New-Keynesian Macroeconomics and the Term Structure

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Macro 102: Standard New Keynesian Dynamic System

1) AS equation (Phillips curve): Inflation dynamics
- Inflation depends on real variables; unemployment, output
- Concept of natural rate of unemployment or output

2) IS equation: Output dynamics
- Output is linked to past and future output and the real interest rate.

3) Taylor rule: Monetary authority reacts to the output gap and deviations of expected inflation from targeted inflation

Monetary Transmission:
- Effect of real interest rate on output in IS equation (ϕ parameter)
- Effect of output gap on inflation in AS equation (κ parameter)
- Expectational Terms

Dual Motivation

- Standard New-Keynesian (NK) Macro Model: has some clear deficiencies:
  - Truly Minimalist (e.g. Clarida, Galí and Gertler (1999)):
    - Only 3 equations: AS, IS, MP rule
    - Only 3 variables: inflation, output, short-term interest rate $\Rightarrow$ Very Limited Information Sets
  - Does not generate enough persistence to match the data

- Models of the Term Structure (T-S) of Interest Rates
  - In principle, no link from Factors to Economics (e.g. Dai and Singleton (2000))
  - Lack of Economic Interpretation of the Term Structure
  - Typically do not match the yield data

Goals in this paper

- Enlarge the NK Macro Model with relevant unobservable variables which are filtered out using Term Structure Information
  - Provide a Better Fit of the data
  - Get more reliable Estimates of structural parameters
  - Enrich Agents´ Information Sets: Add realism
- Nest the NK Macro Model into a standard Affine Term Structure Model $\Longrightarrow$ Explain the Dynamics of the Term Structure in terms of macro variables

Outline Talk

I. Related Literature/Contributions

II. Model

- Motivation New-Keynesian Model
- Term Structure Model

III. Data and Estimation; Model Selection

IV. Empirical Results

- Macro
- Term Structure

V. Extensions

Related Literature / Motivation

- NK Macro Model Estimation: Rotemberg, Woodford (1999), Ireland (2000), Cho, Moreno (2004)

- Phillips Curves and IS Curves: Galí, Gertler (1999), Fuhrer, Rudebusch (2004)

$\Rightarrow$ - weak transmission mechanism

- hard to generate persistence

Related Literature / Motivation

- Empirical links between spreads and macro variables:
- Estrella, Mishkin (1998); Harvey (1988); Ang, Piazzesi and Wei (2004)

  Term structure variables predict real growth
- Diebold, Rudebusch, Aruoba (2003):

  Macro variables predict term structure variables

- Persistence Puzzle: Gurkaynak, Sack, Swanson (2003), Ellingsen, Soderstrom (2001)

Related Literature / Motivation

⌘ Macro finance:

- Ang, Piazzesi (2003): Gaussian price of risk model

$$r_t = a + b'X_t$$

$$X_t = \Phi X_{t-1} + \Sigma \varepsilon_t$$

$$X_t = [\text{3 latent variables, 2 macro variables}]$$

Φ and Σ block diagonal!

Macro factors particularly important for the spread factor

- Competing papers: Rudebusch, Wu (2003), Hördal, Tristani, Vestin (2003)

Key Features of our NK Model

- DSGE model with
  - Monopolistic competition with Inflation Indexation (AS)
  - External Habit Persistence (IS)
  - Modified Taylor Rule (MP)
- Plus Two unobservables

Unobservables

- Time-Varying Inflation Target: π_t^*
  - Central Bank targets π_t^*
- Natural Rate of Output: $y^n{}_t$
  - Output Gap is $y_t - y^n{}_t$
  - Central Bank targets $y^n{}_t$

IS Curve

⌘ Utility function:

$$U(C_t, N_t) = \frac{F_t C_t^{1-\sigma} - 1}{1-\sigma} - \frac{N_t^{1+\chi}}{1+\chi}, \quad F_t = C_{t-1}^{\eta} G_t$$

- Exogenous Habit
- Separable Labour Supply

$$\Rightarrow y_t = \mu E_t y_{t+1} + (1-\mu) y_{t-1} - \phi(i_t - E_t \pi_{t+1}) + \varepsilon_{IS,t}$$

$$\mu = \frac{\sigma}{\sigma+\eta}; \phi = \frac{1}{\sigma+\eta}$$

AS Curve

- Monopolistically competitive firms produce goods but prices are partially sticky:

$$\pi_t = \delta E_t \pi_{t+1} + (1-\delta)\pi_{t-1} + w\hat{s}_t$$

where δ = f (the degree of indexation to previous inflation)

w = f (proportion "optimizing" firms)

$\hat{s}_t$ = log real marginal cost

- Natural rate of output (Y_t^n): output that would prevail at perfectly flexible prices and shocks at steady state. With simple production function ($Y_t = \zeta_t . N_t$):

$$y_t^n = \lambda y^n_{t-1} + \varepsilon_{y^n,t}$$

- Linking marginal cost and output

Model: $\hat{s}_t = (\chi + \sigma)(y_t - y_t^n - \lambda(y_{t-1} - y_{t-1}^n)) - g_t - (1+\chi)\ln \zeta_t$

Standard: $\hat{s}_t = v(y_t - y_t^n)$

Inflation Target

- Anchored in the expectations of long run inflation, adjusted for lagged inflation target.

$$\pi_t^{LR} = (1-d)\sum_{j=0}^{\infty} d^j E_t \pi_{t+j}$$

$$\Rightarrow \pi_t^{LR} = dE_t \pi_{t+1}^{LR} + (1-d)\pi_t$$

$$\pi_t^* = \omega \pi_{t-1}^* + (1-\omega)\pi_t^{LR} + \varepsilon_{\pi^*,t}$$

$$\Rightarrow \pi_t^* = \varphi_1 E_t \pi_{t+1}^* + \varphi_2 \pi_{t-1}^* + \varphi_3 \pi_t + \varepsilon_{\pi^*,t}$$

- Also more standard specification:

$$\pi_t^* = \varphi_2 \pi_{t-1}^* + \varphi_3 \pi_{t-1} + \varepsilon_{\pi^*,t}$$

Enlarged NK Model

$$\pi_t = \delta E_t \pi_{t+1} + (1-\delta)\pi_{t-1} + \kappa(y_t - y_t^{\ n}) + \varepsilon_{AS,t}$$

$$y_t = \mu E_t y_{t+1} + (1-\mu) y_{t-1} - \phi(i_t - E_t \pi_{t+1}) + \varepsilon_{IS,t}$$

$$y_t^n = \lambda y_{t-1}^n + \varepsilon_{y^n,t}$$

$$\pi_t^* = \varphi_1 E_t \pi_{t+1}^* + \varphi_2 \pi_{t-1}^* + \varphi_3 \pi_t + \varepsilon_{\pi^*,t}$$

$$i_t = \rho i_{t-1} + (1-\rho) i^*{}_t + \varepsilon_{MP,t}$$

$$i^*{}_t = \bar{i}_t + \left[\beta_\pi (E_t \pi_{t+1} - \pi^*{}_t) + \gamma(y_t - y_t^{\ n})\right]$$

Desired Nominal Interest Rate

$$i^*_t = \bar{i}_t + \left[\beta(E_t\pi_{t+1} - \pi_t^*) + \gamma(y_t - y_t^n)\right]$$

(1) $\bar{i}_t = \bar{r} + E_t\pi_{t+1}$

(2) $\bar{i}_t = \bar{r}_t + E_t\pi_{t+1}$

(3) $\bar{i}_t = \bar{i}$

$$\bar{r}_t = \frac{1}{\phi}[\mu E_t y_t{}^n + (1-\mu) y_{t-1}{}^n - y_t{}^n]$$

Rational Expectations Equilibrium

- Structural Model

$$Bx_t = AE_t x_{t+1} + Jx_{t-1} + C\varepsilon_t$$

$$x_t = \left[\pi_t, y_t, i_t, y_t{}^n, \pi_t{}^*\right]'$$

- Reduced Form Model

$$x_t = \Omega x_{t-1} + \Gamma \varepsilon_t$$

subject to non-linear restrictions

$\Rightarrow$ Serve as State Variable Dynamics

Term Structure (T-S) Model

- IS Curve Implied by: $E_t\left[M_{t+1}(1+i_t)\right]=1$
- Implied Pricing Kernel:

$$M_{t+1}=\psi\frac{Y_{t+1}{}^{-\sigma}Y_t{}^{\eta}G_{t+1}}{Y_t{}^{-\sigma}Y_{t-1}{}^{\eta}G_t}\Pi_{t+1}{}^{-1}$$

- Bond pricing

$$E_t\left[M_{t+1}P_{n-1,t+1}\right]=P_{n,t}$$

$P_{n,t}$ n-period bond price

Term Structure (T-S) Model

- Implied Pricing Kernel (in logs):

$$m_{t+1} = \ln(\psi) - \sigma y_{t+1} + (\sigma + \eta) y_t - \eta y_{t-1} - \pi_{t+1} + g_{t+1} - g_t$$

- Bond pricing falls into the Affine class:
  - $p_{n,t} = a_n + b'_n x_t$
  - $p_{n,t}$ n-period bond price
  - a_n constant risk premium (EH embedded)
  - b_n factor loading

Term Structure (T-S) Model

- Bond yield: $$i_{n,t} = -\frac{a_n}{n} - \frac{b_n}{n} x_t$$
- Yield Spread: $$sp_{n,t} = -\frac{a_n}{n} - (\frac{b_n}{n} + e_3)' x_t$$

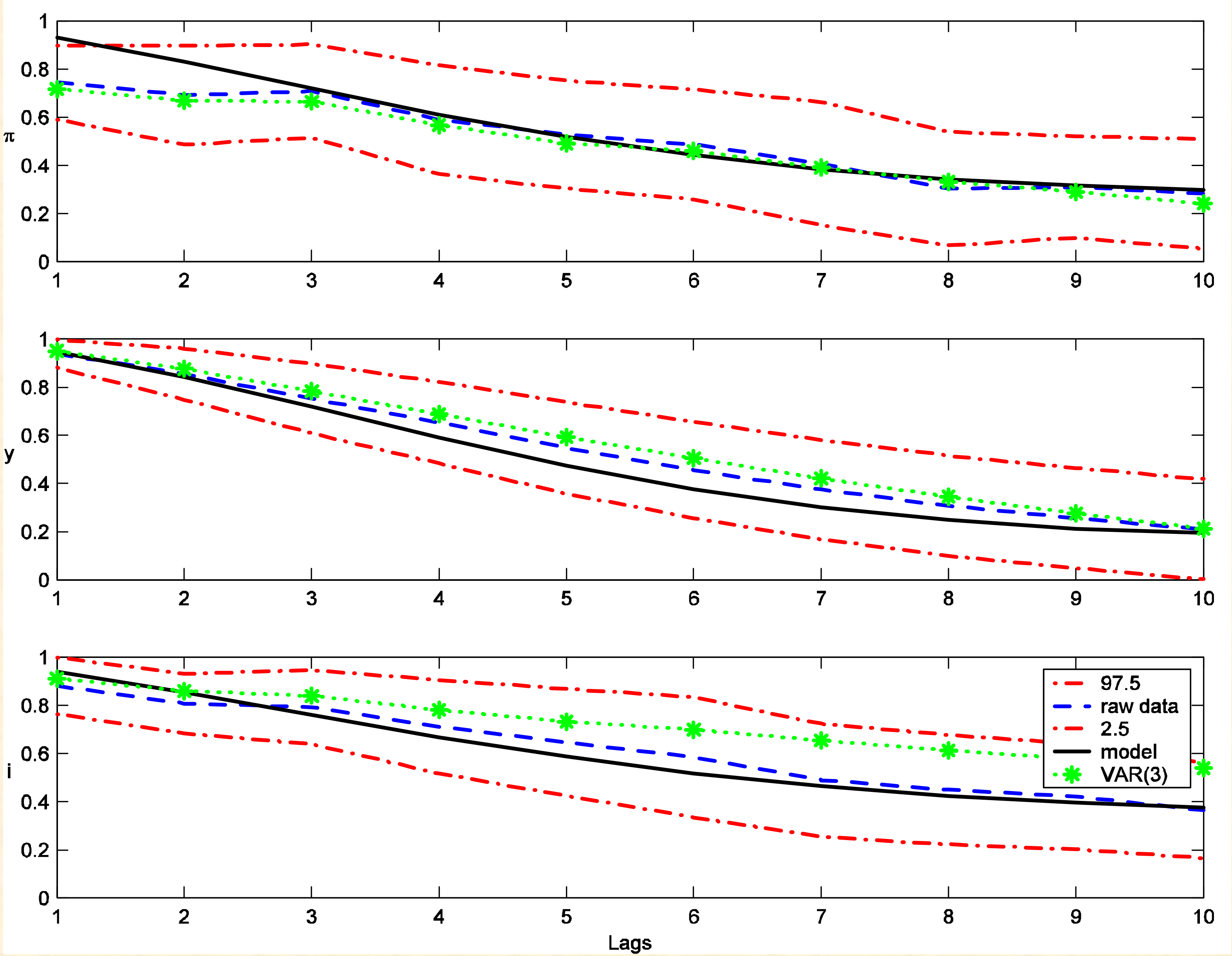
Strategy

- Filter unobservable inflation target and the output gap through the term structure.
- Macro Model Solution expressed as:
  - $x_t = \Omega x_{t-1} + \Gamma \varepsilon_t \qquad x_t = \left[\pi_t, y_t, i_t, y_t^{\,n}, \pi_t^{\,*}\right]'$
- T-S Model Implied by NK System:
  - $z_t = B_z x_t \qquad z_t = \left[\pi_t, y_t, i_t, sp_{n_1,t}, sp_{n_2,t}\right]'$
- Full System of Observables can be estimated:
  - $z_t = \Omega_z z_{t-1} + \Gamma_z \varepsilon_t = B_z \Omega B_z^{-1} z_{t-1} + B_z \Gamma \varepsilon_t$

Data and Estimation

- Model estimated with U.S. data (1961-2003): CPI inflation, Detrended Output, 3 month T-Bill, 3 and 5 year spreads
- GMM Estimation Approach with Bootstrapped Standard Errors
    - First stage with “theoretical” weighting matrix
    - Iterate till convergence
    - 7 of 12 specifications converged

Autocorrelogram: Criterion to Choose among Models



Estimated NK Model

$$\pi_t = 0.61^* E_t \pi_{t+1} + 0.39^* \pi_{t-1} + 0.06^* (y_t - y_t{}^n) + \varepsilon_{AS,t}$$

$$y_t = 0.42^* E_t y_{t+1} + 0.58^* y_{t-1} - 0.13^* (i_t - E_t \pi_{t+1}) + \varepsilon_{IS,t}$$

$$i_t = 0.72^* i_{t-1} + 0.28^* i^*{}_t + \varepsilon_{MP,t}$$

$$i^*{}_t = E_t \pi_{t+1} + \left[0.53^* (E_t \pi_{t+1} - \pi^*{}_t) + 0.001 (y_t - y_t{}^n) \right]$$

$$y_t{}^n = 0.96^* y_{t-1}{}^n + \varepsilon_{y^n,t}$$

$$\pi^*{}_t = 0.492^* E_t \pi^*{}_{t+1} + 0.498^* \pi^*{}_{t-1} + 0.01 \pi_t + \varepsilon_{\pi^*,t}$$

	CR,EI,N	Std Error		Cross-Model			
Parameter	Estimate	GMM	Bootstrap	Average	Std Error	Min	Max
δ	0.611	(0.010)	(0.031)	0.572	(0.038)	0.525	0.626
κ	0.064	(0.007)	(0.022)	0.075	(0.044)	0.041	0.174
σ	3.156	(0.466)	(1.632)	3.205	(0.322)	2.727	4.952
η	4.294	(0.470)	(1.383)	4.780	(1.024)	3.469	6.796
ρ	0.723	(0.028)	(0.083)	0.799	(0.068)	0.705	0.915
β_π	1.525	(0.148)	(0.251)	2.381	(0.954)	1.525	2.999
γ	0.001	(0.047)	(0.020)	0.013	(0.020)	0.001	0.057
λ	0.958	(0.006)	(0.026)	0.945	(0.020)	0.910	0.975
ω	0.877	(0.013)	(0.031)	0.924	(0.040)	0.810	0.979
d	0.866	(0.014)	(0.041)	0.959	(0.062)	0.757	0.990
σ_{AS}	1.249	(0.053)	(0.123)	1.326	(0.162)	1.191	1.690
σ_{IS}	0.671	(0.033)	(0.055)	0.682	(0.027)	0.658	0.739
σ_{MP}	2.177	(0.119)	(0.287)	2.538	(1.105)	1.222	4.18
σ_{y^n}	1.380	(0.115)	(0.817)	1.691	(0.878)	0.601	2.947
σ_{π^*}	0.730	(0.059)	(0.723)	0.854	(0.698)	0.370	2.388

Implied	CR,EI,N	Std Error		Cross-Model			
Parameter	Estimate	GMM	Bootstrap	Average	Std Error	Min	Max
μ	0.424	(0.013)	(0.026)	0.420	(0.013)	0.401	0.445
ϕ	0.134	(0.017)	(0.029)	0.126	(0.023)	0.085	0.160
φ_1	0.500	(0.003)	(0.007)	0.395	(0.229)	0.492	0.533
φ_2	0.492	(0.003)	(0.005)	0.377	(0.219)	0.466	0.497
φ_3	0.008	(0.002)	(0.003)	0.003	(0.004)	0.000	0.009
$\tilde{\varphi}_2$				0.934	(0.006)	0.929	0.941
$\tilde{\varphi}_3$				0.048	(0.012)	0.034	0.057
$\hat{\chi}$				2.022			
$\hat{\varpi}$				0.025			
$\hat{\tau}$				0.703			
$\hat{\theta}$				0.818			
$\hat{\zeta}$				0.293			
$\hat{\vartheta}$				1.685			

Macro Findings

- Statistically significant Monetary Transmission Mechanism: Phillips curve parameter and elasticity of output to real rate significant: T-S Information is doing the job!
- Both Forward and Backward-Looking Components significant. Unobservables quite persistent
- What do the unobservables look like?

Figure 2: Output Gap and Natural Rate of Output

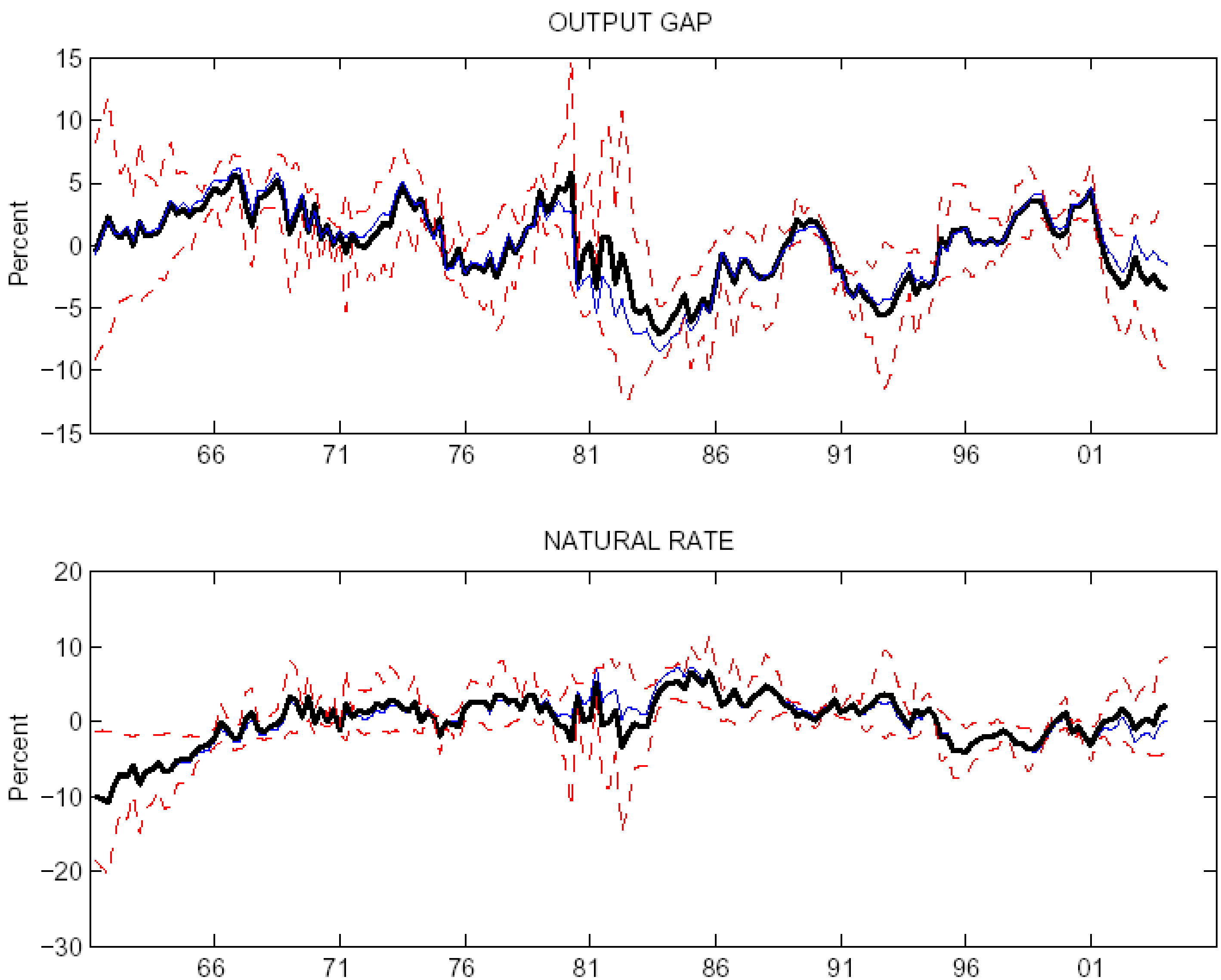


Figure 3: Inflation Target and Inflation

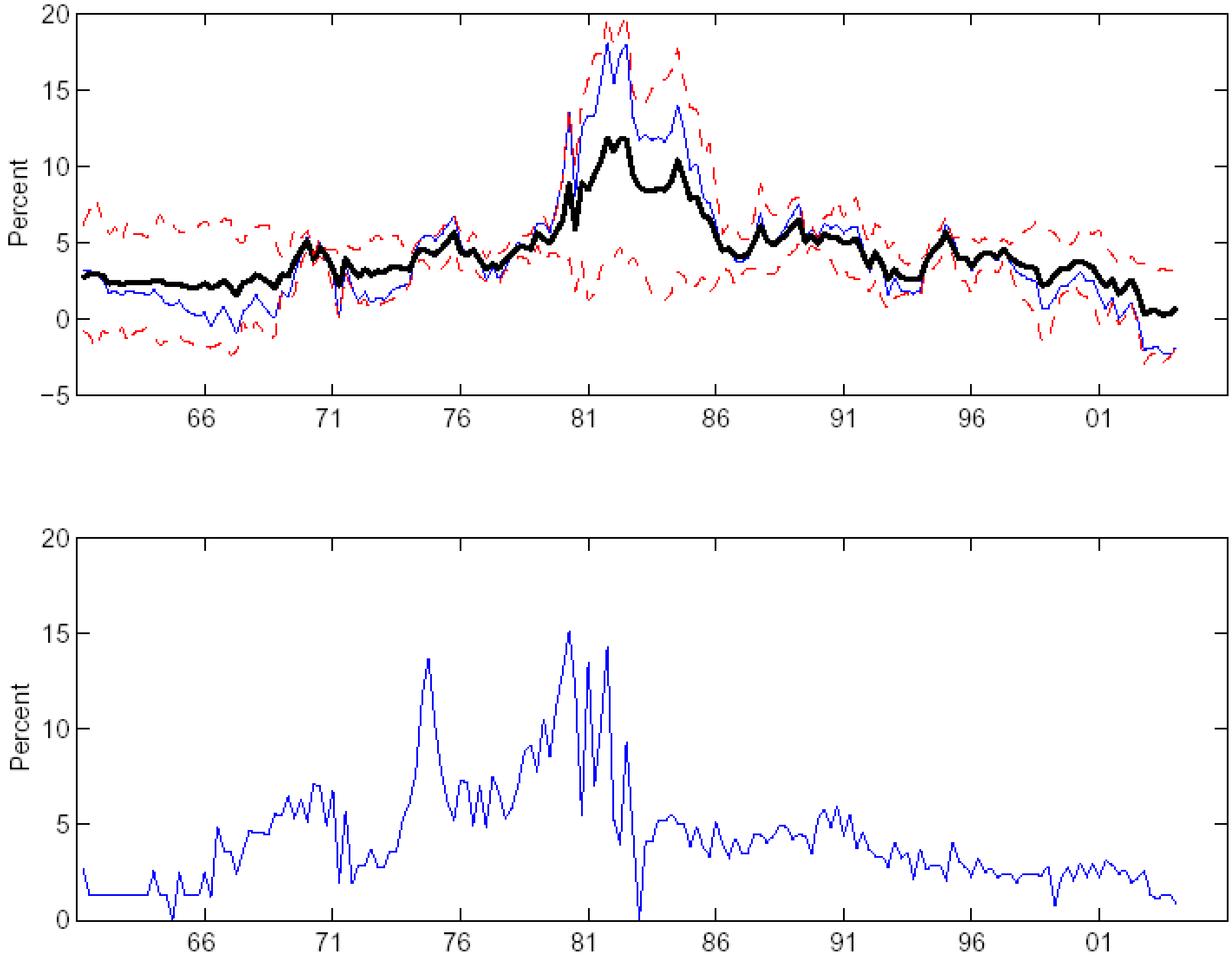


Figure 4: Impulse Response Functions of Macro Variables

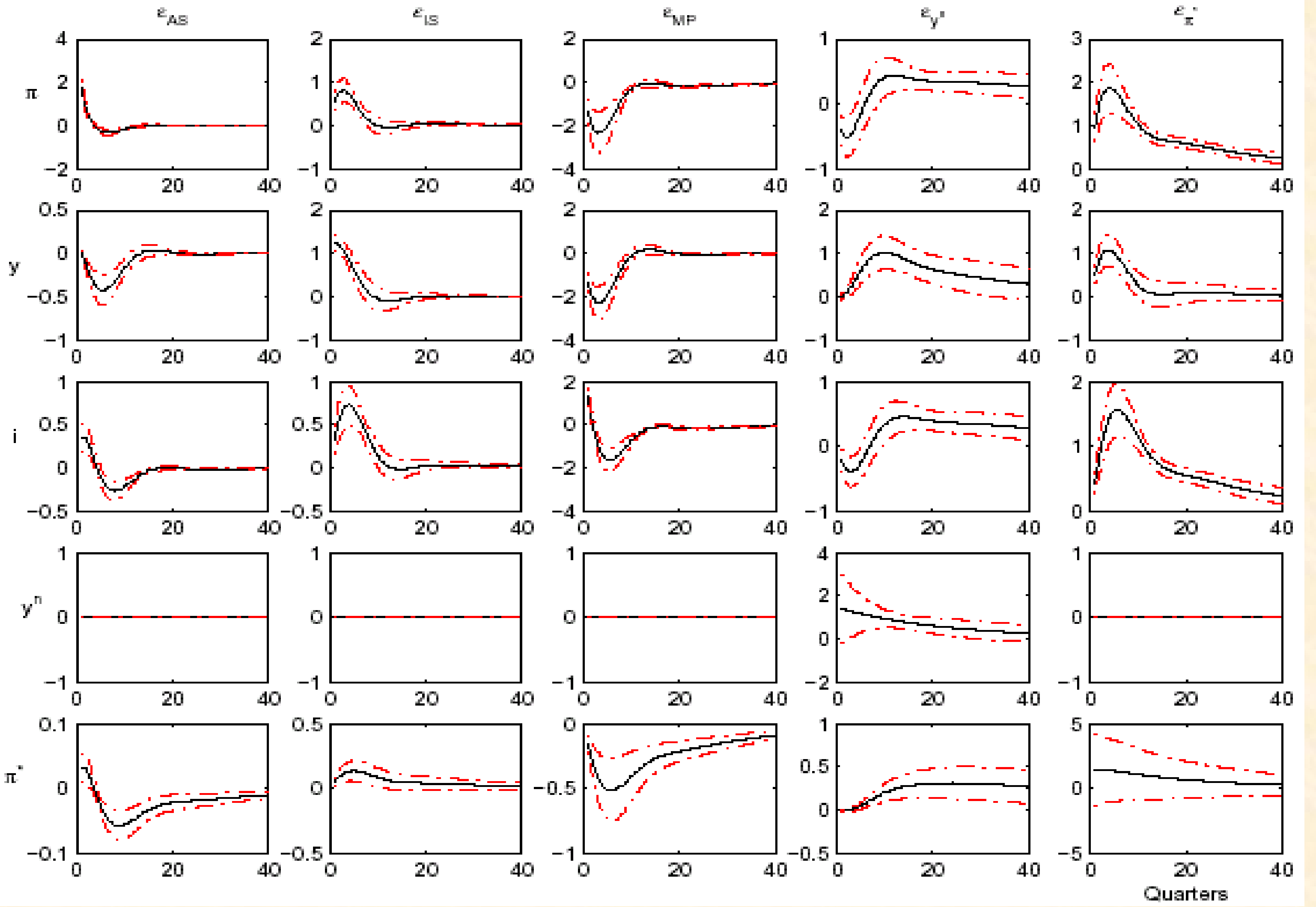
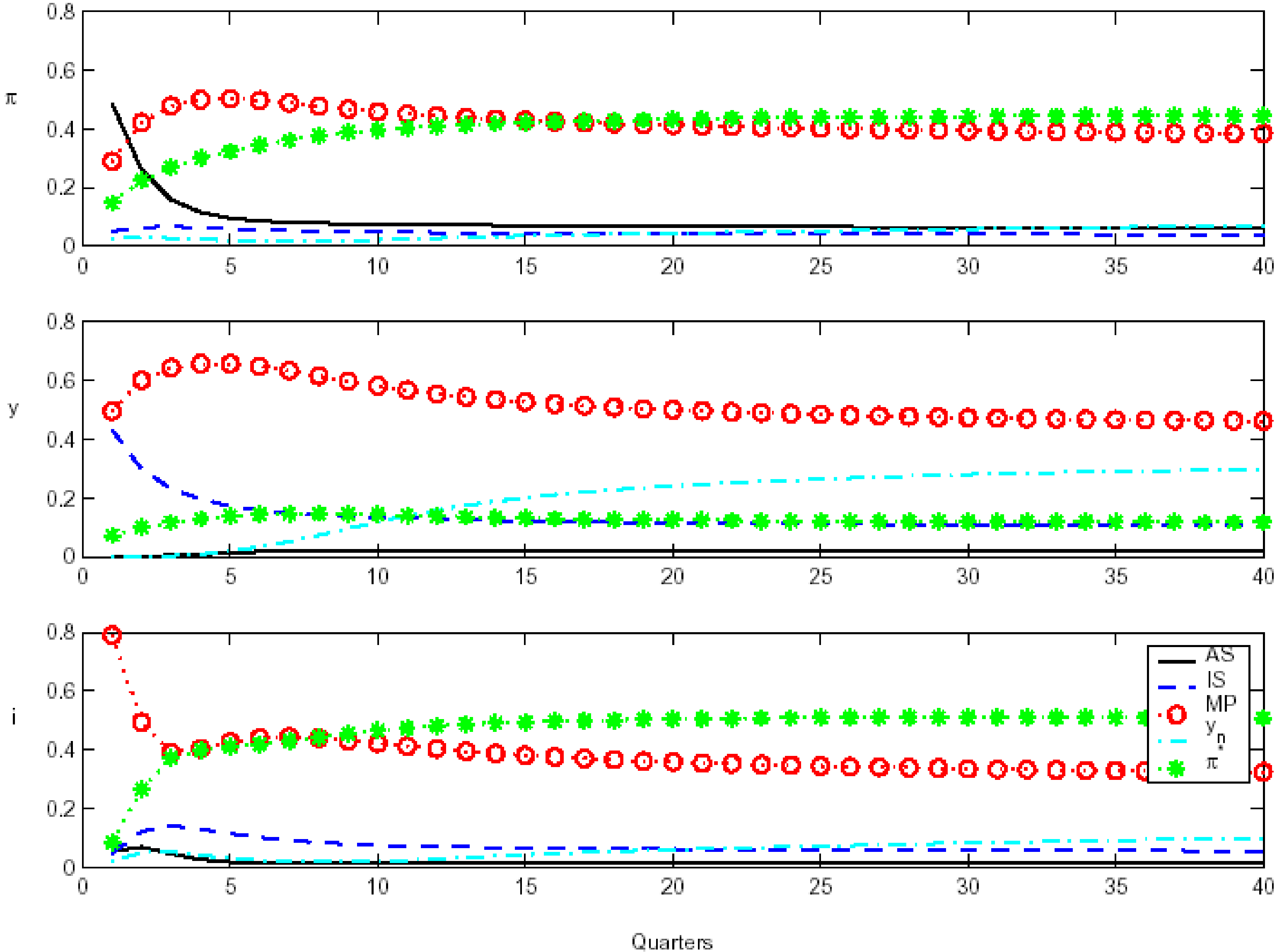


Figure 5: Variance Decompositions for the Macro Variables



Term Structure Findings

- 5 Macro factors match the Yield Fairly well
- Interpretable Yield Movement
  - Factors are not orthogonal
  - Can be interpreted in terms of Structural Shocks

$$i_{n,t} = -\frac{b'_n}{n} x_t = -\frac{b'_n}{n} \Omega x_{t-1} - \frac{b'_n}{n} \Gamma \varepsilon_t$$

- Monetary Policy and Inflation Target shocks are the major driving forces of the T-S.
- Predictability and Excess sensitivity

Figure 6: Fit for Yields

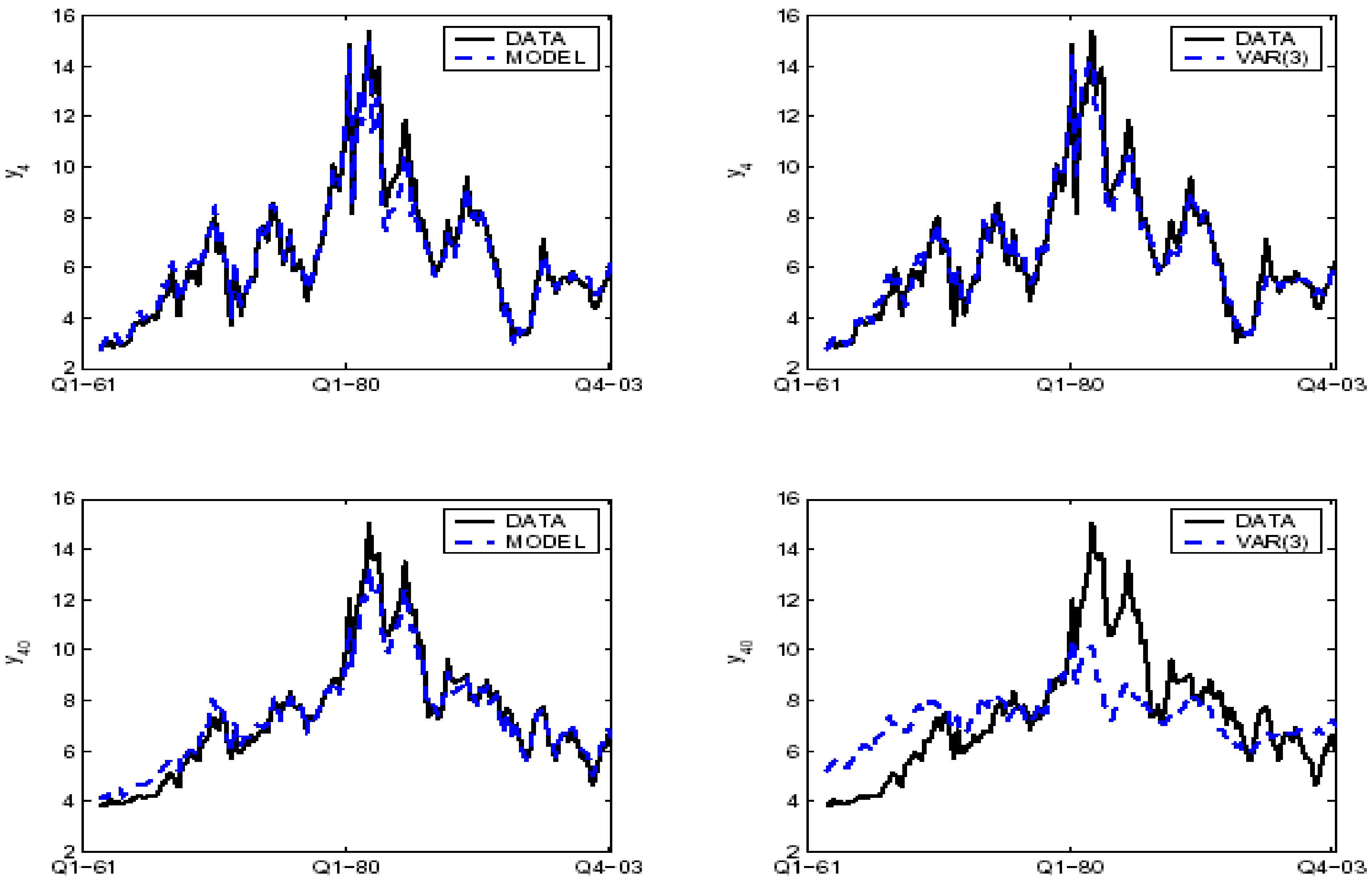


Figure 8: Variance Decompositions for the Term Structure Factors

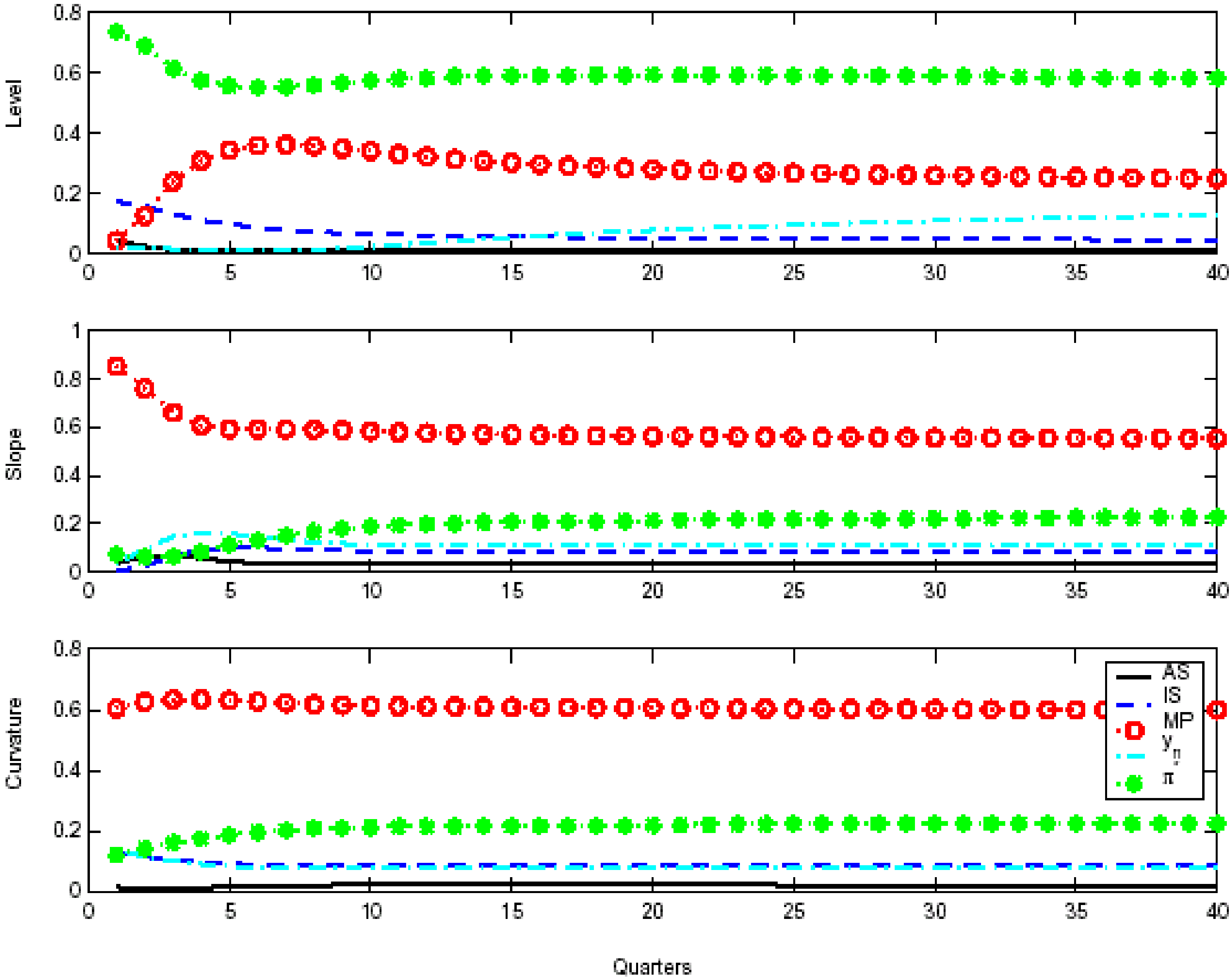
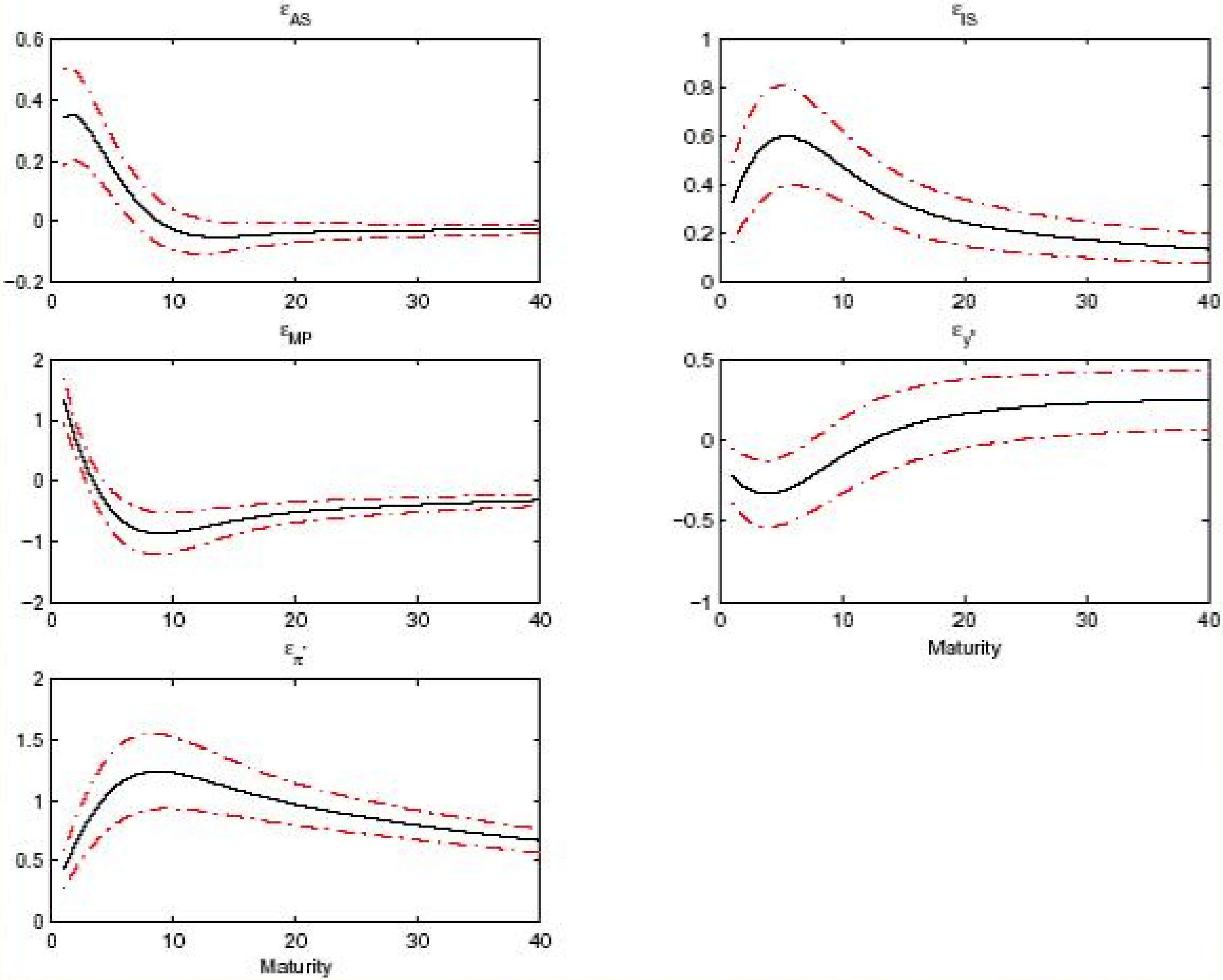


Figure 9: Contemporaneous Responses of Yields to Macro Shocks



Main Results

- Phillips Curve and Interest Rate Demand Channel both Large and Statistically Significant
  - Strong and Significant Monetary Policy Transmission Mechanism to Output and Inflation

- Monetary Factors Drive the Yield Curve
  - Level is driven by inflation target shocks
  - Slope and Curvature driven by Monetary Policy Shock

Extensions

- Include the permanent component of output in the Macro System:
  - Assume that Output and Natural Rate are Cointegrated
- Generate Time-Varying Risk Premia
  - Square Root Processes
  - Devise Theoretical Model with endogenous Risk Premia
- Think about regime shifts/structural breaks