Macroeconomic releases and the interest rate term structure

Biao Lu, Liuren Wu

Tudor Investment Corporation, 1275 King Street, Greenwich, CT 06831, USA
Baruch College, Zicklin School of Business, One Bernard Baruch Way, New York, NY 10010, USA

ARTICLE INFO

Article history:
Received 13 August 2007
Received in revised form 17 June 2009
Accepted 23 June 2009
Available online 30 June 2009

JEL classification:
E12
E43
E44
E52
G12

Keywords:
Macroeconomic releases
Interest rate term structure
Optimal monetary policy
Dynamic factors
Market prices of economic risks
Inflation
Real output growth
Kalman filter

ABSTRACT

We extract two systematic economic factors from a wide array of noisy and sparsely observed macroeconomic releases, and link the dynamics and market prices of the two factors to the interest rate term structure. The two factors predict 77.9–82.1% of the daily variation in Libor and swap rates from one month to 10 years. Shocks on inflation-related releases have large, positive impacts on interest rates of all maturities, leading to parallel shifts of the yield curve, but shocks on output-related releases have larger impacts on the short rate than on the long rate, thus generating a slope effect.

1. Introduction

This paper studies the fundamental relation between numerous macroeconomic releases on the one hand and the term structure of interest rates on the other. Macroeconomic fundamentals influence the bond market, but the direction and magnitude of that influence are notoriously difficult to quantify. Researchers who have tried to link macroeconomic fundamentals to interest rate movements are faced with the difficult issues of how to measure the fundamentals and how to incorporate the fundamentals into models of the interest rate term structure.
Releases of macroeconomic indicators happen almost every day. Each release carries some information on a certain aspect of the economy, but it also contains a large amount of noise. To capture accurately the systematic state of the economy, it is essential to look at a large number of macroeconomic indicators; yet, incorporating all the indicators as state variables into a term structure model generates tractability, stability, and identification issues. Besides, most macroeconomic indicators are released on different days and at different frequencies, making it difficult to match them with the much more frequently and regularly observed interest rate data.

To resolve those issues, this paper uses a dynamic factor model to extract two systematic economic factors from numerous noisy and sparsely observed macroeconomic releases. Furthermore, based on the specifications of the monetary policy rule, the economic factor dynamics, and the market prices of economic risks, the paper uses no-arbitrage arguments to link the entire term structure of interest rates to the two systematic economic factors.

Estimation shows that the two systematic factors extracted from the macroeconomic releases predict 77.9–82.1% of the daily variation in LIBOR and swap rates across maturities from one month to 10 years. Shocks on inflation-related variables—such as CPI, core CPI, PPI, core PPI, PCE deflator, core PCE deflator, and GDP deflator—all produce large, positive impacts on interest rates. Their impacts are relatively uniform across different maturities, leading to parallel shifts of the yield curve. By contrast, shocks on output and employment variables—such as real GDP growth, industrial production, nonfarm payrolls, durable goods orders, capacity utilization, business inventories, consumer spending, and personal income—have larger impacts on the short end than on the long end of the yield curve, thus generating a slope effect on the term structure.

By extracting the two systematic factors from the economic releases first and then analyzing their impacts on the interest rate term structure, the procedure forces a one-way information flow: from the macroeconomic releases to the interest rates. The high predictive variation estimates highlight the important information content in the economic releases about interest rate movements. Nevertheless, in reality, the observed interest rate term structure also contains important information about the state of the economy. Therefore, the interest rate data can be used jointly with the macroeconomic releases to better identify the macroeconomic factors.

When the dynamic factors are re-estimated with this joint identification procedure, the factors predict a much higher percentage of variation in both the interest rates (98–99.9%) and the macroeconomic releases (95.4–98.5%). The increased predictive variation highlights the tight linkage and the two-way information flow between the financial market and the fundamental state of the economy. Adding the interest rate data to extract the systematic factors helps identify the linkages more precisely by better separating the signal from the noise and by better distinguishing actual surprises from the information that has always been anticipated by the financial market.

Our work is related to a series of earlier studies that use regression analysis to investigate the impacts of macroeconomic releases on financial security prices such as bond prices and exchange rates. By using dynamic factors to suppress noise and to reduce dimensions in a large array of macroeconomic releases, our approach significantly alleviates the error-in-variable problem of using raw economic numbers and avoids the multicollinearity issue from incorporating highly correlated variables in one regression. Furthermore, our state-space specification and filtering approach naturally separates each economic release into a surprise component, which the financial market responds to, and a predictable component, which the financial market has already taken into account. Estimation shows that a predominant proportion of the economic release variations are predicted by the financial market. Thus, using the raw economic numbers would dramatically exaggerate the magnitude of the economic surprises and accordingly generate much weaker estimates on their impacts.

The dynamic factor approach has been widely explored in another strand of literature to identify the systematic state of the economy from a large array of economic series. What this paper adds on top of this literature is the incorporation of a no-arbitrage dynamic term structure model. Through this term structure model, the two economic factors provide an internally consistent linkage between the large array of economic releases on the one hand and the term structure of interest rates on the other. The no-arbitrage constraints not only enhance the identification of the relation but also offer insights on how the market prices different sources of economic risks.

Recently, several studies also apply no-arbitrage constraints to the relation between macroeconomic variables and the term structure of interest rates. For examples, Ang and Piazzesi (2003) construct a five-factor term structure model with three latent statistical factors and two macroeconomic factors, which are principal components of a small number of selected economic indicators. Diebold et al. (2006) build a six-factor model with three latent factors and three observable factors, which are the federal funds rate and two macroeconomic indicators. Ang et al. (2004) construct a three-factor model with two latent factors and one macroeconomic indicator as the third factor. These studies typically rely on the latent statistical factors to explain the bulk of the term structure movement. For the sake of tractability, they supplement the latent factors with only a few macroeconomic releases or principal components, the estimated impacts of which on the term structure are marginal compared to those of the latent factors. The key advantage of our approach is to incorporate information from a wide array of macroeconomic indicators into the dynamic term structure model through the systematic

---

1 Examples include Fleming and Remolona (1999), Balduzzi et al. (2001), Andersen et al. (2003), and Faust et al. (2007).

economic factors. By doing so, our model explains as much as or higher percentages of variations in interest rates without having to use any latent factors. As a result, what our model pins down is not the marginal impact of a few macroeconomic series in addition to latent statistical factors but, rather, the fundamental relation between the systematic state of the macroeconomy and the term structure of interest rates.

The rest of the paper proceeds as follows. Section 2 discusses the methodology, data, and results in extracting two systematic factors from many real-time macroeconomic announcements. Section 3 links the extracted economic factors to the interest rate term structure via no-arbitrage arguments. Section 4 estimates the factor dynamics by using the macroeconomic series and the interest rate data jointly. Section 5 concludes.

2. Extracting systematic macroeconomic movements in real time

The actual dimension of the economy is much smaller than the enormous number of economic releases. We propose to use a low-dimensional dynamic factor model to summarize the systematic economic information in a large array of noisy economic releases.

2.1. Estimating dynamic factor models with maximum likelihood and Kalman filter

We assume that the systematic state of the economy is governed by two dynamic economic factors, $X_t$, which propagates according to a first-order vector autoregressive (VAR(1)) process:

$$X_t = \Phi X_{t-1} + \sqrt{\varnothing} e_t,$$

(1)

where $\Phi$ captures the persistence and interaction of the state vector and $e_t$ denotes an iid standard normal random vector. Eq. (1) standardizes the state vector to have zero long-run mean and identity covariance matrix per unit time. $\varnothing = I\Delta t$, where $\Delta t$ denotes the sampling frequency of the state vector, which is daily $(\Delta t = \frac{1}{252})$ in our estimation.

Let $M_t$ denote a vector representing $N$ macroeconomic indicators released at time $t$, which are related to the two systematic economic factors through the following linear structure:

$$M_t = HX_t + e_t, \quad \Phi^M = \mathbb{E}[e_t e_t^T],$$

(2)

where $H$ is an $(N \times 2)$ matrix of factor loading coefficients and $e_t$ denotes a vector of normally distributed measurement errors. Each economic series is standardized to have zero mean and unit standard deviation, and the measurement errors ($e_t$) are assumed to be mutually independent, but with distinct variance.

Treating the factor dynamics (1) as the state equation and the standardized data series relations (2) as the measurement equation, the classic Kalman (1960) filter generates efficient forecasts and updates on the mean and covariance of the state vector. Let $\bar{X}_t$, $\bar{V}_t$, $\bar{M}_t$, $\bar{A}_t$ denote the time-$(t-1)$ forecasts of time-$t$ values of the systematic factors, the covariance matrix of the systematic factors, the macroeconomic measurement series, and the covariance matrix of the measurement series. Let $\bar{X}_t$ and $\bar{V}_t$ denote the update on the systematic factors and their covariance based on observations $(M_t)$ at time $t$. The prediction steps are

$$\bar{X}_t = \Phi \bar{X}_{t-1}; \quad \bar{V}_t = \Phi \bar{V}_{t-1} \Phi^T + \varnothing;$$

$$\bar{M}_t = H \bar{X}_t; \quad \bar{A}_t = H \bar{V}_t H^T + \Phi^M.$$

(3)

The filtering updates are

$$\hat{X}_t = \bar{X}_t + K_t(M_t - \bar{M}_t); \quad \hat{V}_t = \bar{V}_t - K_t \bar{A}_t K_t^T,$$

(4)

where $K_t = \bar{V}_t H^T (\bar{A}_t)^{-1}$ is the Kalman gain, and controls the relative contribution of the $N$ economic series to the updates of the two economic factors. The model parameters are estimated via the maximum likelihood method, with the likelihood function defined on the normally distributed forecasting errors of the measurement series.

Since the economic numbers are observed at different times and frequencies, the daily series $M_t$ have many missing values. The Kalman filter readily accommodates missing data. The updates in (4) are on the available subset of $M_t$. On days with no macroeconomic releases, no updates are performed, and $\hat{X}_t$ is set to $\bar{X}_t$. When multiple economic numbers are released on the same date, their relative contribution to the economic factors is controlled by the relative magnitude of their measurement error variance ($\varnothing^M$), which enters the Kalman gain through the predicted variance $\bar{A}_t$. Economic series with larger measurement error variance contribute less to the economic factor updates.

2.2. Data description

We use 17 macroeconomic release series to extract two systematic economic factors. Table 1 lists the name, the release frequency, a sample release date in April 2004, the sample mean, and the sample standard deviation for each of the 17 series. Each release is dated by its actual release date and the data are used as they are originally released on the scheduled dates. This real-time feature contrasts sharply with most existing studies that date macroeconomic variables by the months in which they are released. As shown in the third column of Table 1, the actual release dates of different series can
extend from the very beginning of the month to the very end. Thus, stacking the actual releases into a monthly data set will create serious, nonsynchronous issues in the estimation and can lead to erroneous conclusions on the relative significance of the different releases.

Among the 17 series, seven are inflation measures: the consumer price index (CPI), the core CPI, the producer price index (PPI), the core PPI, the personal consumption expenditure (PCE) deflator, the core PCE deflator, and the GDP deflator. The CPI measures the average change in the prices of a basket of goods and services bought by a typical urban household. The PPI measures the change in the selling prices received by domestic producers for all finished goods. The PCE deflator measures the average change in the prices of a basket of goods and services purchased by a typical consumer. Their respective core measures exclude food and energy, the prices of which tend to be highly volatile. The GDP deflator measures the average change in prices of all goods and services produced by the domestic economy. The seven inflation variables are measured as year-over-year rates, defined as the percentage change of current index level over the level released 12 months ago.

The output side includes 10 indicators, either nominal or real. The real GDP growth is the broadest measure of the output growth of the domestic economy. Industrial production measures the production of goods. Although it is less comprehensive, it is more timely because industrial production numbers are released monthly, whereas GDP numbers are released quarterly. Nonfarm payrolls measure the number of employees on firms’ payrolls. Farms are excluded because of their seasonal nature. This number is a key indicator of the employment scenario of the economy, and it has far-reaching implications for both inflation and output growth. Included on the demand side of the economy are retail sales and consumer spending, both of which can indicate changes in the state of the economy prior to changes in production. Other chosen indicators include durable goods orders, durable goods orders minus transportation, capacity utilization rate, business inventories, and personal income.

The nonfarm payrolls are measured in 12-month cumulative change, which is the total number of jobs (in millions) created or lost in nonfarm sectors over the past 12 months. Capacity utilization rate is a percentage that reflects the usage of available resources. All other variables are measured in year-over-year percentage changes.

The frequency of all indicators is monthly except that for real GDP growth and the GDP deflator. The data on GDP are quarterly, but there are three scheduled releases for each quarter, which are called preliminary, revised, and final readings. They are released about one, two, and three months after the end of the quarter, respectively. Hence, there is a data release on the GDP number each month, all included in our estimation. The starting dates of these macroeconomic series in our data set vary from January 1960 to July 1989. Our model estimation takes the common sample from January 2, 1990, to May 26, 2004, covering 3,633 business days.

### 2.3. Systematic macroeconomic movements

Table 2 reports the estimates of the factor loading matrix ($H$). To enhance identification, the loading of the first factor on CPI and the loading of the second factor on real GDP growth are constrained to be positive. In principle, factors can rotate and the loadings can change accordingly without impacting the final result. Such rotations make it difficult to interpret the
meanings of the dynamic factors (Stock and Watson, 2004). Nevertheless, the two extracted factors show apparent economic meanings. The loadings on the first factor are positive and significant on all seven inflation variables, and the loadings of the second factor are positive and significant on all 10 output-related variables. Hence, the first factor is positively associated with inflationary pressure in the economy, and the second factor is positively associated with output growth.

The last column of Table 2 reports the predictive variation (PV) for each macroeconomic release, defined as one minus the ratio of the forecasting error variance to the variance of the original series.

The last column of Table 2 reports the predictive variation (PV), defined as one minus the ratio of the forecasting error variance to the variance of the original series. The predictive variation measures the predictive performance of the two dynamic factors on each of the 17 series. It also reflects the relative informativeness of the 17 series on the systematic economic factors. The largest estimate comes from nonfarm payrolls, at 97.2%, and the second largest comes from the core PCE deflator, at 91.6%.

The number on nonfarm payrolls is the first comprehensive indicator to be released every month. It covers almost the entire labor market, and provides the earliest reading on the employment situation, which has far-reaching implications for the strength of consumer spending and the economy. The core PCE deflator is becoming the most-watched price index from the standpoint of monetary policy and is considered a “more reliable measure of inflation” than the CPI by the Federal Reserve for two major reasons. First, the CPI is representative only of the price paid by urban customers, whereas the PCE deflator is a broader measure that covers both urban and rural customers. Second, the PCE deflator is a chain-weighted index that captures shifting spending patterns, whereas the CPI is a fixed-weight index that relies on spending patterns several years ago.

Nevertheless, our estimation shows that all 17 economic releases have significant loading estimates on at least one of the two dynamic economic factors. Therefore, all 17 series contain useful information about the systematic state of the economy.

3. **Estimating yield curve responses to macroeconomic shocks**

Starting with assumptions on the aggregate demand and supply functions, several monetary economists—such as Clarida et al. (1999), Svensson (2003), and Woodford (2003)—derive optimal monetary policies in terms of an instrument rule. The simplest form of such an instrument rule can be a variant of the famous Taylor (1993) rule, which determines the nominal short rate as a linear function of the expected deviation of inflation from its target level and the expected deviation of real output growth from its equilibrium level.

With the economic factors $X_t$ to summarize the nominal and real systematic movements of the economy, a linear instrument rule can take the following generic form:

$$r(X_t) = a_t + b^\top_t X_t,$$  \hspace{1cm} (5)

---

Table 2

<table>
<thead>
<tr>
<th>$M_t$</th>
<th>$H_1$</th>
<th>$H_2$</th>
<th>PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPI</td>
<td>0.579</td>
<td>-0.117</td>
<td>1.46</td>
</tr>
<tr>
<td>Core CPI</td>
<td>0.544</td>
<td>-0.210</td>
<td>2.66</td>
</tr>
<tr>
<td>PPI</td>
<td>0.341</td>
<td>-0.027</td>
<td>0.48</td>
</tr>
<tr>
<td>Core PPI</td>
<td>0.458</td>
<td>-0.173</td>
<td>2.56</td>
</tr>
<tr>
<td>PCE deflator</td>
<td>0.520</td>
<td>-0.195</td>
<td>2.60</td>
</tr>
<tr>
<td>Core PCE deflator</td>
<td>0.482</td>
<td>-0.235</td>
<td>3.18</td>
</tr>
<tr>
<td>GDP deflator</td>
<td>0.485</td>
<td>-0.237</td>
<td>3.31</td>
</tr>
<tr>
<td>Real GDP</td>
<td>0.050</td>
<td>0.387</td>
<td>2.95</td>
</tr>
<tr>
<td>Industrial production</td>
<td>0.236</td>
<td>0.390</td>
<td>6.99</td>
</tr>
<tr>
<td>Nonfarm payrolls</td>
<td>0.414</td>
<td>0.449</td>
<td>6.33</td>
</tr>
<tr>
<td>Durable goods orders</td>
<td>0.053</td>
<td>0.220</td>
<td>5.33</td>
</tr>
<tr>
<td>Durable minus transp</td>
<td>0.117</td>
<td>0.254</td>
<td>5.22</td>
</tr>
<tr>
<td>Retail sales</td>
<td>-0.062</td>
<td>0.284</td>
<td>6.23</td>
</tr>
<tr>
<td>Capacity utilization</td>
<td>0.031</td>
<td>0.327</td>
<td>3.93</td>
</tr>
<tr>
<td>Business inventories</td>
<td>0.387</td>
<td>0.323</td>
<td>5.22</td>
</tr>
<tr>
<td>Consumer spending</td>
<td>0.484</td>
<td>0.111</td>
<td>1.57</td>
</tr>
<tr>
<td>Personal income</td>
<td>0.601</td>
<td>0.333</td>
<td>3.66</td>
</tr>
</tbody>
</table>

Notes: Entries report the estimates (and the absolute values of the t-statistics in parentheses) of loading matrix $H$ that links each macroeconomic series ($M_t$) to two systematic factors. Under $H_1$ are the loading coefficients on the first factor, and under $H_2$ are the coefficients on the second factor. The last column reports the predictive variation (PV) for each macroeconomic release, defined as one minus the ratio of the prediction error variance to the variance of the original series.

3 Quote is from the testimony of Alan Greenspan before the Committee on Financial Services, U.S. House of Representatives, July 18, 2001.
where \( r \) denotes the instantaneous nominal interest rate. The practical analog of that interest rate in the United States is the overnight federal funds rate, on which the Federal Reserve sets a target range to implement its monetary policy.

To derive the equilibrium bond pricing, it is convenient to rewrite the VAR(1) factor dynamics in Eq. (1) in its continuous-time analog,

\[
dX_t = -\kappa X_t \, dt + dW_t, \tag{6}
\]

where \( W_t \) denotes a two-dimensional standard Brownian motion and \( \kappa = -(1/\Delta t) \ln(\Phi) \) controls the mean-reversion speed of the states, with \( \ln(\cdot) \) denoting the principal matrix logarithm operation. The market prices of the two economic risk factors are assumed to be time varying and proportional to the economic risk level,

\[
\gamma(X_t) = \gamma_0 + \gamma_1 X_t, \tag{7}
\]

Under these assumptions, the time-\( t \) equilibrium values of the continuously compounded spot rates on zero-coupon bonds are linear functions of the economic factors (Duffie and Kan, 1996),

\[
y(X_t, \tau) = \frac{a(\tau)}{\tau} + \frac{b(\tau)}{\tau} X_t, \tag{8}
\]

where the coefficients \( [a(\tau), b(\tau)] \) solve the following ordinary differential equations:

\[
a'(\tau) = a_0 - b(\tau)^\top \gamma_0 - b(\tau)^\top b(\tau)/2, \quad b'(\tau) = b_\gamma - (\kappa + \gamma_1) b(\tau), \tag{9}
\]

starting at \( a(0) = 0 \) and \( b(0) = 0 \). Thus, the contemporaneous responses of the yield curve to the economic factors are measured by the loading coefficients, \( b(\tau)/\tau \), which are jointly determined by the monetary policy instrument rule \( (b_\gamma) \), the economic factor dynamics \( (\kappa) \), and the time-varying component of the market prices of economic risks \( (\gamma_1) \).

### 3.1. Estimating the instrument rule to the LIBOR and swap rates

We use the time series of eurodollar LIBOR and swap rates, obtained from Bloomberg, to estimate the instrument rule and the market prices of economic risks. LIBORs are simply compounded interest rates with maturities of 1, 2, 3, 6, and 12 months. The swap rates are par bond yields with maturities of two, three, five, seven, and 10 years. The data are daily from January 2, 1990, to May 26, 2004, matching the sample period for the macroeconomic data and the extracted dynamic economic factors. The interest rate swap market started in the mid 1980s and became liquid in the late 1980s and early 1990s. In recent years, the long end of the swap rate curve has overtaken the U.S. Treasury yield as the benchmark interest rate of the market.

Fig. 1 plots the time series of four selected interest rate series in the top panel and the term structure of interest rates at four selected dates in the bottom panel. During our sample period, the interest rates have experienced large time variations. The one-month LIBOR started at 8.37% on January 2, 1990, but ended at merely 1.1% on May 26, 2004. The long-term rates also vary over time, albeit to a lesser degree. The term structures have experienced a variety of shapes, ranging from upward-sloping shapes during the two recessions around 1992 and 2002 to flat or even downward-sloping shapes at the beginning and the middle of our sample period.

As in the first-stage estimation, we cast the problem into a state-space form, extract the distributions of the states at each date by using a filtering technique, and estimate the model parameters using a quasi-maximum-likelihood method, assuming normal forecasting errors on LIBOR and swap rates. The state propagation equation is the same as in Eq. (1). The measurement equations are defined on the 10 LIBOR and swap rates by assuming additive pricing errors on each series. Since LIBOR and swap rates are nonlinear functions of the state variables, an extended version of the Kalman filter is used to handle the nonlinearity. In the estimation, the economic factors extracted from the economic releases in the first stage are treated as observable, and the filtered values of the economic factors are set to those obtained from the first stage.

### 3.2. The information flow from the economic releases to the interest rate term structure

Table 3 reports the predictive variation from the estimated model on each interest rate series. The two dynamic economic factors extracted from the 17 economic releases predict about 77.9–82.1% of the variation in LIBOR and swap rates. The predictive variations are relatively uniform across all interest rate maturities.

These performance numbers are remarkable given that the systematic factors are extracted purely from the macroeconomic releases. The numbers, especially those at the long end of the yield curve, are dramatically higher than those reported in the literature. The high estimates suggest that the information flow from the economic fundamentals to the interest rate term structure is stronger than what has been found in the literature.

One potential reason for the lower estimates in the previous studies is that those studies often pick one or a few economic releases to directly proxy for systematic economic risks. The large amount of noise in the raw economic series not only leads to a lower explained variation but also generates less significant loading coefficient estimates due to error-in-variable problems. By suppressing the noise and highlighting the information embedded in a large array of economic releases, our dynamic factor structure alleviates the error-in-variable problem and explains a large proportion of interest rate movements through the two dynamic economic factors.
Table 4 reports the maximum-likelihood estimates of the model parameters, with the absolute magnitudes of the $t$-statistics in parentheses. The parameters $(a_r, b_r)$ determine the short-rate function, which can be regarded as the monetary policy instrument rule that links the short-term interest rate to the macroeconomic factors. Since the factors have zero long-run mean and unit instantaneous variance, $a_r$ measures the long-run level of the short rate and $b_r$ measures the contemporaneous response of the short rate to each unit standard deviation shock in the macroeconomic factors. The

### Table 3
Predicting interest rate variation by using economic factors.

<table>
<thead>
<tr>
<th>Maturity</th>
<th>LIBOR with maturities (months)</th>
<th>Swap rates with maturities (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>PV</td>
<td>0.797</td>
<td>0.808</td>
</tr>
</tbody>
</table>

Notes: Entries report the predictive variation (PV) for each interest rate series. The interest rates are predicted by two factors extracted from 17 economic series.

### 3.3. Monetary policy and yield curve responses to macroeconomic releases

Table 4 reports the maximum-likelihood estimates of the model parameters, with the absolute magnitudes of the $t$-statistics in parentheses. The parameters $(a_r, b_r)$ determine the short-rate function, which can be regarded as the monetary policy instrument rule that links the short-term interest rate to the macroeconomic factors. Since the factors have zero long-run mean and unit instantaneous variance, $a_r$ measures the long-run level of the short rate and $b_r$ measures the contemporaneous response of the short rate to each unit standard deviation shock in the macroeconomic factors. The
only with systematic economic risks. Economic releases such as CPI and GDP move the short rate only through their effects factors by assuming zero measurement errors in the releases. In our model estimation, the short-term interest rate moves a similar message on how to adjust the short-term interest rate to economic fundamentals.

### Table 4

Maximum-likelihood estimates of model parameters on interest rate dynamics.

<table>
<thead>
<tr>
<th>(a_r)</th>
<th>(b_r)</th>
<th>(\kappa)</th>
<th>(\gamma_0)</th>
<th>(\gamma_1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.045</td>
<td>0.015</td>
<td>0.252</td>
<td>-0.308</td>
<td>-0.252</td>
</tr>
<tr>
<td>(119.0)</td>
<td>(168.4)</td>
<td>(0.99)</td>
<td>(14.6)</td>
<td>(20.5)</td>
</tr>
<tr>
<td>0.005</td>
<td>0.14</td>
<td>0.252</td>
<td>-1.336</td>
<td>-0.303</td>
</tr>
<tr>
<td>(102.7)</td>
<td>(3.00)</td>
<td>(1.46)</td>
<td>(8.05)</td>
<td>(0.31)</td>
</tr>
</tbody>
</table>

Notes: Entries report the maximum-likelihood estimates (and the absolute magnitude of the t-values in parentheses) on the parameters that govern the monetary policy instrument rule \((a_r, b_r)\), the economic factor dynamics \((\kappa)\), and the market prices of economic risks \((\gamma_0, \gamma_1)\).

### Table 5

The yield curve response to macroeconomic releases.

<table>
<thead>
<tr>
<th>Spot maturity</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>5</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPI</td>
<td>0.24</td>
<td>0.23</td>
<td>0.22</td>
<td>0.21</td>
<td>0.20</td>
<td>0.19</td>
</tr>
<tr>
<td>Core CPI</td>
<td>0.20</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
<td>0.18</td>
</tr>
<tr>
<td>PPI</td>
<td>0.15</td>
<td>0.14</td>
<td>0.14</td>
<td>0.13</td>
<td>0.12</td>
<td>0.11</td>
</tr>
<tr>
<td>Core PPI</td>
<td>0.17</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.15</td>
</tr>
<tr>
<td>PCE deflator</td>
<td>0.19</td>
<td>0.19</td>
<td>0.18</td>
<td>0.18</td>
<td>0.18</td>
<td>0.17</td>
</tr>
<tr>
<td>Core PCE deflator</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>GDP deflator</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Real GDP</td>
<td>0.12</td>
<td>0.10</td>
<td>0.09</td>
<td>0.06</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>Industrial production</td>
<td>0.21</td>
<td>0.18</td>
<td>0.16</td>
<td>0.13</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Nonfarm payrolls</td>
<td>0.30</td>
<td>0.27</td>
<td>0.25</td>
<td>0.21</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>Durable goods orders</td>
<td>0.08</td>
<td>0.07</td>
<td>0.06</td>
<td>0.04</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Durable minus transp</td>
<td>0.12</td>
<td>0.10</td>
<td>0.09</td>
<td>0.07</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Retail sales</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>-0.02</td>
<td>-0.03</td>
</tr>
<tr>
<td>Capacity utilization</td>
<td>0.37</td>
<td>0.34</td>
<td>0.32</td>
<td>0.28</td>
<td>0.23</td>
<td>0.20</td>
</tr>
<tr>
<td>Business inventories</td>
<td>0.26</td>
<td>0.23</td>
<td>0.21</td>
<td>0.18</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td>Consumer spending</td>
<td>0.25</td>
<td>0.23</td>
<td>0.22</td>
<td>0.20</td>
<td>0.17</td>
<td>0.16</td>
</tr>
<tr>
<td>Personal income</td>
<td>0.36</td>
<td>0.33</td>
<td>0.30</td>
<td>0.27</td>
<td>0.22</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Notes: Entries report the instantaneous response of spot rates (in percentage) at selected maturities to unit standard deviation shock in each macroeconomic variable. The responses are computed based on the estimated factor dynamics and factor loadings, under the assumptions that all economic releases can be observed at the same time and that the economic factors can be identified through a least-squares regression without error. The column under zero-year maturity describes the response of the short rate.

A reasonable estimate on \(a_r\) is at 4.5%, close to the sample mean of the short rate. The estimates on the two elements of \(b_r\) have a clear economic interpretation: The short rate responds positively to shocks in both macroeconomic factors. Since the first factor is positively related to inflation and the second factor is positively related to output, our estimated instrument rule suggests that the short-term nominal interest rate increases with both inflation and real output growth.

To link our results to the monetary economics literature, consider a highly hypothetical scenario, under which only real GDP growth and the inflation rate computed from the CPI index are observed and they are observed with zero measurement error. In this case, the two economic factors can be directly inferred from the two macroeconomic numbers.

Specifically, let \(m_t\) and \(h\) denote the two rows in \(M_t\) and \(H\) that correspond to the CPI inflation rate and the real GDP growth rate, the two economic factors \(X_t\) can be inferred from the two economic numbers \(m_t\) by directly inverting the loading matrix, \(X_t = h^{-1} m_t\). Accordingly, the instrument rule can be written in terms of the inflation rate and the real GDP growth rate,

\[
r_t = a_r + b_r^1 X_t = a_r + b_r^1 h^{-1} m_t. \tag{10}
\]

Plugging in the parameter estimates for \(H, b_r\), and the scalings for the two series leads to the following relation:

\[
r_t = 4.54\% + 2.19(\pi_t - \bar{\pi}) + 1.22(g_t - \bar{g}),
\]

\[
(0.06) \quad (0.40) \quad (0.30), \tag{11}
\]

where \((\pi, g)\) denote the inflation rate and the real output growth rate, respectively, \((\bar{\pi}, \bar{g})\) denote their respective sample means, and the numbers in parentheses are the standard errors of the coefficients. The coefficients on the CPI inflation and the output growth (2.19, 1.22) are stronger than those (1.5, 0.5) proposed in the original Taylor (1993) rule, but they deliver a similar message on how to adjust the short-term interest rate to economic fundamentals.

Eq. (11) is derived through a one-to-one mapping between the two release series CPI and GDP and the two economic factors by assuming zero measurement errors in the releases. In our model estimation, the short-term interest rate moves only with systematic economic risks. Economic releases such as CPI and GDP move the short rate only through their effects
on the economic factor updates. According to the updating equation in (4), the Kalman gain, which determines the relative magnitude of the update, decreases with measurement error variance. Therefore, the actual short-rate response to the economic releases is smaller than shown in (11) because of the presence of measurement errors.

More important, our estimation suggests that all 17 economic releases are informative about the systematic state of the economy. Hence, the short rate responds to all of them rather than to CPI and GDP releases alone. Each economic release affects the short rate through its information update on the systematic state of the economy. Ignoring the factor dynamics and the Bayesian updating but assuming that the economic factors can be inferred from a least-squares regression, \( X_t = (H^\top H)^{-1}H^\top M_t \), we can write an expanded version of the instrument rule as,

\[
r_t = a_0 + b_0^\top (H^\top H)^{-1}H^\top M_t, \tag{12}
\]

which links all 17 economic releases to the short-term interest rate.

Going one step further, we can link the entire yield curve to the 17 economic releases,

\[
y(M_t, \tau) = \left[ \frac{a(\tau)}{\tau} \right] + \left[ \frac{b(\tau)}{\tau} \right]^\top (H^\top H)^{-1}H^\top M_t, \tag{13}
\]

where the two economic factors \( X_t \) in the spot rate relation (8) are replaced with the least-squares fitting on the 17 economic release series \( X_t = (H^\top H)^{-1}H^\top M_t \). The factor loading coefficients \( [a(\tau), b(\tau)] \) are determined jointly by the monetary policy instrument rule \( (a_0, b_0) \), the economic factor dynamics \( (r) \), and the market prices of economic risks \( (\gamma_0, \gamma_1) \).

Based on the parameter estimates in Tables 2 and 4, Table 5 computes the spot rate responses at selected maturities to unit standard deviation shocks on each economic release according to (13). The impacts of the seven inflation variables \( (\text{CPI}, \text{core CPI}, \text{PPI}, \text{core PPI}, \text{PCE deflator}, \text{core PCE deflator}, \text{and GDP deflator}) \) on the yield curve are all large and positive. Spot rates at different maturities respond to inflation shocks relatively uniformly. Hence, shocks on inflation pressures lead to a parallel shift of the yield curve. Positive inflation shocks lead to an upward shift of the yield curve.

Despite that the overall CPI generates most of the headlines, all seven inflation measures turn out to be important. These findings demonstrate the importance of using multiple indicators when gauging inflationary pressure in the economy. For instance, if the direction of the core CPI diverges from that of the overall CPI, which often occurs when change in the overall CPI is driven by energy prices, our systematic factors would show minimal changes in inflationary pressure and predict little changes in the yield curve. However, models that incorporate only the overall CPI would predict much larger changes in interest rates. Reversely, calibrating interest rate movements to noisy CPI movements would lead to small coefficient estimates.

In contrast to the parallel shifts induced by inflation shocks, the yield curve responses to most output-related variables generate an obvious slope effect. Shocks on those variables tend to have bigger positive impacts on the short end than on the long end of the yield curve. When the yield curve is upward sloping, positive shocks on those variables flatten the curve and negative shocks steepen the curve.

Although all of the 10 output-related variables generate a slope effect on the yield curve, the magnitudes of the impacts are different for different series. Unit standard deviation shocks on nonfarm payrolls, capacity utilization, business inventories, consumer spending, and personal income also generate relatively large overall positive shifts on the yield curve. Since all of these variables contain nominal components, the overall shifts are related to the impact of inflation. By contrast, shocks on real GDP growth and industrial production generate mainly a slope effect. The impacts of these two real variables on the 10-year rate are close to zero. Finally, compared with other variables, shocks on durable goods orders, durable goods orders minus transportation, and retail sales generate much smaller impacts on the yield curve. The last column of Table 2 also shows that the predictive variation estimates on these three variables are the smallest, showing that they are relatively noisy indicators of the economic state.

### 3.4. Economic risk dynamics and market pricing of economic risks

Yield curve responses to the macroeconomic releases are determined jointly by monetary policy, economic risk factor dynamics, and market prices of economic risks. Table 4 reports the model parameter estimates. The statistical dynamics and interaction of the two economic risk factors are governed by the \( \kappa \) matrix. To enhance identification, we constrain the matrix to be lower triangular. The diagonal terms of the matrix determine the persistence of the two economic factors, whereas the lower off-diagonal element of the matrix governs their dynamic interaction. The estimates for the two diagonal elements of \( \kappa \) are about the same at 0.252, showing that the two economic factors experience similar statistical persistence. The estimate for the lower-triangular off-diagonal term is positive and statistically significant, indicating that the first inflation-related factor negatively predicts the movement of the second output-related factor. High inflation can lead to future deterioration in real growth.

In a Lucas (1982)-type exchange economy with additive constant relative risk aversion utility for the representative agent, the constant relative risk aversion coefficient measures the market price of the consumption risk. Our model decomposes the economic risk \( X_t \) into two sources—one nominal and the other real—and allows the market price of the two sources of risk to vary with the risk level: \( \gamma(X_t) = \gamma_0 + \gamma_1 X_t \). Since the statistical long-run mean of the two economic risk factors \( X_t \) are zero, the constant component \( \gamma_0 \) also measures the average market price on the two economic factors.
Table 4 shows that the estimates for both elements of $g_0$ are negative and statistically significant. Since the short-term interest rate loads positively on both of the economic factors, the market price of the interest rate risk is negative on average. The literature has long attributed the upward-sloping mean interest rate term structure to negative market prices of interest rate risks (Backus et al., 1998).

The coefficient matrix $g_1$ measures how the market price varies with the risk level. The estimates for the two diagonal elements of the $g_1$ matrix are highly significant, but that for the off-diagonal term is not significantly different from zero. Thus, each market price of risk varies mainly with its own risk level. Interestingly, the estimates for the two diagonal elements of the $g_1$ matrix have different signs: negative for the first element but positive for the second element. As a result, the market price of the first inflation-related factor becomes more negative when the inflation rate is high, but the market price of the second real output-related factor becomes less negative when the real output growth rate is high.

The differences in the level dependence of the two market prices affect how shocks on the two economic factors dissipate across the yield curve. As shown in the ordinary differential equation in (9), the $g_1$ matrix adjusts the statistical persistence matrix $\kappa$ to determine the yield curve loading coefficient $b(\tau)$. The two economic factors show similar statistical persistence at 0.252. Thus, shocks from the two risk sources decay at about the same speed over time. However, the market-price-adjusted persistence $(\kappa + g_1)$ becomes much smaller for the inflation factor than for the real output growth factor. As a result, shocks to the inflation factor generate a nearly uniform impact on the yield curve due to its near unit root behavior after market price adjustment, whereas shocks to the real output growth factor decline with increasing interest rate maturity. These different cross-sectional effects explain why inflation-related releases generate parallel shifts on the yield curve but real output growth-related releases generate slope effects.

The time-varying market prices of the two economic risks lead to time-varying risk premiums on the interest rate, which in turn result in different term structure patterns. Take the instantaneous interest rate as an example. Through the instantaneous interest rate function $r(X_t) = a_t + b_t X_t$, one can convert the market prices of the economic risks $\gamma(X_t)$ into risk premiums on the short-term interest rate: $\gamma(r) = b_t^\top \gamma(X_t)$. The positive relation between the risk premium and real
output growth suggests that the interest rate risk premium becomes more negative during recessions and less so during booming periods, leading to steeply upward-sloping term structures during recessions and flat or even downward-sloping yield curves during booming periods. By contrast, the negative relation between the interest rate risk premium and the inflation level suggests that long-term rates tend to be high when inflation is high.

Fig. 2 plots the time series of the two economic factors ($X_t$) in the top left panel, their corresponding market prices in the top right panel, the model-implied instantaneous interest rate ($r(X_t)$) in the bottom left panel, and the interest rate risk premium in the bottom right panel. The time-series plots show large variations in the two economic risk factors and their market prices. The short rate and its risk premium have also varied greatly over our sample period. In particular, the short-rate risk premium is small when the real growth rate is high but inflation is low, but it becomes strongly negative when the real growth is low and inflation is high. The two troughs in the short-rate risk premium plot correspond to the two recessions in our sample period. Furthermore, the overall downward trend in inflation pressure has led to a general decline in the absolute magnitude of the short-rate risk premium and, accordingly, the overall level of long-term interest rates.

4. Extracting dynamic factors jointly from economic releases and interest rates

In the previous sections, a two-stage sequential procedure is used to first extract systematic movements in the macroeconomic releases and then study their impacts on the yield curve. The sequential procedure captures the one-way information flow from the macroeconomy to the bond market. The estimation shows that a large percentage of the variation on the yield curve can be explained by these purely macroeconomic factors.

In reality, the observed interest rates also contain important information about the economy. Therefore, the interest rate data can be used together with the macroeconomic releases to better identify the systematic states of the macroeconomy. We re-estimate the dynamic factor model with this joint identification approach, and compare the results with those from the sequential procedure. Under the joint identification, the factor dynamics still determine the state propagation equation as in (1), but the measurement equation includes both the macroeconomic releases and the interest rate series.

Table 6 summarizes the results from the joint estimation. Panel A reports the factor loadings, the yield curve responses, and the predictive variation for each economic release series. The factor loading estimates show that the factors have rotated and the economic interpretations of the two factors are no longer clear. Nevertheless, the yield-curve-response estimates show that the factor rotation, the impacts of the macroeconomic variables on the yield curve remain qualitatively the same. The impacts of the seven inflation variables are all positive and large and relatively uniform across the whole yield curve. The impacts of most of the output variables are also positive, but much stronger at the short end than at the long end of the yield curve, thus generating the slope effect. Quantitatively, the macroeconomic variables show greater impacts on the yield curve under the joint identification than under the sequential two-stage estimation. Therefore, incorporating the interest rate data in extracting systematic factors does not dilute the importance of the macroeconomic variables. Instead, it helps identify the linkages more precisely by better separating the signal from the noise in each economic release and by enhancing the separation of real surprises from the information that has already been anticipated by the financial market.

The last column of Panel A shows that incorporating the interest rate information dramatically improves the predictive variation on the economic series. The two systematic factors from the joint identification predict all 17 economic series over 95% of their variation. The high predictive variation suggests that the financial market anticipates the economic releases well. The surprise elements are relatively small. Panel B reports the predictive variation on the 10 interest rate series. The estimates are all higher than 98%. As expected, with inputs from interest rates, the extracted factors can explain the interest rate behavior much better. The increased predictive variation on both interest rates and macroeconomic releases from the joint identification highlights the tight linkage and the two-way information flow between the financial market and the fundamental state of the economy.

The jointly identified dynamic factors can predict the economic releases very well. The unpredictable component represents a true surprise to the financial market. Our estimation shows that the financial market responds strongly to such surprises. Historically, economists often use the value changes between two consecutive releases as proxies for surprises and use regression analysis to determine the impacts of the surprises on the financial market. The estimated impacts from such regression analysis are understandably much smaller for several reasons. First, the noise in the release numbers biases the regression coefficient to zero due to well-known errors-in-variable problems. Second, a predominant portion (over 95% based on our estimation) of the variations in the released numbers is well anticipated by the financial market and is hence not a real surprise. Understandably, the financial market no longer responds to information that it has already anticipated and incorporated into security prices. Our dynamic factor model and the joint identification approach correct for both issues. The dynamic factors provide a succinct way of summarizing the information and suppressing the noise in the many economic releases. Joint identification further helps separate real surprises from the information that has already been anticipated by the financial market.

5. Conclusion

In this paper, we use two dynamic factors to succinctly summarize the systematic information in a wide array of macroeconomic indicators, and link the dynamics and market prices of the two economic factors to the term structure of
Table 6

Extracting systematic factors jointly from macroeconomic releases and interest rates.

<table>
<thead>
<tr>
<th>Mt</th>
<th>Factor loading</th>
<th>Spot rate maturity (years)</th>
<th>PV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( h_1 )</td>
<td>( h_2 )</td>
<td>0</td>
</tr>
<tr>
<td>CPI</td>
<td>0.558</td>
<td>-0.005</td>
<td>1.23</td>
</tr>
<tr>
<td>Core CPI</td>
<td>1.024</td>
<td>(0.23)</td>
<td>0.55</td>
</tr>
<tr>
<td>PPI</td>
<td>0.150</td>
<td>(0.67)</td>
<td>0.82</td>
</tr>
<tr>
<td>Core PPI</td>
<td>0.888</td>
<td>(3.32)</td>
<td>0.59</td>
</tr>
<tr>
<td>PCE deflator</td>
<td>1.013</td>
<td>(2.61)</td>
<td>0.62</td>
</tr>
<tr>
<td>Core PCE deflator</td>
<td>1.213</td>
<td>(4.28)</td>
<td>0.62</td>
</tr>
<tr>
<td>GDP deflator</td>
<td>1.308</td>
<td>(4.23)</td>
<td>0.46</td>
</tr>
<tr>
<td>Real GDP</td>
<td>-0.017</td>
<td>(0.49)</td>
<td>1.80</td>
</tr>
<tr>
<td>Industrial production</td>
<td>-0.544</td>
<td>(3.46)</td>
<td>1.02</td>
</tr>
<tr>
<td>Nonfarm payrolls</td>
<td>-0.543</td>
<td>(5.89)</td>
<td>1.91</td>
</tr>
<tr>
<td>Durable goods orders</td>
<td>-0.224</td>
<td>(1.48)</td>
<td>0.22</td>
</tr>
<tr>
<td>Durable minus transp</td>
<td>-0.150</td>
<td>(1.17)</td>
<td>0.38</td>
</tr>
<tr>
<td>Retail sales</td>
<td>-0.490</td>
<td>(2.70)</td>
<td>0.19</td>
</tr>
<tr>
<td>Capacity utilization</td>
<td>0.040</td>
<td>(2.14)</td>
<td>1.96</td>
</tr>
<tr>
<td>Business inventories</td>
<td>-0.622</td>
<td>(5.90)</td>
<td>1.77</td>
</tr>
<tr>
<td>Consumer spending</td>
<td>0.437</td>
<td>(0.03)</td>
<td>1.12</td>
</tr>
<tr>
<td>Personal income</td>
<td>-0.149</td>
<td>(2.67)</td>
<td>2.05</td>
</tr>
</tbody>
</table>

Panel B: Predictive variation on interest rate series

<table>
<thead>
<tr>
<th>Maturity</th>
<th>LIBOR with maturities (months)</th>
<th>Swap rates with maturities (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>PV</td>
<td>0.994</td>
<td>0.998</td>
</tr>
</tbody>
</table>

Notes: Panel A reports the factor loading coefficients (\( h \)), the yield curve responses, and the predictive variation (PV) for the economic series. Panel B reports the predictive variation for the interest rate series. In parentheses behind the factor loading coefficient estimates are their \( t \)-statistics in absolute magnitudes. All entries are computed based on the joint estimation.
interest rates by using a general no-arbitrage framework. The two dynamic factors can explain a high percentage of the interest rate movements at both short and long maturities. Shocks to inflation-related indicators lead to a parallel shift of the yield curve, but shocks on many output-related series generate a slope effect on the term structure. The different impacts can be traced to the differences in the market pricing of the two economic risks.

The estimation results show that our approach is successful in resolving the long-standing difficulty in identifying the big picture of the economy from many noisy macroeconomic numbers and in linking the identified state of the economy to the term structure of interest rates. For future research, one can employ similar dynamic factor structures to study how systematic macroeconomic movements affect the prices of other financial securities, such as corporate bonds, stocks, and exchange rates. Another important line for future research is to use such a dynamic factor approach to study the interactions between central bank actions, private investors’ behaviors, and the dynamic evolution of economic risks.

References


