Term Structure of Interest Rates and the Macroeconomy

Monika Piazzesi
University of Chicago, CEPR & NBER

CEPR Summer Institute, July 28, 2005

- Overview
  - issues
  - old approaches
  - some current approaches
  - future research

- "No Arbitrage Taylor Rules"

  joint with Andrew Ang and Sen Dong, Columbia University

Issues

- Information contained in the term structure

  for *business cycle measurement*

  spread between short & long Treasuries, corporate bond spreads

  ★ leading indicators

  – Stock and Watson 1989 leading index

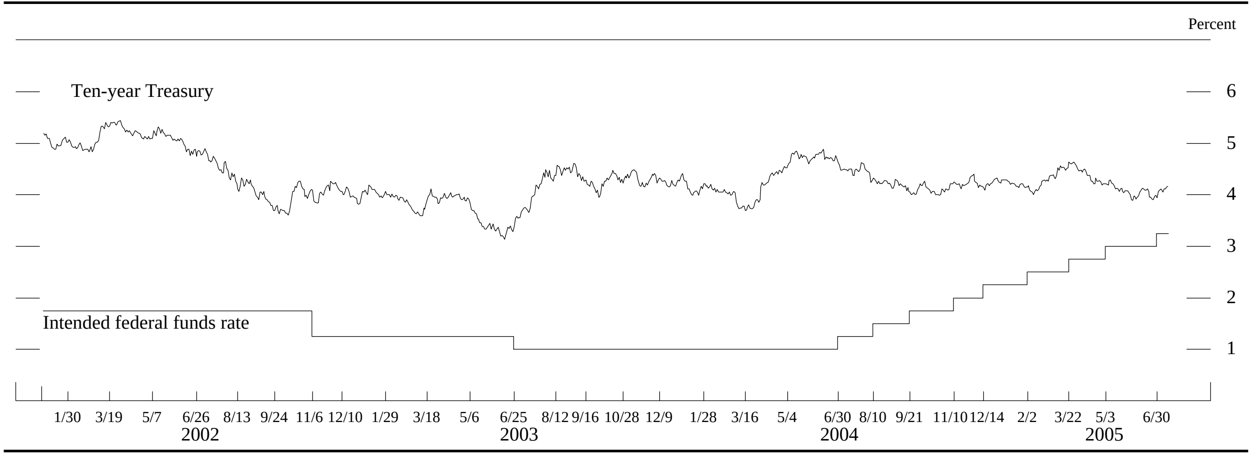
  – Monetary policy

    * 2 famous books in color: Green Book & Blue Book

    * Greenspan's Monetary Policy Report to Congress on July 20, 2005

    * Conundrum!?

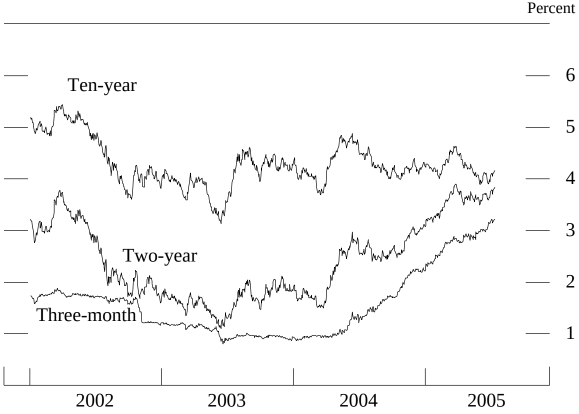
Selected interest rates



NOTE: The data are daily and extend through July 13, 2005. The ten-year Treasury rate is the constant-maturity yield based on the most actively traded securities. The dates on the horizontal axis are those of FOMC meetings.

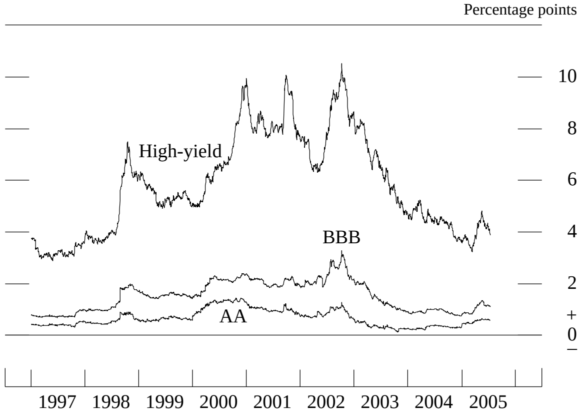
SOURCE: Department of the Treasury and the Federal Reserve.

Interest rates on selected Treasury securities



NOTE: The data are daily and extend through July 13, 2005.
SOURCE: Department of the Treasury.

Spreads of corporate bond yields over comparable off-the-run Treasury yields



NOTE: The data are daily and extend through July 13, 2005. The high-yield index is compared with the five-year Treasury yield, and the BBB and AA indexes are compared with the ten-year Treasury yield.
SOURCE: Merrill Lynch AA and BBB indexes and Merrill Lynch Master II high-yield index.

has fallen about 30 basis points over this period. A second possible explanation is investors' willingness to accept smaller risk premiums on long-term securities amid

Spreads of yields on investment-grade corporate debt over those on comparable-maturity Treasury securities

- information for policy makers: what is the market expecting?
  - inflation

    spread between Treasuries and TIPS

    ★ liquidity, risk premia?
  - next recession

    spread between short and long Treasuries

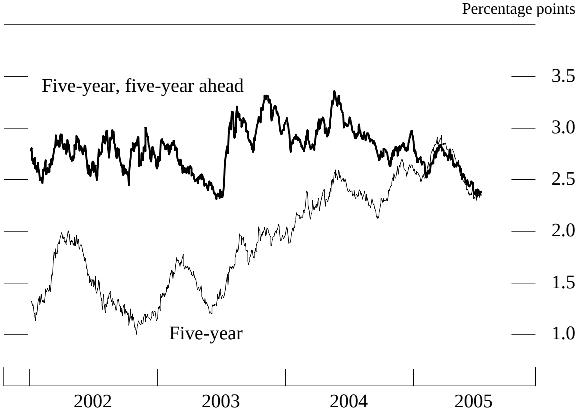
    ★ why univariate regression?
  - "what we are going to do"

    fed funds futures

    ★ risk premia?
  - "how uncertain are they about what we are going to do": implied volatility from interest-rate options

    ★ Black-Scholes?

TIPS-based inflation compensation



NOTE: The data are daily and extend through July 13, 2005. Based on a comparison of the yield curve for Treasury inflation-protected securities (TIPS) to the nominal off-the-run Treasury yield curve.

SOURCE: Federal Reserve Board calculations based on data provided by the Federal Reserve Bank of New York and Barclays.

- effects of monetary policy
  - if the Fed increases the target for the short rate by 25 bp,

    how much will long term rates go up?
  - identification of "monetary policy shocks"

    proxy $E_t[r_{t+1}]$ with high-frequency data on fed funds futures

    $r_{t+1} - E_t[r_{t+1}] =$ "shock"

    ★ risk premia?
  - impulse responses – effects on investment, output, prices, etc.

- how should the Fed conduct monetary policy? e.g. more "transparency"?

- premia on bonds - are they large? do they vary over the business cycle?

  compared with equity premia?

Benchmark — expectations hypothesis

$$\begin{aligned} y_t^{(n)} &= \text{time-}t \text{ yield on bond with } n \text{ periods to go} \\ &= \frac{1}{n} E_t \left[\sum_{i=0}^{n-1} r_{t+i} \right] \end{aligned}$$

- Sargent 1969 imposes *cross equation restrictions* on a VAR with

$$Y_t = \begin{pmatrix} y_t^{(1)} \\ y_t^{(2)} \\ \vdots \end{pmatrix} \text{ where } y_t^{(1)} = r_t$$

- assumes risk neutrality

  ★ why is the equity premium so high?

- ignores Jensen's inequality terms

  ★ Campbell 1985 – are big, especially in the 1970s and for long bonds

Benchmark — expectations hypothesis ctd.

- standard practice at the Fed: e.g., futures rates = expected rates in the future

- nominal rate = real rate + expected inflation

  assume real rate is constant

  $\Longrightarrow$ Treasuries move because expected inflation moves

- e.g. Fama and Schwert 1977 – predict stock returns with "expected inflation"

  "expected inflation" = nominal rate

.... *term structure model*

no arbitrage implies that we can compute bond prices recursively

$$P_t^{(n)} = E_t \left[M_{t+1} P_{t+1}^{(n-1)} \right]$$

starting at $P_t^{(1)} = \exp(-r_t)$

- implied by no arbitrage — there exists an M

- holds in most DSGE models

.... *term structure model*

no arbitrage implies that we can compute bond prices recursively

$$P_t^{(n)} = E_t\left[M_{t+1}P_{t+1}^{(n-1)}\right]$$

starting at $P_t^{(1)} = \exp(-r_t)$

Affine ....

1. linear short rate: $r_t = \delta_0 + \delta_1^\top X_t$

2. linear dynamics: $X_t = \mu + \phi X_{t-1} + \mathbf{\Sigma}\varepsilon_t, \quad \varepsilon_t \sim N(0, I)$

2. linear risk premia: $M_{t+1} = \exp\left(-r_t - \frac{1}{2}\lambda_t{}^\top\lambda_t - \lambda_t{}^\top\varepsilon_{t+1}\right)$

$$\lambda_t = l_0 + l_1 X_t$$

Affine term structure model ctd.

Result: $y_t^{(n)} = a_n + b_n X_t$, where a_n, b_n solve ordinary difference equations

which depend on $(\delta_0, \delta_1, \mu, \phi, \Sigma)$ and (l_0, l_1)

VAR	unstricted dynamic system
⋮	
state space system	fewer dimensions, fewer parameters
⋮	
term structure model	consistency of a_n, b_n with expectations
⋮	discrete time (Ang & Piazzesi 2003): many AR lags
⋮	
DSGE	more restrictions
	standard preferences:
	"bond premium puzzle", predictability of bond returns

Term structure model $\longrightarrow$ DSGE model

- small VAR for some macro variables & interest rates

- same variables are factors

- model guides predictions:

  - macro variables help forecasting interest rates (Ang & Piazzesi 2003)

  - nominal short rate does better at forecasting GDP growth than term spreads in particular: low r forecasts high GDP growth (Ang, Wei & Piazzesi 2005)

    - contradicts OLS regressions where reverse is true

    - verified in out-of-sample forecasts

  - longest nominal - short rate is the best predictors

  - always include lagged GDP growth, at least for short forecasting horizons

Term structure model $\longrightarrow$ DSGE model

- large countercyclical risk premia
  - "tent-shape" function of forward rates
  - matters for using fed funds futures for forecasting and defining monetary policy shocks

- "Great Inflation"
  - Volcker was unlucky – Greenspan was lucky about the size of shocks

    heteroskedasticity – Pearson and Sun 1994, Buraschi and Jiltsov 2005

    regime switches with constant mean parameters – Sims 2004, Sims and Zha 2004, Ang and Bekaert 2005,
  - Volcker and Greenspan conducted policy in different ways

    regime switches in mean parameters – Bansal and Zhou 2002, Bansal, Tauchen and Zhou 2004

- Investors in the 1970s did not see Greenspan coming

  structural breaks – subsample estimations

  Rudebusch and Wu 2005, Ang, Dong & Piazzesi 2004

- Heterogeneous expectations about inflation

  old households expect low inflation, young households expect high inflation

  Piazzesi and Schneider 2005

- What happens after Greenspan???

  tradesports.com: Bernanke 34%, Feldstein 16%, Hubbard 14%, Taylor 2.5%

  do long-term bond prices correctly price in inflation expectations?

Hybrid models

- "IS curve" derived from Euler equation, but pricing kernel is flexible

  Rudebusch and Wu 2004

DSGE model $\longrightarrow$ *term structure model*

- need to take a stance on inflation
  - money in the (nonseparable) utility function – Bakshi and Chen 1996
  - taxes – Buraschi and Jiltsov 2005
  - exogenous process fixed by the monetary authority –

    CIR 1985, Bekaert and Grenadier 2001, Wachter 2005

- "fancy preferences" – explains predictability and matches up with equity predictability – Wachter 2005

"No Arbitrage Taylor Rules"

- Prices & yields of long-term bonds embed expectations about the future

$$
\begin{aligned}
y_t^{(n)} &= \text{time-}t \text{ yield on bond with } n \text{ periods to go} \\
&= \frac{1}{n} E_t \left[\sum_{i=0}^{n-1} r_{t+i} \right] + \text{term premium (+ Jensen's inequality terms)}
\end{aligned}
$$

  - implied by the absence of arbitrage
  - holds in equilibrium of most DSE models

- Nominal short rate r_{t+i} is set using Taylor rule (+ possibly shock)

- Advantages
  - understand term structure movements – in terms of policy expectations
  - estimate policy rules – with panel data on yields

Fix the affine term structure model.......................................

$$r_t = \delta_0 + \delta_1^\top X_t$$

where $X_t = (g_t, \pi_t, f_t^u)^\top$

$g_t =$ GDP growth

$\pi_t =$ inflation

$f_t^u =$ latent factor

$$X_t = \begin{pmatrix} f_t^o \\ f_t^u \end{pmatrix} = \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix} + \begin{pmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{pmatrix} \begin{pmatrix} f_{t-1}^o \\ f_{t-1}^u \end{pmatrix} + \begin{pmatrix} u_t^1 \\ u_t^2 \end{pmatrix}$$

...and consider different policy rules

Fix the affine term structure model..

$r_t = \delta_0 + \delta_1^\top X_t$, where $X_t = (g_t, \pi_t, f_t^u) = (f_t^o, f_t^u)$

..and consider different policy rules

a.) Taylor rule (Taylor 1993)

- $r_t = \gamma_0 + \gamma_{1,g}\, g_t + \gamma_{1,\pi}\pi_t + \varepsilon_t^{MP,T}$
- recursive identification: g_t and π_t don't react within the quarter

  Christiano, Eichenbaum & Evans 1996
- find structural parameters γ:
  - $\gamma_0 = \delta_0$, $\gamma_{1,g} = \delta_{1,g}$, $\gamma_{1,\pi} = \delta_{1,\pi}$
  - $\varepsilon_t^{MP,T} = \delta_{1u} f_t^u$

Fix the affine term structure model...

$r_t = \delta_0 + \delta_1^\top X_t$, where $X_t = (g_t, \pi_t, f_t^u)^\top$

$$X_t = \begin{pmatrix} f_t^o \\ f_t^u \end{pmatrix} = \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix} + \begin{pmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{pmatrix} \begin{pmatrix} f_{t-1}^o \\ f_{t-1}^u \end{pmatrix} + \begin{pmatrix} u_t^1 \\ u_t^2 \end{pmatrix}$$

..and consider different policy rules

b.) Backward-looking Taylor rule (Clarida, Gali & Gertler 1998 and others)

- includes current and lagged macro variables and short rates:

  $$r_t = \gamma_0 + \gamma_{1,g}\, g_t + \gamma_{1,\pi}\pi_t + \gamma_{2,g}\, g_{t-1} + \gamma_{2,\pi}\, \pi_{t-1} + \gamma_{2,r} r_{t-1} + \varepsilon_t^{MP,B}$$

- find structural parameters γ:

  - γ_0, $\gamma_{1,g} = \delta_{1,g}$, $\gamma_{1,\pi} = \delta_{1,\pi}$, ... $\gamma_{2,r} = \phi_{22}$

  - $\varepsilon_t^{MP,B} = \delta_{1,u} u_t^2$

c.) Finite-Horizon Forward-looking Taylor rule (Clarida and Gertler 1997 and others)

- include future expected inflation and GDP growth

$$r_t = \gamma_0 + \gamma_{1,g}\ E_t\left[g_{t+k,k}\right] + \gamma_{1,\pi}\ E_t\left[\pi_{t+k,k}\right] + \varepsilon_t^{MP,F}$$

where

$$\begin{aligned} E_t\left[g_{t+k,k}\right] &= \frac{1}{k}E_t\left[\sum_{i=1}^{k} g_{t+i}\right] \\ E_t\left[\pi_{t+k,k}\right] &= \frac{1}{k}E_t\left[\sum_{i=1}^{k} \pi_{t+i}\right] \end{aligned}$$

- find structural parameters γ by noting that

$$E_t\left[X_{t+1}\right] = \mu + \phi X_t$$

d.) Infinite-Horizon Forward-Looking Rule

- Fed discounts at rate β

$$r_t = \gamma_0 + \gamma_{1,g}\ E_t\left[\sum_{i=1}^{\infty} \beta^i g_{t+i}\right] + \gamma_{1,\pi}\ E_t\left[\sum_{i=1}^{\infty} \beta^i \pi_{t+i}\right] + \varepsilon_t^{MP,F}$$

Estimation Method

Baysian MCMC and Gibbs Sampling

- handles measurement error $\varepsilon_t^{(n)}$ on all yields

$$\widehat{y}_t^{(n)} = y_t^{(n)} + u_t^{(n)}$$

- handles non-linear parameter restrictions
  - no arbitrage restrictions
  - additionally, forward-looking rules restrictions
- handles more flexible parametrization than maximum likelihood
- impose stationarity with prior
- quarterly data 1952-2002 on $g_t =$GDP growth, $\pi_t =$CPI inflation, and CRSP yields

Estimation Results

- Term structure model
  - Model matches (Table 3)
    - unconditional moments
    - autocorrelations
  - Latent factor is highly persistent and highly correlated with the longest yield
  - Model matches predictability regressions of excess returns
- Structural
  - Variance decompositions
  - Policy rules + shocks

Predictability results

LHS = return from buying the n-period bond at t and selling at $t+1$ in excess of the 1-period riskfree rate

	Data				Model			
	g_t	π_t	$y_t^{(20)}$	R^2	g_t	π_t	$y_t^{(20)}$	R^2
n=4	-.07	-.08	0.22	0.04	-.04	-.04	.16	0.04
	(.06)	(.09)	(.10)		(.05)	(.07)	(.08)	
n=20	-.24	-.72	1.13	0.04	-0.36	-.96	1.33	0.06
	(.27)	(.37)	(.45)		(0.27)	(.39)	(.43)	

Risk premia

– are countercyclical: low when GDP and inflation is high, long rates are low

– increase with maturity

– 2/3 of the variance in expected excess returns explained by macro variables

Variance decompositions

Macro variables explain

– roughly 1/3 of the yield variance

– almost all of the variance in yield spreads (especially inflation)

Variance Decompositions (in %, CEE ordering)

	yield levels			yield spreads		
maturity	g	π	f^u	g	π	f^u
1 quarter	12.5	28.7	58.8			
1 year	12.9	25.2	62.0	.5	87.3	12.2
3 years	13.0	21.2	65.8	.2	92.4	7.4
5 years	13.0	19.8	67.2	.6	96.0	3.4

Policy Rules ctd.

Taylor rule: $r_t = \gamma_0 + \gamma_{1,g} g_t + \gamma_{1,\pi} \pi_t + \varepsilon_t^{MP,T}$

	Full Sample		Pre-82:Q4		Post-83:Q1	
	OLS	Model	OLS	Model	OLS	Model
const	.01	.01	.06	.01	.01	.01
	(.001)	(.001)	(.001)	(.05)	(.002)	(.001)
g_t	.04	.06	.004	.05	.24	.03
	(.07)	(.01)	(.08)	(.02)	(.10)	(.04)
π_t	.64	.28	.68	.27	.61	.24
	(.08)	(.03)	(.08)	(.03)	(.13)	(.05)

Policy Rules ctd.

Backward-looking Taylor rule

	const	g_t	π_t	g_{t-1}	π_{t-1}	r_{t-1}	R^2
OLS	.00	.07	.18	-.01	-.08	.88	.89
	(.00)	(.03)	(.05)	(.03)	(.04)	(.04)	
Model	.01	.06	.28	-.01	-.20	.92	.96
	(.00)	(.01)	(.03)	(.02)	(.03)	(.02)	
Taylor	.01	.06	.28				
	(.00)	(.01)	(.03)				

$$r_t = (1-.92)(.001+.72g_t+3.61\pi_t-.16g_{t-1}-2.52\pi_{t-1})+.92r_{t-1}+\varepsilon_t^{\text{MP,B}}$$

Long-run response to inflation: 3.61-2.52=1.09

Policy Rules ctd.

♣ Forward-Looking, Infinite Horizon

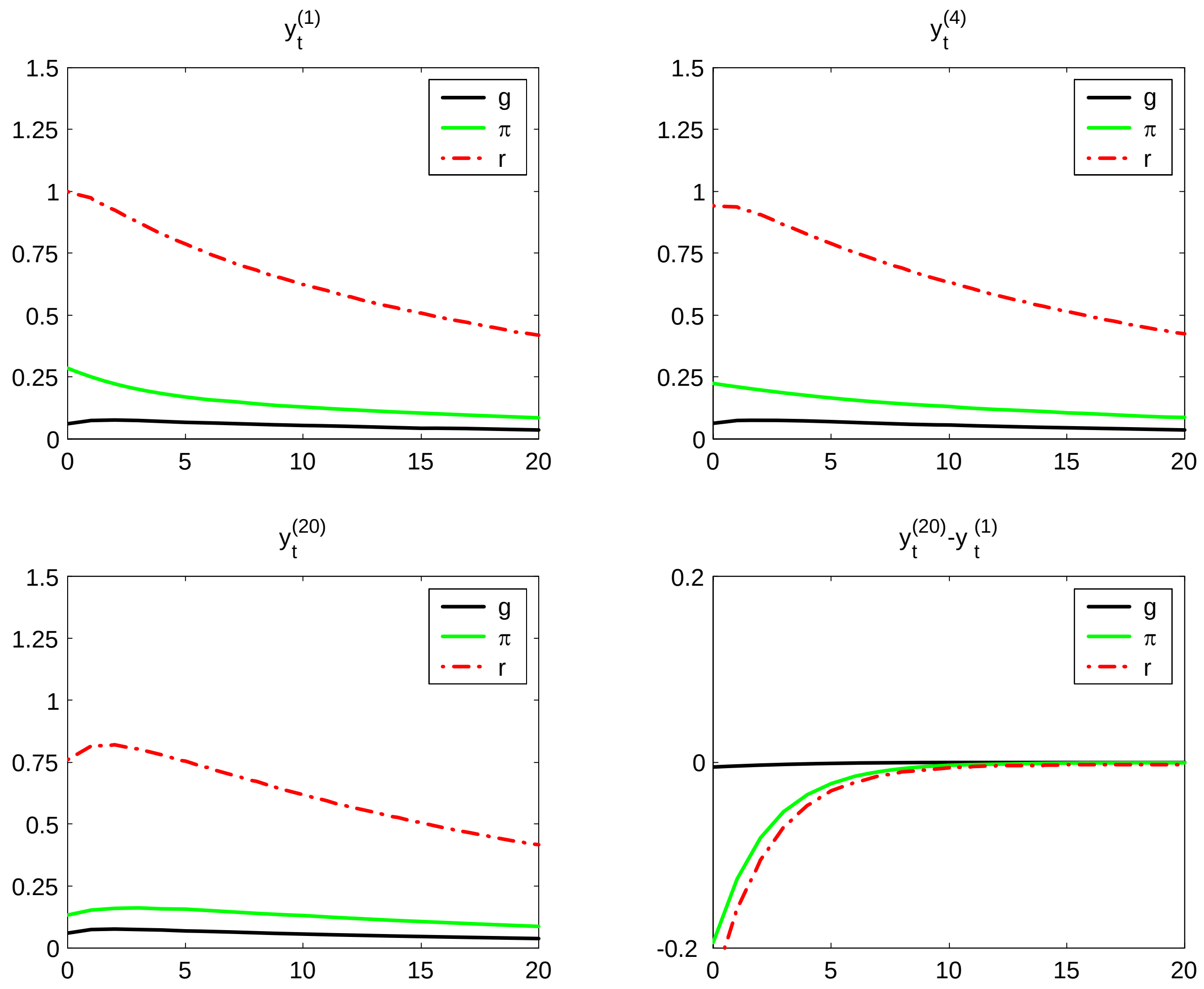
$$r_t = \gamma_0 + \gamma_{1,g} E_t \left[\sum_{i=1}^{\infty} \beta^i g_{t+i} \right] + \gamma_{1,\pi} E_t \left[\sum_{i=1}^{\infty} \beta^i \pi_{t+i} \right] + \varepsilon_t^{MP,F}$$

Taylor Rule

	$\gamma_{1,g}$	$\gamma_{1,\pi}$	β
$k = \infty$	.02	.10	.94
	(.01)	(.01)	(.01)

$\beta = .94$ corresponds to an effective horizon of 4.1 years.

Impulse Responses



Conclusions

- Embed various Taylor rules in an arbitrage-free setup:

  original Taylor rules, backward and forward looking rules.

- Panel data approach improves estimates of policy rules

- Baysian estimation methods help us to estimate more flexible dynamics.

  Find that macro variables – esp. inflation – explain a large fraction of the variation

  - yields
  - yield spreads
  - expected returns on bonds