

# Learning and Judgment Shocks in U.S. Business Cycles

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Tuesday, March 15, 2011

## Explain Expectations

- **Learning:** type of adaptive expectations, agents collect past data and run regressions.
- **Judgment:** agents adjust their expectations based on...
  - something in the news (war in Libya, earthquake in Japan),
  - outcome of an election,
  - complete nonsense.

## Explain Macroeconomic Fluctuations

- 1 How is macroeconomic volatility in U.S. is explained by typical structural shocks versus judgment shocks.
- 2 How much of judgment is explained by actual events versus judgment shocks.

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- Agents' expectations are informed by least-squares forecasts based on past data.
- Forecasts can be directly mapped to past data on observable variables: output gap, inflation, interest rates.

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- Judgment may be informative, include relevant information not in past data.
- Judgment may be ill-informed (destabilizing, independent stochastic shock)
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- Oraphanides and Williams (JEDC, 2005): Monetary authority was optimizing, but misinformed.
- Primiceri (QJE, 2006): Monetary authority misinformed, expectations improved with time.

## Explaining Volatility

- Milani (2008): Time varying expectations.
- Bullard and Singh (2007): bad luck + Bayesian learning.

## Estimation

- Milani (JME, 2007): Explains persistence.
- Slobodyan and Wouters (2009): DSGE models with learning can fit data better than RE.

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- Reifschneider, Stockton, and Wilcox (1997)
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## Exuberance Equilibria

- Bullard, Evans, Honkapohja (2008), (2010).
- Judgment is independent from fundamentals: purely destabilizing.

## Empirical Evaluation

- Missing?

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## Utility maximization conditions

(Special case) Euler equation:  $u'(c_t) = \beta E_t u'(c_{t+1}) \frac{(1+r_t)}{(1+\pi_{t+1})}$

(Linearized) extended model:

$$\tilde{\lambda}_t = E_t \tilde{\lambda}_{t+1} + \hat{r}_t - E_t \pi_{t+1} - r_t^n,$$

$$\tilde{\lambda}_t = \frac{1}{(1-\beta\eta)(1-\eta)} [\beta\eta E_t \tilde{y}_{t+1} - (1 + \beta\eta^2) \tilde{y}_t + \eta \tilde{y}_{t-1}]$$

## Notation

$\tilde{\lambda}_t$ : marginal utility of income.

$\tilde{y}_t$ : output gap.

$\hat{r}_t$ : nominal interest rate.

$\pi_t$ : inflation.

$\eta \in [0, 1)$ : habit.

$\beta \in (0, 1)$ : discount rate.

$r_t^n$ : natural rate shock

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## Profit Maximizing Condition

- Firms choose prices (firms have market power)
- Firms only infrequently update prices.
- Consider expectations of future inflation.
- Aggregate supply depends on price level.

$$\pi_t = \frac{1}{1 + \beta\gamma} \left[ \gamma\pi_{t-1} + \beta E_t \pi_{t+1} + \kappa(\tilde{y}_t - \mu\tilde{\lambda}_t) + u_t \right]$$

## Notation

- Cost push shock:  $u_t$ .
- $\gamma \in [0, 1)$ : price indexation.
- $\kappa \in (0, \infty)$ : price flexibility.

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## Taylor (1993) Rule

- Fed raises interest rates when output above potential.
- Fed raises interest rates when inflation above target.
- Fed gradually adjusts interest rate.

$$\hat{r}_t = \rho_r \hat{r}_{t-1} + (1 - \rho_r) (\psi_\pi E_t \pi_{t+1} + \psi_y E_t \tilde{y}_{t+1}) + \epsilon_{r,t}$$

## Notation

- $\epsilon_{r,t}$ : monetary policy shock.
- $\psi_\pi \in (0, \infty)$ : feedback on inflation.
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- Log-linearized New Keynesian model has the structural form:

$$\Omega_0 x_t = \Omega_1 x_{t-1} + \Omega_2 x_{t+1}^e + \Omega_3 x_{t+2}^e + \Psi z_t$$

$$z_t = A z_{t-1} + \epsilon_t$$

- All observable by the agents:  $x_t = [\tilde{y}_t \ \pi_t \ \hat{r}_t]'$
- Shocks not observable to agents that learn:  $z_t = [r_t^n \ u_t \ \epsilon_{r,t}]'$
- Rational expectations solution:

$$E_t x_{t+1} = G x_t + H z_t$$

- Learning: agents estimate  $G$  with by running a regression.

## Regression Notation

- Let  $Y_\tau \in \{\tilde{y}_\tau, \pi_\tau \hat{r}_\tau\}$  denote one of the dependent variables agents want to forecast.
- Let  $X_\tau = [1 \ \tilde{y}_{\tau-1} \ \pi_{\tau-1} \ \hat{r}_{\tau-1}]'$  denote vector of explanatory variables.
- Let  $\hat{\beta}_t^Y$  be the row in  $G$  for variable  $Y_t$ .

## OLS Regression

$$\hat{\beta}_t^Y = \left( \sum_{\tau=0}^{t-1} X_\tau X_\tau' \right)^{-1} \left( \sum_{\tau=0}^{t-1} X_\tau' Y_\tau \right)$$

$$\text{Econometric Forecast: } E_t^* Y_t = X_t' \hat{\beta}_t$$

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## Recursive Formulation

The least squares regression coefficients can be rewritten as:

$$\hat{\beta}_t^Y = \beta_{t-1}^Y + g_t R_t^{-1} X_t' (Y_t - X_t \hat{\beta}_t)$$

$$R_t = R_{t-1} + g_t (X_t X_t' - R_{t-1}),$$

where  $g_t = 1/t$  is the **learning gain**.

## Learning Gain

- $g_t \rightarrow 0$  as  $t \rightarrow \infty$ , learning disappears over time.
- Constant gain learning:  $g_t = g$ .
- Learning can *always* lead to changes in expectations.
- Allows agents to learn about structural changes.

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## Data Requirements

- Recall rational expectations:  $E_t x_{t+1} = Gx_t + Hz_t$
- Learning agents have data on  $x_t$ , cannot “get data” on structural shocks,  $z_t$ .

## Expectations: Learning with Judgment

- Judgment may include evidence of structural shocks that are evident from news or current events.
- Expectations: sum of econometric forecasts ( $E_t^* x_{t+1}$ ) and judgment ( $\eta_t$ ).

$$x_{t+1}^e = E_t^* x_{t+1} + \eta_t$$

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## Evolution of Judgment

Judgment,  $\eta_t$ , is possibly informed by current structural shocks, and subject to its own shock:

$$\eta_t = \Phi z_t + \zeta_t,$$

$$\zeta_{y,t} = \rho_{\zeta,y} \zeta_{y,t-1} + \xi_{y,t},$$

$$\zeta_{\pi,t} = \rho_{\zeta,\pi} \zeta_{\pi,t-1} + \xi_{\pi,t},$$

## Notation

- $\eta_t$  is 2x1 vector, includes judgment on  $\tilde{y}_{t+1}^e$  and  $\pi_{t+1}^e$ .
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- $\zeta_t$ : judgment shocks.

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- Bayesian Estimation - Metropolis Hastings Simulation Procedure.
- Quarterly data from 1968:Q3 through 2007:Q1 on
  - Output gap: measured by Congressional Budget Office.
  - GDP deflator inflation rate.
  - Federal funds rate.
  - Survey of Professional Forecasters One-Quarter ahead forecast on real GDP.
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- Pre-sample (1954:Q3 - 1968:Q2) data on first three variables initialize VAR(1) learning forecasts.

## New Keynesian Model Parameters

	Median	5th PCT	95th PCT
$\eta$	0.0715	0.0207	0.1420
$\sigma$	2.9178	2.2683	3.5847
$\mu$	2.0691	1.3988	2.8363
$\kappa$	0.0278	0.0161	0.0432
$\gamma$	0.8465	0.7241	0.9146
$\rho_r$	0.9210	0.8578	0.9572
$\psi_y$	0.3185	0.1054	0.5845
$\psi_\pi$	1.5262	1.2789	1.7665
$\rho_n$	0.9798	0.9629	0.9925
$\rho_u$	0.0619	0.0146	0.2714
$\sigma_n$	0.0302	0.0236	0.0376
$\sigma_u$	0.0039	0.0035	0.0045
$\sigma_r$	0.0037	0.0033	0.0040

## Comments

- 1 Low persistence due to habit formation.
- 2 High inflation persistence.
- 3 High persistence in natural rate shock.
- 4 Low persistence in cost-push shock.

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$\rho_{\zeta,y}$	0.7322	0.4884	0.9385
$\rho_{\zeta,\pi}$	0.8729	0.7896	0.9460
$\sigma_{\zeta,y}$	0.0090	0.0082	0.0100
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$\phi_{y,n}$	-0.2220	-0.2937	-0.1466
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$\phi_{\pi,u}$	-0.2890	-0.4411	-0.1428
$\phi_{\pi,r}$	-0.0679	-0.2102	0.0934

## Comments

- ① Typical learning gain  $\sim 43\text{obs.} \sim 11\text{years}$ .
- ② High judgment persistence.
- ③ Informed judgment (non-zero).
- ④ Judgment not informed.

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## Judgment

Recall, judgment is a linear combination of concurrent structural shocks and its own stochastic disturbance:

$$\text{Judgment: } \eta_t = \Phi z_t + \zeta_t,$$

$$\text{Disturbance: } \zeta_t = \zeta_{t-1} + \xi_t,$$

## Variance Decomposition

What percentage of the variability in judgment ( $\eta_t$ ) is,

- ① informed by concurrent structural shocks ( $z_t$ )?
- ② stochastic disturbances ( $\xi_t$ )?

Uses the estimates parameters in  $\Phi$ ,  $\rho_{\zeta,y}$ ,  $\rho_{\zeta,\pi}$  and the variances of  $z_t$ ,  $\xi_{y,t}$ ,  $\xi_{\pi,t}$ .

## Judgment

Recall, judgment is a linear combination of concurrent structural shocks and its own stochastic disturbance:

$$\begin{aligned} \text{Judgment:} \quad \eta_t &= \Phi z_t + \zeta_t, \\ \text{Disturbance:} \quad \zeta_t &= \zeta_{t-1} + \xi_t, \end{aligned}$$

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## Variance Decomposition

Stochastic Shock	Output Judg.	Inflation Judg.
Natural Rate Shock	86.5 %	12.1%
Cost-Push Shock	0.0%	1.1%
Monetary Policy Shock	0.0%	0.0%
Output Judgment Shock	13.5%	–
Inflation Judgment Shock	–	86.7%
Total	100.00%	100.00%

## Comments

- ① Expectations (judgment) are informed by the natural rate shock.
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- ④ Most of the variability in judgment for inflation are from stochastic disturbances.

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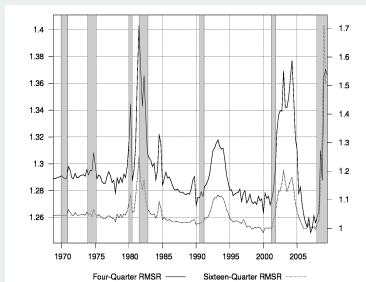
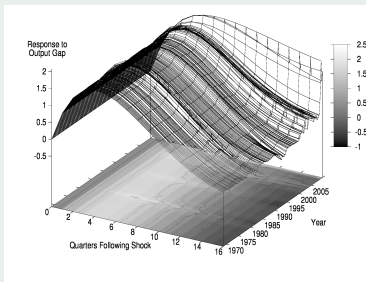
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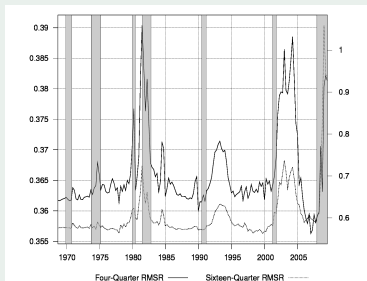
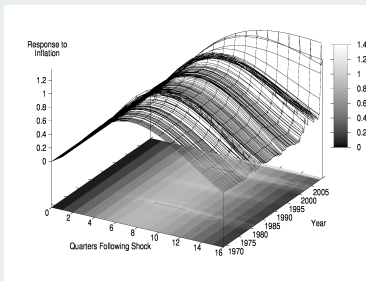
## Response to Output Gap from Output Judgment Shock



## Comments

- Output judgment shock increases output.
- Larger IRF's coincide with 1980s volatility, rapid growth of 1990s, slow growth in 2000s, slow recovery 2010 recession.

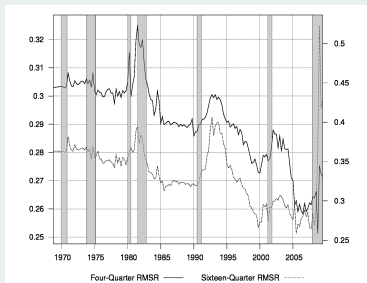
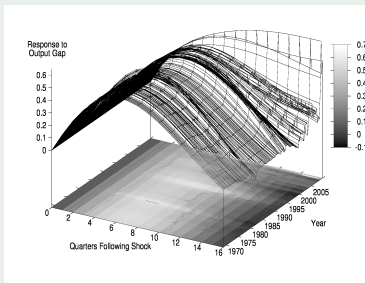
## Response to Inflation from Output Judgment Shock



## Comments

- Output judgment shock increases inflation.
- Larger IRF's occur during same time periods.

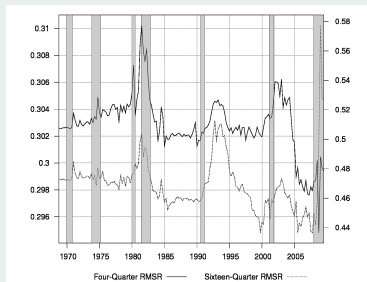
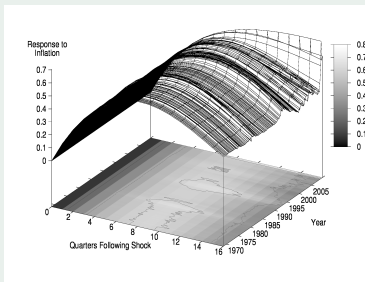
## Response to Output Gap from Inflation Judgment Shock



## Comments

- Inflation judgment shock increases output (reduces expected real interest rate).
- Inflation judgment IRFs on output have diminished over time.

## Response to Inflation from Inflation Judgment Shock



## Comments

- Inflation judgment shock increases inflation.
- Response is not symmetric over time. Largest in last few years of the sample.

## Average Root Mean Squared Responses (One Std.Dev. Shock)

### First Four Periods of IRF

Shock	Output	Inflation
Natural Rate	0.6018	0.1981
Cost-Push	0.1697	1.0864
Monetary Policy	0.6364	0.1787
Output Judgment	1.2952	0.3662
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### First Sixteen Periods of IRF

Shock	Output	Inflation
Natural Rate	0.9918	0.6533
Cost-Push	0.1870	0.6953
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## Comments

- Output judgment shock has largest average impact on output.
- Cost-push shock has largest impact on inflation.
- Both output judgment and inflation judgment influence inflation dynamics.

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- Judgment is a significant source of persistence for output and inflation.
- Inflation judgment is mostly dependent on stochastic disturbances.
- Output judgment is largely informed by concurrent natural rate shock.
- Both output and inflation judgment shocks are important drivers of business cycle fluctuations, along with natural rate shock and cost-push shock.