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INFORMATION IN THE YIELD CURVE: A MACRO-FINANCE APPROACH

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SUMMARY

We use a macro-finance model, incorporating macroeconomic and financial factors, to study the term premium in the US bond market. Estimating the model using Bayesian techniques, we find that a single factor explains most of the variation in bond risk premiums. Furthermore, the model-implied risk premiums account for up to 40% of the variability of one- and two-year excess returns. Using the model to decompose yield spreads into an expectations and a term premium component, we find that, although this decomposition does not seem important to forecast economic activity, it is crucial to forecast inflation for most forecasting horizons. Copyright © 2012 John Wiley & Sons, Ltd.

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Supporting information may be found in the online version of this article.

1. INTRODUCTION

The term structure of interest rates has long been recognized as a potential source of information about future macroeconomic developments. This prevalent belief on the forward-looking characteristic of the yield curve is best represented by the expectations hypothesis (EH). According to this theory, the slope of the yield curve reflects market expectations of the average future path of short-term interest rates. Following the EH, it makes sense then to use yield curve information to forecast macroeconomic aggregates such as real economic activity and inflation.[1]

In its pure version, the EH implies that bond yields are fully determined by the expected path of the short-term interest rate with zero term premium. The extended version of the EH allows for a maturity-specific constant term premium, and forms the basis of recent latent factor, semi-structural or structural models of the yield curve.[2] If, however, bond yields consist in part of significant time-varying term premiums, not only does the EH not hold, and therefore should not be assumed in yield curve models, but also the information content of the yield curve with respect to macroeconomic aggregates may be affected. Therefore, determining the contribution of the expectations and term premium components in bond yields might allow a more precise interpretation of the dynamics of the term structure of interest rates and the construction of better information variables for macroeconomic forecasting.

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[1] Estrella (2005) investigates the theoretical reasons behind the predictive power of the yield curve to forecast output and inflation. Regarding the prediction of economic activity, see, among others, Estrella and Hardouvelis (1991), Estrella and Mishkin (1998), Plosser and Rouwenhorst (1994) and Stock and Watson (1989). For inflation, see, for example, Fama (1990), Mishkin (1990), Estrella and Mishkin (1997), and Jorion and Mishkin (1991).

[2] See, for example, Bekaert *et al*. (2010), De Graeve *et al*. (2009), Dewachter and Lyrio (2008), Hördahl *et al*. (1977), and Vasicek (1977).

The identification of the expectations and term premium components of the yield curve is, however, not straightforward. Despite the fact that the expectations theory has been rejected in a number of empirical studies,[3] Swanson (2007) and Rudebusch *et al*. (2007) show that term premium estimates can differ by more than four percentage points depending on the model used in the decomposition. This lack of identification of term premiums is not surprising given the prominent role of unobserved long-run interest rate expectations in the expectations component of the yield curve (see Kozicki and Tinsley, 2001).

In this paper, we investigate the failure of the EH and its consequences for macroeconomic forecasting. We adopt the Extended Macro-Finance (EMF) model of Dewachter and Iania (2011), which augments standard macro-finance (MF) models of the term structure of interest rate [4] with the inclusion of three financial factors and two stochastic trends. The first two financial factors reflect financial strains in the money market, while the third financial factor is designed to capture time variation in bond risk premiums. The two stochastic trends allow for highly persistent processes capturing time variation in long-run inflation expectations and in the equilibrium real rate, two key components of long-run interest rate expectations. We analyse, through the lens of this MF model, two relevant issues related to the failure of the EH: the dynamics of bond risk premiums and the information content of the yield spread and its expectations and term premium components for the forecasting of economic activity and inflation.

Related literature includes Hamilton and Kim (2002), who decompose yield spreads into an expectations and a term premium component to forecast GDP growth. Ang *et al*. (2006) and Favero *et al*. (2005) adopt the same approach, while Rudebusch *et al*. (2007) assess the implications of structural and reduced-form models for the relationship between term premium and economic activity. Since each of these studies adopts a different technique to decompose yield spreads, they reach different conclusions regarding the importance of each component in the forecasting of output growth. We are not aware of any study that uses such decomposition to forecast inflation.

Our analysis contributes to the current MF literature in several ways. First, we show that the EMF model is able to extract reasonable estimates for the term premium dynamics. The dynamics of our term premium is similar to those reported by Kim and Wright (2005), which is considered by Rudebusch *et al*. (2007) as one of the most representative measures among those examined by these authors. This is achieved by the use of a single factor as the main driving force behind bond risk premiums. This factor turns out to be similar to the return-forecasting factor proposed by Cochrane and Piazzesi (2005), the CP factor.

Second, we find that (i) the expectations component of short-term bonds is mainly driven by monetary policy shocks, whereas that of long-term bonds is affected by all macro shocks and in particular long-run inflation shocks, and that (ii) movements in the term premium component are mainly associated with financial shocks. These results show that the relevance of introducing stochastic endpoints and risk premium dynamics into an MF model is not limited to the improvement of the yield curve fit (as shown in Dewachter and Iania, 2011), but is also essential in the identification of bond yield expectations and term premium components.

Third, we show that while the yield spread decomposition is crucial for forecasting inflation changes, it is less relevant in the forecasting of real activity. Our results suggest that looking at the yield spread to infer future changes in inflation (via, for example, the Fisher hypothesis) might be suboptimal since the information content of the yield spread is affected by the presence of a sizeable, time-varying risk premium component. This finding is robust to the inclusion of control variables. For real activity measures like real GDP growth and the output gap, the decomposition of the yield spread is less important.

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[3] See Fama (1984), Jones and Roley (1983), Mankiw and Summers (1984) and Shiller *et al*. (1983). For more recent studies, see Cochrane and Piazzesi (2005, 2009), Duffee (2011), and Joslin *et al*. (2010). These papers report statistically and economically significant time-varying risk premiums.

[4] See, for example, Ang and Piazzesi (2003), Bekaert *et al*. (2010), Hördahl *et al*. (2006), and Rudebusch and Wu (2008).

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The remainder of the paper is organized as follows. Section 2 explains briefly the EMF model and discusses the implied decomposition of the yield curve in expectations and term premium components. Section 3 describes the data and the Bayesian model specification used to estimate the EMF model. Section 4 analyses the model-implied risk premiums and focus on the yield decomposition and its impact in the forecasting of real activity measures and inflation. The main findings are summarized in the Conclusion.

2. AFFINE MODELS FOR BOND AND TERM PREMIUMS

2.1. Bond and Term Premiums

A standard decomposition of the default-free yield curve separates the expectations and term premium components of n-period zero-coupon bond yields at time t as follows:

$$y_t^{(n)} = \underbrace{\frac{1}{n}\sum_{\tau=0}^{n-1} E_t\left[y_{t+\tau}^{(1)}\right]}_{\text{Expectations component}} + \underbrace{\chi_t^{(n)}}_{\text{Term premium component}} \tag{1}$$

The expectations component denotes the average expected one-period interest rate over the maturity of the bond and the term premium the additional compensation to lock in the money over n periods. The term premium can be written as the average one-period bond risk premium obtained from holding the bond to maturity (Ludvigson and Ng, 2009):

$$\chi_t^{(n)} = \frac{1}{n}\sum_{\tau=0}^{n-1} E_t\left[rx_{t+\tau,t+\tau+1}^{(n-\tau)}\right] \tag{2}$$

where $rx_{t+\tau,t+\tau+1}^{(n-\tau)}$ denotes the one-period excess log return of an n-period bond and is defined as

$$rx_{t,t+1}^{(n)} = \ln\left(P_{t+1}^{(n-1)}/P_t^{(n)}\right) - y_t^{(1)} \tag{3}$$

Under the extended EH, the one-period risk premium is constant but maturity specific, i.e. $E_t\left[rx_{t+\tau,t+\tau+1}^{(n-\tau)}\right] = \phi(n)$, and all variation in the yield curve is generated by changes in market expectations about future short rates. A failure of the EH implies that the yield curve reacts to changes in both the expected short-term rates and the term premiums.

2.2. The Extended Macro-Finance Model of Bond and Term Premiums

2.2.1. Macro-Finance Framework

The class of essentially affine MF models allows one to express the yield on an n-period bond at time t, $y_t^{(n)}$ as an affine function of a state vector, X_t:

$$y_t^{(n)} = A_{y,n} + B_{y,n}X_t \tag{4}$$

More specifically, this class of models, introduced by Duffee (2002) and Ang and Piazzesi (2003), posits (i) a Gaussian linear state space dynamics:

$$X_{t+1} = C + \Phi X_t + \Sigma\varepsilon_{t+1}, \qquad \varepsilon_{t+1} \sim N(0,I) \tag{5}$$

and (ii) an exponential affine structure on the pricing kernel m_{t+1}:

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$$m_{t+1} = \exp\left(-i_t - 0.5\Lambda'_t\Lambda_t - \Lambda_t\varepsilon_{t+1}\right)$$

with

$$\begin{aligned} i_t &= \delta_0 + \delta'_1 X_t, \\ \Lambda_t &= \Lambda_0 + \Lambda_1 X_t \end{aligned} \tag{6}$$

Imposing the no-arbitrage condition on the zero-coupon bond price, i.e. $P_t^{(n)} = E_t\left(m_{t+1}P_{t+1}^{(n-1)}\right)$, results in an affine yield curve representation (see equation (4)), where $A_{y,n}$ and $B_{y,n}$ satisfy the well-known no-arbitrage difference equations (see, for example, Duffee, 2002; Ang and Piazzesi, 2003).

The model summarized by equations (4) and (5) allows an affine representation of the yield components in equations (1) and (2). This is achieved with the use of equation (3) and the relation linking bond prices to bond yields:

$$y_t^{(n)} = -\frac{\ln P_t^{(n)}}{n} \tag{7}$$

since $P_t^{(0)} = 1$. Next, we specify each factor included in the EMF model.

2.2.2. *The Extended Macro-Finance Model*

The EMF model incorporates eight state variables sorted into three groups. The first group includes three observable macroeconomic factors (inflation, π_t, the output gap, $\tilde{y}_t$, and the central bank policy rate, i_t^{cb}). The second group consists of three latent financial factors. The first two are related to the overall liquidity risk in the money market ($l_{1,t}$ and $l_{2,t}$, respectively), while the third ($l_{3,t}$) drives the one-period risk premium. The third group contains two stochastic trends modelling the long-run inflation expectation, π_t^*, and the equilibrium real rate, ρ_t.The state vector is therefore given by

$$X_t = \left[\pi_t, \tilde{y}_t, i_t^{\mathrm{cb}}, l_{1,t}, l_{2,t}, l_{3,t}, \pi_t^*, \rho_t\right]' \tag{8}$$

The inclusion of the observable macroeconomic variables is standard in MF models. The introduction of liquidity factors is motivated by recent evidence documenting the impact of liquidity shocks on the yield curve (see Liu *et al*., 2006; Christensen *et al*., 2009). The liquidity factors are linked to tensions in the money market, which can be measured by the TED spread, i.e. the spread between the unsecured money market rate, i_t^{mm}, and the 1-quarter Treasury bill (T-bill) rate, $y_t^{(1)}$. The liquidity factors decompose the TED spread in specific dimensions of liquidity risk. The spread factor $l_{1,t}$ represents a convenience yield from holding T-bills and can be seen as a flight-to-quality component. A flight-to-quality (i.e. to government bonds) is typically followed by a widening of the spread between the yield on secured or collateralized money market rate, i_t^{repo}, and the T-bill rate. The spread factor $l_{2,t}$ is identified by the difference between unsecured and secured money market rates and reflects a counterparty, credit risk component. Formally:

$$\begin{aligned} \mathrm{TED}_t = i_t^{\mathrm{mm}} - y_t^{(1)} &= l_{1,t} + l_{2,t}, \\ l_{1,t} &= i_t^{\mathrm{repo}} - y_t^{(1)}, \\ l_{2,t} &= i_t^{\mathrm{mm}} - i_t^{\mathrm{repo}} \end{aligned} \tag{9}$$

The third financial factor ($l_{3,t}$) is motivated by evidence from Cochrane and Piazzesi (2005) and Joslin *et al*. (2010) showing that a large fraction of the variation in bond risk premiums cannot be

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explained by macroeconomic factors but should be modelled by an additional return-forecasting factor. In the EMF model, this factor is identified by restrictions on the prices of risk such that it accounts for all the time variation in the one-period risk premium across the yield curve. Finally, the third group of state variables includes two stochastic trends that obtain their macroeconomic interpretation through the following cointegrating restrictions[5]:

$$\begin{aligned}\lim_{s\to\infty} E_t[\pi_{t+s}] &= \pi_t^*,\\ \lim_{s\to\infty} E_t\left[i_{t+s}^{\text{cb}}\right] &= \rho_t + \pi_t^*\end{aligned} \tag{10}$$

2.3. Estimation

The EMF model contains 92 parameters represented by the vector θ. We estimate the model using a standard Metropolis–Hastings algorithm based on relatively loose priors reflecting standard beliefs regarding the macroeconomic dynamics (see Smets and Wouters, 2007, among others).[6] We check convergence by means of standard convergence tests.[7]

We estimate the EMF model on US quarterly data over the period 1960:Q1–2008:Q4 (196 observations), making use of four groups of information variables: (i) standard macroeconomic series; (ii) yield curve data; (iii) money market rates; and (iv) data on inflation forecasts and potential output growth. The first group contains annualized inflation based on the quarterly growth of the GDP deflator, the output gap constructed from data provided by the Congressional Budget Office (CBO), and the central bank policy rate represented by the effective federal funds rate. The data are obtained from the Federal Reserve Bank of St Louis FRED database and are assumed to be observed without errors. The second group includes per annum zero-coupon yield data for maturities of 1, 4, 8, 12, 16, 20, and 40 quarters from the Fama–Bliss Center for Research in Security Prices (CRSP) bond files, with the exception of 40-quarter yields obtained from Gürkaynak *et al.* (2007). We assume all yields are measured with an error. The third group includes the 1-quarter eurodollar rate $\left(i_t^{\text{Ed}}\right)$ from 1971:Q2 to 1986:Q1 and the 1-quarter London Interbank offered rate, LIBOR (Lb) $\left(i_t^{\text{Lb}}\right)$ for the period after that, as our measure for the unsecured money market rate $\left(i_t^{\text{mm}}\right)$, both from Datastream.[8] The secured money market rate $\left(i_t^{\text{repo}}\right)$ is represented by the government-backed collateral repo rate (GC-repo) from Bloomberg (ticker RPGT03M). The fourth group includes survey data on the average 4- and 40-quarter inflation forecasts retrieved from the Survey of Professional Forecasters (Federal Reserve Bank of Philadelphia) and used to identify long-run inflation expectations, and data on potential output growth measured as the quarterly growth of CBO potential output and used to identify the equilibrium real rate.

In the forecasting exercise of Section 3.2.2, we also use inflation forecasts from the Greenbook dataset provided by the Federal Reserve Bank of Philadelphia for the period 1974:Q2–2005:Q4 (127 observations). The data consist of annualized quarterly growth rate of the GDP deflator and end in 2005 due to the five-year lag between the forecast and the release date. Table I presents the summary statistics of all the data used in the estimation.

[5] See Dewachter and Iania (2011) for details on the identification restrictions for these stochastic trends.
[6] Table I of the online Appendix to this paper (supporting information) lists the type of distribution, mean and standard deviation for the prior of the parameter vector θ.
[7] For details of the estimation method, see Dewachter and Iania (2011).
[8] The LIBOR rate is an average of rates at which banks offer funds (offer side), while the eurodollar rate refers to a rate at which banks want to borrow funds (bid side). Typically, the eurodollar rate is about one basis point below the LIBOR rate. In the estimation, we assume there is a spread between these rates equal to a constant plus an idiosyncratic shock.

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Table I. Summary statistics

	Macro				Yields							Surveys		Spreads			
	Δy_t^{pot}	π_t	$\tilde{y}_t$	i_t^{cb}	$y_t^{(1)}$	$y_t^{(4)}$	$y_t^{(8)}$	$y_t^{(12)}$	$y_t^{(16)}$	$y_t^{(20)}$	$y_t^{(40)}$	π_t^{4q}	π_t^{40q}	ted_t	lib_t	cy_t	cr_t
μ ($\times$ 100)	3.2	3.6	−0.3	6.0	5.5	5.9	6.1	6.3	6.4	6.5	6.9	3.9	3.8	1.0	0.7	0.2	−0.3
σ ($\times$ 100)	0.6	2.4	2.3	3.3	2.8	2.8	2.8	2.7	2.6	2.6	2.4	2.0	1.5	1.1	0.5	0.2	0.3
kur	2.5	4.0	3.8	5.3	4.7	4.0	3.9	3.9	3.9	3.6	3.6	3.1	4.2	9.8	12.5	5.8	23.7
skw	0.2	1.2	−0.1	1.2	1.1	0.9	0.9	0.9	1.0	0.9	1.0	1.0	1.3	2.4	2.4	1.4	−4.1
$\rho^{(1)}$	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.7	0.5	0.6
$\rho^{(4)}$	0.9	0.8	0.6	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	0.5	0.5	0.5	0.3

Note: Δy_t^{pot} refers to the quarter-by-quarter growth rate of potential output expressed in annual terms, π_t to inflation, $\tilde{y}_t$ to the output gap, i_t^{cb} to the central bank policy rate. $y_t^{(1)}, \ldots, y_t^{(40)}$ to zero-coupon bond yields with maturities of 1 to 40 quarters, π_t^{4q} and π_t^{40q} to the survey data on the average 4- and 40-quarter inflation forecasts, ted_t to the TED spread, i.e. the difference between the LIBOR rate and the three-month government bond yield, lib_t to the LIBOR spread, i.e. $\text{lib}_t = i_t^{\text{Libor}} - i_t^{cb}$, cy_t to the convenience yield, and cr_t to the credit-risk component. μ denotes the mean, or the sample arithmetic average in percentage p.a., σ the standard deviation, kur the kurtosis, skw the skewness, and $\rho^{(1)}$ and $\rho^{(4)}$ the autocorrelation at lag 1 and 4, respectively.

3. EMPIRICAL RESULTS

Section 3.1 discusses the implications of the estimated EMF model and the implied decomposition of the yield curve for the prediction of excess bond returns. Section 3.2 assesses the impact of such decomposition for the prediction of real economic activity and inflation.

3.1. Bond Risk Premium

The EMF model clearly rejects the extended EH.[9] Figure 1 shows that the model-implied risk premiums exhibit statistically significant time variation (see the 99% error bands), rejecting the null of constant risk premium. The risk premiums also display strong collinearity across maturities, indicating the presence of a dominant factor which is represented by the factor $l_{3,t}$. Figure 2 suggests that this factor is closely related to the benchmark factor of Cochrane and Piazzesi (2005), the CP factor, with a correlation of 67% between the two series. Finally, in line with the literature, risk premiums tend to be countercyclical. The 4-quarter expected excess return for 8- to 20-quarter bonds has a correlation of around $-45\,\%$ with the output gap.

We assess the performance of the EMF model by examining the fit of the bond risk premiums. Table II presents in-sample and out-of-sample results for excess bond returns implied by Cochrane and Piazzesi's (2005) method and the EMF model. The analysis is done for a 20-quarter bond and for 4- and 8-quarter holding periods. Panel A reports the adjusted R^2 for in-sample regressions of the realized excess return on the CP factor and the EMF model-implied risk premium. We find that the EMF model explains a substantial amount of the variation in realized excess returns. This finding is in line with Cochrane and Piazzesi (2005) and Ludvigson and Ng (2009), who show that a limited number of factors can forecast a significant part of realized excess returns. For the 4-quarter horizon, the performance of our model and that of Cochrane and Piazzesi (2005) is comparable, predicting above 30% of the in-sample variation in the realized excess returns. For the 8-quarter horizon, the EMF factor explains almost 40%, while the CP factor explains 21% of the variability in realized excess returns.

Panel B of Table II reports the out-of-sample results for the period 1996:Q1–2008:Q4. We compare the performance in terms of the mean squared error (MSE) of the EMF model against

[9] The parameter estimates of the EMF model are presented in Tables II–IV of the online Appendix to this paper.

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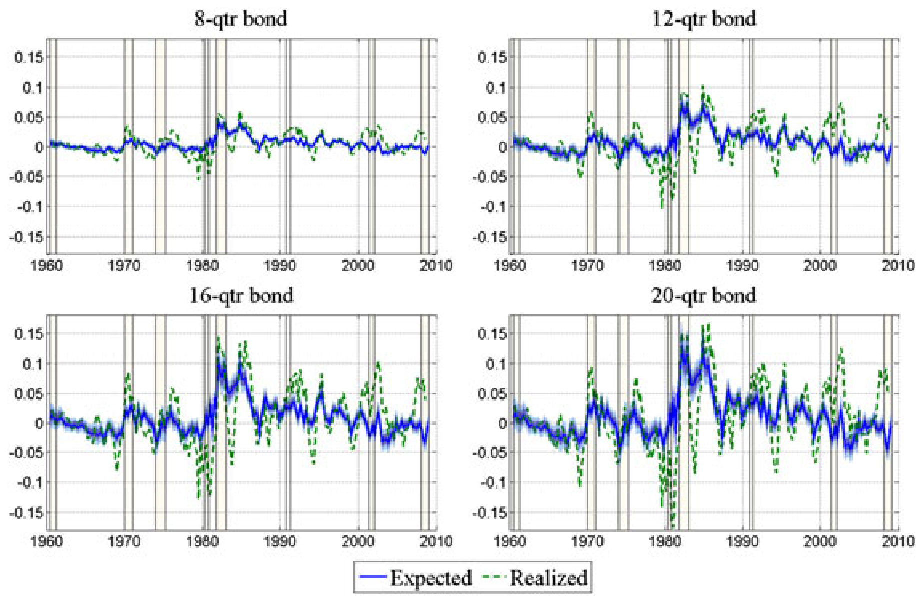

Figure 1. Excess return: expected versus realized. This figure compares the EMF model-implied expected excess return (risk premium, continuous line) with the realized excess return (dashed line). The holding period is 4 quarters for bonds with maturities of 8, 12, 16 and 20 quarters

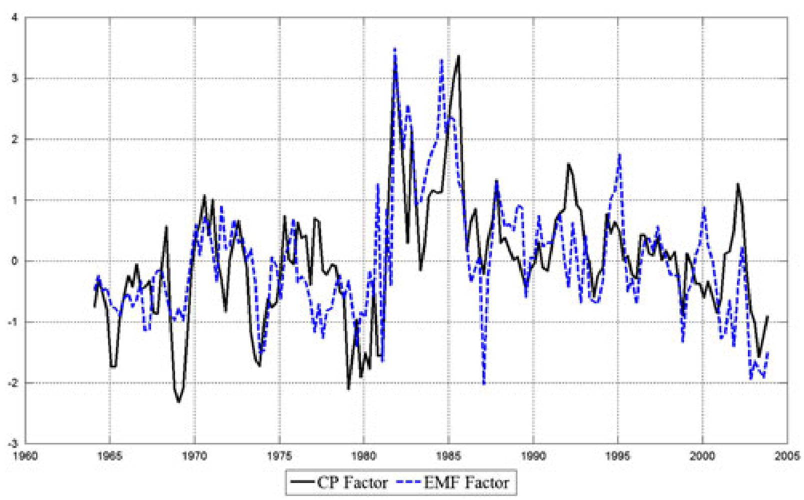

Figure 2. Return-forecasting factor: CP versus EMF factor. This figure compares the Cochrane and Piazzesi (2005) factor (CP) with the EMF risk premium factor. Since the original CP factor is computed using monthly data and we work with quarterly frequencies, we compute the CP factor on a monthly basis and for each quarter we take the average of the monthly series. The correlation between our factor and the CP factor is 0.67

the CP factor and a random walk (RW) model with drift (i.e. with constant risk premium or no predictability for excess returns). The EMF model has a slightly superior performance against the CP model for both forecasting horizons (4 and 8 quarters). Against the RW model, the EMF model has a slightly inferior performance for the 4-quarter horizon but a superior performance over 8

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Table II. Excess returns: in-sample and out-of-sample analysis

Panel A: In-sample statistics			Panel B: Out-of-sample statistics		
Holding period	4 qtr	8 qtr	Holding period	4 qtr	8 qtr
Maturity (n)	20 qtr	20 qtr	Maturity (n)	20 qtr	20 qtr
CP (Adj. R^2)	30.50%	20.53%	EMF (RMSE)	5.08%	5.70%
EMF (Adj. R^2)	31.53%	39.44%	CP (RMSE)/EMF (RMSE)	1.03	1.03
			RW (RMSE)/EMF (RMSE)	0.99	1.05

Note: CP stands for the regression based on Cochrane and Piazzesi (2005); RMSE refers to the root mean squared error; while RW stands for the random walk model. For the EMF and CP models, the forecasts are obtained (i) by estimating the models over the period 1960:Q1–1995:Q4 and (ii) by producing the model-implied forecasts of the excess returns for the period 1996:Q1–2008:Q4. Every quarter the information is updated and the models are re-estimated.

quarters.[10] Therefore, despite the strong in-sample performance of the EMF model, its out-of-sample performance seems less robust.

Additionally, we check the unbiasedness of the estimated bond risk premiums. We regress the realized excess returns on the expected excess returns implied by the EMF model:

$$rx_{t,t+k}^{(n)} = \alpha + \beta E_t\left[rx_{t,t+k}^{(n)}\right] + \varepsilon_{t+k}, \quad n = 20 \text{ qtr}, \quad k = 4,\ 8 \text{ qtr} \tag{11}$$

where $rx_{t,t+k}^{(n)}$ denotes the realized return in excess of the k-quarter risk-free rate of buying a n-quarter bond at time t and selling it after k quarters, and $E_t\left[rx_{t,t+k}^{(n)}\right]$ represents the model-implied risk premium. We test the joint hypothesis that $\alpha = 0$ and $\beta = 1$. Table III shows that the estimated risk premiums are unbiased: (i) all α coefficients are statistically insignificant, while the β coefficients are not statistically different from one; and (ii) based on a standard F-test, we cannot reject the joint hypothesis for α and β.[11]

We now assess the contribution of each type of shock to the dynamics of bond risk premiums making use of a variance decomposition. The EMF model implies that risk premiums are mainly driven by financial shocks, with a marginal contribution from macroeconomic shocks. Panel A of Table IV illustrates this by means of a variance decomposition of the 4-quarter risk premiums of 8- and 20-quarter bonds.[12] The results highlight the importance of three types of shocks: (i) return-forecasting factor (i.e. risk premium) shocks are the dominant source of variation, explaining between 60% and 80% of the variation in risk premiums; (ii) liquidity shocks explain between 12% and 20% of this variation; and (iii) for long horizons, monetary policy shocks account for approximately 15% of the variance decomposition.

3.2. Term Premium

The rejection of the EH raises the question of the relative importance of the expectations and term premium components in the yield curve (and yield spread) dynamics. This is a relevant issue since yield curve changes might entail different macroeconomic interpretations depending on the source of variation (see

[10] For bonds with other maturities (8, 12 and 16 quarters), however, the EMF model has a performance which is equal or superior to both the CP and RW models. The results are available upon request.
[11] This result also holds for bonds with maturities of 8, 12, and 16 quarters. The results are available upon request.
[12] The ordering of the variables is the same as that in the state vector (equation (8)).

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Table III. Unbiasedness of expected excess returns

Holding period	4 qtr	8 qtr
Maturity (n)	20 qtr	20 qtr
α	0.000	0.000
	(0.006)	(0.004)
β	0.969	1.003
	(0.172)	(0.284)
p-value ($\alpha = 0$, $\beta = 1$)	0.984	0.394

Note: The Newey–West standard errors of the coefficients are in parentheses. The sample period goes from 1960:Q1 to 2008:Q4.

Table IV. Variance decomposition

Panel A: Bond risk premium							
			8-qtr bond (4-qtr holding period)				
Horizon	Sup. sh.	Dem. sh.	Pol. rate sh.	Liq. sh.	Risk pr. sh.	LR inf. sh.	Eq. real rate sh.
4 qtr	2.6%	1.1%	5.0%	12.3%	78.8%	0.2%	0.0%
40 qtr	2.5%	1.4%	17.2%	19.1%	59.6%	0.3%	0.0%
			20-qtr bond (4-qtr holding period)				
Horizon	Sup. sh.	Dem. sh.	Pol. rate sh.	Liq. sh.	Risk pr. sh.	LR inf. sh.	Eq. real rate sh.
4 qtr	2.4%	1.0%	4.5%	13.1%	78.8%	0.1%	0.0%
40 qtr	2.4%	1.3%	16.5%	19.3%	60.3%	0.3%	0.0%
Panel B: Expectations component							
			Expected average short-term rate over 4 quarters				
Horizon	Sup. sh.	Dem. sh.	Pol. rate sh.	Liq. sh.	Risk pr. sh.	LR inf. sh.	Eq. real rate sh.
4 qtr	3.5%	2.7%	79.8%	12.8%	0.0%	1.0%	0.2%
40 qtr	2.5%	3.5%	44.5%	15.8%	0.0%	30.6%	3.1%
			Expected average short-term rate over 40 quarters				
Horizon	Sup. sh.	Dem. sh.	Pol. rate sh.	Liq. sh.	Risk pr. sh.	LR inf. sh.	Eq. real rate sh.
4 qtr	1.7%	3.0%	18.6%	17.2%	0.0%	53.9%	5.6%
40 qtr	0.3%	0.6%	2.6%	4.5%	0.0%	83.8%	8.2%
Panel C: Term premium component							
			4-qtr term premium				
Horizon	Sup. sh.	Dem. sh.	Pol. rate sh.	Liq. sh.	Risk pr. sh.	LR inf. sh.	Eq. real rate sh.
4 qtr	1.8%	0.5%	2.5%	18.6%	76.6%	0.1%	0.0%
40 qtr	2.0%	1.0%	12.6%	21.2%	63.0%	0.2%	0.0%
			40-qtr term premium				
Horizon	Sup. sh.	Dem. sh.	Pol. rate sh.	Liq. sh.	Risk pr. sh.	LR inf. sh.	Eq. real rate sh.
4 qtr	3.8%	0.9%	20.7%	8.8%	65.2%	0.6%	0.0%
40 qtr	4.1%	0.8%	23.4%	29.3%	41.4%	1.0%	0.0%

Note: This table reports the forecasting error variance decomposition (computed at the mode of the posterior distribution of the parameters) of the 4-quarter risk premiums of 8- and 20-quarter maturity bonds (Panel A), of the average expected 1-quarter interest rate over 4 quarters and 40 quarters (Panel B), and of the 4-quarter and 40-quarter term premium (Panel C). Sup. sh., supply shocks; Dem. sh., demand shocks; Pol. rate sh., policy rate shocks; Liq. sh., flight-to-quality and credit-crunch shocks; LR inf. sh., long-run inflation shocks; Eq. real rate sh., equilibrium real rate shocks.

Rudebusch *et al.*, 2007; Ludvigson and Ng, 2009). In this section, we first decompose bond yields and analyse the macroeconomic and financial drivers of their components. We then study the predictive power of a popular yield curve indicator, the yield spread, and its expectations and term premium components for economic activity and inflation.

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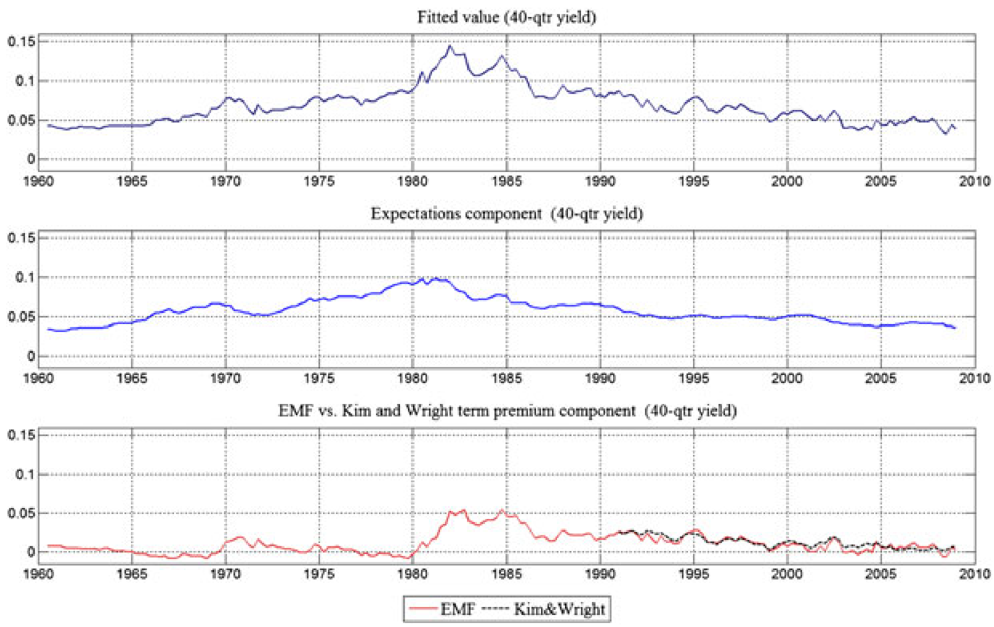

Figure 3. Ten-year yield: fitted value, expectations component and term premium component. The top panel plots the 40-quarter fitted yield. The middle panel depicts the EMF model-implied expected average 1-quarter yield over a period of 40 quarters. The bottom panel compares the EMF model-implied term premim for the 40-quarter bond (continuous line) with the term premium of Kim and Wright (2005) (dashed line)

3.2.1. Decomposing the Yield Curve

Figure 3 illustrates the decomposition of the yield curve. The top panel shows the model-implied time series of the 40-quarter yield, while the middle panel displays its expectations component. The bottom panel plots the term premium implied by the EMF model and compares it to the Kim and Wright (2005) measure (KW).[13] Despite the significant differences in structure between the EMF and KW models,[14] the term premiums derived from these models are remarkably similar. This result might be surprising given the findings of Rudebusch *et al*. (2007). They find that the behaviour of the KW and the Bernanke *et al*. (2004) measures are remarkably similar, while that of Cochrane and Piazzesi (2005) is harder to understand since it is well below the other measures and far too volatile. Our EMF model is able to filter a return-forecasting factor similar to the CP factor while generating a term premium measure similar to that of Kim and Wright (2005).

The time variation in our term premium series is substantial, which indicates that the rejection of the EH documented above has significant economic implications. In particular, the one-to-one relation between yields and expected short rates (implying a constant, maturity-specific term premium) breaks down.

Panels B and C of Table IV show the variance decomposition of the expectations and term premium components, respectively, of 4- and 40-quarter bonds. The expectations component of 4-quarter bonds is dominated by monetary policy shocks, while that of long-term bonds is dominated by long-run inflation shocks. In line with the findings of Section 3.1, the term premium component is driven mainly

[13] The Federal Reserve Board provides data to generate the term premium from the Kim and Wright (2005) model.
[14] The Kim and Wright (2005) model is a standard latent factor model augmented with survey data, whereas the EMF model combines macroeconomic, yield curve and survey data.

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by risk premium shocks. Liquidity and policy rate shocks have a smaller effect over all horizons, while macroeconomic shocks are insignificant. To the extent that financial shocks carry different information from macroeconomic shocks, one may expect a difference in the information content of the expectation and term premium component. This follows as a direct consequence of the difference in relative importance of financial and macroeconomic shocks in, respectively, the term premium and expectations components. As a consequence, it may also blur the informational content of yield spreads, which is the measure mostly used for macroeconomic predictions.

Since in the next section we focus on the predictive content of yield spreads for macroeconomic predictions, we illustrate in Figure 4 the decomposition of yield spreads into an expectations and a term premium component. The top panel of this figure shows the 40-quarter yield spread implied by the EMF model, and the middle and bottom panels display its expectations and term premium components, respectively. As expected, this figure suggests that a significant part of the yield spread variation is due to the variation in the term premium.

3.2.2. Macroeconomic Information in the Yield Curve

We assess the information content of the EMF model-implied expectations $\left(\mathrm{Spr}_t^{e,(n)}\right)$ and term premium $\left(\chi_t^{(n)}\right)$ components of yield spreads $\left(\mathrm{Spr}_t^{(n)}\right)$ in the predictive regressions of real economic activity and inflation, with $\mathrm{Spr}_t^{(n)} = y_t^{(n)} - y_t^{(1)} = \mathrm{Spr}_t^{e,(n)} + \chi_t^{(n)}$. We concentrate on two measures of economic activity: real GDP growth and the output gap. Our analysis of the GDP growth is closely related to Ang *et al*. (2006), Estrella and Mishkin (1997) and Rudebusch *et al*. (2007), while the prediction exercise for the output gap is relatively new. We also use two measures of inflation in our

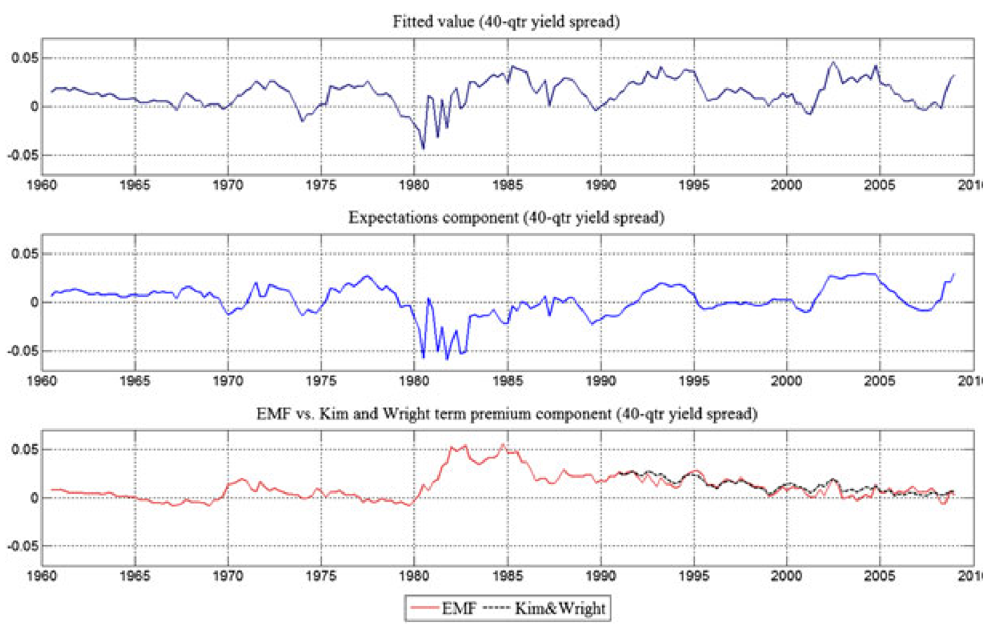

Figure 4. Ten-year spread: fitted value, expectations component and term premium component. The top panel plots the fitted spread of the 40-quarter yield less the 1-quarter yield. The middle panel depicts the EMF model-implied expected average 1-quarter yield over a period of 40 quarters minus the 1-quarter yield. The bottom panel compares the EMF model-implied term premium for the 40-quarter bond (continuous line) with the term premium of Kim and Wright (2005) (dashed line)

analysis. We forecast inflation taking into consideration the main results of Faust and Wright (2011), and predict forward inflation changes as in Estrella and Mishkin (1997) and Mishkin (1990).

Predicting economic activity. For GDP growth, we estimate several predictive regressions, where the most extended version regresses the cumulative real GDP growth for the next k quarters on the yield spread components:

$$g_{t\to t+k} = \alpha + \beta^{\mathrm{EC}}\left(\mathrm{Spr}_t^{e,(n)} + \chi_t^{(n)}\right) + \beta^{\mathrm{TP}}\chi_t^{(n)} + \gamma g_t + \delta y_t^{(1)} + \varepsilon_{t+k} \tag{12}$$

where $g_t \equiv g_{t-1\to t}$ denotes GDP growth in the past quarter, expressed in yearly terms. In line with the literature, we use lagged GDP growth, g_t, and the short-term interest rate, $y_t^{(1)}$, as control variables. For output gap predictions, we use a similar specification:

$$\tilde{y}_{t+k} = \alpha + \beta^{\mathrm{EC}}\left(\mathrm{Spr}_t^{e,(n)} + \chi_t^{(n)}\right) + \beta^{\mathrm{TP}}\chi_t^{(n)} + \gamma \tilde{y}_t + \delta y_t^{(1)} + \varepsilon_{t+k} \tag{13}$$

where $\tilde{y}_{t+k}$ denotes the output gap at time $t+k$. For both regressions, we distinguish between four types of models. Model 1 is the standard representation based solely on the spread and, therefore, imposes that $\beta^{\mathrm{TP}} = \gamma = \delta = 0$. Model 2 allows for different informational content from each spread component, i.e. it allows $\beta^{\mathrm{TP}} \neq 0$. Note that, by construction, a statistical test for the relevance of the spread decomposition consists of testing the null of $\beta^{\mathrm{TP}} = 0$. Model 3 extends model 1 (without the spread decomposition) by allowing for the two control variables. Model 4 is the most general case, as in equations (12) and (13). We estimate each model using 4-, 20-, or 40-quarter yield spreads and for a forecasting horizon (k) of 1, 4, and 8 quarters.

Table V summarizes the results for the GDP growth predictive regressions (equation (12)). The estimates for model 1 show a positive relation between spreads and future GDP growth which is statistically significant for all horizons. Yield spreads are, however, not sufficient statistics for GDP growth predictions. Adding control variables improves the performance of the predictive equations in almost all cases if the yield spread is used (model 3) and in all cases if the decomposed spread is used (model 4). Note, however, that the inclusion of control variables (model 3) does not drive out the yield spread as a predicting variable (unlike Ang *et al*., 2006).

We now assess the impact of the yield spread decomposition to forecast GDP growth. Although a simple decomposition of the yield spread (model 2) improves forecasts of GDP growth, the increase in the adjusted R^2 is smaller than that obtained with the use of control variables (model 3). Finally, comparing models 1 and 2 and models 3 and 4, we observe that although the decomposition of the yield spread into its components leads in most cases to an increase in the adjusted R^2, in all cases we cannot reject the hypothesis that $\beta^{\mathrm{TP}} = 0$. Therefore, surprisingly, the yield spread decomposition as implied by the EMF model improves only marginally (and not statistically significantly) the prediction of GDP growth.[15]

The results in the literature regarding the importance of each yield spread component are contradictory. Our results are in line with Ang *et al*. (2006), who find that only the expectations component is relevant to forecast output growth. Hamilton and Kim (2002) find that both components are important, while Favero *et al*. (2005) attribute more importance to the term premium component.

Table VI summarizes the results for the output gap regressions (equation (13)). The estimates for model 1 show that the yield spread alone has minor predictive power for the output gap. The results

[15] Interestingly, Ang *et al*. (2006) recommend for prediction purposes the use of the longest maturity yield to measure the spread. In their case, this is the 20-quarter yield. Our longest yield has a maturity of 40 quarters but we find that in 9 out of 12 cases the best spread to be used in order to forecast GDP growth is the 20-quarter spread.

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Table V. Forecasting GDP growth

Model 1	$g_{t\rightarrow t+k}=\alpha+\beta \mathrm{Spr}_t^{(n)}+\varepsilon_{t+k}$								
Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	0.026	0.023	0.023	0.025	0.023	0.023	0.026	0.024	0.025
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)
β	1.362	0.838	0.593	1.462	0.840	0.583	1.090	0.675	0.455
	(0.469)	(0.224)	(0.199)	(0.407)	(0.214)	(0.180)	(0.345)	(0.148)	(0.126)
Adj.-R^2	0.044	0.098	0.076	0.078	0.147	0.110	0.072	0.160	0.113

Model 2	$g_{t\rightarrow t+k}=\alpha+\beta^{\mathrm{EC}}\left(\mathrm{Spr}_t^{e.(n)}+\chi_t^{(n)}\right)+\beta^{\mathrm{TP}}\chi_t^{(n)}+\varepsilon_{t+k}$								
Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	0.025	0.025	0.024	0.025	0.024	0.024	0.027	0.025	0.024
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)
β^{EC}	2.544	1.043	0.782	2.027	0.925	0.700	1.129	0.633	0.489
	(0.677)	(0.243)	(0.205)	(0.654)	(0.220)	(0.184)	(0.597)	(0.155)	(0.127)
β^{TP}	−1.198	−0.419	−0.323	−0.705	−0.245	−0.166	−0.083	−0.010	0.042
	(0.733)	(0.255)	(0.247)	(0.663)	(0.234)	(0.228)	(0.500)	(0.176)	(0.172)
Adj.-R^2	0.097	0.132	0.118	0.108	0.159	0.143	0.093	0.153	0.142

Model 3	$g_{t\rightarrow t+k}=\alpha+\beta \mathrm{Spr}_t^{(n)}+\gamma g_t+\delta y_t^{(1)}+\varepsilon_{t+k}$								
Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	0.027	0.023	0.023	0.029	0.025	0.025	0.031	0.026	0.026
	(0.009)	(0.010)	(0.010)	(0.009)	(0.010)	(0.011)	(0.007)	(0.008)	(0.010)
β	1.158	0.601	0.389	1.290	0.670	0.434	0.992	0.622	0.410
	(0.417)	(0.219)	(0.193)	(0.393)	(0.240)	(0.205)	(0.343)	(0.206)	(0.187)
γ	0.269	0.252	0.260	0.169	0.150	0.159	0.047	0.029	0.038
	(0.084)	(0.083)	(0.084)	(0.069)	(0.068)	(0.070)	(0.051)	(0.050)	(0.052)
δ	−0.165	−0.101	−0.095	−0.159	−0.088	−0.081	−0.107	−0.036	−0.028
	(0.103)	(0.113)	(0.122)	(0.100)	(0.115)	(0.128)	(0.085)	(0.097)	(0.112)
Adj.-R^2	0.184	0.194	0.175	0.182	0.199	0.165	0.103	0.157	0.111

Model 4	$g_{t\rightarrow t+k}=\alpha+\beta^{\mathrm{EC}}\left(\mathrm{Spr}_t^{e.(n)}+\chi_t^{(n)}\right)+\beta^{\mathrm{TP}}\chi_t^{(n)}+\gamma g_t+\delta y_t^{(1)}+\varepsilon_{t+k}$								
Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	0.033	0.020	0.018	0.040	0.029	0.026	0.043	0.035	0.032
	(0.009)	(0.010)	(0.010)	(0.010)	(0.012)	(0.012)	(0.009)	(0.012)	(0.013)
β^{EC}	0.671	0.761	0.615	0.023	0.501	0.412	−0.439	0.238	0.217
	(0.898)	(0.324)	(0.273)	(0.973)	(0.386)	(0.319)	(0.971)	(0.422)	(0.353)
β^{TP}	0.536	−0.202	−0.195	1.258	0.136	0.107	1.531	0.371	0.321
	(0.866)	(0.311)	(0.280)	(0.901)	(0.359)	(0.321)	(0.822)	(0.370)	(0.336)
γ	0.248	0.236	0.241	0.156	0.149	0.152	0.043	0.040	0.040
	(0.082)	(0.087)	(0.087)	(0.064)	(0.070)	(0.071)	(0.041)	(0.046)	(0.048)
δ	−0.262	−0.039	−0.005	−0.344	−0.159	−0.124	−0.316	−0.197	−0.162
	(0.130)	(0.140)	(0.144)	(0.138)	(0.170)	(0.176)	(0.114)	(0.175)	(0.186)
Adj.-R^2	0.201	0.197	0.188	0.221	0.199	0.183	0.193	0.172	0.153

Note: The standard errors of the coefficients are in parentheses. We estimate the model over the period 1960:Q1–2008:Q4.

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Table VI. Forecasting output gap

Model 1

$$\tilde{y}_{t+k} = \alpha + \beta \mathrm{Spr}_t^{(n)} + \varepsilon_{t+k}$$

Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	−0.002	0.002	0.002	−0.007	−0.006	−0.006	−0.011	−0.012	−0.012
	(0.003)	(0.005)	(0.005)	(0.004)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)
β	−0.309	−0.543	−0.394	0.673	0.111	0.078	1.256	0.650	0.467
	(0.546)	(0.271)	(0.197)	(0.587)	(0.264)	(0.218)	(0.650)	(0.278)	(0.227)
Adj.-R^2	−0.001	0.063	0.052	0.011	−0.003	−0.003	0.045	0.070	0.056

Model 2

$$\tilde{y}_{t+k} = \alpha + \beta^{\mathrm{EC}} \left(\mathrm{Spr}_t^{e,(n)} + \chi_t^{(n)} \right) + \beta^{\mathrm{TP}} \chi_t^{(n)} + \varepsilon_{t+k}$$

Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	−0.002	0.004	0.006	−0.007	−0.003	−0.001	−0.010	−0.010	−0.010
	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)
β^{EC}	2.215	0.064	−0.035	3.020	0.650	0.432	2.814	0.952	0.708
	(0.555)	(0.198)	(0.173)	(0.572)	(0.220)	(0.185)	(0.776)	(0.221)	(0.182)
β^{TP}	−2.589	−0.852	−0.799	−2.546	−0.852	−0.754	−1.766	−0.559	−0.440
	(0.633)	(0.253)	(0.256)	(0.578)	(0.244)	(0.248)	(0.519)	(0.177)	(0.174)
Adj.-R^2	0.251	0.252	0.242	0.222	0.185	0.162	0.137	0.143	0.126

Model 3

$$\tilde{y}_{t+k} = \alpha + \beta \mathrm{Spr}_t^{(n)} + \gamma \tilde{y}_t + \delta y_t^{(1)} + \varepsilon_{t+k}$$

Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	0.002	−0.000	−0.000	0.006	0.002	0.003	0.007	0.001	0.004
	(0.002)	(0.002)	(0.003)	(0.007)	(0.009)	(0.010)	(0.009)	(0.012)	(0.014)
β	0.227	0.180	0.133	0.859	0.465	0.265	1.095	0.606	0.324
	(0.123)	(0.056)	(0.052)	(0.352)	(0.241)	(0.187)	(0.485)	(0.350)	(0.308)
γ	0.934	0.967	0.964	0.578	0.656	0.624	0.122	0.225	0.178
	(0.032)	(0.032)	(0.033)	(0.092)	(0.105)	(0.099)	(0.130)	(0.156)	(0.154)
δ	−0.064	−0.036	−0.031	−0.220	−0.156	−0.166	−0.297	−0.213	−0.232
	(0.031)	(0.032)	(0.035)	(0.094)	(0.111)	(0.120)	(0.095)	(0.134)	(0.155)
Adj.-R^2	0.871	0.874	0.872	0.401	0.402	0.387	0.163	0.168	0.142

Model 4

$$\tilde{y}_{t+k} = \alpha + \beta^{\mathrm{EC}} \left(\mathrm{Spr}_t^{e,(n)} + \chi_t^{(n)} \right) + \beta^{TP} \chi_t^{(n)} + \gamma \tilde{y}_t + \delta y_t^{(1)} + \varepsilon_{t+k}$$

Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	−0.000	−0.005	−0.005	0.006	−0.003	−0.003	0.010	0.002	0.002
	(0.003)	(0.003)	(0.003)	(0.009)	(0.011)	(0.011)	(0.014)	(0.018)	(0.019)
β^{EC}	0.658	0.374	0.301	1.060	0.668	0.494	0.878	0.567	0.397
	(0.267)	(0.084)	(0.075)	(0.803)	(0.317)	(0.269)	(1.517)	(0.598)	(0.507)
β^{TP}	−0.342	−0.229	−0.190	−0.092	−0.256	−0.183	0.386	0.040	0.113
	(0.288)	(0.081)	(0.074)	(0.709)	(0.224)	(0.201)	(1.223)	(0.467)	(0.408)
γ	0.918	0.943	0.955	0.584	0.623	0.631	0.163	0.220	0.223
	(0.037)	(0.033)	(0.033)	(0.094)	(0.103)	(0.106)	(0.148)	(0.145)	(0.148)
δ	−0.031	0.045	0.052	−0.230	−0.072	−0.071	−0.366	−0.240	−0.245
	(0.044)	(0.041)	(0.043)	(0.131)	(0.146)	(0.154)	(0.187)	(0.258)	(0.274)
Adj.-R^2	0.877	0.880	0.878	0.420	0.413	0.402	0.191	0.175	0.163

Note: The standard errors of the coefficients are in parentheses. We estimate the model over the period 1960:Q1–2008:Q4.

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for model 2 indicate that a decomposition of yield spreads improves significantly their forecasting ability. The expectations component signals most of the time a statistically significant increase in the output gap. The results for model 3, however, reveal that the inclusion of control variables have a greater impact on the forecasting ability for the output gap than the decomposition of the yield spread, although less significant for longer forecasting horizons (8 quarters). This is mostly due to the correlation structure in the output gap series, which is particularly strong for short lags. Also, once control variables are included, the yield spread is statistically significant in only four out of nine cases. Finally, the results for model 4 show, with one exception, that once control variables are included we cannot reject the hypothesis that $\beta^{\mathrm{TP}} = 0$. As a consequence, comparing models 3 and 4 we conclude that the increase in the adjusted R^2 due to the decomposition of the yield spread is no longer significant. Hence, once we control for the current level of the output gap and the short-term interest rate, the yield spread decomposition does not seem to contribute to the prediction of the output gap.

We analyse now whether the predictive content of the yield spread and its components has changed over time. The analysis concentrates on the GDP growth. We use an expanding window starting in 1960:Q1 both to re-estimate the EMF model and for the predictive regressions (equation (12)). Figure 5 shows the end date of the sample period used and the resulting adjusted R^2. We observe a general decrease in the predictive power over time which seems stronger after 2002. The figure also shows that a simple yield spread decomposition (i.e. without control variables) has a higher forecasting ability for short-term horizons. The opposite happens if one allows for control variables, i.e. the yield spread

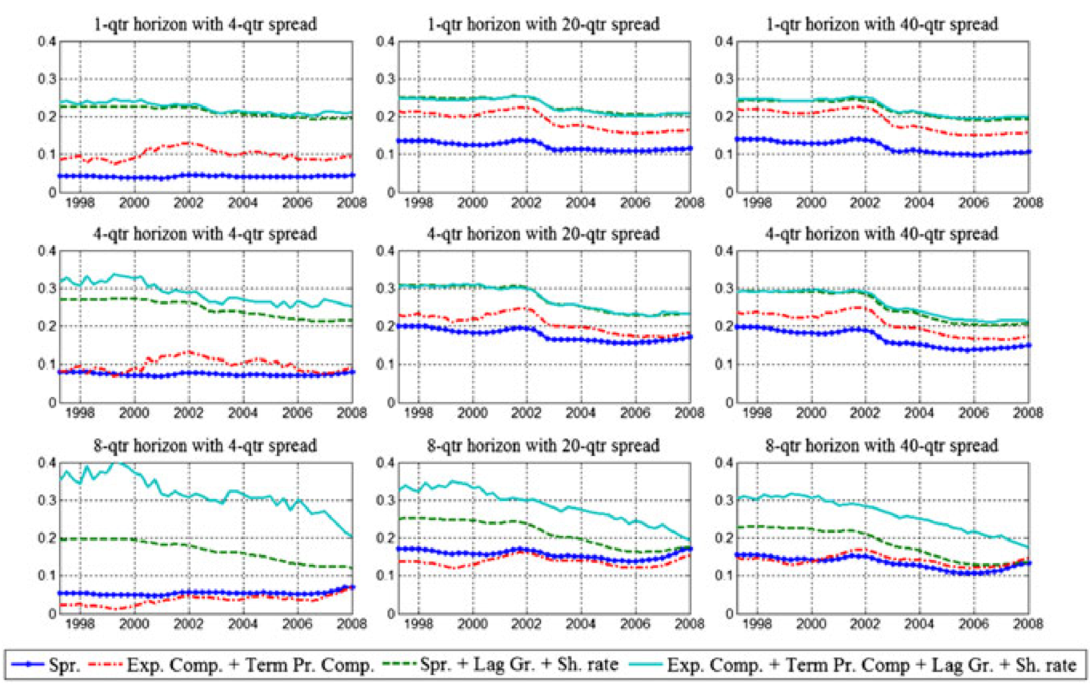

Figure 5. Forecasting GDP growth, expanding window (R^2). Each plot shows the adjusted R^2 over time for a certain predictive horizon using a certain yield spread. The rows of panels define the predictive horizon (1, 4, and 8 quarters) and the columns of panels the maturity of the yield spread used in the regression (4, 20, and 40 quarters). The date on the horizontal axis determines the end date of the sample period. The first point in each graph indicates the adjusted R^2 for the period 1960:Q1–1995:Q4. The EMF model is re-estimated at every quarter using an expanding window

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decomposition becomes more important for long-horizon forecasts. This improvement is significant for the 8-quarter horizon although such gain has decreased over time.[16]

Predicting inflation. We investigate the contribution of the yield spread decomposition in forecasting inflation using two sets of predictive regressions. The first set is based on the work of Faust and Wright (2011), who analyse 17 methods to forecast inflation. They find that for our measure of inflation (GDP deflator) the Federal Reserve's Greenbook forecast outperforms most model-based forecasts and that the random walk-based model of Atkeson and Ohanian (2001), the RW-AO model, does remarkably well in forecasting inflation. We therefore assess whether (i) the yield spread decomposition has predictive power to forecast inflation beyond the RW-AO method and (ii) whether the forecasting power is robust to the inclusion of a set of control variables, including the Greenbook forecast. The second set of regressions is based on the work of Estrella and Mishkin (1997) and Mishkin (1990), who examine the information in the long end of the term structure to forecast future changes in forward inflation.

Our first set of regressions is based on the RW-AO model. This model predicts that the inflation k periods ahead is equal to the average of quarterly inflation over the past four quarters, $\bar{\pi}_{t-3,t} = \frac{1}{4}\sum_{j=0}^{3}\pi_{t-j}$. Hence we evaluate the forecasting power of the yield spread decomposition to predict the deviation of inflation k periods ahead from the forecast based on the RW-AO model at time t, $\bar{\pi}_{t-3,t}$:

$$\pi_{t+k} - \bar{\pi}_{t-3,t} = \alpha + \beta^{\mathrm{EC}}\left(\mathrm{Spr}_t^{e,(n)} + \chi_t^{(n)}\right) + \beta^{\mathrm{TP}}\chi_t^{(n)} + \gamma\left(\pi_t - \bar{\pi}_{t-4,t-1}\right) + \delta y_t^{(1)} + \varepsilon_{t+k} \qquad (14)$$

where π_{t+k} is the level of inflation between quarter $t+k-1$ and $t+k$, expressed in annual terms. The control variables are the deviation of current inflation from the average of quarterly inflation over the periods $t-4$ and $t-1$, $\pi_t - \bar{\pi}_{t-4,t-1}$, and the short-term interest rate, $y_t^{(1)}$. We predict inflation 1, 4 and 8 quarters ahead (k) using 4-, 20- and 40-quarter (n) yield spreads. The model versions are similar to those in Tables V and VI.

Table VII shows that yield spreads alone (model 1) are statistically significant only for a horizon of 8 quarters with minor predictive ability. Using decomposed spreads (model 2), we observe a significant increase in the adjusted R^2 for all forecasting horizons and spread maturities. We also reject the null of $\beta^{\mathrm{TP}}=0$, showing the significance of the spread decomposition. If we allow for control variables instead of decomposing the spread (model 3 versus model 1), we also observe a significant increase in the adjusted R^2. However, a comparison between models 1 and 2 and models 1 and 3 shows that for horizons of one year and above the spread decomposition has a larger effect than the inclusion of control variables. Moreover, the results for model 4 show that even allowing for control variables the spread decomposition is still statistically significant for forecasting horizons of one year and above, and the increase in the adjusted R^2 is higher for longer forecasting horizons. Comparing the coefficients for the yield spread (β) and its components (β^{EC} and β^{TP}) in models 3 and 4, respectively, we observe that while in model 3 some of the coefficients on the spread are negative, once you allow for the spread decomposition all coefficients on the expectations component have a positive sign. We conclude that the yield spread decomposition is crucial for forecasting inflation and becomes more important as the forecasting horizon increases.

Finally, we assess whether the observed forecasting power of the decomposed yield spread is robust to the inclusion of a subjective forecast as an extra control variable:

$$\pi_{t+k} - \bar{\pi}_{t-3,t} = \alpha + \theta\mathrm{Sur}_t^k + \beta^{\mathrm{EC}}\left(\mathrm{Spr}_t^{e,(n)} + \chi_t^{(n)}\right) + \beta^{\mathrm{TP}}\chi_t^{(n)} + \gamma\left(\pi_t - \bar{\pi}_{t-4,t-1}\right) + \delta y_t^{(1)} + \varepsilon_{t+k} \quad (15)$$

[16] Figure 1 of the online Appendix shows the results for the output gap. The predictive power of the yield spread and its components has remained almost constant over time, with a slight decrease at the end of the sample period. Also, in general, the inclusion of control variables has a higher impact on the adjusted R^2 than the decomposition of the yield spread.

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Table VII. Forecasting inflation

Model 1: $\pi_{t+k} - \bar{\pi}_{t-3,t} = \alpha + \beta \mathrm{Spr}_t^{(n)} + \varepsilon_{t+k}$

Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	0.000	0.001	0.001	−0.001	0.000	−0.000	−0.005	−0.005	−0.006
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
β	0.042	−0.086	−0.060	0.195	−0.021	0.015	1.285	0.514	0.420
	(0.251)	(0.096)	(0.074)	(0.408)	(0.157)	(0.120)	(0.544)	(0.180)	(0.137)
Adj.-R^2	−0.005	0.001	−0.000	−0.002	−0.005	−0.005	0.078	0.069	0.073

Model 2: $\pi_{t+k} - \bar{\pi}_{t-3,t} = \alpha + \beta^{\mathrm{EC}} \left(\mathrm{Spr}_t^{e,(n)} + \chi_t^{(n)} \right) + \beta^{\mathrm{TP}} \chi_t^{(n)} + \varepsilon_{t+k}$

Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	0.001	0.002	0.003	0.001	0.003	0.004	−0.002	−0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
β^{EC}	0.535	0.038	0.022	1.514	0.289	0.207	3.286	0.951	0.708
	(0.262)	(0.089)	(0.067)	(0.385)	(0.139)	(0.106)	(0.468)	(0.138)	(0.107)
β^{TP}	−0.777	−0.272	−0.261	−1.701	−0.594	−0.547	−2.749	−0.941	−0.824
	(0.191)	(0.066)	(0.064)	(0.268)	(0.089)	(0.086)	(0.312)	(0.104)	(0.098)
Adj.-R^2	0.089	0.089	0.084	0.204	0.193	0.180	0.369	0.366	0.339

Model 3: $\pi_{t+k} - \bar{\pi}_{t-3,t} = \alpha + \beta \mathrm{Spr}_t^{(n)} + \gamma \left(\pi_t - \bar{\pi}_{t-4,t-1} \right) + \delta y_t^{(1)} + \varepsilon_{t+k}$

Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	0.003	0.005	0.006	0.008	0.011	0.013	0.014	0.016	0.017
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)
β	0.043	−0.096	−0.107	0.127	−0.126	−0.140	1.044	0.226	0.091
	(0.193)	(0.075)	(0.061)	(0.316)	(0.117)	(0.087)	(0.382)	(0.130)	(0.105)
γ	0.350	0.328	0.322	0.458	0.427	0.419	0.212	0.233	0.207
	(0.083)	(0.084)	(0.083)	(0.171)	(0.168)	(0.168)	(0.169)	(0.167)	(0.166)
δ	−0.053	−0.070	−0.082	−0.155	−0.179	−0.195	−0.334	−0.320	−0.334
	(0.028)	(0.029)	(0.030)	(0.050)	(0.048)	(0.049)	(0.048)	(0.055)	(0.059)
Adj.-R^2	0.136	0.142	0.147	0.185	0.190	0.194	0.305	0.262	0.253

Model 4: $\pi_{t+k} - \bar{\pi}_{t-3,t} = \alpha + \beta^{\mathrm{EC}} \left(Spr_t^{e,(n)} + \chi_t^{(n)} \right) + \beta^{TP} \chi_t^{(n)} + \gamma \left(\pi_t - \bar{\pi}_{t-4,t-1} \right) + \delta y_t^{(1)} + \varepsilon_{t+k}$

Horizon (k)	1 qtr			4 qtr			8 qtr		
Maturity (n)	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr	4 qtr	20 qtr	40 qtr
α	0.001	0.001	0.002	0.000	−0.001	0.002	0.002	−0.004	−0.001
	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)	(0.007)
β^{EC}	0.340	0.057	0.018	1.312	0.378	0.237	2.928	1.053	0.741
	(0.368)	(0.120)	(0.098)	(0.607)	(0.184)	(0.150)	(0.851)	(0.260)	(0.206)
β^{TP}	−0.536	−0.209	−0.172	−1.453	−0.586	−0.476	−2.379	−1.019	−0.829
	(0.361)	(0.130)	(0.123)	(0.597)	(0.196)	(0.186)	(0.760)	(0.268)	(0.246)
γ	0.285	0.294	0.299	0.291	0.346	0.362	−0.060	0.080	0.105
	(0.102)	(0.095)	(0.094)	(0.204)	(0.187)	(0.185)	(0.226)	(0.193)	(0.190)
δ	0.008	0.007	−0.008	0.007	0.046	0.013	−0.088	0.055	0.020
	(0.054)	(0.057)	(0.060)	(0.094)	(0.092)	(0.096)	(0.105)	(0.124)	(0.130)
Adj.-R^2	0.152	0.158	0.155	0.233	0.241	0.230	0.370	0.363	0.335

Note: Standard errors of coefficients are in parentheses. We estimate the model over the period 1960:Q1–2008:Q4.

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where Sur_t^k denotes the Greenbook forecast of inflation k quarters ahead. Table VIII shows the results for a regression with yield spreads (i.e. $\beta^{\text{TP}} = 0$, model 1) and decomposed yield spreads (model 2). We adopt a 4-quarter forecasting horizon (k) and use yield spreads of 4, 20 and 40 quarters (n). The first column for each maturity in models 1 and 2 is equivalent to models 3 and 4 of Table VII, respectively. The results are not identical due to the difference in the sample period.

The results from Table VIII are mixed. The estimates from model 1 show that although the inclusion of the Greenbook forecast leads to a slight increase in the adjusted R^2 for all spread maturities, this variable is never statistically significant. This is not surprising since we are trying to forecast inflation above what is predicted by the RW-AO model, which according to Atkeson and Ohanian (2001) is able to forecast inflation remarkably well. Nevertheless, once we control for the Greenbook forecast (second column for each maturity), the yield spread decomposition (model 2) still leads to an increase in the adjusted R^2 for spreads of 20 and 40 quarters relative to the model without the spread decomposition (model 1), although only for the 20-quarter spread is the coefficient on β^{TP} statistically significant. Therefore, the yield spread decomposition seems to add some explanatory power even after the inclusion of the Greenbook forecast.

Our second set of regressions is based on the work of Estrella and Mishkin (1997) and Mishkin (1990), who show that an increase in the yield spread is an indication of positive changes in future

Table VIII. Forecasting inflation: the impact of Greenbook forecasts

Model 1 Horizon (k)	$\pi_{t+k} - \bar{\pi}_{t-3,t} = \alpha + \theta \text{Sur}_t^k + \beta \text{Spr}_t^{(n)} + \gamma(\pi_t - \bar{\pi}_{t-4,t-1}) + \delta y_t^{(1)} + \varepsilon_{t+k}$ 4 qtr					
Maturity (n)	4 qtr		20 qtr		40 qtr	
α	0.009 (0.003)	0.008 (0.003)	0.010 (0.004)	0.010 (0.004)	0.010 (0.005)	0.009 (0.005)
θ		0.137 (0.082)		0.138 (0.081)		0.137 (0.081)
β	0.022 (0.230)	0.013 (0.228)	−0.045 (0.117)	−0.048 (0.116)	−0.029 (0.105)	−0.030 (0.105)
γ	0.573 (0.135)	0.575 (0.134)	0.562 (0.138)	0.564 (0.137)	0.565 (0.138)	0.567 (0.137)
δ	−0.189 (0.038)	−0.263 (0.058)	−0.199 (0.045)	−0.274 (0.063)	−0.199 (0.051)	−0.274 (0.067)
Adj-R^2	0.269	0.279	0.270	0.280	0.269	0.280
Model 2 Horizon (k)	$\pi_{t+k} - \bar{\pi}_{t-3,t} = \alpha + \theta \text{Sur}_t^k + \beta^{\text{EC}}\left(\text{Spr}_t^{e,(n)} + \chi_t^{(n)}\right) + \beta^{\text{TP}} \chi_t^{(n)} + \gamma(\pi_t - \bar{\pi}_{t-4,t-1}) + \delta y_t^{(1)} + \varepsilon_{t+k}$ 4 qtr					
Maturity (n)	4 qtr		20 qtr		40 qtr	
α	0.007 (0.004)	0.009 (0.005)	0.001 (0.005)	−0.001 (0.006)	0.002 (0.005)	0.000 (0.007)
θ		0.137 (0.122)		−0.082 (0.136)		−0.071 (0.146)
β^{EC}	0.288 (0.473)	−0.204 (0.645)	0.301 (0.177)	0.408 (0.252)	0.222 (0.149)	0.303 (0.224)
β^{TP}	−0.485 (0.439)	0.054 (0.651)	−0.409 (0.163)	−0.541 (0.274)	−0.342 (0.147)	−0.450 (0.266)
γ	0.510 (0.144)	0.577 (0.156)	0.506 (0.136)	0.486 (0.140)	0.521 (0.136)	0.507 (0.140)
δ	−0.132 (0.064)	−0.270 (0.139)	−0.036 (0.078)	0.060 (0.177)	−0.048 (0.081)	0.037 (0.195)
Adj-R^2	0.276	0.277	0.301	0.297	0.296	0.291

Note: Standard errors of coefficients are in parentheses. We estimate the model over the period 1974:Q2–2005:Q4.

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inflation. Forecasting inflation at longer horizons is crucial for policymakers since it is known that monetary policy action has an effect on inflation with several lags. We therefore run the following predictive regression:

$$\pi_t^{(k)} - \pi_t^{(4)} = \alpha + \beta^{\mathrm{EC}}\left(\mathrm{Spr}_t^{e,(k)} + \chi_t^{(k)}\right) + \beta^{\mathrm{TP}}\chi_t^{(k)} + \gamma\pi_t^{(-4)} + \delta y_t^{(1)} + \varepsilon_{t+k} \tag{16}$$

Table IX. Forecasting forward inflation changes

Model 1	$\pi_t^{(k)} - \pi_t^{(4)} = \alpha + \beta \mathrm{Spr}_t^{(k)} + \varepsilon_{t+k}$			
k	8 qtr	12 qtr	16 qtr	20 qtr
α	−0.001	−0.002	−0.003	−0.003
	(0.001)	(0.002)	(0.002)	(0.003)
β	0.419	0.655	0.622	0.516
	(0.203)	(0.208)	(0.215)	(0.236)
Adj.-R^2	0.063	0.161	0.155	0.113
Model 2	$\pi_t^{(k)} - \pi_t^{(4)} = \alpha + \beta^{\mathrm{EC}}\left(\mathrm{Spr}_t^{e,(k)} + \chi_t^{(k)}\right) + \beta^{\mathrm{TP}}\chi_t^{(k)} + \varepsilon_{t+k}$			
k	8 qtr	12 qtr	16 qtr	20 qtr
α	−0.001	−0.001	−0.002	−0.001
	(0.001)	(0.001)	(0.002)	(0.003)
β^{EC}	1.045	1.022	0.895	0.727
	(0.239)	(0.228)	(0.229)	(0.249)
β^{TP}	−0.718	−0.693	−0.621	−0.572
	(0.157)	(0.144)	(0.132)	(0.144)
Adj.-R^2	0.302	0.343	0.298	0.233
Model 3	$\pi_t^{(k)} - \pi_t^{(4)} = \alpha + \beta_t \mathrm{Spr}_t^{(k)} + \gamma\pi_t^{(-4)} + \delta y_t^{(1)} + \varepsilon_{t+k}$			
k	8 qtr	12 qtr	16 qtr	20 qtr
α	0.004	0.007	0.010	0.015
	(0.002)	(0.003)	(0.003)	(0.004)
β	0.253	0.353	0.246	0.054
	(0.167)	(0.183)	(0.183)	(0.179)
γ	−0.012	−0.044	−0.102	−0.170
	(0.056)	(0.076)	(0.084)	(0.087)
δ	−0.075	−0.116	−0.135	−0.153
	(0.027)	(0.039)	(0.047)	(0.053)
Adj.-R^2	0.193	0.300	0.325	0.347
Model 4	$\pi_t^{(k)} - \pi_t^{(4)} = \alpha + \beta^{\mathrm{EC}}\left(\mathrm{Spr}_t^{e,(k)} + \chi_t^{(k)}\right) + \beta^{TP}\chi_t^{(k)} + \gamma\pi_t^{(-4)} + \delta y_t^{(1)} + \varepsilon_{t+k}$			
k	8 qtr	12 qtr	16 qtr	20 qtr
α	−0.005	−0.005	−0.001	0.006
	(0.002)	(0.003)	(0.005)	(0.007)
β^{EC}	1.707	1.450	1.071	0.603
	(0.371)	(0.289)	(0.307)	(0.329)
β^{TP}	−1.713	−1.516	−1.233	−0.904
	(0.384)	(0.311)	(0.363)	(0.412)
γ	−0.137	−0.225	−0.280	−0.318
	(0.051)	(0.062)	(0.078)	(0.090)
δ	0.172	0.232	0.212	0.128
	(0.057)	(0.077)	(0.115)	(0.148)
Adj.-R^2	0.388	0.440	0.412	0.394

Note: Standard errors of coefficients are in parentheses. We estimate the model over the period 1960:Q1–2008:Q4.

where $\pi_t^{(k)} - \pi_t^{(4)}$ is the difference between the future k-quarter inflation rate from time t to $t+k$ and the future 4-quarter inflation rate from t to $t+4$, all in annual terms. The control variables are the past inflation between $t-4$ quarters and t $\left(\pi_t^{(-4)}\right)$, and the short-term interest rate. We consider forecasting horizons of 8, 12, 16 and 20 quarters. The results are presented in Table IX and the model versions are similar to those in Tables V, VI and VII.

The results for model 1 show that yield spreads significantly predict inflation changes. The use of decomposed spreads (model 2) leads to a higher increase in the R^2 values for horizons of 2 and 3 years, but the inclusion of control variables (model 3) has a higher impact for longer horizons (4 and 5 years). Finally, even with the inclusion of control variables, the use of decomposed spreads (model 4) leads to an increase in the adjusted R^2, with spread components statistically significant in almost all cases. Interestingly, in both cases where we use decomposed spreads (models 2 and 4), we cannot reject that $\beta^{EC}=1$, a hypothesis implied by the EH assuming a constant real interest rate over time (see also Mishkin, 1990). Our results therefore show that any interpretation of the yield spread variations in terms of long-run inflation expectation can be biased by the presence of time-varying risk premiums.

One reason for the difference in the relevance of the spread decomposition in the regressions for economic activity and inflation is the fact that for the latter the coefficients β^{EC} and β^{TP} have consistently opposite signs and are in most cases statistically significant. This leads to significant differences in the informational content of the expectations (β^{EC}) and term premium ($\beta^{EC}+\beta^{TP}$) components with respect to future inflation, with the expectations component that has a positive association with future inflation (in line with the Fisher parity). These differences can obviously not be captured by the spread itself.

Finally, we analyse the time evolution robustness of the predictive content of the yield spread and its components for inflation changes (equation (16)). Each plot in Figure 6 shows the adjusted R^2 over time for a certain predictive horizon and the corresponding yield spread. As in Figure 5, the EMF model is re-estimated at every quarter using an expanding window starting in 1960:Q1. The dates in

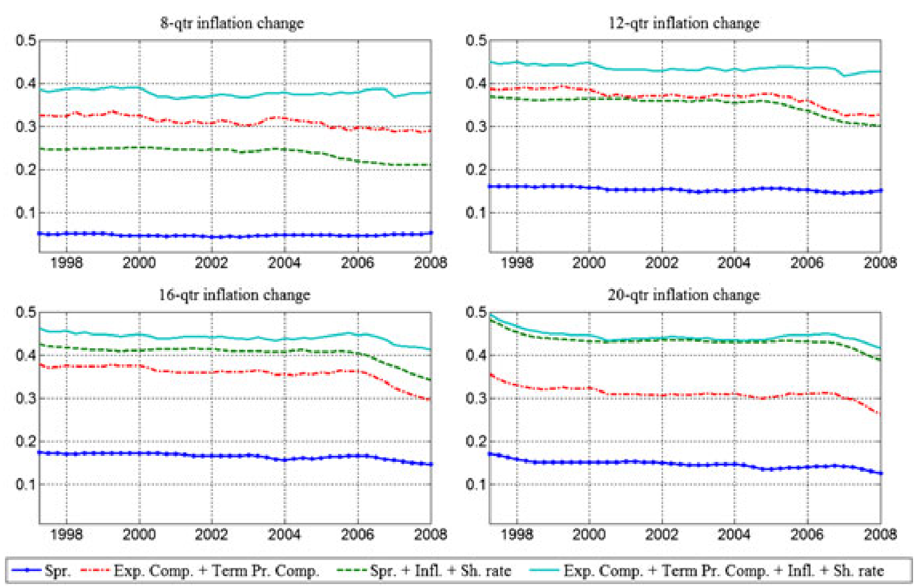

Figure 6. Forecasting inflation changes, expanding window (R^2). Each plot shows the adjusted R^2 over time for a certain predictive horizon and the corresponding yield spread (8, 12, 16 and 20 quarters). The date on the horizontal axis determines the end date of the sample period. The first point in each graph indicates the adjusted R^2 for the period 1960:Q1–1995:Q4. The EMF model is re-estimated at every quarter using an expanding window

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the figure show the end of the sample period used. The results show a slight decrease over time in the predictive power of the yield spread and its components. Nevertheless, we observe a striking improvement in the adjusted R^2 simply by decomposing the spread in its two components. This is especially the case for an 8-quarter horizon. For a 20-quarter horizon, once you allow for control variables the gain from spread decomposition is marginal.

4. CONCLUSION

We use the EMF model of Dewachter and Iania (2011) to study the risk and term premiums in the US bond market. This model extends standard MF models by including next to the standard macroeconomic factors a set of financial factors. The latter include liquidity and risk premium factors, which allow the model to capture in a better way the additional non-macroeconomic drivers of the yield curve.

The estimation results indicate that risk premiums in the US market display significant time variation and strong collinearity across the maturity spectrum. The former is a clear indication that the expectation hypothesis fails. More importantly, a variance decomposition singles out the financial factors, especially risk premium shocks, as the main drivers behind bond risk premiums. This is in line with the recent literature indicating that macroeconomic factors cannot account for the time variation in risk premiums. The significant collinearity of risk premiums suggests that only a few factors drive the entire term structure of risk premiums. We find that one factor, closely related to the CP factor (Cochrane and Piazzesi, 2005), is responsible for most of the variation in risk premiums.

We use the EMF model to decompose the yield spread into an expectations and a term premium component. This decomposition is used to forecast economic activity and inflation. Although the decomposition does not seem important to forecast economic activity, it is crucial to forecast inflation for most forecasting horizons. Also, in general, the inclusion of control variables such as the short-term interest rate and lagged variables does not drive out the predictive power of the spread decomposition.

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