Learning and Judgment Shocks in U.S. Business Cycles

James Murray
Department of Economics
University of Wisconsin - La Crosse

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Purpose

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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Expectations Framework

Constant Gain Learning

- 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.

Expectation = Forecast + Judgment

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- Judgment may be informative, include relevant information not in past data.
- Judgment may be ill-informed (destabilizing, independent stochastic shock)
- Agents' actual expectations are mapped to data from Survey of Professional Forecasters.

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Literature: Learning

Monetary Policy

- 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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Exuberance Equilibria

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

Empirical Evaluation

- Missing?

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Optimal Consumer Behavior

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:

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

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

Notation

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

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

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

π_t: inflation.

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

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

r_t^n: natural rate shock

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Producer Behavior

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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Monetary policy

Taylor (1993) Rule

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

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

Notation

- $\epsilon_{r,t}$: monetary policy shock.
- $\psi_\pi \in (0, \infty)$: feedback on inflation.
- $\psi_y \in (0, \infty)$: feedback on output.
- $\rho_r \in (0, 1)$: gradual adjustment.

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Linear Model

- Log-linearized New Keynesian model has the structural form:

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

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

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

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

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

Learning Regressions

Regression Notation

- Let $Y_\tau \in \{\tilde{y}_t,\ \pi_\tau\ \hat{r}_\tau\}$ 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

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

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

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Learning Algorithm

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

- $g_t \to 0$ as $t \to \infty$, 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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Expectations

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 (η_t).

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

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Judgment

Evolution of Judgment

Judgment, η_t, is possibly informed by current structural shocks, and subject to is 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

- η_t is 2x1 vector, includes judgment on $\tilde{y}^e_{t+1}$ and π^e_{t+1}.
- Φ: dependence of judgment on actual structural shocks.
- ζ_t: judgment shocks.

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Estimation

- 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.

Parameter Estimates

New Keynesian Model Parameters

	Median	5th PCT	95th PCT
η	0.0715	0.0207	0.1420
σ	2.9178	2.2683	3.5847
μ	2.0691	1.3988	2.8363
κ	0.0278	0.0161	0.0432
γ	0.8465	0.7241	0.9146
ρ_r	0.9210	0.8578	0.9572
ψ_y	0.3185	0.1054	0.5845
ψ_π	1.5262	1.2789	1.7665
ρ_n	0.9798	0.9629	0.9925
ρ_u	0.0619	0.0146	0.2714
σ_n	0.0302	0.0236	0.0376
σ_u	0.0039	0.0035	0.0045
σ_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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$\sigma_{\zeta,y}$	0.0090	0.0082	0.0100
$\sigma_{\zeta,\pi}$	0.0050	0.0045	0.0055
$\phi_{y,n}$	-0.2220	-0.2937	-0.1466
$\phi_{y,u}$	0.0916	-0.2233	0.3346
$\phi_{y,r}$	-0.0394	-0.2990	0.3760
$\phi_{\pi,n}$	0.0252	0.0015	0.0503
$\phi_{\pi,u}$	-0.2890	-0.4411	-0.1428
$\phi_{\pi,r}$	-0.0679	-0.2102	0.0934

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1. Typical learning gain $\sim 43 obs. \sim 11 years$.
2. High judgment persistence.
3. Informed judgment (non-zero).
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Informative Content in Judgment

Judgment

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

Variance Decomposition

What percentage of the variability in judgment (η_t) is,

1. informed by concurrent structural shocks (z_t)?
2. stochastic disturbances (ξ_t)?

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

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

Informative vs. Stochastic Judgment

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.
2. Expectations are not informed by cost-push shock.
3. Some variability in judgment for output are from stochastic disturbances.
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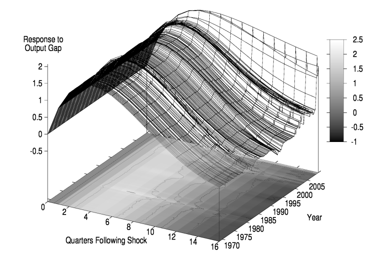
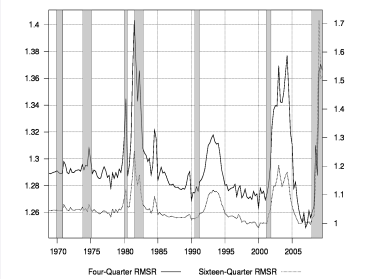
Impulse Responses: Output Judgment Shock

Response to Output Gap from Output Judgment Shock



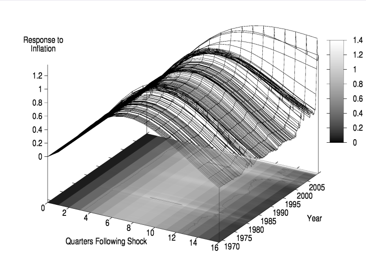


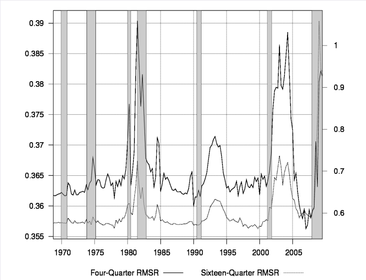
Comments

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

Impulse Responses: Output Judgment Shock

Response to Inflation from Output Judgment Shock



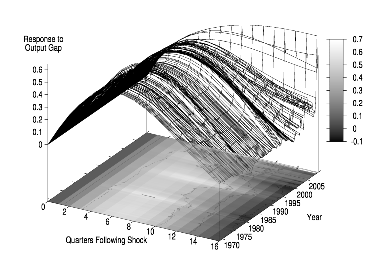


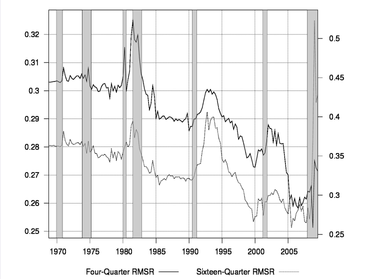
Comments

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

Impulse Responses: Inflation Judgment Shock

Response to Output Gap from Inflation Judgment Shock



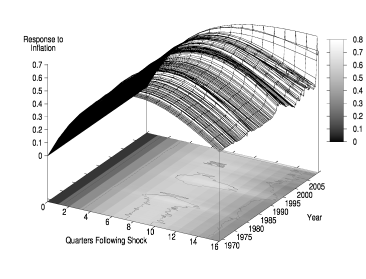


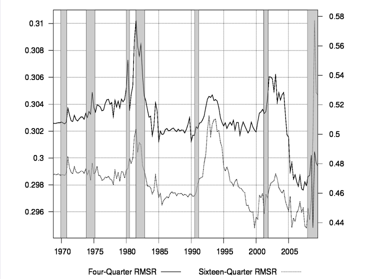
Comments

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

Impulse Responses: Inflation Judgment Shock

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.

Comparing Impulse Responses

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
Inflation Judgment	0.2911	0.3029

First Sixteen Periods of IRF

Shock	Output	Inflation
Natural Rate	0.9918	0.6533
Cost-Push	0.1870	0.6953
Monetary Policy	0.7742	0.4854
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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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Conclusions

- 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.