Initial Expectations in New Keynesian Models with Learning

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Purpose

- Purpose: Determine how learning vs. rational expectations affects our empirical understanding of a standard monetary economics model.
- **Learning**: type of adaptive expectations.
- **Rational Expectations**: assumes perfect knowledge of how the economy works, expectations do not evolve.
- **New Keynesian Monetary Model**:
  - Most commonly used model in monetary economics literature.
  - Provides an explanation for how real GDP, inflation, and the federal funds rate are related.

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Rational Expectations

- Most common assumption in macroeconomic theory and empirical evaluation of macroeconomic models.
- Agents know entire structure of the economy.
- Agents know all parameters that govern consumer and producer behavior:
  - Elasticity of labor supply, intertemporal elasticity of substitution, degree of price flexibility, behavior of monetary policy, etc.
- Stochastic uncertainty: unexpected shocks can still hit the economy.
- Lots of authors have estimated RE monetary models: Ireland (2004, 2006), Rotemburg and Woodford (1997), Smets and Wouters (2003, 2005, 2007).

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Least Squares Learning

- Agents do not know structure of the economy.
- Agents form expectations by running regressions.
- Example: Predicting future inflation
  - Explanatory variables: past inflation, past output, past interest rates.
  - Regression equation:

$$\hat{\pi}_{t+1} = \beta_0 + \beta_1 \pi_t + \beta_2 y_t + \beta_3 r_t$$

  - $\hat{\pi}_{t+1}$: expectation of future inflation.
  - π_t: inflation at time t
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New Keynesian Model: Optimal Consumer Behavior

- Consumers maximize net present value of lifetime utility, subject to their budget constraint.
- As the real interest rate increases, consumers decide to save more, consume less.
- The size of this effect depends on the **intertemporal elasticity of substitution**, estimated in paper.
- As the expected inflation rate rises, expected real interest rate falls.
- Habit formation: current consumption (current utility) depends on past consumption.
- **Degree of habit formation** is between 0 and 1, estimated in paper.
- Consumption subject to a *demand shock*.

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- Monopolistically competitive firms.
- Exogenously sticky prices: it takes firms an uncertain amount time to appropriately adjust prices to maximize profits.
- Sticky prices enable monetary policy to have real effects on short-run output.
- Price indexation: when firms cannot re-optimize prices, they raise their prices by the past period's rate of inflation.
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- Fed adjusts Federal Funds Rate according to Taylor (1993) rule.
- Federal funds rate in response to:
  - output gap
  - inflation rate
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- Learning expectations are adaptive: estimates of the structure of the economy evolve with the data.
- Prolonged periods of inflation - Orphanides and Williams (RED, 2005).
- Bad monetary policy prescriptions - Orphanides and Williams (JEDC, 2005)
- Output and inflation persistence - Milani (JME, 2007)
- Great Inflation followed by Great Moderation - Primiceri (2005).
- Time-varying Volatility - Milani (2007)

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Initial Expectations

- Problem: Need to initialize learning coefficients at the beginning of sample.
- Orphanides and Williams (JEDC, 2005):
  - Central Bank began under-estimating natural rate of unemployment.
- Primiceri:
  - Central Bank began under-estimating unemployment and inflation persistence.
- Milani:
  - Assumes low inflation persistence, sensitivity of output to inflation.
  - Assumes shocks are observable, sets initial impacts to zero.
- Missing from empirical literature:
  - Systematic way for specifying initial conditions.
  - Estimate initial conditions.
  - Sensitivity analysis to initial conditions.

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Strategies for Initial Conditions

- Use the rational expectations solution.
  - Benefit: Initial conditions are consistent with model.
  - Draw back: Learning dynamics are small near the RE equilibrium. (Williams 2003).
- Assume limited information set.
  - Agents cannot observe realizations of stochastic shocks.
  - Initialize beliefs of remaining coefficients equal to RE solution.
  - Benefit: more realistic.
- Using limited information, set initial beliefs to pre-sample least squares estimates.
  - Benefit: Most likely to mirror actual beliefs.
  - Draw back: sometimes so far from RE the learning model is unstable (Slobodyan and Wouters 2007).

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Estimation

- Estimate Four Cases of the New Keynesian Model
  1. Rational Expectations.
  2. Learning with full knowledge of shocks, initial beliefs = RE. This model nests rational expectations when learning gain is zero.
  3. Learning with only realistic variables, initial beliefs = RE.
  4. Learning with only realistic variables, initial beliefs = pre-sample evidence.
- Maximum Likelihood: procedure that specifies probability distributions for stochastic shocks.
- Data: Quarterly data from 1960:Q1 through 2008:Q1
  - Output gap: measured by Congressional Budget Office.
  - CPI inflation rate.
  - Federal funds rate.

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  - Output gap: measured by Congressional Budget Office.
  - CPI inflation rate.
  - Federal funds rate.

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  1. Rational Expectations.
  2. Learning with full knowledge of shocks, initial beliefs = RE. This model nests rational expectations when learning gain is zero.
  3. Learning with only realistic variables, initial beliefs = RE.
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Parameter Estimates: Learning Gain

Learning Gain			
Case 1	Case 2	Case 3	Case 4
–	0.0209 (0.0021)	0.0152 (0.0013)	0.0000 (0.0000)

- Case 2: Learning gain is statistically significantly different from zero.
- Case 2: $g = 0.0209$ corresponds to agents using approximately 12 years of data.
- Case 3: $g = 0.0152$ corresponds to agents using approximately 16.4 years of data.
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Parameter Estimates: Macroeconomic Persistence

Degree of Habit Formation			
Case 1	Case 2	Case 3	Case 4
0.7737 (0.0651)	0.7933 (0.0660)	0.9992 (0.0001)	0.7381 (0.1897)

Price Indexation			
Case 1	Case 2	Case 3	Case 4
0.7997 (0.0406)	0.7665 (0.0604)	0.6943 (0.0462)	0.9999 (0.0000)

- Learning leads still leads to a high level of persistence in output and inflation.

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Parameter Estimates: Intertemporal Substitution

Intertemporal Elasticity of Substitution			
Case 1	Case 2	Case 3	Case 4
0.2098 (0.1303)	0.1952 (0.1147)	0.0000 (0.0000)	0.1113 (0.1722)

- Cases 3: Elasticity of intertemporal substitution falls to zero.
- Recall intertemporal effect: Consumption today depends negatively on expected real interest rate.
- When expected inflation is determined by learning, evidence suggests consumption is unresponsive to expected interest rate.

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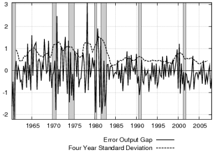
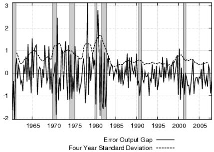
Forecast Errors: Output Gap

Case 1



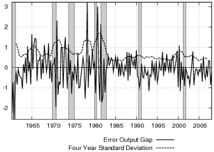
Correlation $= 1.0$
RMSE $= 0.7757$

Case 2



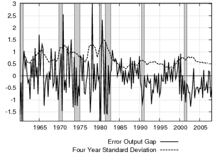
Correlation $= 0.98$
RMSE $= 0.7905$

Case 3



Correlation $= 0.97$
RMSE $= 0.8012$

Case 4



Correlation $= 0.92$
RMSE $= 0.7792$

- RMSE: RE is best fitting model.
- Forecast errors highly correlated with RE.
- All models make larger errors prior to early 1980s.

Forecast Errors: Output Gap

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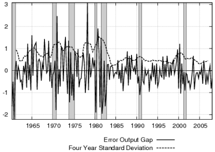

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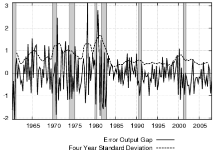

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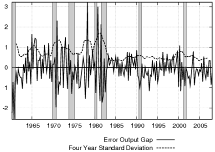

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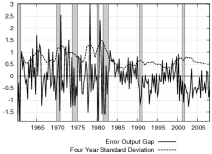

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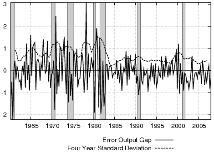

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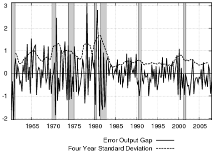

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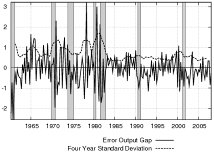

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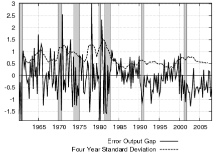

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Forecast Errors: Inflation

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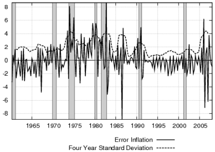
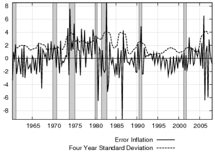


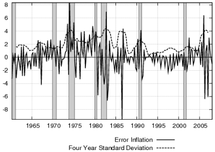
Correlation $= 1.0$
RMSE $= 2.3474$

Case 2



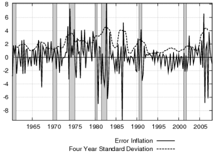
Correlation $= 0.93$
RMSE $= 2.2863$

Case 3



Correlation $= 0.9$
RMSE $= 2.2978$

Case 4



Correlation $= 0.89$
RMSE $= 2.3092$

- RMSE: All models provide similar fit to data.
- All models made similar errors
- Largest errors during recessions in 1970s, early 1980s

Forecast Errors: Inflation

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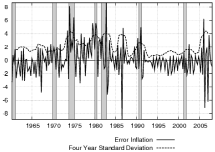

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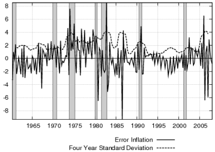

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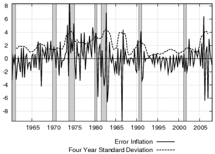

Correlation $= 0.9$
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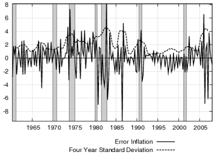
Case 4



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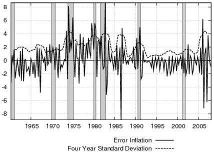

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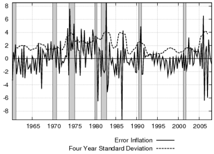

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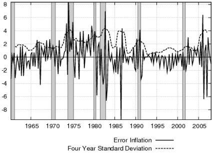

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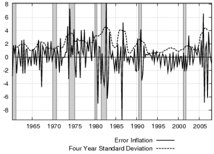

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Impulse Response Functions

- **Impulse response function (IRF):** graph of the impact a shock has on a macroeconomic variable.
- Example: positive demand shock
  - Causes a temporary positive impact on output and inflation.
  - An IRF shows how large the impact is on each of these variables.
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  - Orphanides and Williams (2005) found prolonged inflation IRFs.

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IRF: Natural Rate Shock on Output

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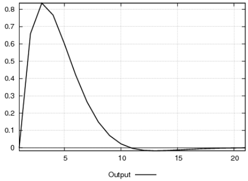

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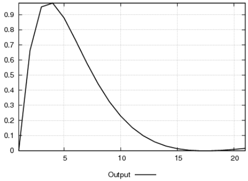
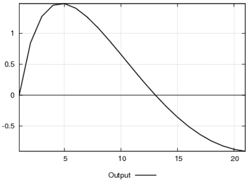
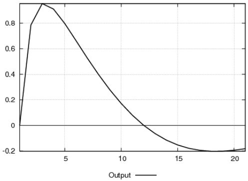


Case 3



Case 4



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IRF: Natural Rate Shock on Output

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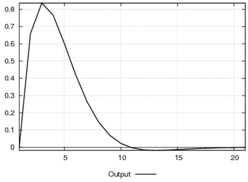

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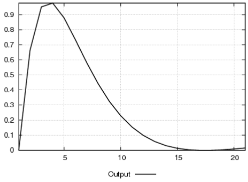

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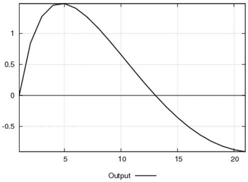

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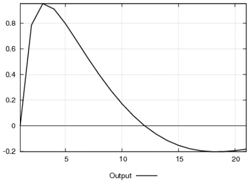

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IRF: Natural Rate Shock on Inflation

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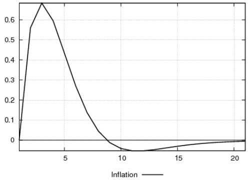
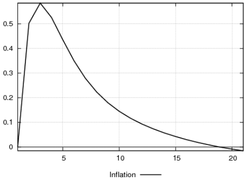
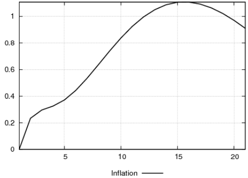


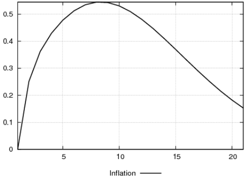
Case 2



Case 3



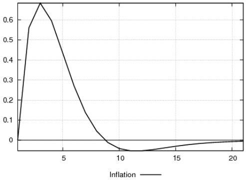
Case 4



- Learning can lead to very prolonged effects on inflation.
- Learning without knowledge of shocks leads to long lasting oscillatory effects.

IRF: Natural Rate Shock on Inflation

Case 1



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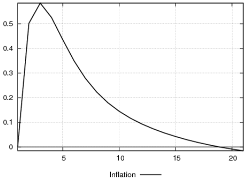
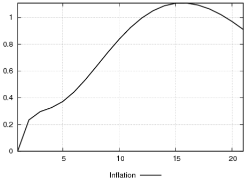
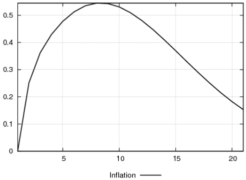


Case 3



Case 4



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Time-varying Impulse Responses

- Under rational expectations - agents always know structure of the economy, therefore impulse responses are always the same.
- Under learning - impulse responses depend on the state of expectations.
- Previous slides - showed the impulse responses for the last sample period (2008:Q1).
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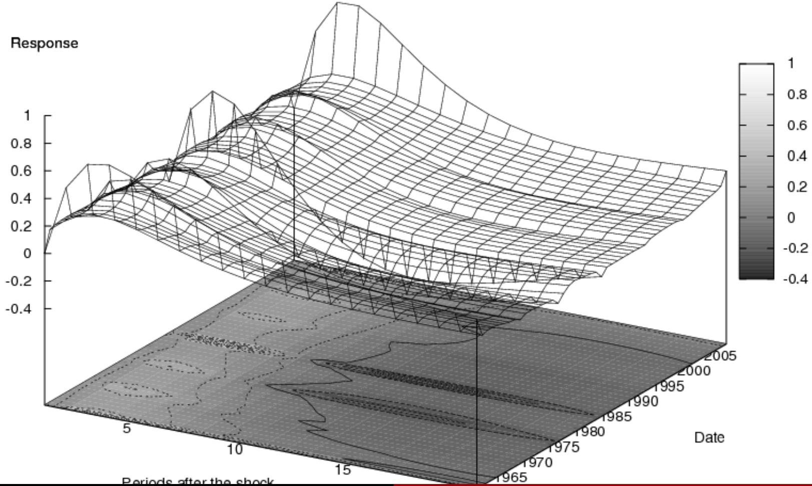

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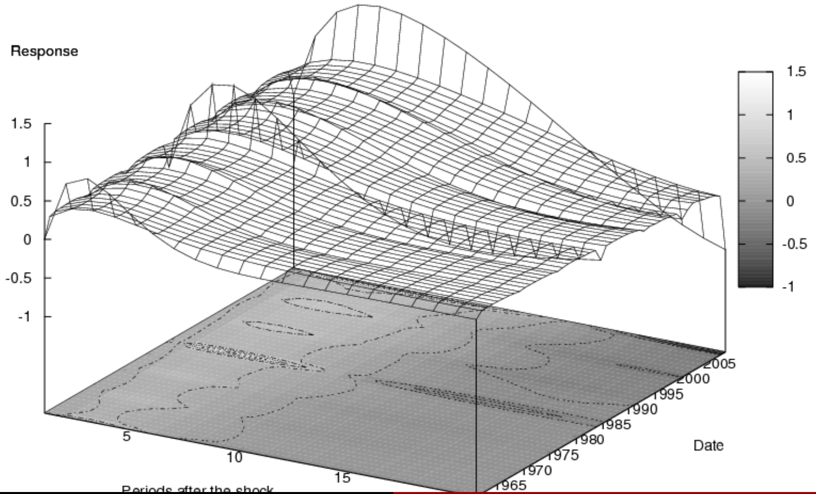

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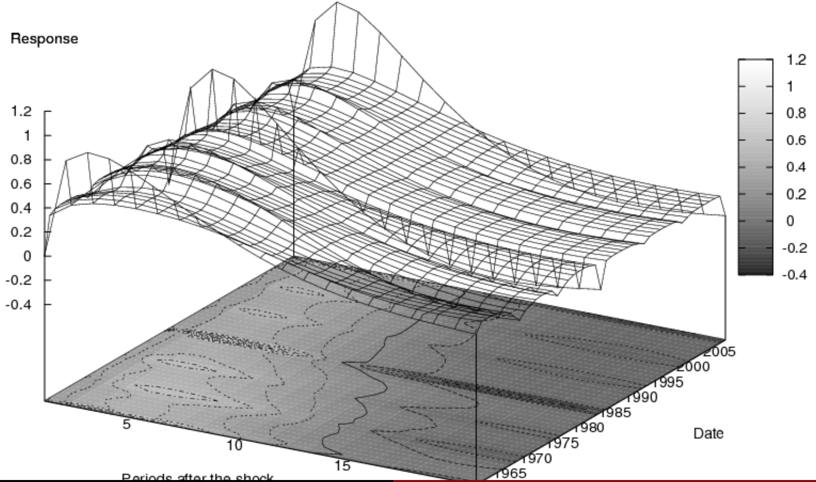

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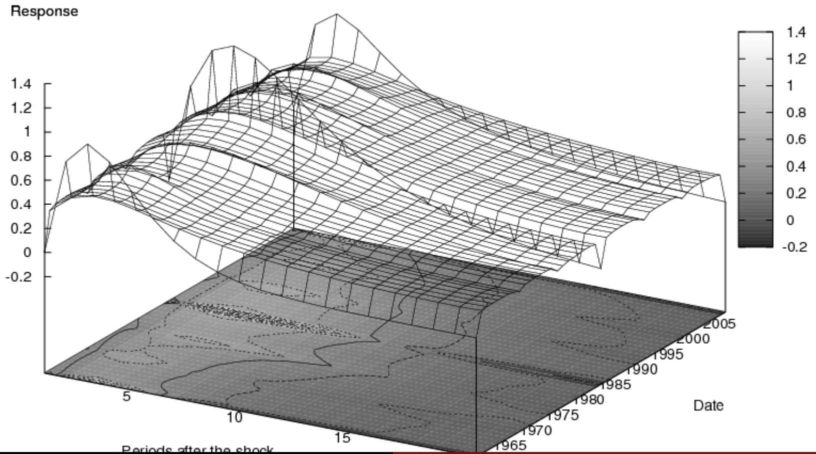

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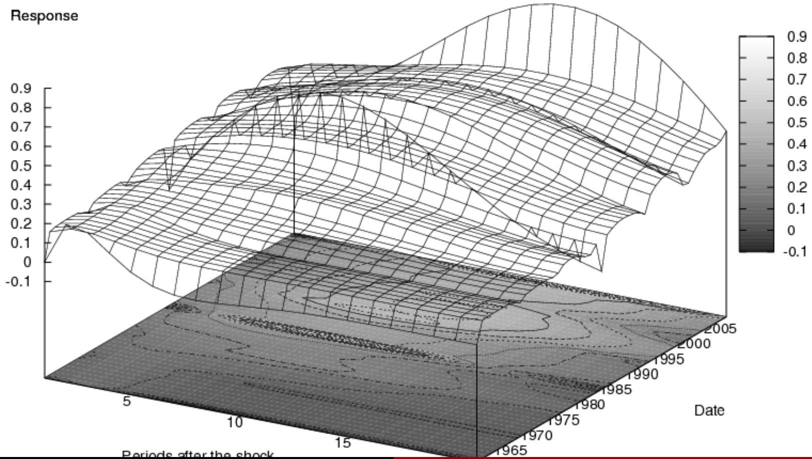

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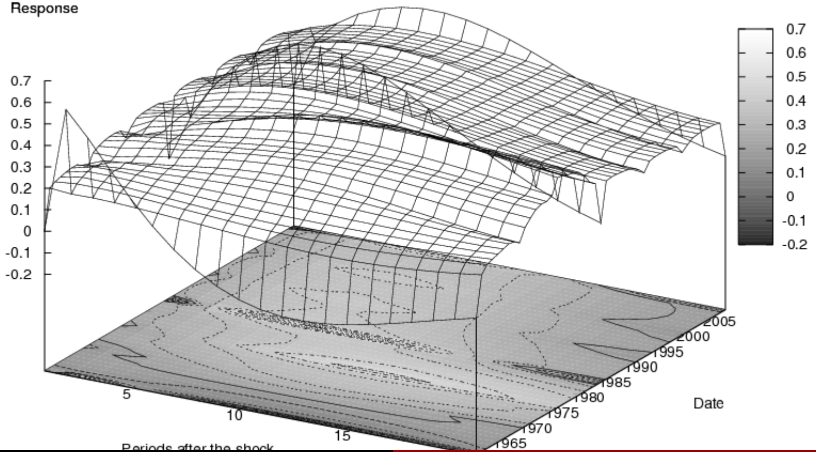

Time Varying Impulse Responses

- Impulse responses are more prolonged in cases 3 and 4 (when agents do not observe structural shocks).
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Conclusions

- Learning gain is statistically significant.
- Otherwise minimal evidence of learning over RE.
- Incorporating learning leads to parameter estimates that imply less sensitivity to expectations.
- Largest errors for every specification still occur during 1970s and early 1980s.
- Learning + Limited information sets leads to prolonged and oscillatory impulse responses.
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