90</td>
<td>2.54</td>
<td>0.27</td>
<td>8.77</td>
</tr>
<tr>
<td>Price of oil</td>
<td>$\sigma_{\epsilon_{oil}}$</td>
<td>0.14</td>
<td>0.94</td>
<td>0.05</td>
<td>0.56</td>
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<tr>
<td>Error in long rate</td>
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<td>0.00</td>
<td>0.00</td>
<td>36.05</td>
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<tr>
<td>Measurement error</td>
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<td>0.19</td>
<td>0.02</td>
<td>0.32</td>
<td>0.21</td>
</tr>
<tr>
<td>Inflation target</td>
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<td>0.10</td>
<td>0.05</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>All shocks</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>
Table: Variance Decomposition, HP filtered data, EA

<table>
<thead>
<tr>
<th>x</th>
<th>shock</th>
<th>stock market</th>
<th>credit</th>
<th>spread</th>
<th>term structure</th>
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<tbody>
<tr>
<td>Risk, contemp</td>
<td>$\sigma_\sigma$</td>
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<td>20.58</td>
<td>0.97</td>
</tr>
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<td>6.79</td>
</tr>
<tr>
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<td>$\sigma_\sigma$ and $\sigma_\sigma^{\text{signal}}$</td>
<td>82.22</td>
<td>49.30</td>
<td>96.48</td>
<td>7.76</td>
</tr>
</tbody>
</table>

Signal matters!

| all shocks | 100.00 | 100.00 | 100.00 | 100.00 |
Importance of Risk Signals

News Specification on Risk and Marginal Likelihood (EA data)

\[ \hat{\sigma}_t = \rho_1 \hat{\sigma}_{t-1} + \xi_{t-0} + \xi_{t-1}^1 + \xi_{t-2}^2 + \ldots + \xi_{t-p}^p \]

\[
p \quad \text{log, marginal likelihood odds (} = \exp(\text{difference in log likelihood from baseline}) \text{)}
\]

<table>
<thead>
<tr>
<th>p</th>
<th>log, marginal likelihood</th>
<th>odds (=exp(difference in log likelihood from baseline))</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 (baseline)</td>
<td>4397.487</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>4394.025</td>
<td>31</td>
</tr>
<tr>
<td>1</td>
<td>4325.584</td>
<td>\infty</td>
</tr>
</tbody>
</table>
Why is Risk Shock so Important?

• According to the model, external finance premium is primarily risk shock.

• To look for evidence that risk might be important, look at dynamics of external finance premium and gdp.

• External finance premium is a negative leading indicator
Figure 1: Correlation (finance premium (t), output (t-n)), HP filtered data, 95% confidence interval

Notes: Premium is measured by the difference between the yield on the lowest rated corporate bonds (Baa) and the highest rated corporate bonds (Aaa). Bond rate data obtained from St. Louis Fed website. GDP data obtained from Balke and Gordon (1986). Filtered output data are scaled so that their standard deviation coincide with that of the premium data.
Why is Risk Shock so Important?: A second reason

- Our data set includes the stock market
  - Output, stock market, investment all procyclical (surge together in late 1990s)
  - This is predicted by risk shock.
Shock to Distribution of Idiosyncratic Shock Across Entrepreneurs

Standard deviation of idiosyncratic shock increased 10% from 0.83 to 0.91
Response to Shock in Cross-entrepreneur Distribution

Output

Investment

Consumption

Real Net Worth

Premium (Annual Rate)

Total Loans (Real)
Impact of Financial Frictions on Propagation

• Effects of monetary shocks on gdp amplified by BGG financial frictions because $P$ and $Y$ go in same direction.

• Effects of technology shocks on gdp mitigated by BGG financial frictions because $P$ and $Y$ go in opposite directions.
Baseline model with no Fisher Effect

Output Response to 40 Basis Point Jump in Interest Rate

Baseline model

Blue line: baseline model with no financial frictions
Out of Sample RMSEs

• There is not a loss of forecasting power with the additional complications of the model.

• The model does well on everything, except the risk premium.
Figure 6.a. EA, RMSE: Confidence band represents 2 std and is centred around BVAR
Models with Financial Frictions Can be Used to Address Important Policy Questions

• When there is an increase in risk spreads, how should monetary policy respond?

• How should monetary policy react to credit variables and the stock market?

• Does monetary policy cause excess asset price volatility?
  
  – Taylor: deviations from Taylor rule may cause asset price volatility
  – Christiano-Illut-Motto-Rostagno: Taylor rule may cause asset price volatility
How Should Policy Respond to the Risk Spread?

- Taylor’s recommendation:

\[
R_t = \alpha \pi_t^e + \beta y_t - \gamma (\text{Risky rate}_t - \text{Risk free rate}_t)
\]

\[
\gamma = 1
\]

- Evaluate this proposal by comparing performance of economy with \( \gamma = 1 \) and \( \gamma = 0 \) against Ramsey-optimal benchmark.
Get a recession, just like in earlier graph.
Taylor suggestion creates a boom
Is it too much?
premium (APR)

consumption

sigma

real GDP

investment

- Taylor proposal
- Taylor rule without spread
- Ramsey Util
Taylor’s suggestion overstimulates
Conclusion of Empirical Analysis with Financial Frictions

• Incorporating financial frictions changes inference about the sources of shocks and of propagation
  
  – risk shock.
  – Fisher debt deflation

• Opens a range of interesting questions that can be addressed