Treasury Bond Volatility and Uncertainty about Monetary Policy

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We show that dispersion-based uncertainty about the future course of monetary policy is the single most important determinant of Treasury bond volatility across all maturities. The link between Treasury bond volatility and uncertainty about macroeconomic variables is much stronger than for the more traditional time-series measures of macroeconomic volatility and adds beyond the information contained in lagged bond market volatility. Uncertainty about monetary policy subsumes the uncertainty about future inflation (CPI and the deflator) and economic activity (unemployment, real and nominal GDP and industrial production). In addition, causality clearly runs one way: from monetary policy uncertainty to Treasury bond volatility.

JEL classification: E44, E58, G12

Keywords: Bond market volatility, monetary policy, macroeconomic factors, survey data

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We thank the editor, Arnold Cowan, and two anonymous referees for very useful comments and suggestions.

1. Introduction

Understanding financial market volatility is an important issue for practitioners in financial markets and central bankers around the world. While time-series models of financial market volatility have some success in capturing the volatility dynamics of asset prices (Engle, 1982; Bollerslev, 1986), their power is based on the use of high-frequency data and their applicability seems confined to short time horizons (Diebold and Christoffersen, 2000). Less is known about the fundamental determinants of financial market volatility. Previous attempts to explain why volatility changes over time have yielded inconclusive results, at best. The volatility puzzle raised by Schwert (1989), which holds that financial market volatility seems disconnected from other measures of economic volatility, is still largely intact today.

This study explores fundamental determinants of volatility in the U.S. Treasury bond market. Using quarterly data for the period 1970-2005, we establish a significant relation between bond volatility and dispersion-based uncertainty about the monetary policy rate, inflation and measures of real activity. A one-standard-deviation increase in macroeconomic uncertainty typically leads to a significant increase of 20 – 50 basis points in quarterly bond market volatility. This link is stronger than for time-series measures of macroeconomic volatility, which adds to a recent literature favoring dispersion-based measures of uncertainty over time-series volatility; see David and Veronesi (2004). We also show that the dispersion in monetary policy rate forecasts captures almost all macroeconomic uncertainty in the data set. Finally, we check for causality and find that monetary policy uncertainty Granger causes bond volatility, rather than the other way around, consistent with predictions from theoretical models and intuition. These conclusions are robust to changes in the way we construct macroeconomic volatility and whether return volatility or the volatility of yield changes is analyzed. Since uncertainty about monetary policy is the single most important driver of Treasury bond market volatility, our results hint at an important role for guiding and monitoring financial markets expectations by monetary authorities.

Theoretically, the relation between financial market volatility and macroeconomic uncertainty is explored in Veronesi (1999) and David and Veronesi (2004). The link can be summarized as follows. Financial market participants make inferences about asset prices based on observations of the macroeconomic fundamentals. The average growth rates of fundamentals are time-varying and not directly observable. When fundamental uncertainty is high, news will cause asset prices to move more than when fundamental uncertainty is low. Asset market volatility will thus increase with fundamental uncertainty.

Empirically, it can be difficult to establish a clear link between macroeconomic fundamentals and the volatility of asset prices, especially with low frequency data. Most prior research therefore resorts to linking asset prices and their volatilities to macroeconomic announcements using intraday data. For the interdealer bond market, Balduzzi, Elton and Green (2001) analyze the effect of macroeconomic announcements on prices, trading volume and bid-ask spreads. Surprises in public news releases have a significant impact on Treasury bills and bonds and the adjustment to new information occurs within one minute after the announcement. Heuson and Su (2003) consider the effects of macroeconomic announcements on implied volatilities in the Treasury sector index market. They conclude that implied volatilities are predictable, but accounting for trading costs, informed traders cannot make arbitrage profits.

A number of papers focus on the effect of monetary policy surprises. Using event-study regressions, Cook and Hahn (1989) find that changes in the Fed´s funds target rate have large impact on short-term interest rates, a moderate impact on intermediate-term rates, and a small (but significant) impact on long-term rates during the 1970s. Kuttner (2001) separates the anticipated part from the unanticipated part of Fed actions using forecasts incorporated in the Federal funds futures market. He finds a strong reaction to unanticipated funds rate changes, but not to anticipated rate changes. Gürkaynak, Sack and Swanson (2005) show that long-term forward interest rates react significantly to U.S. monetary policy surprises. Their findings suggest that economic agents adjust their long-term inflation expectations in response to macroeconomic and monetary policy surprises. For the currency market Wang, Yang and Simpson (2008) report that intraday currency futures prices react significantly to both changes in the federal funds target rate and changes in the path of expected rate changes. The reaction to both factors is roughly of similar magnitude, but is short-lived. Taking a non-announcement perspective, Laopodis (2006) studies the dynamic interactions among the equity market, economic activity, inflation, and monetary policy under three different monetary policy regimes. There is no evidence of any systematic relationship among the variables since the 1990s.

The present paper takes a very different perspective than the existing empirical literature. Rather than analyzing short-term intraday windows around macroeconomic announcements, we employ low frequency quarterly data. We use the Survey of Professional Forecasters to link macroeconomic uncertainty to Treasury bond market volatility. Traditionally, macroeconomic volatility is measured by a transformation of the residuals of a time-series model for a macroeconomic variable (see Schwert, 1989 in the context of stock market volatility). But there are limitations to this approach (see also Giordani and Söderlind, 2003). First, the time-series approach is backward looking, whereas we are interested in ex-ante uncertainty. Second, time-series are often subject to structural breaks. Third, there is no universal time-series model to extract expectations. Different models will yield different volatility estimates. Fourth, and finally, time-series volatility captures the volatility in a single realized time path of a macroeconomic variable out of many possible ex-ante scenarios. Such a path may appear smooth ex-post, notwithstanding significant ex-ante uncertainty as to which way the path would go. The time-series dimension of the data cannot adequately capture this cross-sectional notion of uncertainty. For example, Schwert (1989) mentions Robert Merton's interpretation of the Great Depression as a "Peso problem". At that time, there was significant uncertainty whether the economic system as a whole would survive. This is not apparent by looking at the ex-post data.

The empirical potential of this approach is demonstrated by David and Veronesi (2004), who show that measures of uncertainty about future inflation and earnings growth from survey data forecast asset market volatility. We add to their work in several ways. First, we consider a much broader set of macroeconomic fundamentals. Second, we explicitly compare the performance of measures of dispersion-based uncertainty to equivalent measures of time-series volatility that are common in the literature. Third, we focus on uncertainty in the monetary policy rate and show that the dispersion in forecasts for the future monetary policy rate dominates all other macroeconomic uncertainty in the data set. Finally, we account for small sample bias and for the generated nature of macroeconomic volatility by bootstrapping critical values. As far as we know, this is the first time in this literature. Since the bootstrapped critical values are substantially higher than their asymptotic counterparts, this correction is important. We also check the robustness of our main conclusions when we use the volatility of yield changes rather than returns and when we construct GARCH-based measures of macroeconomic volatility.

2. Data

2.1 Bond volatility

We calculate daily bond returns using the Federal Reserve H.15 constant maturity interest rate series for maturities of 30, 10, five and one years. Our approach is similar to Jones, Lamont and Lumsdaine (1998). Assuming a hypothetical bond that trades at par at the end of day $t-n$, the coupon rate is equal to the yield-to-maturity and the value of the bond is 1. We then use the yield at the end of day t to calculate the price under the assumption that coupons are paid semi-annually. The total return is calculated as the sum of the price change and the interest income earned over the holding period (assuming 365 days in a year):

$$(1) \qquad r_{j^*,t} \approx \sum_{i=1}^{2j} \frac{\frac{1}{2} y_{j,t-n}}{\left(1+\frac{1}{2} y_{j,t}\right)^i} + \frac{1}{\left(1+\frac{1}{2} y_{j,t}\right)^{2j}} + \frac{n}{365} \times y_{j,t-n} - 1,$$

where $r_{j^*,t}$ is the return on a bond with a time-to-maturity of j^* years on day t, which reflects that the maturity of the bond is j minus the number of holding days (n) rather than exactly j. $y_{j,t-n}$ ($y_{j,t}$) is the yield on a bond with time-to-maturity j years at day $t-n$ (t) and n is the holding period of the bond. For example, $n=1$ for weekdays and $n=3$ for Mondays. The final term in equation (1) reflects the price of the bond at the end of day $t-n$, (which is 1 since the bond is assumed to trade at par at day $t-n$). The equation ignores the change in return due to the change in the time value of money over the holding period. Although this effect is insignificant, our return measure is therefore an approximation rather than an identity. We finally multiply $r_{j^*,t}$ by 100 to express the returns in percentage points.

Following French, Schwert and Stambaugh (1987), we calculate quarterly bond volatility as:[1]

$$(2) \qquad \sigma_{maturity\, j,\, t} = \sqrt{\sum_{i=1}^{N_i} (r_{j^*,i} - \mu_t)^2}\ ,$$

where N_i is the number of daily observations in quarter t, $r_{j^*,i}$ is the daily return of a Treasury bond with a time-to-maturity of j^* years on day i as defined above and μ_t is the average daily return of Treasury bond j during quarter t. Table 1 reports descriptive statistics. As is well-

[1] Our data frequency is dictated by the periodicity of the Survey of Professional Forecasters, which is quarterly.

known, the volatility of Treasury bond returns increases with time-to-maturity. Volatility is also serially correlated, but Phillips-Perron unit root tests (unreported) reject the null hypothesis of a unit root at the 5%-level of significance. We use a bootstrap to account for the persistence of bond volatility when reporting significance levels in the remainder of this paper. Due to a change in the Fed's operating procedures, bond volatilities are much higher from the fourth quarter of 1979 onwards. Bond volatilities peak in the fourth quarter of 1987 (stock market crash), the second quarter of 1994 (bond market crisis) and the third quarter of 2001 (terrorist attacks). The empirical approach described in section 3 provides details on how we deal with these issues econometrically.

2.2 Macroeconomic uncertainty

We use the Survey of Professional Forecasters (SPF) to construct our macroeconomic uncertainty measures. The SPF was started in 1968 by the American Statistical Association and the National Bureau of Economic Research. The Federal Reserve Bank of Philadelphia took over the SPF in June 1990. Participants in the survey are professional forecasters, who submit their forecasts anonymously. Anonymity should allow forecasters to submit their true forecasts, even if these contradict the firm's official position (Croushore, 1993). Keane and Runkle (1990) and Zarnowitz and Braun (1992) show that SPF forecasts are consistent with rational expectations and outperform a variety of time-series models. Hafer and Hein (1985) compare the accuracy of inflation forecasts derived from a univariate time-series model, an interest rate model and the SPF. The general conclusion is that the SPF provides the most accurate forecasts over the period 1970Q1 – 1984Q2. More recently, Ang, Bekaert and Wei (2007) conduct a comprehensive study on the forecasting abilities of time-series ARMA models, Phillips curve inspired regressions, term structure models, and survey-based measures to predict inflation. Surveys, including the SPF, provide the best forecasts for inflation and there is little evidence that combining predictions improves upon survey forecasts.[2] Overall, the SPF is considered to be a high-quality survey of professional forecasters.[3]

We take seven variables from the SPF. Some have been part of the survey since inception (1968Q4), others have been added in 1981Q3. Table 2 lists the variables including start date and abbreviation. The SPF contains expectations about the future short term interest rate (TBILL). We take the dispersion in this variable as our measure of uncertainty about future monetary policy. This is consistent with most empirical studies, where the short-term interest rate is a common choice for the central bank's main instrument to conduct monetary policy (see for example Leeper, Sims and Zha, 1996). Our monetary policy uncertainty variable measures the uncertainty about the monetary policy rate at each quarter as the cross-sectional dispersion of individual forecasts. This is different from the monetary policy surprise developed by Kuttner (2001), which contrasts actual target rate changes with expectations embedded in the Fed funds future. The selection of the other variables is guided by theory on the economic determinants of interest rates. The Taylor rule (Taylor, 1993) and its variations are the most common framework to relate economic variables to the short-term interest rate. Monetary policy is linked to expectations regarding inflation and economic activity through the central bank's reaction function. The SPF contains measures of inflation expectations using either the GDP deflator (PGDP) or the consumer price index (CPI). Expectations of future economic activity are measured using the following SPF variables: unemployment (UN), real GDP (RGDP), nominal GDP (NGDP) and industrial production (IP). If the Fed counters inflationary pressure and developments in real eco-

[2] The macro-term structure literature also starts to link state vector volatility to the volatility of bonds; see for example Ang, Dong and Piazzesi (2007). Chun (2005) incorporates survey forecasts.
[3] Money Market Services International (MMS) is another popular survey often used in the literature. As far as we know, however, MMS does not provide the expectations of individual forecasters which we need to construct our macroeconomic uncertainty measure. Furthermore, MMS asks participants for their expectations of upcoming macroeconomic releases. This differs from the approach of the SPF, where participants provide their multi-period-ahead forecasts for various macroeconomic variables. Finally, the SPF starts almost 10 years earlier than MMS.

nomic activity with appropriate changes in monetary policy (for example in the spirit of the Taylor rule), much of the macroeconomic uncertainty should be captured by the uncertainty about the future short interest rate.[4] We further explore this issue in section 3.3.

Our construction of uncertainty measures from survey data follows the literature. Giordani and Söderlind (2003) and Bomberger (1996) conclude that disagreement on a point forecast, measured by the cross-sectional standard deviation, is a good representation of uncertainty. For each variable in each quarter, we calculate cross-sectional standard deviations. For series that are not reported in percentage terms (all except unemployment, inflation and the T-bill rate), we calculate predicted growth rates as follows: $E(\Delta Y_{i,t}^{t+k}) = (E(Y_{i,t}^{t+k}) / Y_{i,t}^{t-1}) - 1$, where $E(\Delta Y_{i,t}^{t+k})$ is the predicted growth rate between the previous quarter and quarter $t+k$ of variable Y at time t by forecaster i. $Y_{i,t}^{t-1}$ is the level of variable Y in the quarter preceding the survey date t as observed by forecaster i. Since the advance release for the previous quarter´s value is known when participants submit their forecasts, forecasters rarely disagree on this value. $E(Y_{i,t}^{t+k})$ is the predicted value of Y in quarter $t+k$ made at time t by forecaster i. We use U1 and U4 for uncertainty for k=1 and k=4, respectively. At each survey date, the cross-sectional standard deviation based on n forecasters is:

(3) $$Uk_t = \sqrt{\sum_{i=1}^{n} \left[E(\Delta Y_{i,t}^{t+k}) - \frac{1}{n} \sum_{i=1}^{n} E(\Delta Y_{i,t}^{t+k}) \right]^2 / (n-1)}$$

Since the order of magnitude is different for each of the uncertainty and macroeconomic volatility variables, we normalize all variables by dividing each measure by its time-series stan-

[4] How much of the macroeconomic uncertainty is reflected in uncertainty about the future short interest rate depends on monetary policy inertia, interest rate smoothing and on how much weight the Fed places on the various macroeconomic variables. We thank an anonymous referee for pointing this out.

dard deviation. This step is innocuous, as it does not affect significance levels or the explanatory power of the regressions. However, it enhances comparability across the variables.

When the Philadelphia Fed took over the survey in the summer of 1990, they were too late to send out the 1990Q2 survey. The 1990Q2 survey was mailed out together with the 1990Q3 edition. In filling in the 1990Q2 data, forecasters thus had the benefit of hindsight. A re-run with a 1990Q2 dummy does not affect the results.

We calculate bond volatility over periods that match the survey deadlines, rather than calendar quarters, to bring them in line with the SPF. For example, the 1993Q1 and 1993Q2 survey deadlines were February 19th 1993 and May 5th 1993, respectively. We calculate the 1993Q2 bond volatility using daily returns between these dates. This procedure makes sure that bond volatility is matched with the information that was available for forecasters in the SPF. From 1990Q2 onwards, when the Philadelphia Fed took over the survey, deadline dates are exactly available. For the period prior to that we take the 20th as the deadline, which is the average date in the post-1990 period. Varying this date does not have an impact on our conclusions.

Table 3 shows that uncertainty is larger for k=4 than for k=1, as one would expect. The first-order autocorrelation is high, indicating that uncertainty does not die out very quickly. Phillips-Perron unit root tests (unreported) show that the null hypothesis of a unit root in uncertainty is rejected at the 5%-level of significance for all variables.

2.3 Macroeconomic volatility

Realizations for the macroeconomic variables in the SPF come from two data sources. First, we use the February 2006 edition of the Real Time Dataset for Macroeconomists (RTDSM) from the Federal Reserve Bank in Philadelphia. We are able to match six out of seven SPF series with the RTDSM database. The variable definitions are identical. When we compare median values across forecasters from the quarter preceding the survey date (for which most participants use the published advance release) with initial unrevised data from the RTDSM, we observe a perfect fit. Second, our data source is Thomson Financial Datastream for industrial production. This series is also closely related to the corresponding SPF data: the correlation of levels (first differences) between SPF previous quarter values and this series is 0.99 (0.94).

We follow Bansal, Khatchatrian and Yaron (2005) in constructing macroeconomic volatility measures. For each macroeconomic series *Y*, we estimate an AR(1)-model and collect the residuals ε_t^Y. Volatility is calculated as:

(4) $$\sigma_{t-1,J}^{Y} = \log\left(\sum_{j=1}^{J}\left|\varepsilon_{t-j}^{Y}\right|\right)$$

As with macroeconomic uncertainty, we divide each macroeconomic volatility measure by its time-series standard deviation. This does not affect t-values or R-squares of our main regressions.

Akaike Information Criterion and Schwartz Information Criterion based AR(p) models yield similar results. The log in equation (4) makes the volatility measure less susceptible to outlier observations, but comes at the cost of potentially negative values for volatility, which are difficult to interpret. Dropping the log in (4) does not affect our conclusions, however. We consider lag values for J=1 and 4. Table 3 reports summary statistics for macroeconomic volatility, denoted V1 and V4 for respectively J=1 and J=4. Mean values are higher for four-quarter volatility than for one-quarter volatility. Standard deviations are lower for four-quarter volatility as absolute residuals from the AR(1) models are smoothed in the summation in (4). First-order autocorrelations are also higher for four-quarter volatilities, but Phillips-Perron unit root tests (unreported) reject the null-hypothesis of a unit-root at the 5%-level for all variables. Both the persistence and the fact that macroeconomic volatility is generated rather than observed are taken into account using a bootstrap.

3 Results

3.1 Contemporaneous relationship

This paragraph explores the contemporaneous relationship between bond volatility and macroeconomic uncertainty and volatility. To this end, we estimate the following regression:

(5) $$\sigma_{maturity\, j,t} = \alpha + \beta \sigma_t^Y + \gamma \sigma_{maturity\, j,t-1} + \delta D_{MPolicy,t} + \varepsilon_t ,$$

where $\sigma_{maturity\, j,\, t}$ is the volatility of Treasury bonds with maturity j = 1, 5, 10 and 30 years at time t; σ_t^Y is either macroeconomic uncertainty (U1 or U4) or macroeconomic volatility (V1 or V4) at time t. $D_{MPolicy,t}$ is a dummy variable to account for the effect of the change in the Fed's operating procedures on volatility. It equals one from 1979:4 onwards and zero otherwise. The error term is denoted ε_t. Adding dummy variables to account for the stock market crash of 1987, the bond market crisis of 1994 and the terrorist attacks of 2001 does not change the conclusions. We use quarterly data over the period 1969:1 – 2005:4. Estimating equation (5) with calendar quarters rather than SPF deadline matched quarters for V1 and V4 leads to only minor differences with the reported results. We therefore report the results based on SPF-deadline-matched quarters throughout the paper.

Tables 4 and 5 report the β estimates, Newey-West t-values and ΔR^2s.[5] We do not report the estimates and t-values for the constant, lagged volatility and the dummy. The ΔR^2 measures the incremental explanatory power of the macroeconomic variable beyond what is contained in lagged bond volatility and the dummy variable (and are hence substantially lower than the total

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[5] We use Newey-West standard errors because Treasury bond market volatility is both autocorrelated and heteroskedastic. The number of lags is in line with the original suggestion of Newey and West (1987):
$floor(4/(T/100)^{2/9})$ where T is the number of observations.

R^2 of the regression). Significance levels for β and the ΔR^2s are based on a bootstrap similar to Mark (1995). We fit univariate time-series models to the data for bond volatility and macroeconomic uncertainty. Subsequently, we generate 10,000 artificial samples by drawing innovations from a distribution with similar variance as the error term from the time-series model. In each of the 10,000 runs, we regress the simulated bond volatility on the simulated macroeconomic uncertainty. The parameter estimates, Newey-West *t*-values and ΔR^2s from all runs form the bootstrap distributions under the null hypothesis that bond volatility is unrelated to macroeconomic uncertainty. For macroeconomic volatility, the procedure is slightly different. In each run, we simulate macroeconomic growth, rather than volatility, and construct the volatility measure according to (4). Hence, the *t*-values and ΔR^2s take into account that macroeconomic volatility is constructed in a two-step procedure. The critical values are substantially different from asymptotic statistics, which illustrates the importance of this correction. Further details are available from the authors.

Table 4 shows the results for the first quarter and Table 5 for the fourth quarter. The tables shows that uncertainty about future monetary policy has the strongest contemporaneous relationship with bond volatility. All parameter estimates are significantly different from zero and the parameter estimates are higher than for the other variables. In moving from longer to shorter maturities, the variation explained by monetary policy uncertainty increases from 13% (U1) - 14% (U4) for 30-year bonds to 37% (U1) - 35% (U4) for one-year bonds. One should keep in mind that this is the variation explained after the influence of lagged bond market volatility and the dummy is accounted for. Other macroeconomic uncertainty measures are also significant, but less consistently so. Table 4 and 5 also show that the contemporaneous relation between bond volatility and macroeconomic volatility is rather weak. This confirms earlier volatility studies (see Schwert, 1989 and David and Veronesi, 2004). Our bootstrapped critical values are substantially higher than the asymptotic ones. Taking the 30-year bond volatility as an example, the *t*-values for V4 CPI (2.12) and U4 IP (2.05) are significant at the 10% level only. Taking the small sample bias and the persistence of the variables into account hence makes a difference.

3.2 Uncertainty versus volatility

We next explicitly contrast the abilities of macroeconomic volatility and macroeconomic uncertainty with each other using the following regression:

$$(6) \qquad \sigma_{maturity\,j,t} = \alpha + \beta_{uncert.}\sigma_t^{Y,uncert.} + \beta_{vol.}\sigma_t^{Y,vol.} + \gamma\sigma_{maturity\,j,t-1} + \delta D_{MPolicy,t} + \varepsilon_t,$$

where $\sigma_{maturity\ j,t}$ is bond volatility in quarter t and $\sigma_t^{Y,uncert}$ and $\sigma_t^{Y,vol}$ are respectively macroeconomic uncertainty and volatility for variable Y in quarter t. The estimated coefficients are denoted β_{uncert}, β_{vol}, γ and δ; ε_t is the error term. As before, $D_{MPolicy,t}$ is the dummy for the shift in monetary policy. Estimation results on the constant term, lagged bond market volatility and the dummy are not reported.

When both measures are included in the regression, the uncertainty measure usually outperforms the volatility measure in explaining bond volatility, see Table 6 for the first quarter and Table 7 for the fourth quarter. First, parameter estimates for macroeconomic uncertainty are higher than the parameter estimates for macroeconomic volatility. Since both measures are normalized, the magnitude of the parameters can be compared directly. Second, the macroeconomic uncertainty variable is often significant, whereas the macroeconomic volatility variable is not. This suggests that the impact of macroeconomic volatility disappears when macroeconomic uncertainty is taken into account. Tables 4 and 5 show that T-bill volatility is one of the few significant volatility measures, yet its significance disappears when monetary policy uncertainty is included. Re-running the analysis with calendar quarters instead of SPF deadline matched quarters leads to the same conclusions.

3.3 Monetary policy uncertainty

We next address the question whether there is a role for other macroeconomic variables once monetary policy uncertainty is accounted for. For each macroeconomic uncertainty variable, we run the regression:

(7) $$\sigma_{maturity\,j,t} = \alpha + \phi\sigma_t^{MPolicy} + \beta\sigma_t^{Y\,orth.} + \gamma\sigma_{maturity\,j,t-1} + \varepsilon_t\,,$$

where $\sigma_{maturity\,j,t}$ is bond volatility with maturity j = 1, 5, 10 and 30 years at time *t*, $\sigma_t^{MPolicy}$ denotes monetary policy uncertainty and ε_t is the error term. Since the sample for the monetary policy uncertainty variable starts after the change in the Fed's operating procedures, the model does not include the shift-in-monetary-policy dummy The new term ($\sigma_t^{Y\,orth.}$) denotes the uncertainty about macroeconomic variable *Y*, orthogonalized with respect to monetary policy uncertainty. The orthogonalization allows us to test whether any residual macroeconomic uncertainty (once monetary policy uncertainty is accounted for) explains bond volatility.

Table 8 (9) reports estimates of ϕ and β, as well as *t*-values and ΔR^2s with significance levels derived using the bootstrap for quarter one (four). Estimates and t-values of α and γ are not reported. The findings indicate that monetary policy uncertainty dwarfs the significance of other macroeconomic uncertainty variables. Parameter estimates for monetary policy uncertainty are substantially higher than for the other variables. Once monetary policy uncertainty is included, few variables add significantly to the relationship with bond volatility. This conclusion stays intact if we do not orthogonalize. In addition to the univariate analysis, we also run a regression of Treasury bond volatility on a constant, lagged bond volatility, monetary policy uncertainty and all other orthogonalized uncertainty variables. We estimate the following:

(8) $$\sigma_{maturity\,j,t} = \alpha + \phi\sigma_t^{MPolicy} + \sum_Y \beta^Y \sigma_t^{Y\,orth.} + \gamma\sigma_{maturity\,j,t-1} + \varepsilon_t$$

The variables are as in equation (7), but the equation now estimates all other orthogonalized macroeconomic uncertainty variables simultaneously. Table 10 reinforces the conclusions from Tables 8 and 9: virtually no other uncertainty variable adds to explaining bond volatility once lagged bond volatility and uncertainty about the monetary policy rate are taken into account. The only exceptions are uncertainty about the deflator and unemployment, but only for the one-year maturity in combination with the four-quarter horizon. Some of the other variables are also significantly different from zero, but these have the incorrect (negative) sign. Apparently, once monetary policy uncertainty has been taken into account, any residual uncertainty about these macroeconomic variables reduces Treasury bond volatility. The incremental explanatory power of all regressions is significantly different from zero. We also test for joint insignificance of the non-monetary-policy uncertainty variables with a likelihood ratio test, $H_0 : \sum_Y \beta^Y = 0$. Bootstrapped significance levels indicate that this hypothesis is only rejected for the fourth quarter with the five-year maturity and both horizons for the one-year maturity. Apart from the fourth quarter for the one-year maturity, the rejection is caused by significant variables that have an incorrect sign.

Apparently, uncertainty about the future course of monetary policy summarizes most of the relevant macroeconomic information. It is striking to see that neither uncertainty about inflation, nor economic activity adds substantially once monetary policy uncertainty has been taken into account. If the reaction of the central bank to inflation and economic activity imbalances would be inadequate, these factors could become distinct pieces of information relevant to bond holders.

3.4 Granger causality

The previous sections report a strong contemporaneous link between monetary policy uncertainty and bond volatility. However, this does not imply causality. In Veronesi's (1999) model, causality runs from macroeconomic uncertainty to asset volatility. Yet we cannot exclude the possibility of reverse causality in our empirical work, where the dispersion between the monetary policy forecasts by SPF participants is influenced by current bond volatility. To address this issue, we conduct Granger causality tests. For each maturity we estimate unrestricted first-order bivariate vector autoregressions of the form:

(9) $$Z_{t+1} = AZ_t + BX_t + \varepsilon_{t+1},$$

where Z_t contains bond volatility and macroeconomic uncertainty at time t and X_t contains exogenous variables (in this case, the dummy for the shift in monetary policy and a constant). A and B are matrices with estimated parameters and ε_t is the error term. Table 11 reports F-values and bootstrapped significance levels for all bond maturities. The results provide strong evidence that causality runs from monetary policy uncertainty to bond volatility, rather than the other way around. This is consistent both with theory and intuition. In the model of Veronesi (1999), for example, market participants react stronger to new information during times when uncertainty about fundamentals is high. This, in turn, translates into higher volatility when uncertainty is high.

4. Robustness tests

4.1 Yield changes versus returns

This section evaluates the robustness of our main conclusions when we calculate volatility based on changes in bond yields, rather than returns. The correlations between the volatility series are very high: 0.855 (30-year), 0.969 (10-year), 0.990 (five-year), and 0.999 (one-year). We re-run all tests from section 3 with the new volatility measure (i.e. the analysis from section

3.2, where we explicitly contrast macroeconomic uncertainty with macroeconomic volatility and the Granger causality tests from section 3.4). We briefly summarize the conclusions, but the tables are available upon request.

Re-running the analysis summarized in Table 6 with bond yield changes instead does not change the conclusion. With only a handful of exceptions, macroeconomic uncertainty dominates macroeconomic volatility. Working with the volatility of yield changes even leads to somewhat more pronounced results. Especially for monetary policy uncertainty, coefficients are high and significant compared to both the previous results and the other variables. More uncertainty about the monetary policy rate is thus related to higher (yield) volatility in the Treasury bond market for all maturities.

We also analyze whether there is a role for other macroeconomic uncertainty variables once uncertainty about the monetary policy rate is accounted for. Similar to Table 10, the multiple regression equation contains all other (orthogonalized) macroeconomic uncertainty variables. Again, the results are very similar under the new definition of bond volatility. Once monetary policy is taken into account, uncertainty about additional macroeconomic uncertainty variables is not significant. Likelihood ratio tests show that joint insignificance of all other uncertainty variables cannot be rejected, except for the one-year maturity. This rejection, however, is attributable to the negative but statistically significant influence of CPI uncertainty. Granger causality tests reinforce the original conclusion from section 3.4: causality runs from TBILL uncertainty to Treasury bond volatility rather than the vice versa.

4.2 A different measure of macroeconomic volatility

In section 2.3, we follow the approach of Bansal, Khatchatrian and Yaron (2005) in constructing our measure of macroeconomic volatility. To assess whether the conclusions are driven by our specific choice for macroeconomic volatility, we use an alternative AR(1) – GARCH(1,1)-based volatility measure. We estimate:

(10) $Y_t = c + \gamma Y_{t-1} + \varepsilon_t$

(11) $E(\varepsilon_t^2 \mid \Omega_{t-1}) = h_t$

(12) $h_t = \omega + \alpha \varepsilon_t^2 + \beta h_{t-1}$

The mean process for macroeconomic series Y_t contains a constant and an AR-term. The variance, conditional on the information set at $t-1$, is time-varying and follows a standard GARCH(1,1) process. We take the square root of $\hat{h}_t$ as our alternative measure for macroeconomic volatility. The alternative macroeconomic volatility measures are strongly related: the average correlation of the GARCH-based measures is 0.24 for V1 and 0.68 for V4.

Although the GARCH-based macroeconomic volatility measures perform slightly better, none of our main conclusions is affected. Indeed, when explicitly contrasted in the form of the "horse-race" regression of section 3.2, macroeconomic uncertainty still dominates the new macroeconomic volatility measure in most cases. Over all maturities and all macroeconomic variables, the mean t-value of the uncertainty variables is 2.57 in the horse-race of Table 6 (first quarter). The average t-value of the V1 variables is 0.40. When Q1 macroeconomic volatility is replaced by the GARCH-based volatility measure and contrasted with Q1 uncertainty, the average t-value for the uncertainty variables changes to 2.49 and 0.66 for the volatility variables. At the fourth quarter (cf. Table 7), results are also very similar. The average t-value of the uncertainty variables changes from 2.34 to 2.09 and the t-value of the volatility measures increases slightly from 0.80 to 1.12, on average. Since the conclusions are similar to the GARCH-based volatility measure, we do not report these results in detail.

5. Conclusions

We study the fundamental determinants of U.S. Treasury bond volatility over 1969 – 2005. There is a strong link between dispersion-based uncertainty and bond market volatility. This link is much stronger than for the time-series measures of macroeconomic volatility typically used in the literature. In addition, we show that dispersion-based uncertainty about the monetary policy rate dwarfs the uncertainty about other macroeconomic variables. This finding adds to findings of the relevance of monetary policy for bond market volatility in the announcements literature. We also show that causality clearly runs one way: uncertainty about the monetary policy rate causes bond market volatility, rather than vice versa. These conclusions are robust to changes in the way we construct macroeconomic volatility and do not change when we calculate the volatility of Treasury bonds using yield changes rather than returns. From an econometric perspective, we bootstrap critical values of our tests to account for small sample bias and the generated nature of some of the variables. Although this has not been done in the literature, it turns out to be important as bootstrapped critical values are substantially higher than their asymptotic counterparts.

The dominance of uncertainty about the future course of monetary policy leads to an interesting conclusion. Treasury bond volatility is important for policy makers. Rudebusch (2001), for example, incorporates Treasury bond market volatility in the reaction function of the Fed. We show that uncertainty about the monetary policy rate is the single most important determinant of bond market volatility. This is a variable over which the Fed has at least some direct control. By designing and further developing a careful strategy to guide and manage financial markets' expectations, the Fed may reduce uncertainty about the policy rate and hence reduce the volatility in the Treasury bond market.

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Table 1
Summary statistics for bond volatilities

For 30-year maturity the sample period is 1977Q1 – 2005Q4, for the maturities 10-year, five-year and one-year the sample period is 1969Q1 – 2005Q4. ρ_1 is the first order autocorrelation coefficient.

Maturity	Mean	Median	Maximum	Minimum	Std. dev.	ρ_1
30-year	5.39	5.21	11.19	0.97	1.92	0.67
10	3.41	3.13	9.72	0.80	1.52	0.71
5	2.30	2.05	6.75	0.72	1.05	0.72
1	0.60	0.48	2.25	0.21	0.43	0.85

Table 2
List of variables

Codes, descriptions and start dates for the macroeconomic variables are from the SPF.

Code	Description	Start date
NGDP	Nominal GDP (GNP prior to 1992)	1968-Q4
PGDP	GDP price index (prior to '96 GDP implicit price deflator, prior to '92 GNP deflator)	1968-Q4
UN	Civilian Unemployment rate	1968-Q4
IP	Industrial production index	1968-Q4
CPI	Consumer price index, %-change from prev. Quarter	1981-Q3
TBILL	3-month Treasury bill rate	1981-Q3
RGDP	GDP in constant dollars (GNP prior to 1992)	1981-Q3

Table 3
Summary statistics

U1 (U4) is SPF uncertainty for quarter 1 (4) and V1 (V4) is time-series volatility for quarter 1 (4) generated as described in the text. The sample period is 1969Q1 – 2005Q4 for NGDP, PGDP, UN and IP and 1981Q3 – 2005Q4 for CPI, TBILL and RGDP. ρ_1 is the first order autocorrelation coefficient.

	Variable	Mean	Median	Maximum	Minimum	Std. dev.	ρ_1
U1	NGDP	0.74	0.64	2.50	0.28	0.37	0.59
	PGDP	0.48	0.40	2.17	0.14	0.28	0.55
	UN	0.22	0.19	0.53	0.10	0.09	0.72
	IP	1.18	1.10	2.87	0.44	0.48	0.67
	CPI	0.75	0.59	2.74	0.37	0.42	0.73
	TBILL	0.36	0.30	1.87	0.12	0.27	0.79
	RGDP	0.49	0.39	1.52	0.23	0.26	0.75
U4	NGDP	1.65	1.56	3.86	0.62	0.76	0.75
	PGDP	1.09	0.87	6.35	0.43	0.73	0.46
	UN	0.39	0.36	0.89	0.18	0.14	0.83
	IP	2.39	2.22	4.83	0.89	0.94	0.71
	CPI	0.78	0.62	2.83	0.35	0.43	0.73
	TBILL	0.68	0.58	2.31	0.31	0.36	0.83
	RGDP	0.98	0.80	2.28	0.48	0.44	0.59
V1	NGDP	-0.93	-0.66	1.40	-5.22	1.19	0.19
	PGDP	-1.99	-1.83	0.01	-8.10	1.24	-0.02
	UN	-1.89	-1.76	0.52	-4.99	1.01	0.19
	IP	-0.63	-0.45	1.59	-4.75	1.19	0.08
	CPI	-1.72	-1.40	0.28	-7.93	1.37	0.17
	TBILL	-1.37	-1.20	1.06	-4.75	1.15	0.33
	RGDP	-1.36	-1.07	0.75	-6.22	1.27	0.19
V4	NGDP	0.79	0.76	2.06	-0.52	0.56	0.86
	PGDP	-0.23	-0.20	0.90	-1.47	0.49	0.82
	UN	-0.26	-0.29	1.30	-1.42	0.58	0.83
	IP	1.10	1.12	2.61	-0.17	0.60	0.87
	CPI	0.05	0.04	1.08	-1.42	0.61	0.86
	TBILL	0.30	0.29	1.97	-2.07	0.80	0.90
	RGDP	0.42	0.36	1.90	-1.40	0.62	0.81

Table 4
Explaining bond volatility: first quarter

The table reports coefficient estimates, Newey-West (1987) t-values and incremental R^2s (ΔR^2) for regressions of bond volatility on macroeconomic uncertainty (U1) or volatility (V1). For NGDP, PGDP, UN and IP the sample period is 1969Q2 – 2005Q4 (1977Q2 – 2005Q4 for 30-year), for CPI, TBILL and RGDP the sample period is 1981Q4 – 2005Q4.

		NGDP	PGDP	UN	IN	CPI	TBILL	RGDP
30-year maturity								
U1	β	0.39	0.39	0.47	0.42	0.36	0.50	0.33
	t	1.64	2.80 **	2.38 **	2.41 **	2.22 **	5.02 ***	2.08 *
	ΔR^2	0.07 ***	0.07 ***	0.09 ***	0.07 ***	0.07 ***	0.13 ***	0.06 **
V1	β	0.11	-0.15	0.06	0.41	0.17	0.37	0.16
	t	0.64	-1.20	0.44	2.96 ***	1.88 *	2.76 **	1.13
	ΔR^2	0.01	0.01	0.00	0.09 ***	0.02	0.09 ***	0.02
10-year maturity								
U1	β	0.44	0.28	0.43	0.43	0.31	0.58	0.43
	t	2.15 **	2.45 **	3.08 ***	3.12 ***	2.42 **	8.24 ***	3.22 ***
	ΔR^2	0.13 ***	0.05 ***	0.13 ***	0.11 ***	0.08 ***	0.26 ***	0.15 ***
V1	β	0.03	-0.04	0.07	0.33	0.09	0.32	0.18
	t	0.27	-0.40	0.77	3.04 ***	1.31	2.64 **	1.56
	ΔR^2	0.00	0.00	0.00	0.09 ***	0.01	0.11 ***	0.03 *
Five-year maturity								
U1	β	0.29	0.18	0.28	0.27	0.17	0.44	0.33
	t	1.91 *	2.23 **	2.42 **	2.51 **	2.20 **	7.19 ***	3.03 ***
	ΔR^2	0.11 ***	0.04 **	0.11 ***	0.09 ***	0.05 **	0.29 ***	0.17 ***
V1	β	0.02	-0.02	-0.01	0.16	0.04	0.22	0.10
	t	0.31	-0.40	-0.09	2.26 **	0.80	2.68 **	1.30
	ΔR^2	0.00	0.00	0.00	0.05 **	0.00	0.12 ***	0.02
One-year maturity								
U1	β	0.07	0.04	0.08	0.07	0.02	0.19	0.13
	t	1.33	1.78 *	1.73 *	1.50	1.30	5.69 ***	2.59 **
	ΔR^2	0.05 ***	0.02 *	0.08 ***	0.04 ***	0.01	0.37 ***	0.20 ***
V1	β	0.01	0.02	0.00	0.04	0.00	0.06	0.03
	t	0.31	1.11	-0.22	1.48	0.01	2.34 **	1.63
	ΔR^2	0.00	0.01	0.00	0.02 *	0.00	0.09 ***	0.03 *

***, ** and * indicate statistical significance at the 1%, 5% and 10% level based on a bootstrap.

Table 5
Explaining bond volatility: fourth quarter

The table reports coefficient estimates, Newey-West (1987) t-values and incremental R^2s (ΔR^2) for regressions of bond volatility on macroeconomic uncertainty (U4) or volatility (V4). For NGDP, PGDP, UN and IP the sample period is 1969Q2 – 2005Q4 (1977Q2 – 2005Q4 for 30-year), for CPI, TBILL and RGDP the sample period is 1981Q4 – 2005Q4.

		NGDP	PGDP	UN	IN	CPI	TBILL	RGDP
30-year maturity								
U4	β	0.32	0.33	0.37	0.27	0.18	0.54	0.21
	t	1.51	1.71	3.00 ***	2.05 *	0.93	3.89 ***	1.28
	ΔR^2	0.04 **	0.04 **	0.07 ***	0.03 *	0.02	0.14 ***	0.02
V4	β	0.23	0.10	0.10	0.30	0.26	0.16	0.07
	t	1.21	0.69	0.72	1.53	2.12 *	1.36	0.43
	ΔR^2	0.02 *	0.00	0.00	0.04 **	0.04 **	0.02	0.00
10-year maturity								
U4	β	0.51	0.26	0.43	0.33	0.22	0.61	0.29
	t	2.91 ***	1.75 *	4.31 ***	3.22 ***	1.44	6.02 ***	2.23 **
	ΔR^2	0.14 ***	0.04 **	0.13 ***	0.07 ***	0.04 **	0.27 ***	0.08 ***
V4	β	0.21	0.12	0.14	0.34	0.14	0.28	0.14
	t	1.46	1.13	1.74 *	2.32 **	1.49	2.92 **	1.05
	ΔR^2	0.03 **	0.01	0.02 *	0.07 ***	0.02	0.07 ***	0.02
Five-year maturity								
U4	β	0.38	0.16	0.30	0.19	0.13	0.49	0.19
	t	3.10 ***	1.54	3.57 ***	2.45 **	1.38	6.06 ***	2.58 **
	ΔR^2	0.14 ***	0.03 **	0.12 ***	0.04 **	0.03 *	0.33 ***	0.07 ***
V4	β	0.19	0.11	0.09	0.22	0.06	0.24	0.10
	t	1.96 *	1.63	1.84 *	2.41 **	0.98	3.99 ***	1.18
	ΔR^2	0.04 ***	0.02 *	0.01	0.06 ***	0.01	0.11 ***	0.02
One-year maturity								
U4	β	0.09	0.05	0.07	0.02	0.03	0.17	0.06
	t	2.01 *	1.54	1.63	0.78	0.61	6.17 ***	3.13 ***
	ΔR^2	0.06 ***	0.03 **	0.06 ***	0.01	0.01	0.35 ***	0.07 ***
V4	β	0.06	0.04	0.02	0.05	0.01	0.06	0.04
	t	1.96 *	2.10 **	1.05	1.94 *	0.54	3.26 ***	1.46
	ΔR^2	0.03 ***	0.02 **	0.00	0.03 ***	0.00	0.08 ***	0.03 **

***, ** and * indicate statistical significance at the 1%, 5% and 10% level based on a bootstrap.

Table 6
Uncertainty versus volatility: first quarter

The table reports coefficient estimates, Newey-West (1987) t-values and incremental R^2s (ΔR^2) for regressions of bond volatility on macroeconomic uncertainty and volatility (U1 versus V1). For NGDP, PGDP, UN and IP the sample period is 1969Q2 – 2005Q4 (1977Q2 – 2005Q4 for 30-year), for CPI, TBILL and RGDP the sample period is 1981Q4 – 2005Q4.

		NGDP	PGDP	UN	IN	CPI	TBILL	RGDP
30-year maturity								
U1	β	0.38	0.40	0.50	0.30	0.33	0.39	0.31
	t	1.62	2.73 **	2.38 **	1.67	1.97 *	3.08 ***	2.11 *
V1	β	0.05	-0.16	-0.08	0.33	0.08	0.20	0.11
	t	0.34	-1.50	-0.62	2.47 **	0.83	1.55	0.85
	ΔR^2	0.07 **	0.08 ***	0.09 ***	0.13 ***	0.07 **	0.15 ***	0.07
10-year maturity								
U1	β	0.44	0.28	0.47	0.34	0.30	0.52	0.41
	t	2.18 **	2.41 **	3.22 ***	2.48 **	2.34 **	5.54 ***	3.37 ***
V1	β	-0.02	-0.02	-0.09	0.25	0.01	0.10	0.12
	t	-0.24	-0.21	-1.24	2.43 **	0.13	1.03	1.32
	ΔR^2	0.13 ***	0.05 **	0.14 ***	0.16 ***	0.08 **	0.27 ***	0.16 ***
Five-year maturity								
U1	β	0.29	0.18	0.34	0.23	0.17	0.40	0.31
	t	1.91 *	2.21 **	2.85 ***	2.08 *	2.21 **	5.17 ***	3.10 ***
V1	β	0.00	-0.01	-0.12	0.11	-0.01	0.06	0.05
	t	-0.08	-0.15	-2.09 **	1.55	-0.19	0.99	0.91
	ΔR^2	0.11 ***	0.04 **	0.14 ***	0.11 ***	0.05	0.30 ***	0.18 ***
One-year maturity								
U1	β	0.07	0.04	0.10	0.06	0.03	0.19	0.12
	t	1.33	1.90 *	1.96 *	1.28	1.34	4.62 ***	2.80 **
V1	β	0.00	0.02	-0.03	0.03	-0.01	0.01	0.03
	t	0.28	1.32	-1.54	1.04	-0.62	0.38	2.16 *
	ΔR^2	0.05 **	0.03	0.10 ***	0.05 **	0.01	0.37 ***	0.22 ***

***, ** and * indicate statistical significance at the 1%, 5% and 10% level based on a bootstrap.

Table 7

Uncertainty versus volatility: fourth quarter

The table reports coefficient estimates, Newey-West (1987) t-values and incremental R^2s (ΔR^2) for regressions of bond volatility on macroeconomic uncertainty and volatility (U4 versus V4). For NGDP, PGDP, UN and IP the sample period is 1969Q2 – 2005Q4 (1977Q2 – 2005Q4 for 30-year), for CPI, TBILL and RGDP the sample period is 1981Q4 – 2005Q4.

		NGDP	PGDP	UN	IN	CPI	TBILL	RGDP
30-year maturity								
U4	β	0.27	0.33	0.37	0.20	0.09	0.64	0.23
	t	1.24	1.70	3.28 ***	1.60	0.41	3.88 ***	1.41
V4	β	0.12	0.04	-0.02	0.24	0.23	-0.16	-0.05
	t	0.68	0.32	-0.12	1.20	1.67	-1.13	-0.34
	ΔR^2	0.05	0.04 *	0.07 **	0.05	0.04	0.15 ***	0.03
10-year maturity								
U4	β	0.48	0.25	0.41	0.26	0.19	0.61	0.29
	t	2.78 **	1.79 *	4.01 ***	2.61 **	1.12	5.41 ***	2.17 **
V4	β	0.09	0.12	0.05	0.27	0.08	-0.01	0.00
	t	0.65	1.20	0.59	1.78 *	0.80	-0.09	-0.04
	ΔR^2	0.14 ***	0.05	0.13 ***	0.10 ***	0.05	0.27 ***	0.08 **
Five-year maturity								
U4	β	0.34	0.16	0.29	0.15	0.12	0.46	0.19
	t	2.74 **	1.58	3.27 ***	1.77 *	1.16	5.17 ***	2.32 **
V4	β	0.12	0.13	0.03	0.19	0.03	0.06	0.01
	t	1.27	1.83 *	0.47	1.91 *	0.39	1.24	0.17
	ΔR^2	0.16 ***	0.06	0.12 ***	0.08 ***	0.03	0.34 ***	0.08 **
One-year maturity								
U4	β	0.08	0.05	0.07	0.02	0.02	0.16	0.06
	t	1.87 *	1.57	1.61	0.54	0.48	5.62 ***	2.69 **
V4	β	0.06	0.04	-0.00	0.05	0.00	0.02	0.02
	t	1.81 *	2.09 **	-0.00	1.65 *	0.17	1.56	0.77
	ΔR^2	0.09 ***	0.05 **	0.06 ***	0.03	0.01	0.36 ***	0.08 ***

***, ** and * indicate statistical significance at the 1%, 5% and 10% level based on a bootstrap.

Table 8

Monetary policy uncertainty versus other uncertainty (univariate): first quarter

The table reports coefficient estimates, Newey-West (1987) t-values and the incremental R^2s (ΔR^2) for regressions of bond volatility on a constant, lagged bond market volatility, U1 monetary policy uncertainty and an (orthogonalized) macroeconomic uncertainty variable (U1). Estimates for the constant and lagged bond market volatility are not shown. For all variables, the sample period is 1981Q4 – 2005Q4.

		NGDP	PGDP	UN	IN	CPI	RGDP
30-year maturity							
U1	ϕ	0.49	0.50	0.49	0.49	0.50	0.50
	t	4.99 ***	5.02 ***	5.01 ***	5.19 ***	5.06 ***	5.11 ***
	β	-0.09	0.09	-0.12	-0.12	0.01	-0.03
	t	-0.72	0.46	-0.43	-0.64	0.03	-0.18
	ΔR^2	0.13 ***	0.13 ***	0.13 ***	0.13 ***	0.13 ***	0.13 ***
10-year maturity							
U1	ϕ	0.58	0.58	0.57	0.57	0.57	0.58
	t	7.98 ***	7.79 ***	8.19 ***	8.09 ***	8.22 ***	8.04 ***
	β	0.01	0.00	-0.10	-0.04	-0.15	0.08
	t	0.11	0.02	-0.59	-0.33	-0.90	0.66
	ΔR^2	0.26 ***	0.26 ***	0.27 ***	0.26 ***	0.27 ***	0.27 ***
Five-year maturity							
U1	ϕ	0.45	0.44	0.45	0.44	0.42	0.45
	t	7.02 ***	6.70 ***	7.50 ***	7.30 ***	7.12 ***	7.14 ***
	β	0.04	0.02	0.04	0.01	-0.15	0.10
	t	0.49	0.19	0.36	0.06	-1.37	0.96
	ΔR^2	0.29 ***	0.29 ***	0.29 ***	0.29 ***	0.31 ***	0.30 ***
One-year maturity							
U1	ϕ	0.21	0.21	0.22	0.21	0.18	0.22
	t	6.29 ***	6.48 ***	8.04 ***	8.08 ***	5.35 ***	6.21 ***
	β	0.03	0.04	0.08	0.03	-0.05	0.07
	t	0.72	1.39	1.83 *	0.86	-2.25 **	1.38
	ΔR^2	0.38 ***	0.38 ***	0.41 ***	0.38 ***	0.40 ***	0.43 ***

***, ** and * indicate statistical significance at the 1%, 5% and 10% level based on a bootstrap.

Table 9

Monetary policy uncertainty versus other uncertainty (univariate): fourth quarter

The table reports coefficient estimates, Newey-West (1987) t-values and the incremental R^2s (ΔR^2) for regressions of bond volatility on a constant, lagged bond market volatility, U4 monetary policy uncertainty and an (orthogonalized) macroeconomic uncertainty variable (U4). Estimates for the constant and lagged bond market volatility are not shown. For all variables, the sample period is 1981Q4 – 2005Q4.

		NGDP		PGDP		UN		IN		CPI		RGDP	
30-year maturity													
U4	ϕ	0.53		0.54		0.54		0.54		0.55		0.54	
	t	3.75	***	3.84	***	3.83	***	3.90	***	3.74	***	3.97	***
	β	-0.40		-0.16		-0.06		-0.03		-0.30		-0.11	
	t	-2.47	**	-0.48		-0.36		-0.15		-2.03	*	-0.69	
	ΔR^2	0.18	***	0.14	***	0.14	***	0.14	***	0.16	***	0.14	***
10-year maturity													
U4	ϕ	0.60		0.61		0.61		0.61		0.60		0.61	
	t	5.83	***	6.06	***	6.28	***	5.85	***	6.04	***	6.00	***
	β	-0.14		0.06		0.11		0.10		-0.25		0.00	
	t	-1.03		0.25		0.77		0.87		-2.18	**	-0.02	
	ΔR^2	0.27	***	0.27	***	0.27	***	0.27	***	0.30	***	0.27	***
Five-year maturity													
U4	ϕ	0.48		0.51		0.51		0.49		0.47		0.49	
	t	5.75	***	5.96	***	6.24	***	5.87	***	6.51	***	6.06	***
	β	-0.03		0.15		0.16		0.05		-0.20		-0.01	
	t	-0.34		1.03		1.47		0.75		-2.51	**	-0.18	
	ΔR^2	0.33	***	0.34	***	0.35	***	0.33	***	0.37	***	0.33	***
One-year maturity													
U4	ϕ	0.19		0.22		0.23		0.18		0.16		0.18	
	t	5.56	***	7.20	***	6.23	***	5.62	***	6.35	***	6.11	***
	β	0.04		0.19		0.14		0.03		-0.04		0.03	
	t	1.33		4.02	***	2.98	***	1.33		-0.98		1.47	
	ΔR^2	0.37	***	0.48	***	0.47	***	0.36	***	0.37	***	0.36	***

***, ** and * indicate statistical significance at the 1%, 5% and 10% level based on a bootstrap.

Table 10
Monetary policy uncertainty versus other uncertainty (multiple)

The table reports coefficient estimates, Newey-West (1987) t-values and the incremental R^2s (ΔR^2) for regressions of bond volatility on a constant, lagged bond market volatility, monetary policy uncertainty and all (orthogonalized) macroeconomic uncertainty variables. Estimates for the constant and lagged bond market volatility are not shown. LR shows the likelihood ratio test statistic for joint redundancy of all orthogonalized macroeconomic uncertainty variables. The sample period is 1981Q4 – 2005Q4.

		TBILL	NGDP	PGDP	UN	IN	CPI	RGDP
30-year maturity								
U1	β	0.50	-0.13	0.26	-0.13	-0.13	0.03	0.09
	t	5.21***	-1.13	0.97	-0.37	-0.65	0.11	0.39
	ΔR^2	0.14**						
	LR	1.74						
U4	β	0.53	-0.52	0.23	0.05	0.07	-0.17	0.13
	t	3.51***	-2.02*	0.42	0.20	0.33	-0.87	0.70
	ΔR^2	0.20***						
	LR	7.03						
10-year maturity								
U1	β	0.57	0.02	0.09	-0.17	-0.03	-0.15	0.15
	t	7.14***	0.18	0.47	-0.80	-0.19	-0.82	0.87
	ΔR^2	0.29***						
	LR	2.86						
U4	β	0.61	-0.11	0.09	0.10	0.15	-0.35	0.12
	t	5.67***	-0.66	0.24	0.54	1.12	-2.36**	0.81
	ΔR^2	0.33***						
	LR	8.41						
Five-year maturity								
U1	β	0.44	0.04	0.04	0.02	-0.04	-0.17	0.10
	t	6.75***	0.42	0.37	0.17	-0.40	-1.40	0.75
	ΔR^2	0.33***						
	LR	5.43						
U4	β	0.50	0.02	0.16	0.12	0.03	-0.29	0.04
	t	6.54***	0.21	0.77	1.01	0.39	-2.89***	0.38
	ΔR^2	0.42***						
	LR	13.23**						
One-year maturity								
U1	β	0.23	0.01	0.04	0.05	-0.01	-0.07	0.05
	t	7.54***	0.59	1.73	1.54	-0.23	-2.72**	1.04
	ΔR^2	0.50***						
	LR	22.72***						
U4	β	0.23	0.01	0.16	0.08	-0.02	-0.06	0.02
	t	8.14***	0.32	3.27***	3.04***	-1.00	-1.48	0.74
	ΔR^2	0.57***						
	LR	39.53***						

***, ** and * indicate statistical significance at the 1%, 5% and 10% level based on a bootstrap.

Table 11
Granger causality tests

The table reports F-statistics for the hypothesis that bond volatility does not Granger cause TBILL uncertainty and vice versa. The F-statistics are based on bivariate first-order VARs.

Maturity:	*30 year*	*10 year*	*5 year*	*1 year*
Bond volatility does not Granger cause TBILL uncertainty				
U1	1.81	1.85	0.19	3.31
U4	1.37	2.60	1.78	0.08
TBILL uncertainty does not Granger cause bond volatility				
U1	7.05 **	19.05 ***	20.92 ***	61.26 ***
U4	3.27	12.29 ***	13.02 ***	13.53 ***

***, ** and * indicate statistical significance at the 1%, 5% and 10% level based on a bootstrap.