Uncertainty Shocks in a Model of Effective Demand

Susanto Basu
Boston College
NBER

Brent Bundick
Federal Reserve Bank of Kansas City

"I believe that overall uncertainty is a large drag on the economic recovery." – Narayana Kocherlakota (2010)

Can higher uncertainty reduce overall economic activity?

Uncertainty shock in data

Contraction in output, consumption, investment, & hours worked

Comovement is key stylized fact after uncertainty shock

Study uncertainty shocks in representative-agent DSGE model

Uncertainty shock is exogenous increase in aggregate shock volatility

Flexible-price models struggle to generate comovement

Endogenously-varying markups via sticky prices restores comovement

Model is consistent with empirical evidence

Identifying Uncertainty Shock in the Data

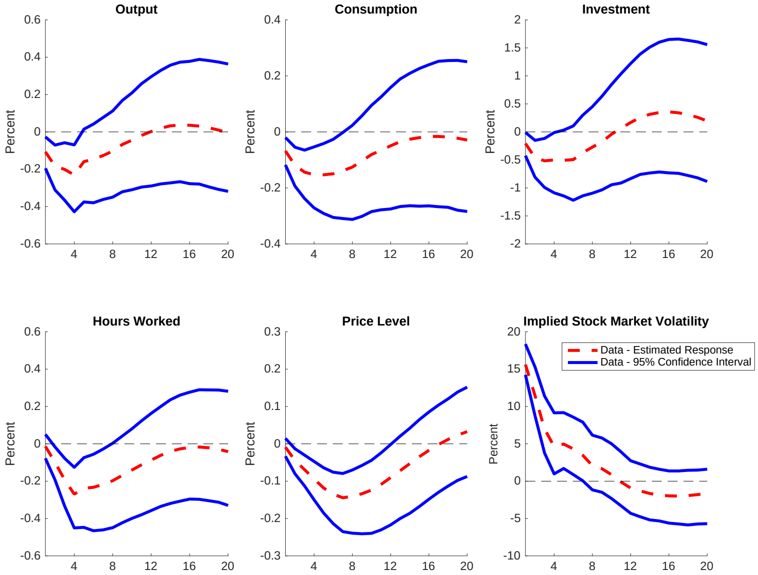
- Estimate VAR and use Cholesky identification scheme
  - Measure of uncertainty
  - Real quantities: Y, C, I, H
  - Nominal variables: GDP deflator, $M2$, monetary policy stance

- Use CBOE VXO index as measure of uncertainty
  - VXO is implied volatility of S&P 100 over next 30 days

- Uncertainty shock is exogenous increase in VXO

- Model supports empirical identification scheme

Empirical Impulse Responses to Uncertainty Shock



Comovement is key stylized fact after uncertainty shock

- Simultaneous drops in Y, C, I, H

Robust across a variety of different empirical specifications

Why does uncertainty causes decline in output & components?

Transmission of Uncertainty to Macroeconomy

Increased uncertainty in typical partial-equilibrium models

Reduces consumption through precautionary saving

Decreases investment via real options effects

Intuitive economy-wide effects of increased uncertainty

Reduction in consumption and investment

Fall in output via $Y = C + I$

Decrease in hours through $Y = F(K, ZN)$

Model Summary

Does the partial-equilibrium intuition hold in general equilibrium?

Standard New-Keynesian sticky price model with capital

Shares features with Ireland (2003, 2010) & Jermann (1998)

Household holds equity shares and one-period risk-free bonds

Epstein-Zin preferences over streams of consumption and leisure

Model Summary

1st & 2nd moment shocks to household discount factors (demand)

$$a_t = (1 - \rho_a)\, a + \rho_a a_{t-1} + \sigma^a_{t-1} \varepsilon^a_t \qquad \varepsilon^a_t \sim N(0,1)$$

$$\sigma^a_t = (1 - \rho_{\sigma^a})\, \sigma^a + \rho_{\sigma^a} \sigma^a_{t-1} + \sigma^{\sigma^a} \varepsilon^{\sigma^a}_t \quad \varepsilon^{\sigma^a}_t \sim N(0,1)$$

1st moment shocks to technology

$$Z_t = (1 - \rho_z)\, Z + \rho_z Z_{t-1} + \sigma^z \varepsilon^z_t \quad \varepsilon^z_t \sim N(0,1)$$

Model Summary

Firms own capital stock, issue debt, & pay dividends

Quadratic cost of adjusting nominal price

Adjustment costs to changing rate of investment

Variable capital utilization

Monetary authority follows standard Taylor rule

Model Calibration and Solution

Calibrate some parameters to estimates of Ireland (2003, 2010)

Estimate several parameters using moment matching

Examine impulse responses of uncertainty shocks under two cases:

1. Flexible Prices
2. Sticky Prices

Solve model using 3rd-order approximation to policy functions

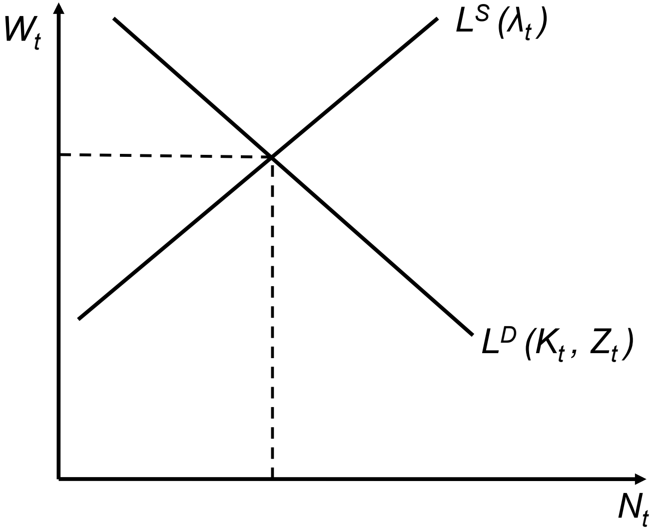
Flexible Price Model Intuition

Can increased uncertainty generate drop in Y, C, I & N ?

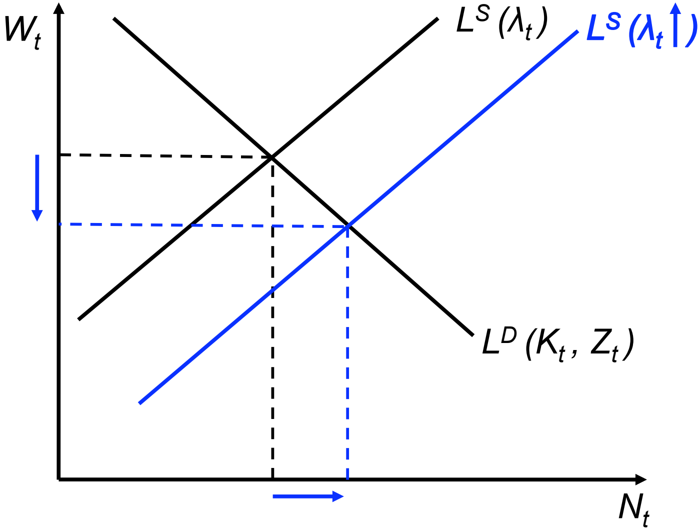
Increased uncertainty	$\Rightarrow$	Precautionary saving & lowers C_t
Precautionary saving	$\Rightarrow$	Precautionary working
$Y_t = F(K_t, Z_t N_t)$	$\Rightarrow$	Increase in total output
$Y_t = C_t + I_t$	$\Rightarrow$	Investment must rise

Increased uncertainty lowers C_t, but *raises* Y_t, I_t, and N_t

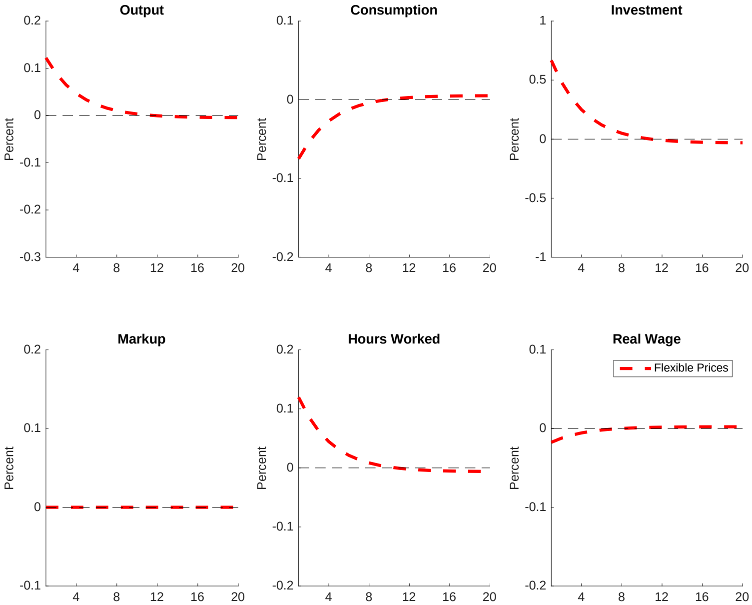
Flexible Price Model Intuition



Flexible Price Model Intuition



Second Moment Preference Shock with Flexible Prices



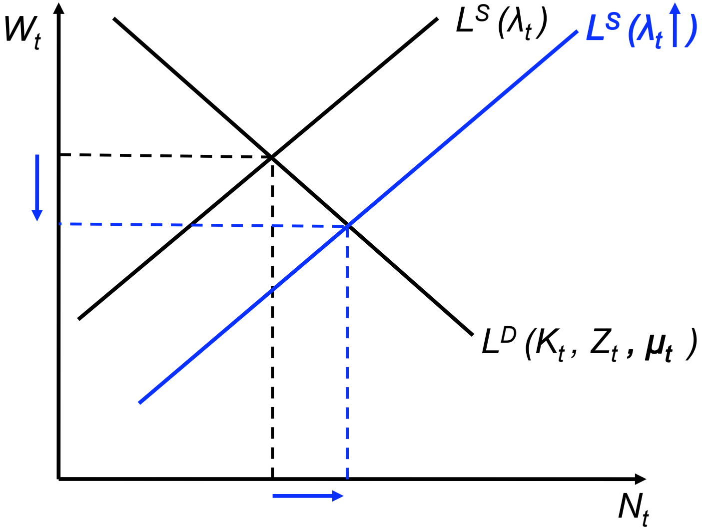
Sticky Price Model Intuition

Increased uncertainty	$\Rightarrow$	Precautionary saving & working
Precautionary Working	$\Rightarrow$	Fall in marginal costs
Markup = Price / Marginal Cost	$\Rightarrow$	Higher markup lowers labor demand

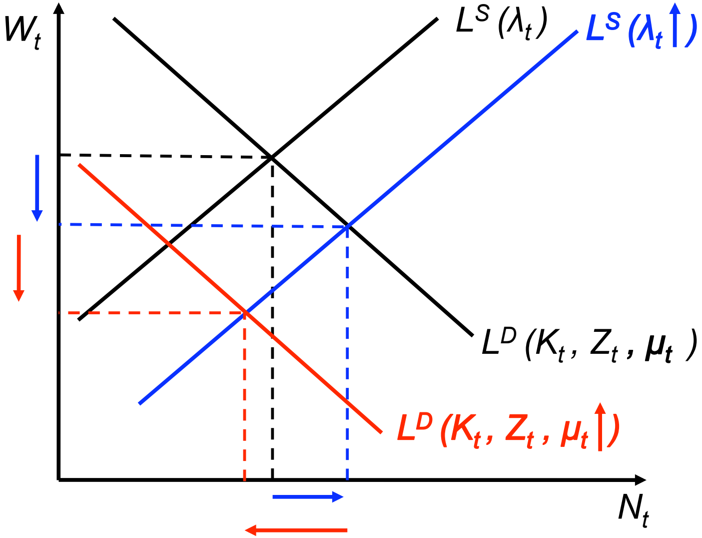
Labor demand may fall enough to reduce N_t and Y_t

Can lead to further reduction in C_t and decline in I_t

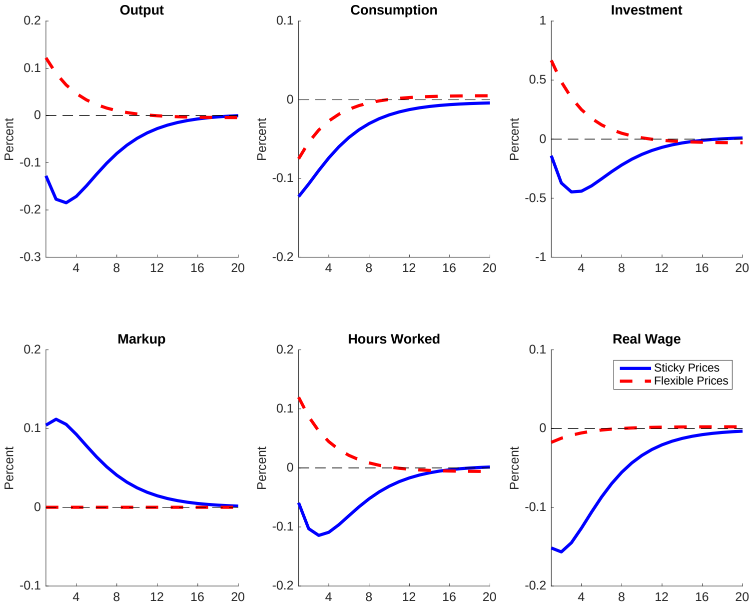
Sticky Price Model Intuition



Sticky Price Model Intuition



Second Moment Preference Shock with Sticky Prices



Calibrating Magnitude of Uncertainty Shocks

Increased uncertainty can reduce Y, C, I, & N under sticky prices

What does model predict for a reasonable-sized uncertainty shock?

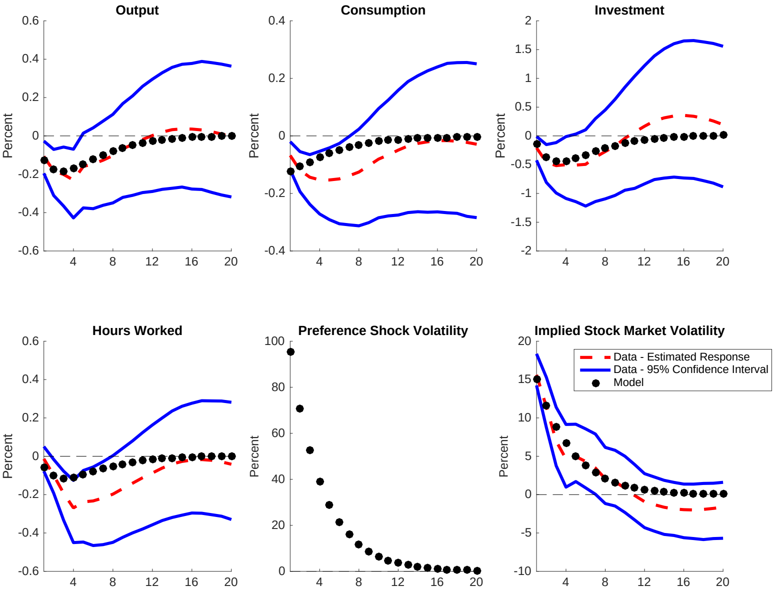
Generate model-implied VXO

- Expected annualized volatility of equity returns

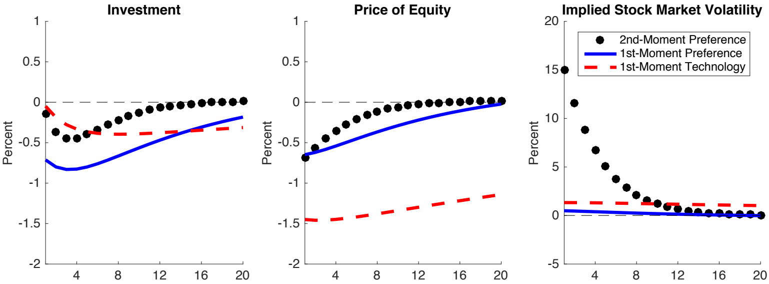
Estimate model parameters to match empirical impulse responses

- Risk aversion, investment adjustment costs
- 1st- & 2nd-moment shock processes
- Ensure not too much unconditional volatility in Y, C, I, & N

Empirical and Model-Implied Impulse Responses



Model Support for VAR Identification Scheme

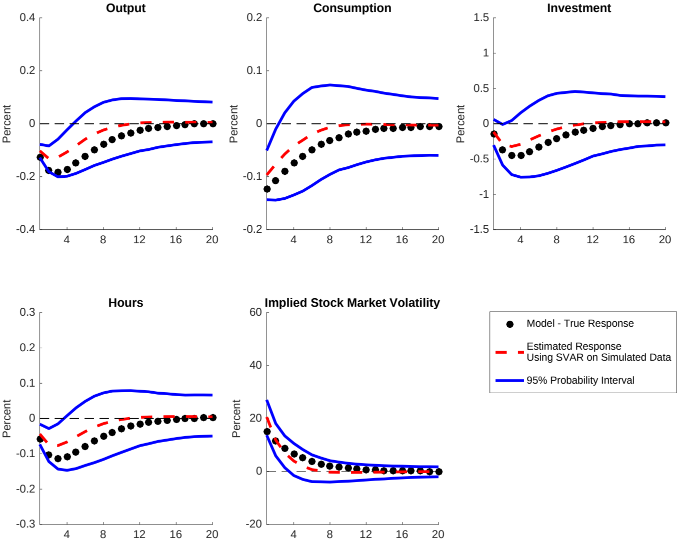


Only 2nd-moment shocks significantly move model-implied VXO

Can test empirical identification scheme using model

Run empirical VAR on simulated data from model

Estimating VAR on Simulated Model Data



Correlation between identified & true uncertainty shocks = 0.77

Quantitative Implications of Uncertainty Shocks

Did uncertainty play a role in the Great Recession?

VAR implies 2.75 standard deviation uncertainty shock in 2008:Q4

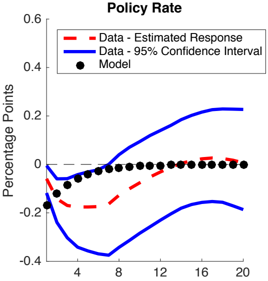
2.75 standard deviation uncertainty shock in model
$\Rightarrow$ Peak drop in output of 0.6 percent

Suggests uncertainty contributed to severity of Great Recession

Uncertainty Shocks and Monetary Policy

Monetary authority follows conventional active interest rate rule

Policy responds to inflation & output growth



Helps stabilize economy by offsetting uncertainty shock

Alternative Monetary Policy Rules

Optimal monetary policy replicates flexible-price allocation

$$r_t = r_t^n + \pi + \rho_\pi (\pi_t - \pi) + \rho_x x_t$$

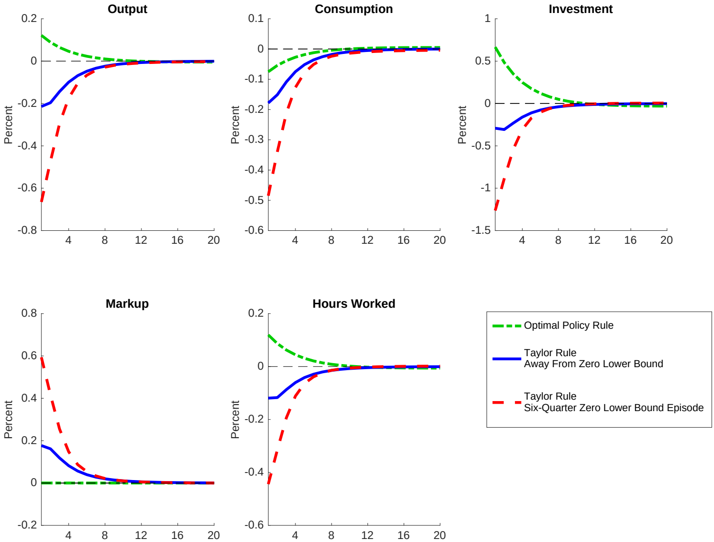
Cannot replicate optimal policy at zero lower bound

$$r_t^d = r + \rho_\pi (\pi_t - \pi) + \rho_y \Delta y_t$$

$$r_t = \max \left(0, r_t^d\right)$$

Large increase in uncertainty occurred when policy rates near zero

Uncertainty Shock Under Optimal Policy & At ZLB



Role of Uncertainty in the Great Recession

2.75 standard deviation uncertainty shock in 2008:Q4

2.75 standard deviation shock in baseline model
⇒ Peak drop in output of 0.6 percent

Zero lower bound more than doubles the impact of shock
⇒ Peak drop in output of 1.5 percent

CBO estimates -5.0 percent output gap in 2008:Q4

Results suggest uncertainty may explain one-fourth output decline

Conclusions

Comovement is key stylized fact after uncertainty shock

Simultaneous drops in Y, C, I, H

Decline in output and its components is quantitatively significant

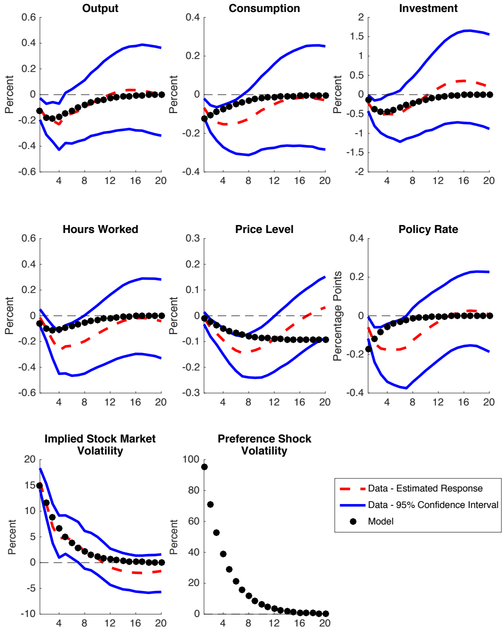
A model with nominal rigidities can replicate empirical evidence

Need demand-determined output

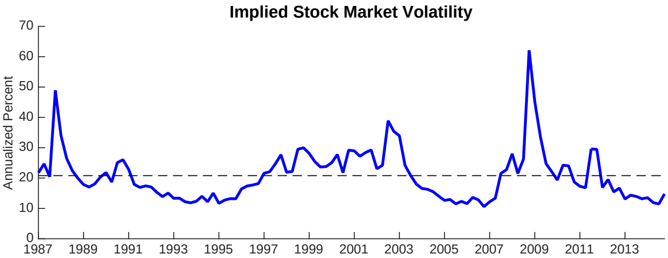
Effects of uncertainty are even larger at the zero lower bound

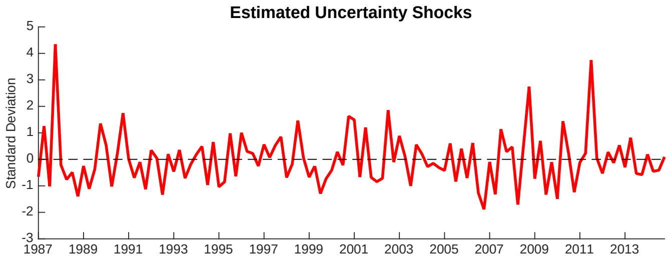
Full replication package available: `www.brentbundick.com`

Additional Details

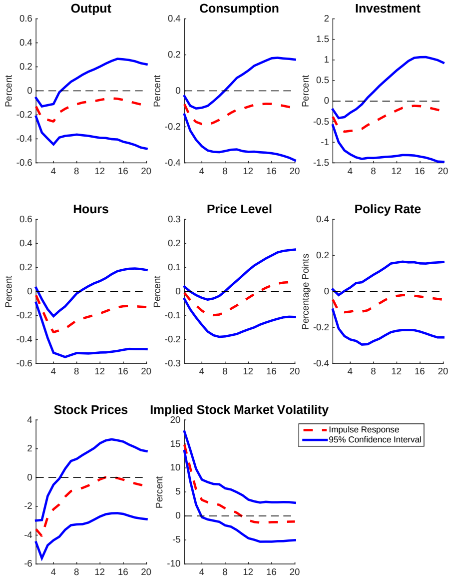

Output
Consumption
Investment
Hours Worked
Price Level
Policy Rate
Implied Stock Market Volatility
Preference Shock Volatility
Percent
Percentage Points
Data - Estimated Response
Data - 95% Confidence Interval
Model

VIX & Identified Shocks

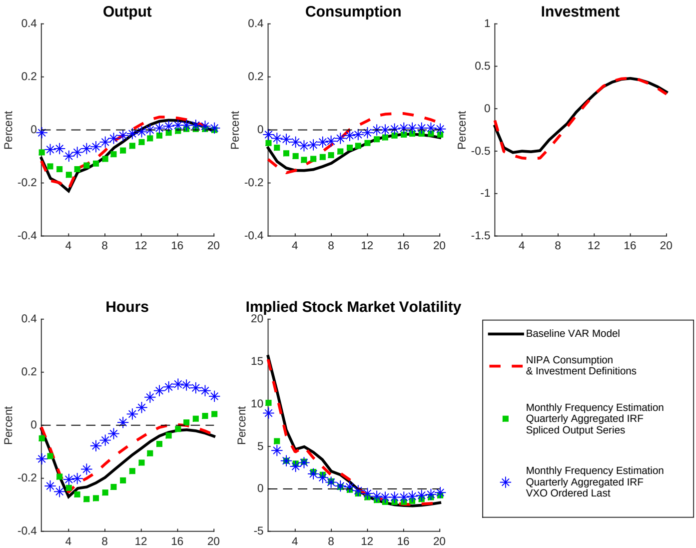




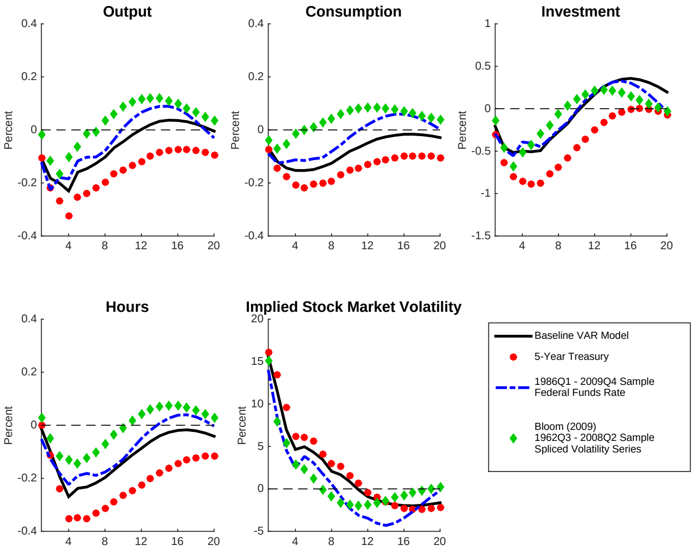
Include Stock Prices in the VAR



Alternative VAR Specifications I



Alternative VAR Specifications II



Representative Household (I)

Household maximizes lifetime utility from consumption and leisure

$$V_t = \max \left[a_t \left(C_t^{\eta} (1 - N_t)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_V}} + \beta \left(\mathbb{E}_t V_{t+1}^{1-\sigma} \right)^{\frac{1}{\theta_V}} \right]^{\frac{\theta_V}{1-\sigma}}$$

$$\psi \triangleq \text{IES} \qquad \theta_V \triangleq \frac{1-\sigma}{1-\frac{1}{\psi}}$$

Household stochastic discount factor

$$M_{t+1} = \left(\beta \frac{a_{t+1}}{a_t} \right) \left(\frac{C_{t+1}^{\eta} \left(1 - L_{t+1}\right)^{1-\eta}}{C_t^{\eta} \left(1 - L_t\right)^{1-\eta}} \right)^{\frac{1-\sigma}{\theta_V}} \left(\frac{C_t}{C_{t+1}} \right) \times \left(\frac{V_{t+1}^{1-\sigma}}{\mathbb{E}_t \left[V_{t+1}^{1-\sigma} \right]} \right)^{1-\frac{1}{\theta_V}}$$

Representative Household (II)

Household budget constraint

$$C_t + \frac{P_t^E}{P_t} S_{t+1} + \frac{1}{R_t^R} B_{t+1} = \frac{W_t}{P_t} N_t + \left(\frac{D_t^E}{P_t} + \frac{P_t^E}{P_t} \right) S_t + B_t$$

Stochastic process for preference (demand) shocks

$$a_t = (1 - \rho_a)\, a + \rho_a a_{t-1} + \sigma_{t-1}^a \varepsilon_t^a \qquad \varepsilon_t^a \sim N(0,1)$$

$$\sigma_t^a = (1 - \rho_{\sigma^a})\sigma^a + \rho_{\sigma^a} \sigma_{t-1}^a + \sigma^{\sigma^a} \varepsilon_t^{\sigma^a} \quad \varepsilon_t^{\sigma^a} \sim N(0,1)$$

Representative Goods-Producing Firm (I)

Firm owns capital stock $K_t(i)$ & employs labor $N_t(i)$

Quadratic cost of changing nominal price $P_t(i)$

$$\frac{\phi_P}{2}\left[\frac{P_t(i)}{\Pi P_{t-1}(i)}-1\right]^2 Y_t$$

Cobb-Douglas production function subject to fixed costs

$$Y_t(i)=\left[U_t(i)K_t(i)\right]^{\alpha}\left[Z_t N_t(i)\right]^{1-\alpha}-\Phi$$

Adjustment costs to changing rate of investment

$$K_{t+1}(i)=\left(1-\delta\Big(U_t(i)\Big)-\frac{\phi_K}{2}\left(\frac{I_t(i)}{K_t(i)}-\delta\right)^2\right)K_t(i)+I_t(i)$$

Representative Goods-Producing Firm (II)

Firm i chooses $N_t(i)$, $K_{t+1}(i)$, $I_t(i)$, and $P_t(i)$ to max cash flows

$$\max E_t \left\{ \sum_{s=0}^{\infty} M_{t+s} \left(\frac{D_{t+s}(i)}{P_{t+s}} \right) \right\}$$

Definition of firm cash flows

$$\frac{D_t(i)}{P_t} = \left[\frac{P_t(i)}{P_t} \right]^{1-\theta_\mu} Y_t - \frac{W_t}{P_t} N_t(i) - I_t(i) - \frac{\phi_P}{2} \left[\frac{P_t(i)}{\Pi P_{t-1}(i)} - 1 \right]^2 Y_t$$

Firm issues 1-period bonds to finance fraction of K each period

$$B_{t+1}(i) = \nu K_{t+1}(i)$$

Bonds earn 1-period real risk-free rate R_t^R

Representative Goods-Producing Firm (III)

Total cash flows divided between payments to debt or equity

Payments to equity

$$\frac{D_t^E(i)}{P_t} = \frac{D_t(i)}{P_t} - \nu \left(K_t(i) - \frac{1}{R_t^R} K_{t+1} \right)$$

Leverage does not affect firm value or optimal firm decisions
(Modigliani & Miller (1963) theorem holds)

Equity becomes more volatile with leverage

Aggregation

All users of final output assemble the final good Y_t using the range of varieties $Y_t(i)$ in a CES aggregator

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\theta_\mu - 1}{\theta_\mu}} di \right]^{\frac{\theta_\mu}{\theta_\mu - 1}}$$

Aggregate production function

$$Y_t = (U_t K_t)^{\alpha} (Z_t N_t)^{1-\alpha} - \Phi$$

Stochastic process for technology

$$Z_t = (1 - \rho_z) Z + \rho_z Z_{t-1} + \sigma^z \varepsilon_t^z \quad \varepsilon_t^z \sim N(0, 1)$$

Monetary Policy & National Income Accounting

Nominal interest rate rule

$$r_t = r + \rho_\pi (\pi_t - \pi) + \rho_y \Delta y_t,$$

$$r_t = \ln(R_t) \qquad \pi_t = \ln(\Pi_t) \qquad \Delta y_t = \ln(Y_t / Y_{t-1})$$

National income accounting

$$Y_t = C_t + I_t + \frac{\phi_P}{2} \left(\frac{\Pi_t}{\Pi} - 1 \right)^2 Y_t$$

Model Parameters

Table: Model Parameters

Household		Firm				Policy		Shocks			
β	0.994	α	0.333	$\boldsymbol{\phi_K}$	**2.09**	Π	1.005	$\boldsymbol{\rho_a}$	**0.94**	$\boldsymbol{\rho_Z}$	**0.99**
σ	80.0	δ	0.025	ϕ_P	100	ρ_π	1.5	$\boldsymbol{\sigma^a}$	**0.003**	$\boldsymbol{\sigma^Z}$	**0.001**
ψ	0.95	δ_1	0.03	θ_μ	6.0	ρ_y	0.2	$\boldsymbol{\rho_{\sigma^a}}$	**0.74**		
η	0.35	δ_2	0.0003	ν	0.9			$\boldsymbol{\sigma^{\sigma^a}}$	**0.003**		

Note: Parameters listed in bold are estimated via impulse response and moment matching.

Model-Implied Unconditional & Stochastic Volatility

Moment	Percent		Relative to Output	
	Data	Model	Data	Model
Unconditional Volatility				
Output	1.1	1.0	1	1
Consumption	0.7	0.8	0.6	0.7
Investment	3.8	4.7	3.4	4.5
Hours Worked	1.4	0.8	1.3	0.8
Stochastic Volatility				
Output	0.4	0.2	1	1
Consumption	0.2	0.2	0.5	0.7
Investment	1.6	1.2	3.6	5.0
Hours Worked	0.5	0.2	1.0	0.9

Note: Unconditional volatility is measured with the sample standard deviation. We measure stochastic volatility using the standard deviation of the time-series estimate for the 5-year rolling standard deviation. The empirical sample period is 1986 - 2014.