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Term Premia and Inflation Uncertainty: Empirical Evidence from an International Panel Dataset

By Jonathan H. Wright*

Nominal yield curves nearly always slope up, implying that investors typically demand positive risk premia—or term premia—to induce them to hold long-term nominal bonds. Moreover, the available evidence strongly suggests that these term premia vary over time. Time variation in term premia complicates the transmissions mechanism of monetary policy, as it clouds the relationship between the very short-term interest rates that are controlled by central banks and longer-term interest rates, while the whole term structure of interest rates is relevant for the spending decisions of households and businesses. It also makes it difficult to use the yield curve to measure expectations of future short-term interest rates.

Estimation of term premia is very important in macroeconomics, monetary economics and asset pricing, and enormous progress has been made on the topic over the last decade. Yet, nearly all of the existing literature on the estimation of term premia has used only data on a single country, most often the United States. Obtaining estimates of term premia for many countries is useful because it gives us more information about the macroeconomic and financial market determinants of bond risk premia.

However, to estimate term premia, we first need a dataset of zero-coupon yields. Accordingly, in this paper, I construct a panel dataset of nominal zero-coupon government bond yields at maturities out to ten years for ten different industrialized countries with separate monetary policies: the United States, the United Kingdom, Canada, Japan, Germany, Norway, Sweden, Switzerland, Australia, and New Zealand, going back to 1990, though the data start a bit later for the Scandinavian countries. Euro-zone countries other than Germany are omitted because their term structures have necessarily been highly correlated with those of Germany, at least since 1999 (although they diverged for a while in late 2008 and early 2009). Otherwise the dataset includes all significant industrialized economies, and is to my knowledge the first paper to fit zero-coupon yield curves to all of these countries.[1] I then use these data to decompose long-term forward rates into term premia and expected future short-term interest rates. I find that term premia have declined globally over the sample period, with particularly sharp drops in some countries including Australia, Sweden, and the United Kingdom. A possible interpretation of this

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[1] Authors including Michael J. Brennan and Yihong Xia (2006), Francis X. Diebold, Canlin Li, and Vivian Z. Yue (2008), and Mardi Dungey, Vance L. Martin, and Adrian R. Pagan (2000) have constructed zero-coupon yields for several countries and have fitted factor models to these. These papers have not, however, provided term premium estimates, nor do their datasets include as many countries as are in the current paper.

TABLE 1—YIELD CURVE DATA SOURCES

Country	Source	Start Date	Frequency	Methodology
US	Gürkaynak, Sack, and Jonathan H. Wright (2007)	Nov 1971	Daily	Svensson
Japan	Datastream and author's calculations	Jan 1987	Daily	Svensson
Germany	Bundesbank and BIS database	Jan 1973	Daily	Svensson
UK	Nicola Anderson and John Sleath (2001)	Jan 1975	Daily	Spline
Canada	Bank of Canada and BIS database	Jan 1986	Daily	Spline
Switzerland	Swiss National Bank and BIS database	Jan 1988	Weekly	Svensson
Norway	Norges Bank and BIS database	Jan 1998	Monthly	Svensson
Sweden	Riksbank and BIS database	Dec 1992	Weekly	Svensson
Australia	Datastream and author's calculations	Feb 1987	Daily	Nelson-Siegel
New Zealand	Datastream and author's calculations	Mar 1991	Daily	Nelson-Siegel

Notes: Zero-coupon yields are available at maturities out to ten years in all cases from the start date to May 2009. Data from before January 1990 are not used in this paper, and the term structure models estimated in this paper are all based on data that have been aggregated to the quarterly frequency (end-of-quarter), although data are available at the frequencies shown in this table. For Japan, Australia, and New Zealand, I downloaded the prices of sovereign noncallable fixed-rate government bonds from Datastream and fitted Svensson and Nelson-Siegel curves to these prices, as described for the United States in Refet S. Gürkaynak, Brian Sack, and Wright (2007), using only dates when bonds in those countries existed at maturities out to ten years. The yield curves described in Gürkaynak, Sack, and Wright (2007) and Nicola Anderson and John Sleath (2001), are available on the websites of the Federal Reserve and Bank of England, respectively, and are updated regularly. Those websites also include yield curves for index-linked government bonds.

is that it owes in part to declining inflation uncertainty amid substantial changes in the monetary policy frameworks of several central banks. During the recent financial crisis, term premium estimates have remained flat and declined even further in some countries, though not in Germany. This may reflect "flight-to-quality" flows into government securities and/or the effects of purchases of long-term bonds by a number of central banks.

The plan for the remainder of the paper is as follows. The next section explains the construction of zero-coupon yields. Section II uses alternative methods to decompose these yields into term premium and expected future interest rate components. Section III discusses possible interpretations of the patterns in estimated term premia, with particular focus on inflation uncertainty. Section IV concludes.

I. Zero-Coupon Yield Curves

I obtained or constructed local currency zero-coupon government yield curves at the monthly (or higher) frequency from January 1990 to May 2009 for ten industrialized countries. The data in all cases refer to the yields on the last day of each month. Table 1 lists the available maturities, sources, and sample periods of these ten different yield curves. All yields in the dataset are continuously compounded and at maturities from three months to ten years, in increments of three months. For some countries, the data begin a bit later than January 1990. For others, the data are available even farther back, but I start the sample in 1990 as a trade-off between maximizing the sample size and minimizing the likelihood of a large structural break, and also because this lines up with the available data in the survey datasets that will be used later in this paper.

Distant-horizon forward rates are useful for measuring the determinants of the yield curve other than the direct effects of the current stance of monetary policy, because these forward rates represent the sum of long-run inflation expectations, the

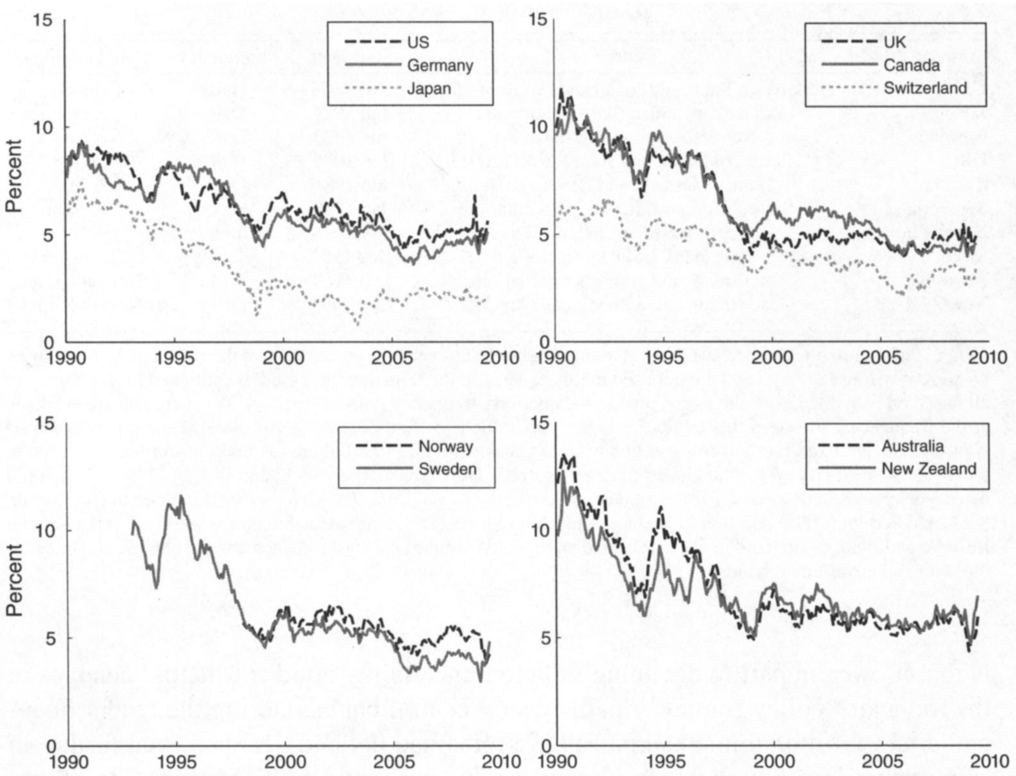

FIGURE 1. FIVE-TO-TEN-YEAR FORWARD RATES

Note: This chart shows the estimated five- to ten-year forward rates for the ten countries in the sample, with continuous compounding.

long-run expected real short-term interest rate, and a forward term premium. Figure 1 shows the time series of five- to ten-year forward rates in all ten countries in the dataset. We can see a number of facts about these long-term forward rates:

(i) They have trended down in all countries since the early 1990s, and have also tended to converge. The range of forward rates in the early 1990s was around 10 percentage points. In May 2009, all forward rates were between 3.5 and 7 percent, with the exception of Japan.

(ii) Distant-horizon forward rates are highly correlated across countries; for example, the decline in forward rates in 2004–2005 was evident to varying degrees in all the countries in our sample, again with the sole exception of Japan.

(iii) Distant-horizon forward rates rose in Sweden around the time of the banking crisis in that country, as the recapitalization of banks may have led to greater expected bond supply, or higher inflation or inflation uncertainty, and spiked up in the US in August and September of 2008, perhaps for many of the same reasons.

(iv) Forward rates have been volatile during the recent financial crisis, but rose somewhat during the first half of 2009.

(v) In recent years, the five- to ten-year forward rates in the US have been toward the top of the relatively narrow range across countries. In fact, in every month from 2002 to 2009, the five- to ten-year forward rate in the US was uniformly higher than the corresponding forward rate in Germany, the UK, Switzerland, Canada, Japan, and Sweden. As a matter of accounting, this must represent higher inflation expectations in the US than abroad, a higher expected real short-term interest rate (possibly reflecting faster expected productivity growth), or a higher term premium.

The secular international decline, and convergence, in forward rates (point (i) above) is consistent with a decline and convergence in long-run inflation expectations. However, the magnitude of the drop in forward rates seems too big to be due to a revision to inflation expectations alone, for this would mean that inflation expectations had fallen by 5 to 10 percentage points in many industrialized countries since the early 1990s. Some light can be shed on the plausibility of this by looking at survey evidence. Professional surveys by Andrew Ang, Geert Bekaert, and Min Wei (2007) provide excellent forecasts of inflation, at least in the US. Consensus Forecasts provides a range of forecasts for all the countries in the panel, as listed in the Data Appendix. These include, at the semiannual frequency, long-horizon forecasts of average inflation and growth from five to ten years after the survey date. Figures 2 and 3 show the long-horizon forecasts of inflation and GDP growth. The inflation forecasts did trend downward, but only by about a couple of percentage points, far less than the fall in forward rates. Meanwhile, there is no evident global trend in long-term growth expectations. For Japan and Germany, long-term growth expectations deteriorated markedly, but for the US, they improved around the turn of the century and have remained close to 3 percent, despite falling off a little in the last few years. All in all, it seems hard to account for the magnitude of the decline in forward rates in terms of revisions to inflation (or growth) expectations alone. A declining term premium also seems likely to be part of the story. To shed some light on this and on the other empirical patterns seen in Figure 1, I next turn to decomposing forward rates around the world into expectations of future short-term interest rates and term premia.

II. Term Premium Estimates

A. *Estimates Based on Affine Models*

In this section, I use quarterly data (end-of-quarter) on yields from 1990:I to 2009:I.[2] I decompose forward rates into average future expected three-month interest rates and the term premium by fitting an affine term structure model (as proposed by Qiang Dai and Kenneth J. Singleton 2002, and others) to each country separately.

[2] The analysis is conducted at a quarterly frequency because many of the macroeconomic series used below are available only at that frequency (e.g., New Zealand has no monthly inflation data).

Figure 2. Long-Horizon Consensus Forecasts of Inflation

Note: This chart plots the consensus forecasts of average consumer price inflation from five to ten years hence against the survey date.

Because the payoffs of bonds are deterministic, the absence of arbitrage implies restrictions on the time series and cross-maturity properties of bond yields. Affine term structure models exploit these restrictions.

Specifically, I consider a homoskedastic, discrete-time affine term structure model of the sort employed by Ang and Monika Piazzesi (2003) and John H. Cochrane and Piazzesi (2008). Let $P_t^{(n)}$ denote the price at time t of an n-period zero-coupon bond; let $y_t^{(n)} = -\log(P_t^{(n)})/n$ denote its yield; and let M_{t+1} be the nominal pricing kernel. The price of the bond must be $P_t^{(n)} = E_t(\Pi_{j=1}^n M_{t+j})$. Assume that the pricing kernel is conditionally lognormal:

$$M_{t+1} = \exp(-r_t - \frac{1}{2}\boldsymbol{\lambda}_t'\boldsymbol{\lambda}_t - \boldsymbol{\lambda}_t'\boldsymbol{\varepsilon}_{t+1}), \tag{1}$$

where $\boldsymbol{\lambda}_t = \boldsymbol{\lambda}_0 + \boldsymbol{\lambda}_1\mathbf{X}_t$ is an affine function of an $m \times 1$ vector of state variables, $\mathbf{X}_t$, $\boldsymbol{\varepsilon}_{t+1}$ is i.i.d. $N(\mathbf{0},\mathbf{I})$, and $r_t = \delta_0 + \boldsymbol{\delta}_1'\mathbf{X}_t$ is the one-period (i.e., three-month) interest rate. Assume, further, that the vector of state variables follows a vector autoregression (VAR):

$$\mathbf{X}_{t+1} = \boldsymbol{\mu} + \boldsymbol{\Phi}\mathbf{X}_t + \boldsymbol{\Sigma}\varepsilon_{t+1}. \tag{2}$$

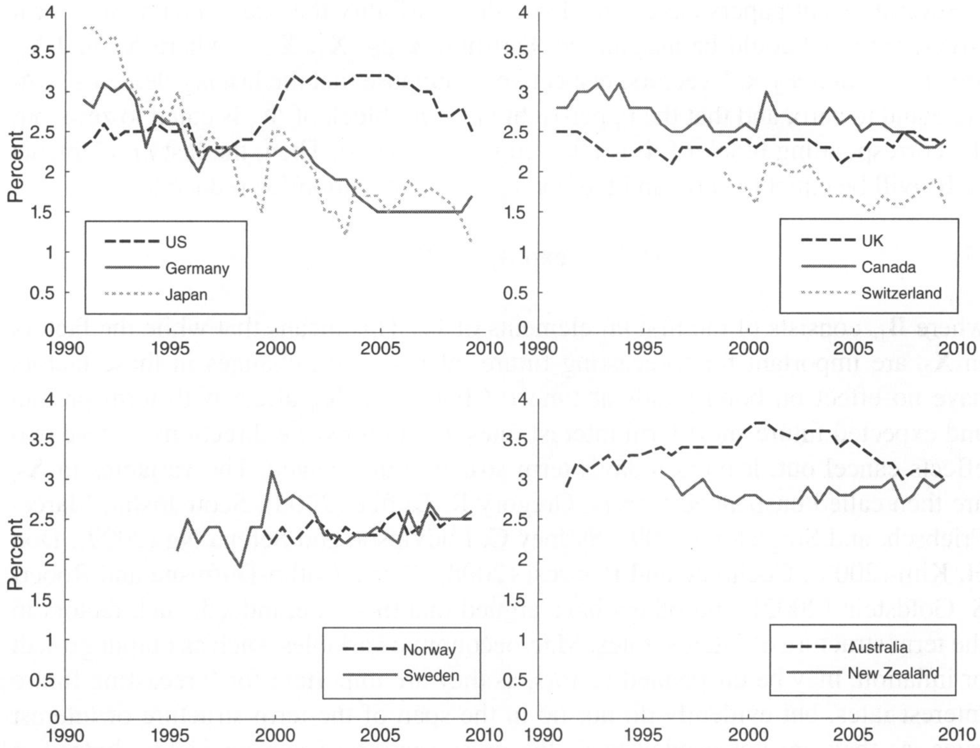

FIGURE 3. LONG-HORIZON CONSENSUS FORECASTS OF INTERNATIONAL GROWTH

Notes: This chart plots the consensus forecasts of average real GDP growth from five to ten years hence against the survey date.

It then follows that

$$P_t^{(n)} = \exp(A_n + \mathbf{B}_n'\mathbf{X}_t), \tag{3}$$

where A_n is a scalar and $\mathbf{B}_n$ is an $m \times 1$ vector that satisfy the recursions

$$A_{n+1} = -\delta_0 + A_n + \mathbf{B}_n'(\boldsymbol{\mu} - \Sigma\boldsymbol{\lambda}_0) + \frac{1}{2}\mathbf{B}_n'\Sigma\Sigma'\mathbf{B}_n, \tag{4}$$

$$\mathbf{B}_{n+1} = (\boldsymbol{\Phi} - \Sigma\boldsymbol{\lambda}_1)'\mathbf{B}_n - \boldsymbol{\delta}_1, \tag{5}$$

starting from $A_1 = -\delta_0$ and $\mathbf{B}_1 = -\boldsymbol{\delta}_1$. The bond prices in (3)–(5) are the same as though agents were risk-neutral ($\boldsymbol{\lambda}_0 = \boldsymbol{\lambda}_1 = 0$), but the state vector followed an alternative law of motion:

$$\mathbf{X}_{t+1} = \boldsymbol{\mu}^* + \boldsymbol{\Phi}^*\mathbf{X}_t + \Sigma\boldsymbol{\varepsilon}_{t+1}, \tag{6}$$

where $\boldsymbol{\mu}^* = \boldsymbol{\mu} - \Sigma\boldsymbol{\lambda}_0$ and $\boldsymbol{\Phi}^* = \boldsymbol{\Phi} - \Sigma\boldsymbol{\lambda}_1$. Equations (2) and (6) are known as the physical and risk-neutral representations of the law of motion for the state vector, or the P and Q measures, respectively.

Several recent papers have considered the possibility that some factors in a term structure model could be *unspanned*. Partition $\mathbf{X}_t$ as $(\mathbf{X}_{1t}', \mathbf{X}_{2t}')'$, where $\mathbf{X}_{1t}$ and $\mathbf{X}_{2t}$ are $m_1 \times 1$ and $m_2 \times 1$ vectors, respectively. Suppose that the last m_2 elements of $\boldsymbol{\delta}_1$ are equal to zero, and that the upper-right $m_1 \times m_2$ block of $\boldsymbol{\Phi}^*$ is equal to zero, but the corresponding block of $\boldsymbol{\Phi}$ is allowed to be nonzero. Then, the last m_2 elements of $\mathbf{B}_n$ will be equal to zero, and the bond prices in equation (3) reduce to

$$P_t^{(n)} = \exp(A_n + \mathbf{B}_{1n}' \mathbf{X}_{1t}), \tag{7}$$

where $\mathbf{B}_{1n}$ consists of the first m_1 elements of $\mathbf{B}_n$. This means that while the factors in $\mathbf{X}_{2t}$ are important for forecasting future interest rates, changes in these factors have no effect on bond yields at time t. Changes in $\mathbf{X}_{2t}$ affect both term premia and expected future short-term interest rates, but in opposite directions—these two effects cancel out, leaving today's term structure unchanged. The variables in $\mathbf{X}_{2t}$ are then called unspanned factors. Gregory R. Duffee (2008), Scott Joslin, Marcel Priebsch, and Singleton (2009), Sydney C. Ludvigson and Serena Ng (2009), Don H. Kim (2008), Cochrane and Piazzesi (2008), Pierre Collin-Dufresne and Robert S. Goldstein (2002), and others have argued that there are, indeed, such factors in the term structure of interest rates. Macroeconomic variables, such as output growth or inflation, may be unspanned factors, as they are important for forecasting future interest rates, but evidently do not lie in the span of the term structure of interest rates, as they are not needed to fit the cross section of current yields. Indeed, a regression of current inflation or output growth onto interest rates yields a low or moderate R^2.

Accordingly, following Joslin, Priebsch, and Singleton (2009), in this paper the state vector $\mathbf{X}_t$ consists of the first three principal components of zero-coupon yields from three months to ten years in that country,[3] plus the exponentially weighted moving average of quarterly inflation and GDP growth, constructed as described in the Data Appendix. The macroeconomic variables are treated as unspanned factors.

My approach to estimation also follows Joslin, Priebsch, and Singleton (2009). As the state vector $\mathbf{X}_t$ is observed, the maximum likelihood estimates of $\boldsymbol{\mu}$ and $\boldsymbol{\Phi}$ can be obtained from fitting a VAR to $\mathbf{X}_t$. The remaining identified parameters of the model are $\boldsymbol{\mu}_1^*$, $\boldsymbol{\Phi}_{11}^*$, δ_0, $\boldsymbol{\delta}_{1,1}$ and $\boldsymbol{\Sigma}$, where $\boldsymbol{\mu}_1^*$ is the vector of the first m_1 elements of $\boldsymbol{\mu}^*$, $\boldsymbol{\delta}_{1,1}$ is the vector of the first m_1 elements of $\boldsymbol{\delta}_1$, and $\boldsymbol{\Phi}_{11}^*$ is the upper-left $m_1 \times m_1$ block of $\boldsymbol{\Phi}^*$. These parameters can also be estimated by maximum likelihood, assuming that the observed yields are equal to the model-implied yields plus i.i.d. Gaussian measurement errors[4]. The model-implied yields are obtained from equation (7), and so the restriction that the upper-right $m_1 \times m_2$ block of $\boldsymbol{\Phi}^*$ is equal to zero is imposed. Having estimated the model parameters, the difference between the five- to ten-year forward rate under the Q measure and the average expected three-month interest

[3] Specifically, the 1, 2, 3, 4, and 6 quarter and 2, 3,... 10 year zero-coupon yields. These are also the observed yields that are used in estimation.

[4] As in Joslin, Priebsch, and Singleton (2009), the model is reparameterized with a latent state vector, $\mathbf{Y}_t$, that follows a VAR with zero intercept and diagonal slope coefficient matrix, $\mathbf{I} + \boldsymbol{\Lambda}$, and with short-term interest rates that are of the form $r_t = r^* + \mathbf{i}'\mathbf{Y}_t$, where $\mathbf{i}$ is a vector of ones. The likelihood is maximized with respect to these parameters, but there is a mapping (given in that paper) from $\{r^*, \boldsymbol{\Lambda}\}$ to the original parameters. This can then be used to recover the parameters corresponding to the observed state vector.

TABLE 2—FIT OF AFFINE TERM STRUCTURE MODELS

Canada	0.043
Switzerland	0.054
Germany	0.043
Norway	0.031
Sweden	0.043
UK	0.069
US	0.051
Australia	0.040
New Zealand	0.023
Japan	0.025

Notes: This table shows the root mean square fitting error (the square root of the average squared difference between actual yields and the fitted yields from the estimated affine term structure model) for each country, in annualized percentage points.

rate from five to ten years hence under the P measure is the term premium, TP_t^{AFFINE}. Term premia at other horizons can, of course, be computed in the same way.

Table 2 summarizes the fit of the model. For each country, the table shows the root mean square fitting error of yields.[5] The typical fitting errors are small, at 2–7 basis points. This indicates that the first three principal components of domestic yields together are able to account for virtually all the cross-sectional variation in yields—no other factor is required for this purpose. That, in turn, motivates including only yields in the state vector under the Q measure.

Table 3 reports Wald statistics testing the hypothesis that lags of macroeconomic variables do not enter the equations for yields. The hypothesis is rejected for all ten countries, indicating that macroeconomic variables do help to predict future interest rates, and motivating the inclusion of these variables in the state vector under the P measure.

The full set of parameter estimates from fitting this affine model for the ten different countries is reported in the online Appendix, which contains supplemental materials, http://www.aeaweb.org/articles.php?doi=10.1257/aer.101.4.1514.

Figure 4 shows the fitted five- to ten-year forward term premia. Like the distant-horizon forward rates in Figure 1, these have generally tended to trend downward over time, especially sharply so in the UK, Sweden, Australia, New Zealand, and the US. The term premium estimates are typically, but not always, positive. In the last few years, the term premium estimates for all ten countries have for the most part been in a range from -1 to $+2$ percentage points. On average, over the last few years, term premium estimates were higher for the US and Germany than for most other countries, helping to explain the relatively high level of forward rates in the US. Finally, even although forward rates generally rose during 2009 (Figure 1), the term premium component of forward rates was flat or fell in most countries. It declined in the UK and the US, but increased in Germany.

One can, of course, construct other affine term structure models, differing in the variables that are included in the state vector. Possibilities include yields only (omitting the macro variables—notwithstanding the evidence in Table 3), short-term

[5] That is, the square root of the average squared difference between actual yields and the fitted yields from the estimated affine term structure model, averaged across all quarters and all maturities.

Table 3—Relevance of Macro Factors under the P-measure

Canada	518.1***
Switzerland	292.7***
Germany	155.7***
Norway	14.2**
Sweden	238.4***
UK	297.3***
US	312.4***
Australia	281.8***
New Zealand	348.8***
Japan	222.4***

Note: This table reports the Wald statistic testing the hypothesis that all elements of the matrix Φ that represent the effects of macroeconomic variables onto domestic yields are jointly equal to zero.
***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

interest rates and macroeconomic variables (following Ben S. Bernanke, Vincent R. Reinhart, and Sack 2004), principal components of both global and country-specific interest rates, and the Nelson-Siegel level, slope, and curvature factors (as implemented by Jens H. E. Christensen, Diebold, and Glenn D. Rudebusch 2009). Each of these four different models has advantages and disadvantages. The yields-only model and the dynamic Nelson-Siegel model of Christensen, Diebold, and Rudebusch are parsimonious and fit the cross-section of bond yields well. However, adding more variables into the state vector could give better forecasts of future interest rates, notwithstanding the extra parameters that must be estimated. Also, using macroeconomic variables as factors is appealing because they have a substantive economic interpretation. Results for all four models are included in the online Appendix.[6] While the results clearly differ from model to model—and term premia are more countercyclical in some specifications than in others—the general patterns of term premia declining over time and being higher in the US than abroad are remarkably common among the benchmark model and all four alternative specifications.

B. *Survey-Based Term Premium Estimates*

Statistical models of the term premium—such as the affine model considered in the previous subsection—are, of course, vulnerable to model misspecification and structural breaks.[7] Also, the models are estimated on the whole sample period, and do not take account of any learning (which is important, as argued by Thomas Laubach, Robert J. Tetlow, and John C. Williams 2007, and others).

Surveys may provide an alternative, model-free, real-time, and arguably more robust way of decomposing yields into expected future short-term interest rates and term premia. The idea is simple: if we can measure expectations of future

[6] Rudebusch, Sack, and Eric T. Swanson (2007) likewise consider a set of five different term premium estimates for the US alone, each of which they find exhibit a downward trend over time.

[7] See Sharon Kozicki and P. A. Tinsley (2001) for a discussion of term structure models in which endpoints of the short rate process are allowed to shift over time.

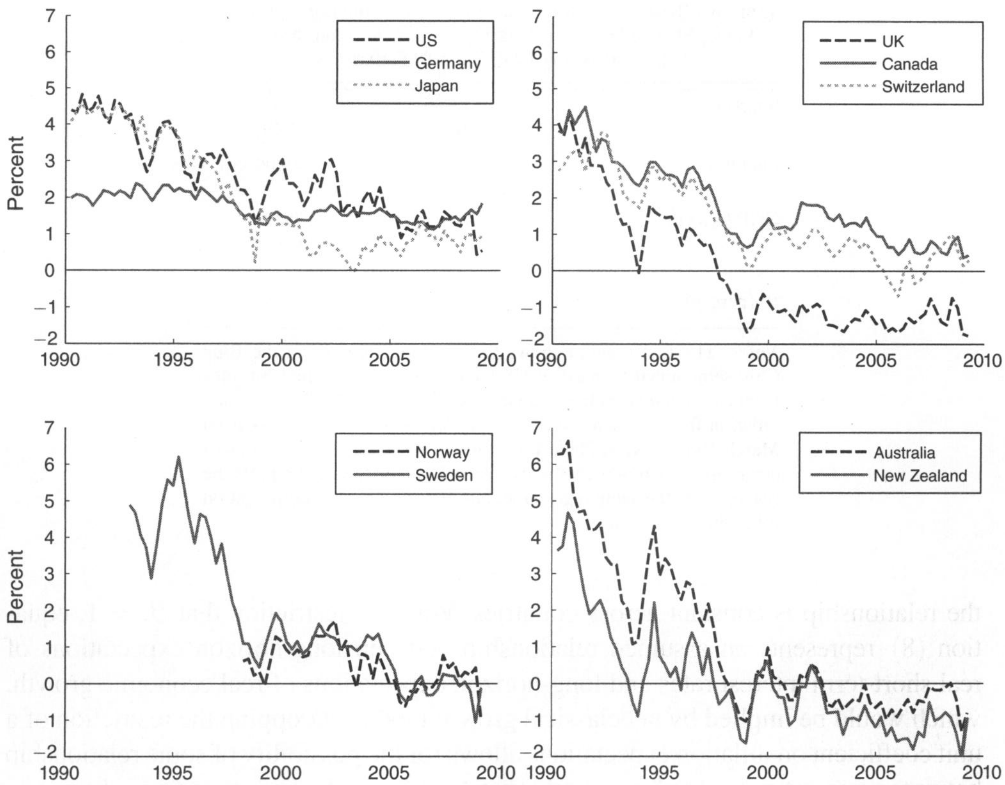

FIGURE 4. AFFINE MODEL FIVE-TO-TEN-YEAR FORWARD TERM PREMIUM ESTIMATES

Note: This plots the term premium component of the five-to-ten-year forward rate, as estimated from the homoskedastic exponential affine term structure model described in the text.

three-month interest rates from surveys, then the term premium is just the difference between an actual yield or forward rate and the average expected future three-month interest rate over the corresponding horizon. Consensus Forecasts provides long-horizon forecasts for all countries in the panel twice a year. Unfortunately, however, these long-horizon forecasts ask respondents to predict macroeconomic aggregates, including consumer inflation and real GDP growth, but not short-term interest rates.

I thus have to adopt a device to impute the approximate interest rate expectations of survey respondents. Blue Chip is a separate survey that is very similar to Consensus Forecasts, and many financial and economic forecasters contribute to both surveys. But, for the US alone, twice a year, Blue Chip provides forecasts of the average level of three-month interest rates from five to ten years hence, in addition to forecasts for consumer inflation and real GDP growth at the same horizon. Let these be r_t, π_t, and y_t, respectively, and consider the regression

$$r_t = \beta_0 + \beta_\pi \pi_t + \beta_y y_t + \varepsilon_{rt}. \tag{8}$$

This regression can be estimated, either imposing the restriction that $\beta_\pi = 1$, or without this constraint. The parameter estimates can then be applied to *other* countries to obtain imputed survey expectations for their short-term interest rates, assuming that

Table 4—Regression Coefficients of Blue Chip Long-Horizon Three-Month Interest Rate Forecasts on Corresponding Inflation and GDP Growth Forecasts

Intercept	1.85	1.53
	(0.53)	(0.49)
Inflation	0.95	1.00 (imposed)
	(0.07)	
GDP Growth	0.12	0.18
	(0.17)	(0.17)
R^2 (percent)	73.1	72.5

Notes: The first column shows the results of regressing the Blue Chip semiannual forecast of US three-month average interest rates from five to ten years hence on the forecasts of US GDP growth and inflation from the same surveys. The regression uses surveys from March 1987 to April 2009, for a total of 45 observations. Standard errors are shown in parentheses. The column on the right reports the results from the same regression, but imposing a unit coefficient on inflation.

the relationship is constant across countries. With the restriction that $\beta_\pi = 1$, equation (8) represents an assumed relationship between long-horizon expectations of real short-term interest rates and long-horizon expectations of real economic growth, which would be implied by neoclassical growth models. Dropping the restriction of a unit coefficient on inflation expectations allows for the possibility of some relationship between expectations of real rates and inflation, even at the five- to ten-year horizon.

The coefficient estimates are shown in Table 4. I then used these coefficient estimates—imposing the restriction that $\beta_\pi = 1$—to obtain implied predictions from Consensus Forecasts of average three-month interest rates at the five- to ten-year horizon for all the countries.[8] That is, the term premium estimate is

$$TP_t^{SURVEY} = f_t^{5,10} - (\hat{\beta}_0 - \pi_t - \hat{\beta}_y y_t), \tag{9}$$

where $f_t^{5,10}$ denotes the five- to ten-year forward rate, and the coefficient estimates are obtained from the estimation of equation (8) using US data.[9] To be sure, the assumption that this equation can approximate distant-horizon expectations of short-term interest rates with the same parameters for all countries is a strong one, but having these alternative term premium estimates seems useful, at least as a robustness check on their counterparts using affine term structure models.

The survey-based term premium estimates are shown in Figure 5. Like the affine model term premium estimates, they show a tendency of trending down. They are typically positive and, with the exception of Japan, never go very negative. Given how consistently nominal yield curves slope up, this seems to be a desirable property in a reasonable term premium estimate. The survey-based term premium estimates declined especially sharply over the sample period in the UK, Canada, Sweden, and Australia. Thus, both affine and survey-based term premium estimates fell sharply in Australia, Sweden, and the UK. The survey-based term premium estimates declined

[8] Equation (8) fits Blue Chip forecasts for the US well, with an R^2 of 73 percent.
[9] Piazzesi and Martin Schneider (2008) also estimate term premia from surveys.

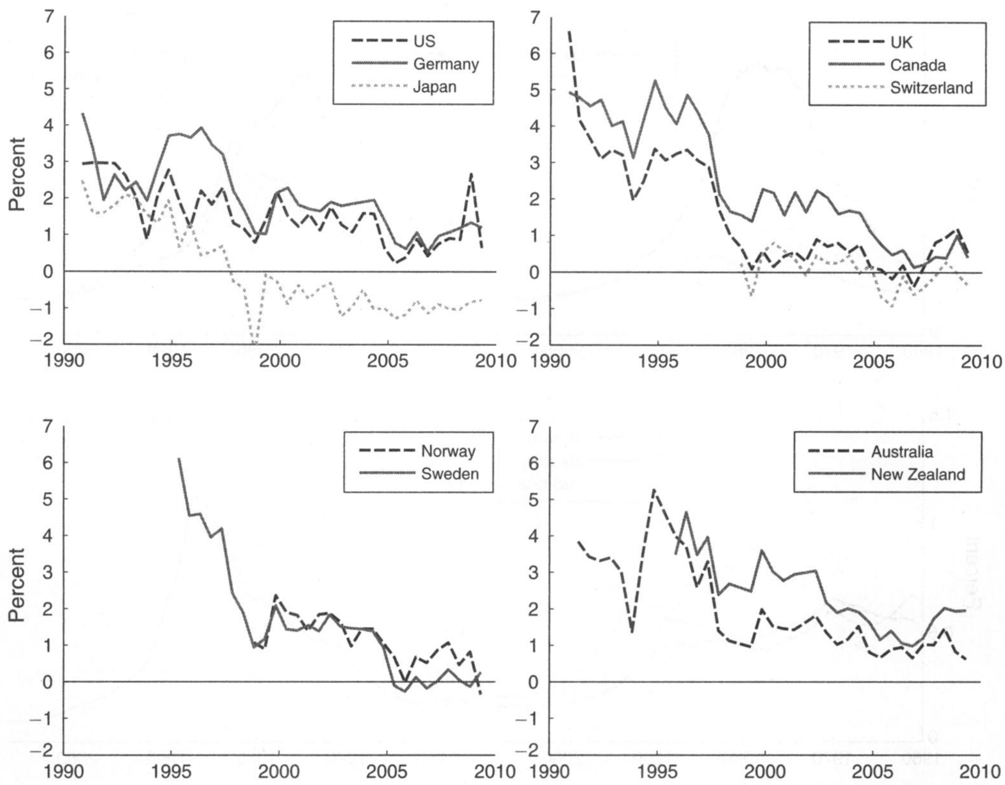

FIGURE 5. SURVEY-BASED FIVE- TO TEN-YEAR FORWARD TERM PREMIUM ESTIMATES

Note: This plots the term premium component of the five- to ten-year forward rate, as estimated from surveys, as described in the text.

further at the end of the sample period in the US, the UK, Canada, and Norway. They nevertheless remained higher in the US than in most other countries.

III. Discussion and Interpretation

Neither affine term structure models nor the survey-based estimates explain bond risk premia in terms of fundamental preference parameters. However, having obtained cross-country evidence on term premia from these methods, we can discuss the possible macroeconomic and financial market forces that may be driving bond risk premia.

Piazzesi and Schneider (2007), John Y. Campbell, Adi Sunderam, and Luis M. Viceira (2007), Rudebusch and Swanson (2008), and others argue that bond risk premia mainly reflect uncertainty about future inflation; inflation erodes the value of a nominal bond in precisely those states of the world in which investors' marginal utility is high. In any of these models, reducing inflation uncertainty, then, ought to lower term premia.

I find several pieces of empirical evidence supporting this view. I first relate term premium estimates to two different measures of inflation uncertainty:

(i) A time series measure: James H. Stock and Mark W. Watson (2007) proposed an unobserved components stochastic volatility (UCSV) model that appears to provide good forecasts for inflation. The model is a univariate specification

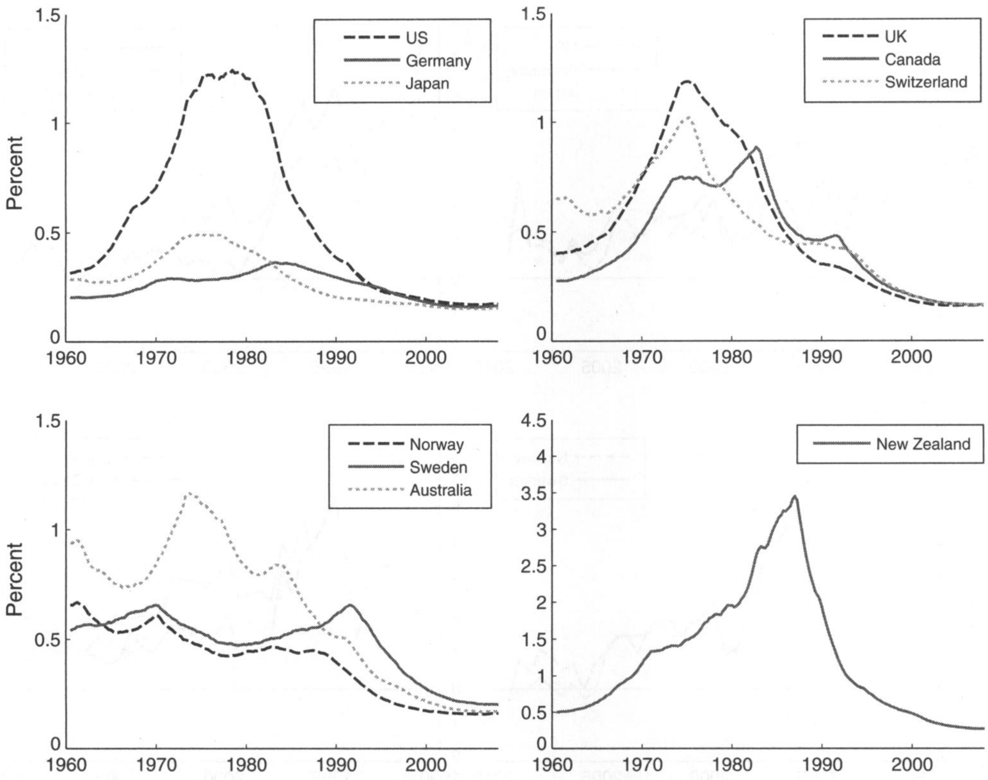

FIGURE 6. ESTIMATE OF THE STANDARD DEVIATION OF THE PERMANENT COMPONENT OF INFLATION

Note: This plots the estimated permanent component of inflation, obtained from fitting UCSV models to quarterly consumer price inflation at an annualized rate for each country separately.

that inflation is $\pi_t = \tau_t + \eta_t$, where $\tau_t = \tau_{t-1} + \varepsilon_t$, η_t is i.i.d. $N(0, \sigma^2_{\eta,t})$, ε_t is i.i.d. $N(0, \sigma^2_{\varepsilon,t})$, $\log(\sigma^2_{\eta,t}) = \log(\sigma^2_{\eta,t-1}) + \psi_{1,t}$, $\log(\sigma^2_{\varepsilon,t}) = \log(\sigma^2_{\varepsilon,t-1}) + \psi_{2,t}$, and $\psi_t = (\psi_{1,t}, \psi_{2,t})'$ is i.i.d. $N(\mathbf{0}, \mathbf{I}_2)$. The interpretation of the model is that inflation is the sum of a stochastic trend and noise, with both the volatility of the noise (temporary shocks) and the shocks to the stochastic trend (permanent shocks) being time-varying. The model can be estimated by Markov Chain Monte Carlo methods. I fitted the model to quarterly consumer price inflation for the panel of countries and show the estimated time series of the standard deviation of the permanent component in Figure 6—presumably asset prices are more affected by uncertainty about the permanent component of inflation than by uncertainty about the transitory piece. Stock and Watson (2007) found that the standard deviation of the permanent component of inflation in the US rose in the 1970s, peaked around 1980, and has come back down to a low level since then. I find this pattern as well, and find that it applies to several other countries. Germany and Japan, however, apparently did not have as much of a run-up in the volatility of the permanent component of inflation. New Zealand is shown on a different scale as the peak in the volatility of the permanent component of inflation was much higher, and later (mid 1980s), than for the other industrialized countries.

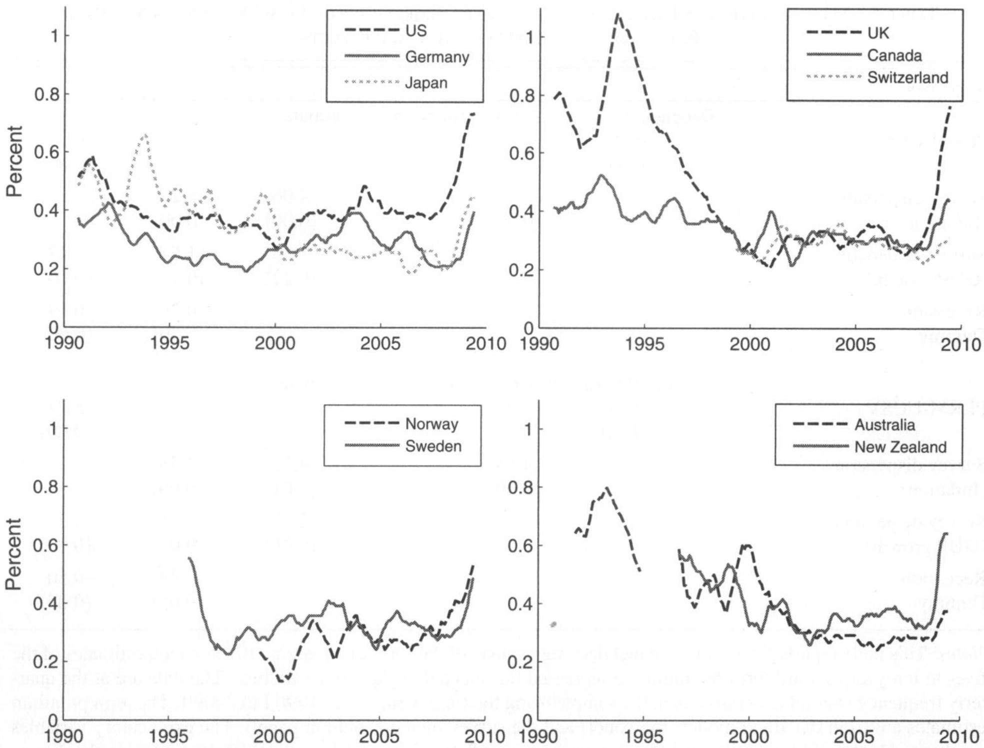

FIGURE 7. DISPERSION OF YEAR-AHEAD SURVEY FORECASTS OF INFLATION

Notes: This shows the 12-month moving average of the dispersion (standard deviation of point forecasts) of consensus survey expectations of year-ahead consumer price inflation (calendar year over calendar year percent change in prices). The dispersion is plotted against the month in which the 12-month window ends. There is a gap for Australia because of missing data from December 1994 to September 1995 (see Data Appendix).

(ii) Dispersion of survey forecasts. Consensus Forecasts reports the dispersion of its inflation forecasts (the standard deviation of individual forecasts) and this can be used as a proxy for uncertainty.[10] Figure 7 plots the 12-month moving average of the dispersion of next-year inflation forecasts. Dispersion has trended down in most countries since the early 1990s, though it rose again at the very end of the period. The countries with the largest declines in this measure of inflation uncertainty (until the end of 2007) were the UK, New Zealand, and Australia.

Both measures of inflation uncertainty declined around the world in the 1990s, as did estimates of term premia.[11] And it seems noteworthy that the inflation uncertainty and

[10] See Alex Cukierman and Paul Wachtel (1979), Victor Zarnowitz and Louis A. Lambros (1987), R. W. Rich, J. E. Raymond, and J. S. Butler (1992), and Rich and Joseph S. Tracy (2006).

[11] Milton Friedman (1977), Laurence Ball, N. Gregory Mankiw, and David Romer (1988), and Mankiw, Ricardo Reis, and Justin Wolfers (2004) all examine the relationship between the level of actual/expected inflation and uncertainty, and conclude that there is a strong positive relationship—low inflation tends to be stable inflation. This could arise because economies with high inflation tend to get rid of nominal rigidities and so shocks fall more heavily on prices than on the output gap. Empirically, this relationship seems to show up in the data used in this paper: the inflation risk measures all trended down during the 1990s in line with survey-based inflation expectations

TABLE 5—SLOPE COEFFICIENT ESTIMATES IN PANEL DATA REGRESSIONS OF TERM PREMIUM ON SELECTED EXPLANATORY VARIABLES, WITH FIXED EFFECTS

Regressor						
	Dependent variable: Affine term premium estimate					
PERM-UCSV	6.99					6.39
	(0.00)					(0.00)
Survey dispersion		5.42		4.96	5.27	
(Inflation)		(0.00)		(0.00)	(0.00)	
Survey dispersion			3.11	1.35	1.57	2.47
(GDP growth)			(0.01)	(0.22)	(0.11)	(0.00)
Recession					−0.26	−0.39
Dummy					(0.30)	(0.00)
	Dependent variable: Survey term premium estimate					
PERM-UCSV	6.07					5.74
	(0.00)					(0.00)
Survey dispersion		4.85		4.15	4.58	
(Inflation)		(0.00)		(0.01)	(0.00)	
Survey dispersion			3.55	2.00	2.31	3.21
(GDP growth)			(0.00)	(0.06)	(0.01)	(0.00)
Recession					−0.34	−0.50
Dummy					(0.05)	(0.00)

Notes: This table reports the results of panel data regressions of the form of equation (10) in which estimates of the five- to ten-year forward term premium are regressed on selected explanatory variables. The data are at the quarterly frequency over all ten countries in the sample using the time period from 1990:I to 2009:I. The term premium estimates are from the affine model (top panel) and the survey method (bottom panel). The explanatory variables are the standard deviation of the permanent component of inflation in the UCSV model (PERM-UCSV), the dispersion of survey forecasts of inflation or GDP growth and/or recession dummies using NBER business cycle dates for the US and Economic Cycle Research Institute dates for all other countries. Data sources are as listed in the Data Appendix. Fixed effects are included in all cases. Entries in parentheses are bootstrap p-values, using a block bootstrap in which each bootstrap sample consists of blocks of four quarters of data using the same four-quarter windows for each country in the panel. There are 1,000 replications in each application of the bootstrap.

term premium estimates declined substantially in those countries that adopted inflation targeting and/or made their central banks more independent and more transparent.

To investigate the relationship between term premia and inflation uncertainty more formally, I ran panel data regressions of term premia on these two different inflation risk measures. Country fixed effects were included, so as to allow for the possibility that some other country-specific factors that may affect term premia are also correlated with inflation risk measures. The regressions are of the form

$$TP_{it} = \alpha_i + \boldsymbol{\beta}'\mathbf{x}_{it} + \varepsilon_{it}, \tag{10}$$

where TP_{it} denotes the term premium in country i in quarter t (with the term premium being either the affine model or survey-based estimate), $\mathbf{x}_{it}$ is a vector of regressors, and α_i denotes a country fixed-effect. The regressors are the two measures of inflation uncertainty, the dispersion of year-ahead consensus forecasts of GDP growth (to control for real-side volatility which may be correlated with inflation volatility), and a recession dummy (using NBER business cycle dates for the

(Figure 2). The empirical relationship between inflation expectations and inflation uncertainty could mean that a decline in inflation expectations might be accompanied by a fall in inflation uncertainty and hence in term premia, leading to a larger decrease in forward rates.

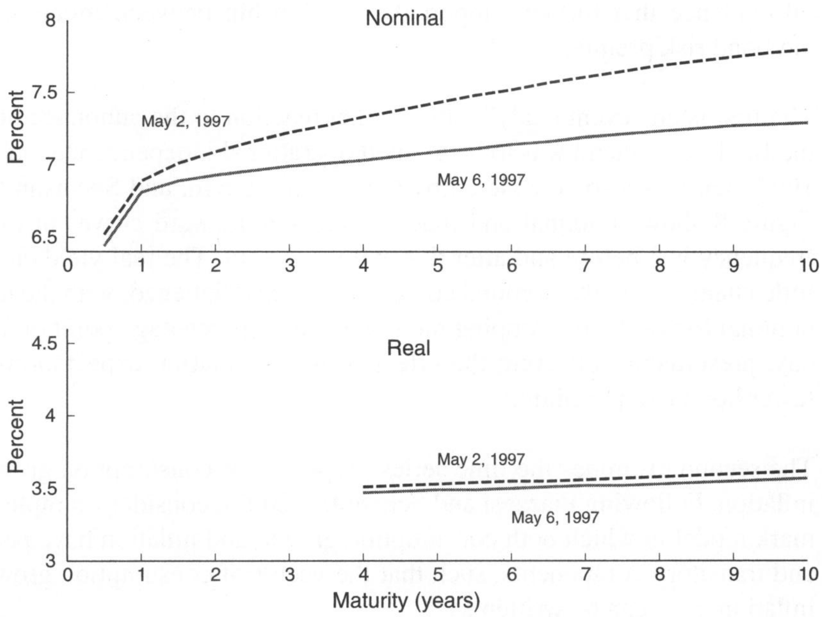

Figure 8. United Kingdom Nominal and Real Forward Curves before and after Operational Independence

Notes: This shows the UK nominal and index-linked instantaneous forward real curves (source: Bank of England) on the last business day before the Bank of England was granted operational independence (Friday May 2) and the day that the announcement of independence was made (Tuesday May 6). Note that May 5 was the May Day holiday in that year.

US and dates from the Economic Cycle Research Institute for the other countries). Significance is tested by a bootstrap algorithm that allows the errors to be correlated across countries and over time. In each bootstrap sample, I resampled blocks of four quarters of data using the same four-quarter windows for each country in the panel, and then used these to construct bootstrap p-values.

The results are shown in Table 5 for a number of regression specifications. Both measures of inflation uncertainty are consistently significant positively related to both premium term estimates. The coefficient on the dispersion of GDP growth forecasts is estimated to be positive, while the coefficient on the recession dummy is estimated to be negative, but these latter coefficients are significant only in some specifications.

The view that inflation uncertainty is an important driver of term premia may offer an explanation for the comparatively high level of forward rates and term premia in the US over recent years. The survey-based measure of inflation uncertainty (Figure 7) has generally been higher in the US than in any foreign country over recent years. Other papers using quite different methodologies have also argued that inflation expectations are relatively poorly anchored in the US. (*For example*, Refet S. Gürkaynak, Sack, and Swanson (2005), Meredith J. Beechey, Benjamin K. Johannsen, and Andrew T. Levin (2008), and Gürkaynak, Levin, and Swanson (2010) reached this conclusion from noting that distant-horizon forward rates are more sensitive to economic news in the US than abroad.)

The regression in equation (10) may suffer from econometric problems, as all the variables are quite persistent. There are, however, two quite separate pieces of empirical evidence that further support the relationship between inflation uncertainty and bond risk premia:

(i) The first is an "event study"—the market reaction to the announcement that the Bank of England was to be granted operational independence, on May 6, 1997, that was also considered by Gürkaynak, Levin, and Swanson (2010). Figure 8 shows nominal and index-linked UK forward curves at the daily frequency just before and after this announcement. The real yield curve was little changed, but the nominal curve declined and flattened, with the ten-year nominal forward rate dropping more than half a percentage point on a single day, presumably reflecting the effect of lower inflation expectations and a lower bond risk premium.[12]

(ii) The second examines the time series properties of consumption growth and inflation. Following Piazzesi and Schneider (2007), consider a simple benchmark model in which both consumption growth and inflation have persistent and transitory components, such that the vector of consumption growth and inflation, z_{t+1}, can be written as

$$\mathbf{z}_{t+1} = \boldsymbol{\mu} + \boldsymbol{\alpha}_t + \mathbf{v}_{t+1}, \tag{11}$$

$$\boldsymbol{\alpha}_{t+1} = \boldsymbol{\alpha}_t + \mathbf{K}\mathbf{v}_{t+1}, \tag{12}$$

where $\mathbf{v}_{t+1}$ is i.i.d. $N(\mathbf{0}, \boldsymbol{\Omega})$ and $\boldsymbol{\alpha}_t$ is a vector of expected consumption growth and expected inflation. The covariance between shocks to expected consumption growth and to expected inflation is given by the off-diagonal element of $\mathbf{K}\boldsymbol{\Omega}\mathbf{K}'$. The model can be estimated by maximum likelihood. Estimates of the covariance between shocks to expected consumption growth and expected inflation are shown in Table 6 for all ten countries considered in this paper, over the sample periods 1981:I–1994:IV and 1995:I–2009:I. Table 6 also shows the p-value from a test of the hypothesis that the covariance is equal over these two subsamples. In the early subsample, the covariances are all estimated to be negative. This means that inflation tended to erode the value of nominal bonds at times when consumption contracted, making these bonds risky assets, and in turn implying positive term premia, as in the explanation of Piazzesi and Schneider (2007). In the later subsample, the estimated covariances are mostly positive and of smaller absolute magnitude. The difference across the two subsamples is statistically significant for three countries, Canada, the UK, and the US, countries that all had sizeable declines in term premium estimates.

Inflation uncertainty has presumably increased during the recent financial crisis. Although the time series measure of inflation uncertainty has changed little (Figure 6), the forward-looking survey-based measure has risen sharply (Figure 7). Nevertheless, term premium estimates remained flat and even declined further in some countries

[12] If we think that agents expect inflation to reach its long-run expected value within five years (even though that long-run expectation may change from over time), then the flattening of the nominal forward curve beyond the five-year horizon shown in Figure 8 must represent, at least in part, a decline in the inflation risk premium.

Table 6—Covariance of Shocks to Expected Consumption Growth and Inflation

Country	1981I–1994:IV	1995:I–2009:I	p-value for no structural break
Australia	−0.33**	0.02	*0.12*
Canada	−0.91*	0.46**	*0.01*
Germany	−0.23	−0.02	*0.30*
Japan	−0.81	3.55	*0.32*
New Zealand		0.77*	
Norway	−0.63	−0.50	*0.46*
Sweden	−0.12	0.01	*0.31*
Switzerland	−0.05	0.08	*0.39*
UK	−2.32**	1.12***	*0.00*
US	−0.43*	0.31	*0.01*

Notes: Entries represent the off-diagonal elements of $\mathbf{K}\Omega\mathbf{K}'$ when the model consisting of equations (11) and (12) is fitted by maximum likelihood to quarterly consumption growth and inflation. Standard errors are based on the Hessian matrix. Data sources are as listed in the Data Appendix. Quarterly consumption data for New Zealand are available only back to 1987:I, and no subsample results are shown for this country. The column on the right reports the p-value in a test that the covariance of shocks is equal in the 1981–1994 and 1995–2009 subsamples.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

during late 2008 and early 2009. Perhaps this owes to "flight-to-quality" flows as investors increased their demand for the comparative liquidity of government bonds, and/or to the effects of purchases of government bonds and other long-term securities by central banks. Such explanations—in which the effective supply of bonds influences term premia—make sense in a segmented markets environment (see, for example, Robin Greenwood and Dimitri Vayanos 2008; Arvind Krishnamurthy and Annette Vissing-Jorgenson 2008).

IV. Conclusions

To date, there has been little empirical evidence comparing term premia in different countries. Accordingly, in this paper, I have compiled a dataset of nominal sovereign yield curves spanning nearly two decades for ten industrialized countries, which are all the major industrialized countries that have separate monetary policies at present. I then use these to construct country-specific time-varying term premium estimates.

The evidence indicates that the term premium components of forward rates trended down in all countries over the last 20 years with some of the largest declines evident in Australia, Sweden, and the United Kingdom.

In this paper, term premia are estimated from affine models (with yields and macroeconomic variables as factors) and surveys. Neither method explains bond risk premia in terms of fundamental preference parameters. However, the patterns in term premia across countries and over time are suggestive of the economic forces at work. It is very much consistent with inflation uncertainty being an important component of bond risk premia, as the largest term premia declines occurred in countries that made radical changes in their monetary policy frameworks, such as introducing inflation targeting and increasing the independence of their central banks. The sharp drop in forward rates in the United Kingdom on the day that the Bank of England was granted operational independence is further evidence for this explanation. During the recent financial crisis, term premium estimates have remained flat and even declined further in some countries, perhaps reflecting the effects of quantitative easing actions by many central banks and/or "flight-to-quality" flows into government securities.

These findings have a number of substantive policy implications. In particular, they imply that measures to improve the credibility of the nominal anchor could lower longer-term interest rates and facilitate the transmissions mechanism of monetary policy. They also imply that if index-linked and nominal bond markets are equally liquid, the expected debt servicing costs to a government should be lower from issuing index-linked debt.

Data Appendix

Besides the zero coupon yields, this paper also used data on CPI inflation, GDP growth, and private consumption growth. These were obtained from OECD's Main Economic Indicators, at the quarterly frequency. For the purpose of fitting affine models, these were then smoothed by applying an exponential weighted moving average filter with a smoothing parameter of 0.75. No such smoothing was applied to the consumption growth and inflation used in Section III. For New Zealand, consumption and GDP data go back only to 1987:II; all other series are available back to 1960:I.

The paper also used survey data. The survey dataset consists of the Consensus Forecast predictions for consumer price inflation next year, from the survey taken each month from October 1989 to June 2009, inclusive. In addition to the point forecasts, the dispersion (standard deviation) of the forecasts is also included. The following countries are included in these surveys:

(i) All months: US, Japan, Germany, UK, Canada.

(ii) From January 1996 on: Sweden.

(iii) From June 1998 on: Switzerland and Norway.

(iv) From November 1989 on: Australia (December 1994 to September 1995 are missing).

(v) From October 1995 on: New Zealand.

Because the surveys are taken at the very start of each month, and the yield curve data refer to the last business day of the month, the timing convention that I adopt is to treat the survey for any given month as referring to beliefs at the end of the previous month. For example, the December 2008 observation is the survey dated January 2009.

In addition, each April and October, there is a "long-horizon" survey, asking respondents for their predictions of GDP growth and inflation from five to ten years hence. The dataset includes responses from each of these surveys from April 1990 to

October 2007, inclusive. The following countries are included in these long-horizon surveys:

(i) All surveys: US, Japan, Germany, UK, Canada.

(ii) From April 1995 on: Sweden.

(iii) From October 1998 on: Switzerland and Norway.

(iv) From April 1991 on: Australia.

(v) From October 1995 on: New Zealand.

Since October 1995, the data have been in the publication "Consensus Forecasts for G-7 Countries and Western Europe" for all countries except Australia and New Zealand, which are instead provided in "Asia Pacific Consensus Forecasts." Prior to that, the available data were in a single publication called "Consensus Forecasts."

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