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!?
unit labor costs were to prove more persistent than currently appears likely, the outlook for inflation would be adversely affected. Economic growth and inflation will also be shaped importantly by the evolution of the imbalance in the U.S. current account.

The Conduct of Monetary Policy over the First Half of 2005

Despite increases in the federal funds rate totaling 1¼ percentage points in 2004, monetary policy was still judged to be accommodative at the start of 2005. At the time of the February FOMC meeting, the available information indicated that the economy had expanded at a robust pace through the end of 2004 and retained considerable momentum. Accordingly, the Committee voted to raise its target for the federal funds rate from 2¼ percent to 2½ percent and to make minimal changes to the text of the accompanying statement. The statement reiterated that “the Committee believes that policy accommodation can be removed at a pace that is likely to be measured.” Members noted, however, that this forward-looking language was clearly conditioned on economic developments and therefore would not stand in the way of either a pause or a step-up in policy firming depending on events.

By March, the data were pointing to a further solid gain in activity during the first quarter, fueled especially by continued increases in consumption expenditures and residential investment. In addition, private nonfarm payrolls were posting widespread advances, and slack in resource utilization appeared to be diminishing. The Committee voted at its March meeting to raise the federal funds rate another 25 basis points, to 2¾ percent. In view of the rise in prices of energy and other commodities and recent elevated readings on inflation in core consumer prices, the Committee altered the text of the policy statement to note the pickup in inflationary pressures. The Committee also decided to modify the assessment of the balance of risks to make it explicitly conditional on an assumption of “appropriate” monetary policy, so as to underscore that maintaining balanced risks would likely require continued removal of monetary policy accommodation.

The evidence that had accumulated by the spring pointed to some moderation in the pace of activity. Retail spending flattened out for a time, likely in response to higher energy prices, and the growth of capital spending dropped back from its elevated pace of late last year. Nonetheless, with long-term interest rates still quite low and with employment and profits continuing to rise, economic activity appeared to retain considerable momentum, suggesting that the softness would be short lived. Against this backdrop, the FOMC decided to raise the federal funds rate another 25 basis points at its May meeting and to make few changes to the text of the accompanying statement.

In the weeks after the May meeting, incoming indicators supported the view that the underlying pace of activity was not faltering. The information that the Committee reviewed at the time of the June FOMC meeting showed that consumer spending and business investment had turned up, on balance, and that demand for housing continued to be strong. With economic activity remaining firm and crude oil prices ratcheting higher, the FOMC...
Interest rates on selected Treasury securities

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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

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<td>2</td>
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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.

Spreads of yields on investment-grade corporate debt over those on comparable-maturity Treasury securities fell during the first quarter of 2005, and risk spreads on high-yield corporate debt reached very low levels. However, in March, news about difficulties in the domestic motor vehicle industry apparently became a focal point for a revision of investors’ assessment of risks. Further revelations of accounting irregularities in the insurance industry also seem to have made investors somewhat charier of risk. As a result, risk spreads on corporate bonds and credit default swaps have widened; speculative-grade bond spreads are now about 50 basis points higher than at the start of the year.

Equity Markets

Broad equity price indexes fell modestly in the first quarter, but they rebounded and are now little changed, on net, since the start of 2005. Thus far this year, stock prices have been buoyed by continued strong profits and low long-term interest rates, but higher oil prices and a few high-profile earnings disappointments have weighed on share prices outside the energy sector. The forward earnings–price ratio held about steady despite the fall in real interest rates. Equity price volatility implied by quotes on stock options declined, as the implied volatility on the S&P 500 index dropped to a record low level of less than 11 percent.

Net inflows into equity mutual funds were moderate in the first half of 2005, down from the rapid pace during the same period last year. These flows likely followed the pattern set by share prices, which surged about

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 declining macroeconomic and interest rate uncertainty. The volatility of short-term interest rates and Treasury yields implied by option prices has indeed declined to historically low levels. A third possibility is that several factors have spurred an excess of global saving over planned investment, such as rising incomes in countries with high saving rates, the desire by the aging citizens of many industrialized countries to save for retirement, and apparently diminished investment prospects in many industrialized and developing economies.
• 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?
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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.

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• 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

\[ y_t^{(n)} = \text{time-}t \text{ yield on bond with } n \text{ periods to go} \]

\[ = \frac{1}{n} E_t \left[ \sum_{i=0}^{n-1} r_{t+i} \right] \]

- Sargent 1969 imposes \textit{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

  \[ \implies \text{Treasuries move because expected inflation moves} \]

• 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
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: \( r_t = \delta_0 + \delta_1^T X_t \)
2. linear dynamics: \( X_t = \mu + \phi X_{t-1} + \Sigma \varepsilon_t, \quad \varepsilon_t \sim N(0, I) \)
2. linear risk premia: \( M_{t+1} = \exp \left( -r_t - \frac{1}{2} \lambda_t^T \lambda_t - \lambda_t^T \varepsilon_{t+1} \right) \)

\[ \lambda_t = l_0 + l_1 X_t \]
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 : unstructured 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 → 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 $\rightarrow$ 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 $\rightarrow$ 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

\[ y_t^{(n)} = \text{time-} t \text{ yield on bond with } n \text{ periods to go} \]

\[ = \frac{1}{n} E_t \left[ \sum_{i=0}^{n-1} r_{t+i} \right] + \text{term premium ( + Jensen's inequality terms)} \]

- 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
$r_t = \delta_0 + \delta_1^T X_t$

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

$g_t = \text{GDP growth}$

$\pi_t = \text{inflation}$

$f_t^u = \text{latent factor}$

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

and consider different policy rules
Fix the affine term structure model.........................................................

\[ r_t = \delta_0 + \delta_1^\top X_t, \text{ where } X_t = (g_t, \pi_t, f^u_t) = (f_t^o, f_t^u) \]

............................................................................................................and consider different policy rules

a.) Taylor rule (Taylor 1993)

- \[ r_t = \gamma_0 + \gamma_{1,g} g_t + \gamma_{1,\pi} \pi_t + \epsilon_{MP,T} \]

- recursive identification: \( g_t \) and \( \pi_t \) don’t react within the quarter

  Christiano, Eichenbaum & Evans 1996

- find structural parameters \( \gamma \):

  - \( \gamma_0 = \delta_0, \gamma_{1,g} = \delta_{1,g}, \gamma_{1,\pi} = \delta_{1,\pi} \)

  - \( \epsilon_{MP,T} = \delta_{1,u} f^u_t \)
Fix the affine term structure model.................................................

\[ r_t = \delta_0 + \delta_1^\top X_t, \text{ where } X_t = (g_t, \pi_t, f_t^u)^\top \]

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

..................................................................................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 \( \gamma \):
  \[- \gamma_0, \gamma_{1,g} = \delta_{1,g}, \gamma_{1,\pi} = \delta_{1,\pi}, \ldots \gamma_{2,r} = \phi_{22} \]
  \[- \varepsilon_{t}^{MP,B} = \delta_{1,u} u_t^2 \]
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

\[ E_t \left[ g_{t+k,k} \right] = \frac{1}{k} E_t \left[ \sum_{i=1}^{k} g_{t+i} \right] \]

\[ E_t \left[ \pi_{t+k,k} \right] = \frac{1}{k} E_t \left[ \sum_{i=1}^{k} \pi_{t+i} \right] \]

- find structural parameters \( \gamma \) by noting that

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

d.) Infinite-Horizon Forward-Looking Rule

- Fed discounts at rate \( \beta \)

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

Baysian MCMC and Gibbs Sampling

- handles measurement error $\varepsilon_t^{(n)}$ on all yields
  \[ \hat{y}_t^{(n)} = y_t^{(n)} + u_t^{(n)} \]

- 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

\[ \text{LHS} = \text{return from buying the } n\text{-period bond at } t \text{ and selling at } t + 1 \text{ in excess of the 1-period riskfree rate} \]

<table>
<thead>
<tr>
<th>Data</th>
<th>Model</th>
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<tr>
<td>( g_t )</td>
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<tr>
<td>( \pi_t )</td>
<td>( \pi_t )</td>
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<tr>
<td>( y_t^{(20)} )</td>
<td>( y_t^{(20)} )</td>
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<tr>
<td>( R^2 )</td>
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</table>

| \( n=4 \) | \( -.07 \) | \( -.08 \) | \( 0.22 \) | \( 0.04 \) | \( -.04 \) | \( -.04 \) | \( .16 \) | \( 0.04 \) |
| \( (.06) \) | \( (.09) \) | \( (.10) \) | \( (.05) \) | \( (.07) \) | \( (.08) \) |

| \( n=20 \) | \( -.24 \) | \( -.72 \) | \( 1.13 \) | \( 0.04 \) | \( -.36 \) | \( -.96 \) | \( 1.33 \) | \( 0.06 \) |
| \( (.27) \) | \( (.37) \) | \( (.45) \) | \( (0.27) \) | \( (.39) \) | \( (.43) \) |

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)

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<th>maturity</th>
<th>yield levels</th>
<th>yield spreads</th>
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<td>1 quarter</td>
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<td>1 year</td>
<td>12.9</td>
<td>25.2</td>
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<td>13.0</td>
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<tr>
<td>5 years</td>
<td>13.0</td>
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Taylor rule: \( r_t = \gamma_0 + \gamma_{1g} g_t + \gamma_{1\pi} \pi_t + \varepsilon_{MP,T} \)

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<tr>
<th></th>
<th>Full Sample OLS</th>
<th>Full Sample Model</th>
<th>Pre-82:Q4 OLS</th>
<th>Pre-82:Q4 Model</th>
<th>Post-83:Q1 OLS</th>
<th>Post-83:Q1 Model</th>
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<td>( \pi_t )</td>
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<td>.28 (.003)</td>
<td>.68 (.008)</td>
<td>.27 (.003)</td>
<td>.61 (.13)</td>
<td>.24 (.005)</td>
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Policy Rules ctd.

Backward-looking Taylor rule

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<td>.96</td>
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</table>

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

Long-run response to inflation: \( 3.61 - 2.52 = 1.09 \)
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

<table>
<thead>
<tr>
<th>( k = \infty )</th>
<th>( \gamma_{1,g} )</th>
<th>( \gamma_{1,\pi} )</th>
<th>( \beta )</th>
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<td>( .02 )</td>
<td>( .10 )</td>
<td>( .94 )</td>
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<td>(.01)</td>
<td>(.01)</td>
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</table>

\( \beta = .94 \) corresponds to an effective horizon of 4.1 years.
Impulse Responses

\[ y_t^{(1)} \]

\[ y_t^{(4)} \]

\[ y_t^{(20)} \]

\[ y_t^{(20)} - y_t^{(1)} \]
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

• Bayesian 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