The Response of Tail Risk Perceptions to Unconventional Monetary Policy*

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The Response of Tail Risk Perceptions to Unconventional Monetary Policy

Abstract

We examine the impact of unconventional monetary policy (UMP) on stock market tail risks and the risks of extreme interest rate movements. We find that UMP announcements substantially reduced option-implied equity market tail risks and interest rate risks. Most of the impact derives from forward guidance rather than asset purchase announcements. Communication about the future path of policy rates thus had a strong combined effect on measures of expected volatility and risk premia in equity and fixed income markets. The reaction of equity market tail risks, in particular, points to the risk-taking channel of monetary policy, as the commitment to low funding rates may have relaxed financial intermediaries' risk-bearing constraints.

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I. Introduction

There is a widespread notion that unconventional monetary policy (UMP) actions undertaken by central banks over the past years have helped to alleviate some of the immediate downside risks to financial markets and the global economy. Thus far, however, any evidence on the impact on (expectations of) financial market risks and investors' risk attitudes has been mostly anecdotal. While the impact on the prices of main fixed income asset classes (e.g. U.S. Treasury bonds, mortgage-backed securities or corporate bonds) has been well documented, the impact of monetary policy innovations on the market assessment of downside risks is less well understood. Yet, the impact on the pricing of risks and risk-taking behavior is implicit in the theoretical "risk-taking channel" of monetary policy, (see, e.g. Borio and Zhu, 2012; Bruno and Shin, 2012). In a related vein, Brunnermeier and Sannikov (2012) posit that central bank asset purchases can provide insurance against tail events, if accompanied by clear communication and a commitment device conditional on future states of the world.

Focusing on *unconventional* policy, this paper presents quantitative evidence that UMP announcements by the Federal Reserve substantially reduced the option-implied likelihood of tail risks in the stock market. Additional insights are gleaned by comparing the response of equity market tail risks to the response of interest rate risk metrics. This is because the response of the latter reflects broader UMP transmission to bond yields and spreads, whereas the transmission to equity market tail risks is of a different nature.

We construct our risk measures from the extremes in probability densities of future price movements reflected in derivatives contracts. For stock prices, we rely on S&P500 index options. For interest rates, we rely on derivatives known as swaptions. The areas in the tails of the respective risk-neutral densities provide a gauge of market participants' views on the likelihood of a stock market crash or a large swing in interest rates. These option-implied risk measures serve as inputs into standard event study regressions to quantify UMP announcement effects on investors' assessments of adverse market states.

Our event study results show significant mitigating effects of UMP announcements on both equity market tail risks and interest rate risks. During various episodes of the global

financial crisis, market participants' expectations of extreme tail risks were highly elevated, but these tail risk assessments were substantially reduced by the Federal Reserve's policy actions. We find that the forward looking likelihood of a 20% fall in stock prices (over a one-month horizon) declined on average by 13.6% on UMP announcement days. Similarly, the likelihoods of +/-150 basis point (*bp*) shifts in 10-year rates fell by 7.0% and 3.0%, respectively.

We explore these mitigating effects of UMP announcements from various angles. We differentiate between effects of announcements containing changes to Federal Reserve's forward guidance about the future path of policy rates (FG) and news related to asset purchases only (QE). We also look at the impact on risk assessments across various horizons and for different magnitudes of extreme asset price movements. The UMP announcement effects on tail risk measures are also compared to the effects on broader volatility in equity and bond markets.

In most cases, we find that the impact of unconventional policies on tail risk derives from forward guidance rather than QE announcements. As such, forward guidance announcements reduced the probability of a 20% fall in the stock market by up to one-third. Notably, while measures of tail risks in equity markets exhibited a significant response, implied volatility, as captured by the VIX, was affected to a lesser extent. The comparable impact of UMP news on the risk of 150*bp* interest rate swings reached up to one-seventh (one-eighth) for long-term (short-term) rate risks. In addition, we find that when the FOMC began conditioning the fist rate hike on macroeconomic conditions, the sensitivity of measured interest rate risks to macroeconomic news increased.

Our findings can be interpreted in several ways. First, FG announcements may have led to a resolution of uncertainty, consistent with Birru and Figlewski (2010), who find that (conventional) announcements of new federal funds rate targets are associated with lower uncertainty implied by S&P 500 risk-neutral density. Second, the reduction in option-implied tail risk probabilities is consistent with a reduction in investor risk aversion, in line with Bekaert, Hoerova, and Duca (2013), who decompose the VIX into a measure of uncertainty and a volatility risk premium. They show that the latter can be considered as a risk aversion proxy and falls in response to accommodative (conventional) monetary policy. Finally, even

if investors are risk-neutral, such reduction in option-implied tail risk measures is consistent with a relaxation of balance sheet constraints of leveraged investors. In fact, Danielsson, Shin, and Zigrand (2010) show that the portfolio choice of risk-averse mean-variance investors is virtually equivalent to that of risk-neutral investors facing a value-at-risk (VaR) constraint. When we recast the stock market tail risk measures in terms of 99% VaR, that is, the amount of losses which will not be exceeded with a fixed probability of 1%, we find that FG announcements are associated on average with a contemporaneous boost to stock market returns of about 2% via their correlation with option-implied VaR.

The response of long-term interest rate risks measures to FG announcements, in turn, is consistent with the recently emerging empirical literature which finds that monetary policy announcements targeting the federal funds rate can affect term premia of long-term bonds (see, e.g. Bauer and Rudebusch, 2014; Hanson and Stein, 2015). That is, the effects on long-term yields of central bank communication about short-term rates (including forward guidance) appear to go beyond the expected future short rates, exerting also a combined effect on interest rate volatility expectations and risk premia.

The remainder of the paper is organized as follows. To set the stage, Section II provides a brief account of the monetary accommodation by the Federal Reserve and related empirical literature. Section III describes the construction of empirical proxies of equity market tail risk and interest rate risk extracted from derivatives prices and illustrates their behavior. Section IV presents event-study results on the impact of UMP announcements. This section also presence evidence on the persistence of announcement effects and discusses them in the context of known transmission channels. Section V concludes.

II. Unconventional monetary policy transmission

Since taking the target federal funds rate to 0-25 basis points (*bp*) in December 2008, the Federal Reserve had been employing large scale asset purchases or quantitative easing (QE) and forward guidance (FG) to keep long-term real interest rates low and broader financial conditions more accommodative. Extensive empirical work that documents the impact of

QE on long-term bond yields and asset prices includes Gagnon, Raskin, Remache, and Sack (2011); Krishnamurthy and Vissing-Jorgensen (2011); Wright (2012); D'Amico and King (2013); Woodford (2012); Christensen and Rudebusch (2012); Bauer and Rudebusch (2014).

These studies broadly find supporting evidence for the portfolio rebalancing and signalling channel of QE transmission. According to the former, investors with preferences for bonds with specific maturity or safety characteristics ("preferred habitat investors") are induced to shift into investment grade corporate bonds and similar assets when the central bank acts as a large buyer of Treasury bonds. This in turn may bring down yields primarily by compressing the term premium. According to the signalling channel, asset purchases (and their announcements) can signal commitment to monetary stimulus, with the transmission mostly attributed to lower expected path of future short-term rates.

Several recent studies find evidence that monetary policy induced changes to expected short rates are also associated with changes in term premia of long-term rates. Bauer and Rudebusch (2014) find that policy induced changes in future risk-neutral rates during the 2001 to 2003 period correlated with a fall in the 10-year term premium. Looking at the 1999 to February 2012 period (excluding five QE announcements), Hanson and Stein (2015) show that the effects of monetary policy shocks on distant forward rates are transmitted via changes in the term premia rather than expected future short rates. Related studies that look at monetary policy effects on real borrowing costs also document evidence of transmission via term premia reacting to policy shifts (see, e.g. Gertler and Karadi, 2015; Gilchrist, Lopez-Salido, and Zakrajsek, 2015).

Hence, the findings of these studies suggest that forward guidance, which, unlike QE, works only via the signalling channel, could have had substantial impact on volatility expectations and risk premia of long-term rates. In line with this, Swanson and Williams (2014) find that FOMC calendar-based forward guidance reduced the volatility (sensitivity to news) of medium- and longer-term interest rates even when short-term rates were stuck at the zero lower bound.

Yet other studies have looked at the broader transmission of conventional and unconventional monetary policy via financial sector risk-taking. Empirical studies of conventional mon-

etary policy transmission which point into a similar direction as our work include Bernanke and Kuttner (2005), who find an empirical link between news about the federal funds rate target and stock market returns, Birru and Figlewski (2010), who study changes in the S&P500 risk-neutral distribution around FOMC announcement days to find that announcements of new federal funds rate targets are associated with greater resolution of uncertainty compared to ordinary days, and Bekaert, Hoerova, and Duca (2013), who decompose the VIX to test the hypothesis that expansionary conventional monetary policy can dampen investor risk aversion. Examining the impact of unconventional policy measures, Gilchrist and Zakrajsek (2013) include financial sector CDS spreads in their event study to account for the effects of Federal Reserve policies on the risk bearing capacity of financial intermediaries. Chodorow-Reich (2014), in turn, evaluates UMP announcement effects on debt instruments issued by banks and life insurance companies, as well as several performance metrics of money market funds (MMFs).[1]

These studies are most related to our paper in that they assess the effects of monetary policy going beyond the immediate impact on the yield curve. Like our work, the motivation of this recent set of studies is to identify the broader policy impact, particularly on market participants' attitudes towards risk.

III. Measuring tail risk via options

Our baseline tail risk measure captures the forward-looking likelihood of "tail events" embedded in derivatives prices. We rely on standard methods to recover the risk-neutral probability density (RNPD) of the asset price distribution. Characterising the full distribution of anticipated price movements sheds light on how investors evaluated the likelihood of adverse market states and how such assessments changed over time. The option-implied probability density functions not only provides a useful gauge of the perceived likelihood of asset price movements during the life of the option, but also reflect investors' attitude towards risk. In the following, we briefly sketch the construction of our option-implied tail risk measures for

[1]Subsequent to our initial work, Roache and Rousset (2013) independently look at the effects of UMP announcements on 5th and 95th percentiles of risk-neutral densities from exchange rate, an equity index, and commodities options.

U.S. equity prices as well as measures of interest rate risks.

A. Equity market

We construct the risk-neutral density for the U.S. equity market as follows. First, we obtain market quotes of implied volatilities (IVs) for S&P500 index options for different maturities. Our sample of options data spans from 01/01/2008 to 05/30/2014 and is obtained from MorganMarkets, covering up to 17 strike prices (K); moneyness (K/S) of the quoted option prices ranges between 50% to 130% of the current spot price S. Hence, the support of our options data covers fairly extreme market states.[2]

The basic idea of obtaining implied densities draws on the seminal work by Breeden and Litzenberger (1978) who show that the second derivative of the price of a call with respect to the strike is equivalent to the risk-neutral probability density. We first filter the option quotes and eliminate obvious outliers. For a given day and (constant) maturity, we then fit a smooth curve through the IVs across different strikes using an interpolation technique. To fit the volatility "smile" we rely on a 5th order spline with three knots, which gives enough flexibility to accommodate the shape of the smile (see, e.g. Figlewski, 2009; Malz, 2014, for a discussion of various interpolation techniques). We then extrapolate the IVs beyond the support of the strike prices via the popular method of constant IV extrapolation (also see Malz, 2014). The next step is to map the IVs into call prices using the Black-Scholes formula. The second derivative of the call price can be easily numerically approximated for a dense grid of strike prices.[3] In this way, for a given maturity (e.g. 1-month) and a particular day of the sample, we obtain the RNPD based on the information embedded in options with different strikes.

[2]The panel of the option quotes is unbalanced, however, i.e. not always are option quotes available for the full range of strikes. On average, we observe 15 strikes for a given day in our sample.

[3]We set the step size in the grid to 0.025 as a fraction of the current S&P500 index level.

B. *Interest rates*

We also investigate the impact of the Federal Reserve's policies on market-implied expectations of future interest rate movements. As in the case of equities, we obtain pricing information on interest rate derivatives via MorganMarkets. The sample spans from 01/01/2008 to 05/30/2014. We rely on swaptions, a class of interest rate derivatives, giving the holder the right (but not the obligation) at the date of expiry to enter into an interest rate swap at a pre-arranged fixed rate. Swaptions are a useful class of interest rate derivatives to infer market-based expectations of future interest rate movements across different maturities and over various horizons (see, e.g. Trolle and Schwartz, 2014). We primarily focus on swaptions with a two-year expiry and a 10-year swap tenor to extract market expectations of future movements in long-term interest rates. These interest rate derivatives can be interpreted as options on the 10-year swap rate two-years from now.

The basic principle to recover the RNPD is similar to the case of equities. Our swaptions data cover a smaller set of strikes (+100bp, -50bp, at-the-money (ATM), +50bp, +100bp), but this coverage is fairly complete for swaptions with maturities of two-years and beyond. When fitting the smile, we rely on the parameter restrictions implied by a standard stochastic volatility model for interest rates (Hagan, Kumar, Lesniewski, and Woodward, 2002). The fitted RNPDs provide a market view of the distribution of 10-year swap rates in n-years time.[4] As in the case of equity market RNPDs, it is important to note that these probabilities also reflect investors' risk preferences and not just expectations of future interest rates.

C. *Illustration*

We rely on the shape of the risk-neutral densities to construct a measure that captures the evolution of market expectations of extreme (downside) movements in asset prices. Each day we estimate the area under the RNPD for a given return threshold to obtain a daily time-series capturing how the risk assessments were embedded in options evolved over time. This measure then serves as input in event study regressions in Section IV.

[4]When estimating the RNPD via a numerical approximation of the second-order derivative, we set the increments in the grid of strike prices to 0.5 basis points.

Stock market tail risks. To gain better intuition, examples for U.S. equity market RNPDs for selected days are shown in Figure 1. One major repricing occurred on 16 December 2008 when the FOMC lowered the target federal funds rate to a range between 0-25*bp*. Together with expectations that the first phase of the Federal Reserve's large-scale asset purchase programme (LSAP-1) would include Treasury purchases in addition to mortgage backed securities (MBS), this policy announcement led to a rightward shift in the RNPD and a further reduction in the tail mass (especially in the left tail) over the following 10 business days (Figure 1, top left panel). Similarly, the 9 August 2011 FOMC minutes release introducing time-contingent forward guidance (low federal funds rate at least until mid-2013) triggered an immediate reduction in the left skew of the forward-looking probability density. In the same vein, the January 2012 release of FOMC minutes and Chairman Bernanke's Jackson Hole speech in August 2012, both led to a considerable reduction of the probability mass in the left tail of the distribution (Figure 1, bottom left and right panels).

Figure 1 about here

Focusing on the likelihood of a 20% drop in the S&P500 over a 1-and 3-month period, Figure 2 illustrates how these stock market tail risk measures evolved over time. They peaked following the Lehman collapse in October 2008, with the risk-neutral likelihood of a 20% stock market drop exceeding 10% and 20% for 1- and 3-month horizons respectively. The perceived crash risk then began to decline as the Federal Reserve announced the plans to purchase agency debt and MBS on 25 November 2008 (LSAP-1) and cut the federal funds rate target to the 0-25*bp* range on 16 December 2008. The decline continued as LSAP-1 was phased out beginning August 2009. Stock market tail risks then spiked again in 2010, when the European sovereign debt crisis began unravelling. In response to a deteriorating macroeconomic outlook, the Federal Reserve announced LSAP-2. Much of the subsequent decline in stock market tail risk measures is associated with LSAP-2 announcements.

Figure 2 about here

As tail risks rose again with the escalation of the European sovereign debt crisis in August 2011, the FOMC downgraded its growth outlook and switched to the calendar-based forward

guidance, stating that the policy rate will be kept low at least until mid-2013. Perceived tail risks declined subsequently, particularly visibly following the 25 January and 13 September 2012 announcements, when the FOMC extended rate guidance first through 2014 and then until mid-2015. Our tail risk measures declined further subsequently, but there was also a divergence between near-term and medium-term risk perceptions. As such, while the likelihood of a 20% stock market drop over a 1-month horizon fell to 0.04% by January 2013, the likelihood of a 20% drop over a 3-month horizon was much higher, fluctuating at round 2%.

Interest rate risks. Announcements of the Federal Reserves's policy innovations also triggered considerable shifts in the implied probability distribution of 10-year rates two-years ahead, as shown in Figure 3. A leftward shift in the RNPDs around the 16 December 2008 announcement, for instance, indicates that market participants significantly lowered their expectations of a rise in long-term rates. Hence, the entire shape of the distributions of future long-term rates quickly reflected the news about the future monetary policy path. The 9 August 2011 announcement effects were concentrated in the tail at first, then a leftward shift in the entire distribution of subsequent days. The 31 August 2012 speech by Chairman Bernanke also induced a leftward shift in the implied density, but the effects appear to have dissipated after a 10-day period.

Figure 3 about here

Figure 4 shows the time-series of implied probabilities of a 150*bp* rise and of a 150*bp* fall in 10-year rates, respectively.[5] Focusing on the risk-neutral probability of a 150*bp rate rise*, we observe a peak in the aftermath of Lehman collapse, followed by a drop subsequent to LSAP-1 introduction. The LSAP-2 and MEP announcements were also followed by declines in measured interest rate risks. A rise of interest rate risk during the "taper tantrum" is in

[5]A notable difference with equity market tail risk measures is that the interest rate risk measures tend to fluctuate around higher long-run levels. While during the peak of the crisis the probabilities associated with our definitions of rare events in both equity returns and interest rates ranged between 20% and 25%, the non-crisis level of measured interest rate risks is significantly higher compared to equities. This suggest that, even though we focus on interest rate shocks which would take us into the extremes of the implied distribution, they still by-and-large reflect "Gaussian" shocks.

line with bond market turmoil and heightened volatility observed in late May and June 2013, as investors brought forward their expectations of future rate hikes.

Figure 4 about here

The odds of a 150*bp rate fall*, by contrast, increased significantly by mid-2009. This happened not during the initial set of LSAP-1 announcements, but during LSAP-1 implementation phase. Following the announcements and implementation of maturity extension programme (MEP) the probability of a further 150*bp* drop in 10-year yields fell rapidly to almost zero, indicating that investors by and large perceived a further drop in long-term yields to be highly unlikely. The interest rate risk metric then bounced back again during the "taper tantrum" in mid-2013 (Sub-section E looks at this episode in more detail).

IV. Announcement effects

In this section, we study how investors' expectations of future stock market outcomes and interest rate movements responded to the Fed's UMP announcements. First, we present a brief overview of UMP announcements and changes in our risk measures around these dates. Second, we quantify the effects of UMP announcements from November 2008 through September 2012 on equity market tail risk and interest rate risk measures using standard event-study regressions. Third, we expand the sample to assess how expectations of extreme equity and interest rate movements reacted to news about the scaling back of UMP measures beginning from May 2013.

A. Changes around individual UMP announcements

Table I lists the UMP announcement dates along with a brief summary of the news content of each announcement and the associated policy phase. These are the first two large-scale asset purchase programs (LSAP-1 and LSAP-2), the maturity extension program (MEP), and the open-ended program of monthly purchases (LSAP-3). In addition, we take into account whether an announcement contained modifications to the Federal Reserve's forward guidance

(FG) about the federal funds rate target. The bottom of Table I also lists dates associated with the "taper tantrum" in mid-2013, when investor uncertainty about the Federal Reserve's policy stance rose sharply following several official statements (see, e.g. Feroli, Kashyap, Schoenholtz, and Shin, 2014). Table I also lists events associated with the actual slowing of the pace of purchases beginning December 2014. These later events are included in the expanded sample event-study regressions discussed in Sub-section IV.E.

Table I about here

Table II shows the changes in the tail event probabilities around each of the UMP announcements. For each tail risk measure, we report *absolute changes* in the left-hand columns and *relative changes* (expressed in %) in the right-hand columns.

Table II about here

The table shows that most UMP announcement days were associated with marked declines in perceived tail risks. For 12 out of 18 expansionary announcements we observe a drop in the likelihood of a near-term 20% stock market crash and a decline in the ex-ante likelihoods of a 150*bp* rise in 10-year rates. One notable exception is 1 December 2008, when most tail risk gauges moved up quite significantly. This was when the NBER officially confirmed that the U.S. economy had been in a recession since December 2007. On the same day, the S&P500 fell by about 8% despite the LSAP-1 related announcement. Still, in terms of *relative magnitudes,* the rise in measured tail risks on this date is significantly lower than the decreases associated with a number of other announcements, most notably 9 August 2011 and 13 September 2012, when the probability of a 20% decline in S&P500 dropped by 72% and 51% relative to their pre-announcement levels. Overall, these initial observations point to a sizeable economic impact of the Federal Reserve's policy announcements on market participants' assessments of the likelihood of adverse outcomes.

B. Baseline event-study regressions

In the following, we conduct a more formal analysis to quantitatively assess how tail risk responded to UMP policy announcements via standard event-study regressions:

$$\Delta RISK^{\tau}_{t,n} = \beta A^{UMP}_{t} + \sum_{j=1}^{J} \gamma_j s_{j,t} + \epsilon_t, \tag{1}$$

where $RISK^{\tau}_{t,n}$ refers to either equity tail risks or interest rate risks, and Δ is the log-difference operator. For equities, our baseline is the option-implied probability of a $\tau = -20\%$ return on the S&P500 during a period of n=1 month. For interest rates, our baseline results are obtained with swaption-implied probabilities of a τ=+/- 150 *bp* change in 10-year rates over a period of n=2-years. A_t is a dummy variable indicating days with UMP announcements.

We also control for regular macroeconomic announcements, with $s_{j,t}$ denoting the standardized surprise component of each announcement of type j, similar to Kitsul and Wright (2013). We use surprise components (difference between the actual announcement value and median survey expectations) for each macro announcement type. The source of these data is the Bloomberg economic surprise monitor (ECSU).[6] In addition to macro news, we also control for surprise components of regular FOMC minutes and other Fed announcements released on the days not included in A based on the measure of Wright (2012).

To compare the response of our tail risk gauges to that of more common volatility measures, we also estimate variants of Equation (1) based on alternative risk measures. In the case of equities, we replace $\Delta RISK^{\tau}_{t,n}$ with innovations in the VIX, ΔVIX_t, or in realized

[6]The source of these data is the Bloomberg economic surprise monitor (ECSU). We use announcement data for the following set of macro variables: Nonfarm payroll, housing starts, new home sales, existing home sales, retail sales, initial jobless claims, unemployment rate, business inventories, factory orders, and construction spending data releases. The announcement surprises are standardized to have zero mean and unit variance.

volatility of the S&P500 index, ΔRV_t.[7] RV is a proxy for the actual volatility of equity returns. It is computed from historical high-frequency (intra-day) returns (e.g. Andersen, Bollerslev, Diebold, and Labys, 2003). In the case of interest rates, we consider $\Delta MOVE_t$ – a broad measure of (implied) Treasury bond yield volatility.[8]

Table III, top panel, presents the results for stock market tail risks. The coefficient in the regression of $\Delta RISK : -20\%$ on the announcement dummy variable is negative and significant. It indicates that market participants revised the near-term tail risk probabilities down by 13.6% on days with UMP news. Other macro news do not display a similar impact on perceived tail risk. The Wald test of their joint significance is insignificant.[9]

Table III about here

Table III also reports the results of event study regressions for more common volatility measures as dependent variables. The impact of UMP news on ΔVIX_t is not statistically significant, indicating that broader forward-looking measures of stock market volatility (capturing the second moment of the risk-neutral density) did not respond to UMP announcements in the way that tail risk did. The impact of UMP announcements on realized volatility ΔRV_t is positive and statistically significant. This indicates that realized volatility tends to pick up on announcement days, consistent with higher market activity and turnover in response to news.[10]

The bottom panel of Table III reports analogous results for gauges of the likelihood of extreme interest rate moves. The coefficient of -0.07 for $\Delta RISK : -150bp$ indicates that the probability of a sharp decline in 10-year rates dropped on average by 7.0% on UMP

[7] VIX stands for the Chicago Board of Exchange S&P500 option implied volatility index, a commonly used "fear gauge" (Whaley, 2000). The way it is constructed by CBOE ensures that it is a risk-neutral expectation of S&P500 return volatility. Hence, the VIX does not specifically capture downside risks, but is a symmetric measure of the risk-neutral expectation of volatility (i.e. the second moment). The measure of realized volatility we use is computed from the sum of squared continuously compounded five minute returns on the S&P500. These data are obtained from the Oxford-Man Institute: http://realized.oxford-man.ox.ac.uk/.

[8] Merrill Option Volatility Expectations Index of Treasury bond yields; obtained from Bloomberg.

[9] We do not report individual coefficients on macroeconomic news, but merely report a Wald test of the null that their impact is jointly equal to zero. Detailed results can be obtained by the authors upon request.

[10] The pickup of realized volatility is consistent with high-frequency studies by, for example, Andersen, Bollerslev, Diebold, and Vega (2007), who find that intra-day realized volatility jumps tend to be associated with macroeconomic and monetary policy news.

announcement days. Similarly, the coefficient of -0.03 for $\Delta RISK : +150bp$ indicates a decline in the probability of sharp rate rises. The magnitude of the impact of UMP news on the likelihood of upward shifts in long-term interest rates, however, is somewhat smaller. It is similar to the response of $\Delta MOVE$, which suggests that, unlike equity market tail risk, the risk of extreme upward interest rate shifts behaved broadly in tandem with overall implied volatility in U.S. Treasury markets.

Forward guidance vs. asset purchases. To examine which types of UMP announcements were instrumental in driving investors' repricing of tail risks, we separate UMP dates into those days containing changes to the FOMC forward guidance on the future path of short-term rates, FG announcements, and those that merely contained news about the Federal Reserve's asset purchase programs, QE announcements. The event-study regression is modified as follows:

$$\Delta RISK^{\tau}_{t,n} = \beta^{FG} A^{FG}_t + \beta^{QE} A^{QE}_t + \sum_{j=1}^{J} \gamma_j s_{j,t} + \epsilon_t, \tag{2}$$

where A^{FG}_t is a dummy variable indicating announcement days that include forward guidance news and A^{QE}_t is a dummy variable for all other UMP announcement days.

Table IV about here

The top panel of Table IV shows the results of forward guidance related news on stock market tail risk. The coefficient estimate $\hat{\beta}^{FG}$=-0.322 indicates that the association between FG announcements and the decline in equity market tail risk, $\Delta RISK$, is two times greater compared to the previous case when both FG and QE announcements are treated jointly. Our main measure of equity market tail risk (the likelihood assigned by market participants to a 20% crash over one month) dropped by around a third (32.2%) in response to changes in guidance about the future path of the policy rate.

Broader implied volatility, measured by the VIX, also fell significantly on forward guidance announcement days. This indicates a stronger response compared to the previous case when

all announcements were assigned the same coefficients. Still, the relative economic impact on the VIX is smaller (Column 3), and exhibits lower statistical significance, compared to the decline in tail risk $\Delta RISK$ (Columns 1 and 2). It is noteworthy that the coefficients on A_t^{QE}, while also negative, are not statistically significant. Hence, the bulk of UMP announcements impact on equity $\Delta RISK$ derived from the FG element of the announcement rather than QE news. In contrast, the coefficients for realized volatility, ΔRV, remain positive and significant with virtually identical magnitudes for FG announcements and QE announcements.

The bottom panel of Table IV shows analogous results for the response of extreme interest rate movements. Similar to the stock market tail risk regressions, the coefficient estimate on the FG announcement dummy is approximately double in magnitude to the pooled UMP announcement effects reported in Table III. This again suggests that forward guidance had a particularly strong dampening effect on interest rate risks.

C. Interpreting the tail risk and interest rate risk responses

Transmission to equity prices. The decline in the option-implied stock market tail risk measures in response to FG announcements could be interpreted in several ways. First, FG announcements may have reduced uncertainty, consistent with Birru and Figlewski (2010), who find that (conventional) announcements of new federal funds rate targets were associated with reduced uncertainty implied by S&P 500 risk-neutral density. Second, monetary easing may dampen investor risk aversion, consistent with the line of argument in Bekaert, Hoerova, and Duca (2013), who decompose the VIX into a measure of uncertainty and a volatility risk premium. They show that the latter proxies for investor risk aversion and tends to fall in response to an accommodative (conventional) monetary policy. Alternatively, even if investors are risk-neutral, our results are consistent with a relaxation of investors' Value-at-Risk (VaR) constraints. This is because a greater certainty that funding rates will stay low-for-long would support risky asset prices, reducing the risk of breaching VaR limits of leveraged investors (see e.g. Adrian, Moench, and Shin, 2013). While we do not test for these competing hypotheses, we can check if our results imply economically meaningful changes in the associated equity market VaR.

Table V about here

To do so, we recast the tail risk measures in terms of a 99% stock market VaR, that is, the amount of losses which will not be exceeded with a fixed probability of 1% given our option-implied RNPDs. We can obtain an estimate of the UMP announcement impact on stock market VaR by replacing n=1-month horizon equity tail risk in Equations (1) and (2) with the VaR measure derived from the RNPD, $\Delta 99\% VaR$. Table V shows the results. The coefficient on the FG announcement dummy is -1.65, indicating that for a dollar of equity, VaR on average declined by 1.65 cents.[11]

Figure 5 about here

The forward looking $\Delta 99\% VaR$ also exhibits an apparent inverse relationship with returns on the S&P500 index. This negative association is significant, as indicated by the fitted regression line between S&P500 returns and daily changes in the 99% VaR, shown in Figure 5. The slope of the fitted line indicates that a relaxation of the VaR by 1% (or 1 cent on the dollar) is associated with a 1.28% rise in the S&P500 index. This would suggest that FG announcements are associated with an immediate rise in stock market returns of about 2% (-1.65 $\times$ -1.28).

Forward guidance and interest rate risks. The response of long-term interest rate risks measures to FG announcements suggests that the signalling channel of monetary policy transmission goes beyond the mere expectations of future real rates. As Bauer and Rudebusch (2014) point out, it is important to keep in mind that the split between the signalling and portfolio rebalancing channels is not the same as the decomposition of long-rates into expectations and risk premium components. Hence, guidance about future risk-free rates has room to impact risk premia or volatility expectations of long-term rates. Our findings corroborate the recently emerging empirical evidence presented by Bauer and Rudebusch (2014) and Hanson and Stein (2015). These studies use different term structure models and focus

[11] The insignificant coefficient in the second column of Table V confirms our finding that tail risk impact in equity markets came from forward guidance rather than announcements related to asset purchases.

on different periods, yet both find that monetary policy shocks to short-term rates also exert significant influence on term premia of long-term yields.

Sustained impact. The total effect of forward guidance on equity market tail risks and interest rate risks likely exceeds the immediate announcement effects documented in the event study regressions above. This is because, on average, the effects appear to be sustained for at least one month (22 business days) following the announcements, as can be gleaned from Figure 6 and Figure 7, respectively. The figures show the levels of $RISK^{\tau}_{n,t}$ averaged across all five FG announcement days. The plots cover a -10 to +22-day window.

Figure 6 about here

The tail risk measure reflecting the ex-ante likelihood of a 20% drop in stock prices over a 1-month horizon exhibits a marked decline on announcement days. In addition, as seen in Figure 6, it took some time (approximately 5 business days) for FG announcement effects to be fully incorporated into equity option prices. Such sustained impact suggests that market participants reacted to Federal Reserve's forward guidance by demanding less insurance against adverse outcomes and by taking on more risk for a prolonged period after the announcement. Furthermore, the delayed, stepwise, adjustment would be consistent with a feedback loop between leveraged balance sheet management and risky asset prices, as an initial reduction in risk premia or volatility outlook would boost asset prices, thereby feeding into demand for risky assets and a downward pressure on option-implied tail risk measures (see, e.g. Danielsson, Shin, and Zigrand, 2010; Adrian, Moench, and Shin, 2013).

Figure 7 about here

The response of forward-looking interest rate risk measures are also sustained, but appear to be fully incorporated on the day of the announcement, as shown in Figure 7. Such quick pass-through of announcement effects to measure interest rate risks suggest the absence of a type of feedback loop observed for equity tail risks (see Figure 6 above) and instead points to a one-time revision to expectations of future rates, their volatility, as well as the associated risk premia.

D. *Horizon effects and crash size*

We also examine how the tail risk impact varies across horizons. Column 1 of Table VI shows coefficient estimates following regression specification in Equation (1) for $\Delta RISK_n^\tau$ based on maturities of n=1-month, 2-months, and 3-months. The coefficients are declining monotonically as the maturity increases, from -13.6% to -7%. This indicates that the relative impact of UMP announcement is greater for expectations of near term risks than those in the more distant future.

Table VI about here

Another interesting dimension to examine is the UMP impact for different magnitudes of the expected "crash size". Hence, we add downturns of $\tau = -5\%$ and -10% in addition to the -20% benchmark event. Again, a pattern of a monotonic decline in coefficient magnitudes (as well as significance) emerges when moving from large tail events towards smaller (Gaussian) events. Taking 1-month options as an example, the coefficient declines from statistically significant -0.136 ($\Delta RISK : -20\%$) to -0.017 ($\Delta RISK : -5\%$). The last three columns of Table VI repeat the exercise for FG announcements. As can be seen, the effects across horizons and the "crash size" spectrum are qualitatively similar, but tend to be more pronounced compared to the case when all UMP announcements are considered jointly.

Overall, the results reported in Table VI indicate that UMP announcements had the strongest impact on option-implied probabilities of immediate and sizeable downside risks.

E. *Expanded sample & "taper" and exit announcements*

This sub-section expands the sample of the event-study regressions to include observations up to June 2014, also controlling for exit announcements (FOMC phasing out its asset purchases) and the so-called "taper tantrum" (e.g. Feroli, Kashyap, Schoenholtz, and Shin, 2014) of May and June of 2013. The expanded sample also covers the period during which the FOMC has been employing "threshold-based" forward guidance, stating that the the 0-25bp fed funds

rate target was appropriate as long as unemployment remained above a particular threshold level.

Equity market tail risks. Looking back at Figure 2, the largest spike during this period took place on 19 June 2013, when the Federal Reserve Chairman emphasised that the envisaged slowdown of asset purchases should be consistent with the unemployment rate decreasing to 7% by mid-2014. Arguably, such joint mentioning of a slowdown in asset purchases with the unemployment rate threshold, commonly associated with forward guidance, led to some confusion among market participants.[12] When the FOMC finally announced the slowdown in monthly purchases in successive rounds, on 18 December 2013, then on 29 January 2014, and again on 19 March 2014, there was a clear delineation between communication about bond purchases and forward guidance about the future federal funds rate target. Thus, of the three exit announcements, the two with complementary (accommodative) FG announcements did not generate a spike in equity market tail risk measures (18 December 2013 and 19 March 2014). By contrast, the 29 January 2014 announcement, which was not accompanied by accommodative forward guidance, resulted in a spike.

In addition to expanding the sample up to June 2014, the event study regressions is modified as follows:

$$\Delta RISK^{\tau}_{t,n} = \beta^{FG} A^{FG}_t + \beta^{QE} A^{QE}_t + \beta^{Taper} A^{Taper}_t + \beta^{Exit} A^{Exit}_t + \sum_{j=1}^{J} \gamma_j s_{j,t} + \epsilon_t \qquad (3)$$

where β^{Taper} and β^{Exit} are additional coefficients on dummy variables associated with exit announcements and the so-called taper tantrum.

Table VII about here

Table VII shows the results. The negative and significant coefficients β^{FG} re-affirm the

[12]The FOMC later noted that "the path of the federal funds rate implied by financial market quotes steepened notably during the period, in part reflecting some increase in uncertainty about the outlook for monetary policy." See Minutes of the Federal Open Market Committee, September 17-18, 2013: http://www.federalreserve.gov/monetarypolicy/fomcminutes20130918.htm.

strong dampening effect of forward guidance on equity market tail risks. The taper episode is associated with a rise in the likelihood of a 10% drop in the stock market, but the impact of the taper announcements on the option-implied odds of the more adverse scenario (20% equity market drop) are not significant. β^{Taper} is also insignificant in the regression with the VIX as the dependent variable, but highly significant in the realized volatility regression, ΔRV. Hence, the taper episode appears to have triggered contemporaneous volatility in equity markets, but the impact on forward-looking downside risk expectations or risk premia were milder.[13]

Interest rate risks. Looking back at Figure 4, the taper episode also triggered upward adjustments in 10-year interest rate risk measures. By contrast, actual exit announcements did not seem to have material effect on measured interest rate risks.

Table VIII about here

Table VIII shows expanded sample results estimating Equation 3 for risks of sharp movements in 10-year rates and the $MOVE$ index. The reaction to the taper episode is more evident in the $\Delta MOVE$ than in interest rate risk regressions. While positive, the coefficients are not significant in the 10-year interest rate risk regressions, somewhat at odds with Figure 4. A caveat is that since we only have two daily dummies for the taper announcements, their effects may be hard to pick up with such simple regressions employing a multitude of other controls.

Expanded sample regressions, which also add FG announcement dates without contemporaneous QE news, also confirm that interest rate risks were revised down in response to FG rather than QE announcements.

[13]When examining coefficients on each macroeconomic surprise, we noted that unemployment rate and housing starts exhibit significant coefficients once the sample is expanded to cover the 2013 and 2014 periods. Interestingly, the coefficient on unemployment surprise announcements is negative, that is, it is perverse in a sense that higher than expected unemployment rate is associated with lower risk of a 10% drop in the stock market. When we ran the regression in Equation 3 over a rolling (3-month) window, we found that the (perverse) negative coefficient estimate on unemployment rate surprises in the full sample is driven entirely by the announcements during the threshold-based forward guidance regime onwards, when lower unemployment became associated with greater likelihood of a rate hike by the Federal Reserve.

Another noteworthy result from the expanded sample regressions is the joint significance of other news in two out of three specifications. When examining individual coefficients (not reported), non-farm payroll constituted the only macro news surprises significant across three specifications: coefficients of 0.22***, 0.004** and 0.010*** in the -150*bp* risk, +150*bp* risk, and $\Delta MOVE$ regression respectively. Hence, positive labor market news tended to increase (rather than reduce) interest rate risks, likely reflecting threshold-based forward guidance, because it tied positive labor market news to a rate hike. Overall, the significance of macro news surprises in the extended sample indicates that when the FOMC introduced forward guidance relating the first rate hike to the state of the macroeconomy, the sensitivity of interest rate risks to select macroeconomic news increased.[14]

V. Conclusion

We examine the impact of unconventional monetary policy (UMP) on investors' expectations of tail risks in equity markets and extreme swings in interest rates. We construct these forward looking measures from risk-neutral densities implied by S&P500 index options and swaptions, respectively. These risk gauges then serve as inputs into standard event study regressions, allowing us to quantify how market participants altered their assessments of adverse market outcomes as a response to policy announcements by the Federal Reserve.

The event study results show significant mitigating effects of UMP announcements on both equity market tail risks and interest rate risks. Most of the impact derives from forward guidance (FG), rather than news related to asset purchases (QE) alone. As such, FG announcements reduced the option-implied likelihood of a tail event of a 20% drop in stock prices by approximately one third.

The response of long-term interest rate risk measures to FG announcements adds to recently emerging evidence that monetary policy engineered via short-term rates (including guidance about future rates) can affect term premia of long-term rates (see, e.g. Bauer and

[14]The insignificance of macro news surprises in the baseline regressions (see Tables III and IV above), which cover open-ended and calendar-based forward guidance periods (2008 to end 2012), corroborate Swanson and Williams (2014), who find that FOMC calendar-based forward guidance was particularly effective in reducing the sensitivity volatility of medium- and longer-term interest rates to news.

Rudebusch, 2014; Hanson and Stein, 2015). Specifically, our findings indicate that guidance about future risk-free rates had an impact on volatility expectations and risk premia of long-term rates.

The significant reduction in equity market tail risks also points to broader effects of the signalling channel than found in the previous literature. While assumptions about risk preferences and the role of leverage would alter how one interprets these findings, the presence of the effects documented in this paper lends support to the literature on the risk-taking channel of monetary policy (see, e.g. Borio and Zhu, 2012; Brunnermeier and Sannikov, 2012; Bruno and Shin, 2012; Bekaert, Hoerova, and Duca, 2013). The transmission of (unconventional) monetary policy to financial conditions and risk taking via intermediaries' risk constraints, in particular, warrants further empirical and theoretical study.

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Figures and Tables

Table I. Overview of unconventional monetary policy announcements

Date	Program	FG	Statement summary
25.11.2008	LSAP-1	No	Purchase $100bn of agency debt and $500bn agency MBS
01.12.2008	LSAP-1	No	Bernanke speech on further QE: open to purchase long-term Treasuries
16.12.2008	LSAP-1	Yes	Fed funds rate target range 0-25*bp*; possibility of long-term Treasury purchases
28.01.2009	LSAP-1	No	Expansion of QE to include long-term Treasuries
18.03.2009	LSAP-1	Yes	$300bn in Treasuries, $750bn of agency MBS, increase holdings of agency debt to $200bn; low federal funds rate for an extended period
12.08.2009	EXIT	No	Slow pace of purchases, conditions in financial markets have improved
23.09.2009	EXIT	No	Gradually slow pace of purchases, economic activity has picked up
04.11.2009	EXIT	No	Limit agency debt purchases below previously announced maximum of $200bn
10.08.2010	LSAP-2	No	Reinvest MBS principal into Treasuries; low rates for an extended period
27.08.2010	LSAP-2	No	Bernanke mentions potential additional purchases of long-term securities.
21.09.2010	LSAP-2	No	Maintain reinvestment policy; low rates for an extended period likely
15.10.2010	LSAP-2	No	Bernanke speech: prepared for additional policy accommodation if needed
03.11.2010	LSAP-2	No	Purchase of a further $600bn of longer-term Treasuries
09.08.2011	MEP	Yes	Growth slower than expected; low federal funds rate at least until mid-2013
21.09.2011	MEP	No	MEP using $400bn Treasury securities announced
25.01.2012	MEP	Yes	Low federal funds rate at least until late 2014
20.06.2012	MEP	No	MEP extended until end-2012; low federal funds rate through late 2014
01.08.2012	MEP	No	Monitor incoming data and provide additional accommodation as needed
31.08.2012	LSAP-3	No	Bernanke Speech, Jackson Hole, Wyoming
13.09.2012	LSAP-3	Yes	Fixed monthly MBS and Treasury purchases; rate guidance through mid-2015
12.12.2012	LSAP-3	Yes	6.5% unemployment threshold introduced in federal funds rate guidance
22.05.2013	TAPER	No	Bernanke alludes to "drawbacks of persistently low rates..."
19.06.2013	TAPER	No	FOMC statement offers no clarification to the Chairman's speech in May.
18.12.2013	EXIT	Yes	Cut monthly purchases of MBS and Treasuries to $35bn and $40bn Unemployment rate threshold of 6.5% for lift-off abandoned.
29.01.2014	EXIT	No	Cut monthly purchases of MBS and Treasuries to $30bn and $35bn
19.03.2014	EXIT	Yes	Cut monthly purchases of MBS and Treasuries to $25bn and $30bn Expand the range of information assessed in determining the lift-off date.
30.04.2014	EXIT	No	Cut monthly purchases of MBS and Treasuries to $20bn and $25bn

Sources: Board of Governors of the Federal Reserve System; Gagnon, Raskin, Remache, and Sack (2011); Wright (2012); Fratzscher, Duca, and Straub (2012); BIS (2014); authors' summary of statement news content. Baseline regressions focus on announcements dates of expansionary policies only, up to the announcement of LSAP-3 on 13.09.2012. Expanded sample regressions also include "exit" and "taper" announcements, covering until 30.04.2014.

Table II. UMP announcements and changes in the option-implied likelihood of tail events

			S&P500 Index				10-year rates			
		RISK:	-20%, 1-month		-20% 3-month		-150*bp*		+150*bp*	
Date	Program	FG	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.
25.11.2008	LSAP-1		-0.24	-3.1%	-0.69	-3.4%	-2.46	-18.8%	0.74	3.7%
01.12.2008	LSAP-1		2.21	28.8%	2.99	15.0%	-1.73	-10.0%	0.73	3.1%
16.12.2008	LSAP-1	YES	-0.97	-14.0%	-1.25	-6.5%	-2.56	-21.6%	-2.01	-9.9%
28.01.2009	LSAP-1		-0.79	-20.1%	-1.56	-11.0%	0.90	5.4%	-0.45	-2.7%
18.03.2009	LSAP-1	YES	0.01	0.3%	-0.04	-0.3%	-3.73	-21.5%	-1.62	-10.1%
12.08.2009	EXIT		-0.03	-4.3%	-0.14	-2.0%	-0.29	-1.3%	-0.09	-0.6%
23.09.2009	EXIT		0.03	5.2%	0.12	2.1%	-0.60	-2.8%	-0.18	-1.2%
04.11.2009	EXIT		-0.09	-11.1%	-0.22	-3.2%	0.17	0.8%	0.02	0.1%
10.08.2010	LSAP-2		0.04	7.0%	0.16	2.5%	-0.80	-6.2%	-0.46	-3.5%
27.08.2010	LSAP-2		-0.32	-27.8%	-1.63	-21.2%	-1.83	-15.8%	-1.55	-12.7%
21.09.2010	LSAP-2		0.02	3.8%	0.05	0.8%	0.21	1.5%	0.09	0.7%
15.10.2010	LSAP-2		-0.01	-1.6%	-0.06	-1.1%	-0.11	-1.0%	-0.15	-1.4%
03.11.2010	LSAP-2		-0.10	-31.6%	-0.67	-14.1%	-1.83	-16.0%	-0.78	-6.7%
09.08.2011	LSAP-2	YES	-1.09	-72.0%	-2.83	-31.1%	-2.41	-15.5%	-2.06	-14.3%
21.09.2011	MEP		0.45	25.9%	0.91	9.9%	-0.77	-6.3%	-0.16	-1.2%
25.01.2012	MEP	YES	-0.05	-16.9%	-0.34	-7.8%	-0.64	-6.5%	0.79	6.2%
20.06.2012	MEP		-0.07	-22.3%	-0.48	-10.9%	0.01	0.2%	-0.36	-3.4%
01.08.2012	MEP		-0.02	-7.0%	-0.18	-4.1%	0.74	30.1%	-0.20	-1.9%
31.08.2012	LSAP-3		-0.06	-24.9%	-0.64	-14.9%	-0.32	-6.3%	0.99	8.4%
13.09.2012	LSAP-3	YES	-0.04	-50.9%	-0.57	-20.3%	-0.72	-11.8%	-0.49	-4.6%
12.12.2012	LSAP-3	YES	0.01	13.9%	0.14	5.8%	0.51	12.3%	0.13	1.4%
22.05.2013	TAPER		0.00	-3.1%	-0.03	-2.0%	0.41	5.5%	0.19	1.9%
19.06.2013	TAPER		0.00	6.8%	0.10	4.3%	-0.02	-0.2%	-0.08	-0.7%
18.12.2013	EXIT	YES	-0.01	-67.0%	-0.44	-27.2%	-0.71	-5.5%	-1.34	-10.6%
29.01.2014	EXIT		0.01	33.1%	0.23	12.4%	0.19	1.7%	0.07	0.6%
19.03.2014	EXIT	YES	0.01	19.9%	0.06	3.4%	-0.01	-0.1%	0.18	1.7%
30.04.2014	EXIT		0.00	-14.0%	-0.03	-1.9%	-0.05	-0.6%	-0.08	-0.9%

Notes: The table shows changes in measures of equity market tail risk and interest rate risk around each of the UMP announcements considered in our event-study. Each value represents the change relative to previous business day close. Entries in the columns labelled "Abs." report changes in the probability mass (ranging from 0 to 1.0) of the implied risk-neutral density associated with select extreme outcomes: $RISK^{\tau}_{t,n} - RISK^{\tau}_{t-1,n}$. Entries in the columns labelled "Rel." report changes in the identically defined probability mass, but relative to its previous value expressed in per cent: $\Delta RISK(i)^{\tau}_{t,n} \equiv ln(RISK^{\tau}_{t,n}) - ln(RISK^{\tau}_{t-1,n})$. For equity tail risk, extreme outcomes are defined as τ=-20% return over n=1- and 3-months period. For interest rate risk, extreme outcomes are defined as τ=+/-150bp move in 10-year rates over a n=2 year period.

Table III. UMP announcements and (tail) risks

	Stock market returns:		
	$\Delta RISK: -20\%$	ΔVIX	ΔRV
UMP	-0.136**	-0.040	0.289***
	(0.059)	(0.025)	(0.056)
Other news: p-val.	0.544	0.433	0.917
R-squared	0.014	0.012	0.017
F-stat	1.170	1.067	2.488
Observations	1,182	1,182	1,182
	Interest rates:		
	$\Delta RISK: -150bp$	$\Delta RISK: +150bp$	$\Delta MOVE$
UMP	-0.070**	-0.030**	-0.032*
	(0.029)	(0.015)	(0.016)
Other news: p-val.	0.217	0.748	0.101
R-squared	0.037	0.012	0.037
F-stat	2.245	0.898	1.655
Observations	1,213	1,213	1,213

Notes: Sample period: daily Jan-03-2008 to Nov-06-2012. The dependent variable in each regression is the 1-day log change in the specified risk indicator: $RISK: -20\%$ = probability of a 20% drop in the S&P500 over 1-month period, VIX = CBOE S&P500 option-implied volatility, RV = S&P500 realized volatility, $RISK: -150bp$ = probability of a $150bp$ drop in 10-year rates over a 2-year period, $RISK: +150bp$ = probability of a $150bp$ rise in 10-year rates over a 2-year period, MOVE = Merrill Lynch option volatility estimate index measuring implied volatility for U.S. Treasury bonds. UMP is a 0/1 indicator for days containing news related to asset purchases and/or forward guidance (listed in Table I). Other news include (updated) measure of Wright (2012) for other FOMC announcements and standardized surprise components of regular macroeconomic releases; we report the p-value of the Wald test of the null that these announcement effects are jointly equal to zero. Heteroskedasticity and autocorrelation (HAC) robust standard errors based on Newey and West (1987) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table IV. Announcement effects: Forward guidance (FG) vs. asset purchases (QE)

	Stock market returns:		
	$\Delta RISK: -20\%$	ΔVIX	ΔRV
UMP (FG content)	-0.322***	-0.118**	0.288***
	(0.120)	(0.048)	(0.060)
UMP (QE only)	-0.061	-0.007	0.315***
	(0.059)	(0.025)	(0.075)
Other news: p-val.	0.501	0.427	0.922
R-squared	0.019	0.019	0.017
F-stat	1.282	1.177	3.212
Observations	1,182	1,182	1,182
	Interest rates:		
	$\Delta RISK: -150bp$	$\Delta RISK: +150bp$	$\Delta MOVE$
UMP (FG content)	-0.148***	-0.065**	-0.061***
	(0.025)	(0.032)	(0.015)
UMP (QE only)	-0.038	-0.016	-0.019
	(0.037)	(0.015)	(0.020)
Other news: p-val.	0.230	0.817	0.112
R-squared	0.045	0.018	0.034
F-statistic	4.123	0.954	2.444
Observations	1,213	1,213	1,213

Notes: Sample period: daily Jan-03-2008 to Nov-06-2012. The dependent variable in each regression is the 1-day log change in the specified risk indicator, $\Delta RISK$. FG is a 0/1 indicator for days containing Federal Reserve forward guidance news and QE is a 0/1/ indicator of days containing Fed asset purchase program news only; both are listed in Table I. Heteroskedasticity and autocorrelation (HAC) robust standard errors based on Newey and West (1987) in parentheses; *** p<0.01, ** p<0.05, * p<0.1. See notes to Table III for additional details.

Table V. Value-at-Risk and UMP announcements

	Δ 99% VaR	Δ 99% VaR
UMP (FG content)	-1.652**	
	(0.743)	
UMP (QE only)	0.051	
	(0.430)	
UMP		-0.452
		(0.427)
Other news: p-val.	0.549	0.572
R-squared	0.016	0.008
F-stat	1.081	0.875
Observations	1,182	1,182

Notes: Sample period: daily Jan-03-2008 to Nov-06-2012. The dependent variable in each regression is the 1-day change in S&P500 returns associated with the 99% VaR implied by the risk neutral probability density obtained from 1-month index options. Heteroskedasticity and autocorrelation (HAC) robust standard errors based on Newey and West (1987); *** p<0.01, ** p<0.05, * p<0.1. See notes to Tables III and IV for additional details.

Table VI. Effects across horizons and crash risk magnitudes

	$\Delta RISK$: -20%	$\Delta RISK$: -10%	$\Delta RISK$: -5%
Maturity:		UMP	
1-month	-0.136**	-0.057**	-0.017
	(0.059)	(0.026)	(0.012)
2-month	-0.086**	-0.035*	-0.009
	(0.035)	(0.018)	(0.009)
3-month	-0.070**	-0.027*	-0.005
	(0.027)	(0.015)	(0.008)
Maturity:		UMP (FG content)	
1-month	-0.322***	-0.133***	-0.054**
	(0.120)	(0.048)	(0.022)
2-month	-0.187***	-0.083***	-0.037**
	(0.067)	(0.030)	(0.016)
3-month	-0.139***	-0.065***	-0.031**
	(0.050)	(0.024)	(0.015)

Notes: Sample period: daily Jan-03-2008 to Nov-06-2012. The dependent variable in each regression is the 1-day log change in the specified risk indicator: $RISK_n^\tau$ for probability of a τ= 20%, 10%, and 5% drop in S&P500 index over n=1-month, 2-month, and 3-month period. Heteroskedasticity and autocorrelation (HAC) robust standard errors based on Newey and West (1987) in parentheses; *** p<0.01, ** p<0.05, * p<0.1. See notes to Tables III and IV for additional details.

Table VII. Regressions including taper and exit announcements: stock market tail risks

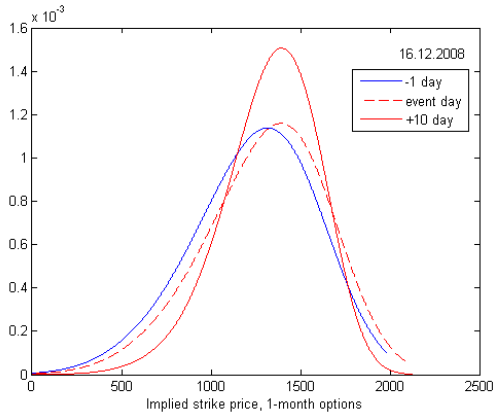
	$\Delta RISK$ -20%	$\Delta RISK$ -10%	ΔVIX	ΔRV
UMP (FG content)	-0.228**	-0.111***	-0.082**	0.291***
	(0.113)	(0.042)	(0.039)	(0.074)
UMP (QE only)	-0.060	-0.027	-0.006	0.319***
	(0.059)	(0.028)	(0.025)	(0.074)
Taper	0.020	0.013***	0.019	0.811***
	(0.036)	(0.004)	(0.012)	(0.068)
Exit	-0.037	0.004	-0.002	0.253**
	(0.088)	(0.037)	(0.022)	(0.122)
Other news: p-val	0.566	0.460	0.659	0.846
R-squared	0.017	0.020	0.015	0.023
F-statistic	1.247	2.549	1.356	10.630
Observations	1,566	1,566	1,566	1,566

Notes: Sample period from Jan-03-2008 to Jun-03-2014, daily frequency. Heteroskedasticity and autocorrelation (HAC) robust standard errors based on Newey and West (1987) in parentheses; *** p<0.01, ** p<0.05, * p<0.1. See notes to Tables III and IV for additional details.

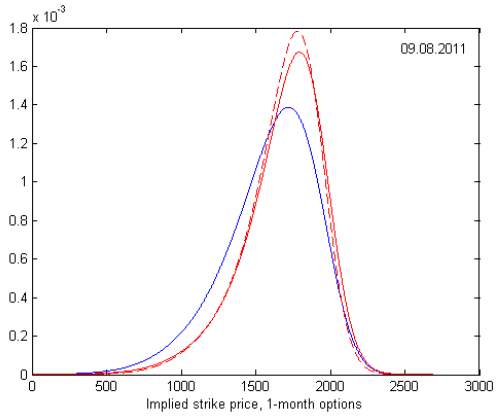
Table VIII. Regressions including taper and exit announcements: 10-year interest rate risks

	$\Delta RISK$ -150bp	$\Delta RISK$ +150bp	$\Delta MOVE$
UMP (FG content)	-0.087**	-0.049**	-0.026
	(0.037)	(0.024)	(0.023)
UMP (QE only)	-0.038	-0.016	-0.021
	(0.037)	(0.015)	(0.021)
Taper	0.027	0.007	0.080***
	(0.020)	(0.009)	(0.007)
Exit	-0.002	-0.012	-0.013
	(0.009)	(0.009)	(0.010)
Other news: p-val	0.072	0.252	0.007
R-squared	0.036	0.016	0.036
F-statistic	2.317	1.543	10.880
Observations	1,670	1,670	1,670

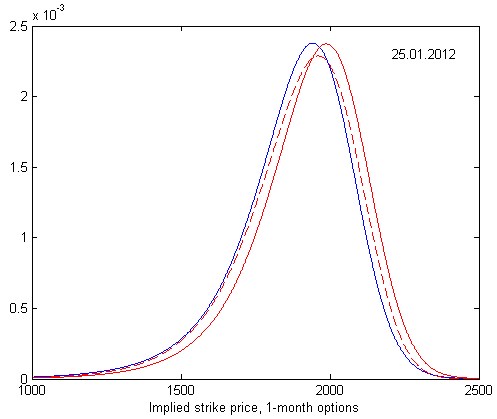
Notes: Sample period from Jan-03-2008 to Jun-03-2014, daily frequency. Heteroskedasticity and autocorrelation (HAC) robust standard errors based on Newey and West (1987) in parentheses; *** p<0.01, ** p<0.05, * p<0.1. See notes to Tables III and IV for additional details.



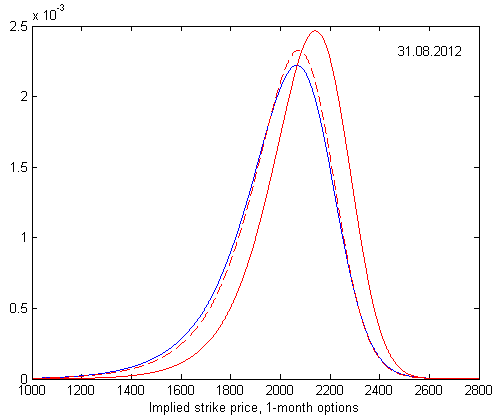
(a) Fed funds target lowered to 0-0.25*bp*, longer-term Treasury securities purchases considered



(b) Low Fed funds rate at least until mid-2013



(c) Low Fed funds rate at least until late 2014



(d) Bernanke Jackson Hole speech on merits of UMP

Figure 1. Option-implied probability distributions for S&P500 prices (1-month ahead) around selected announcement dates. The Figure shows risk-neutral probability densities at market close one day before the announcement, the announcement day itself, and ten business days afterwards.

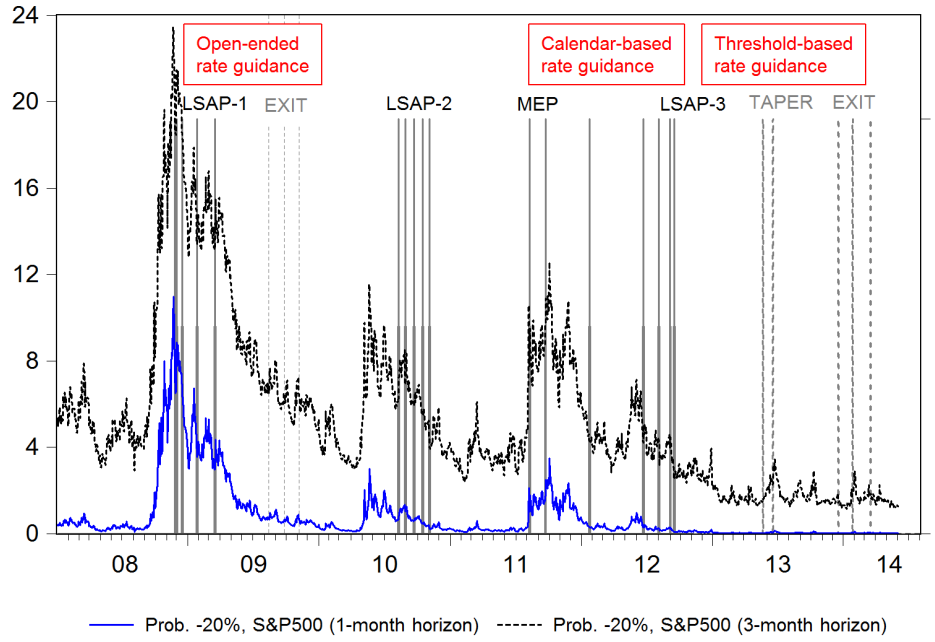
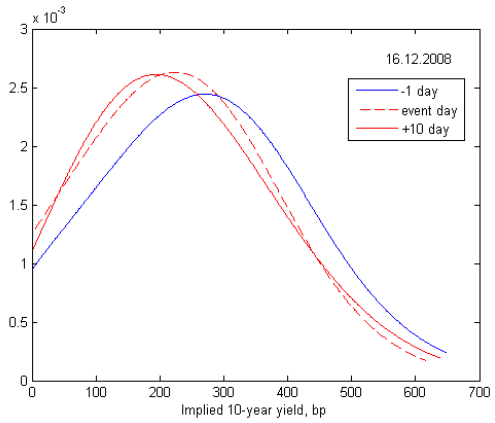
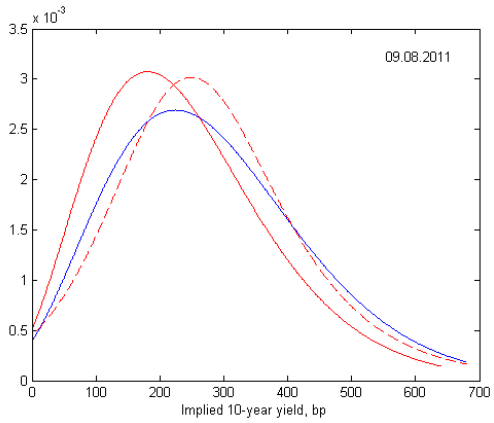


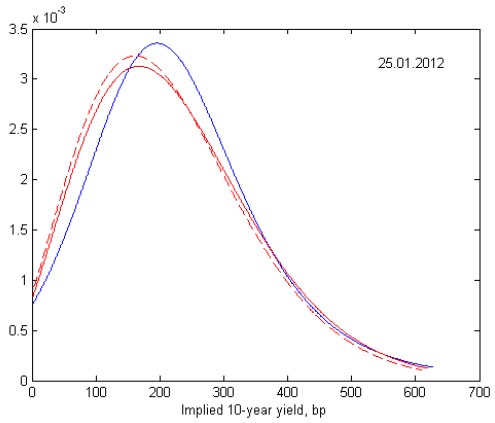
Figure 2. This graph depicts the time-variation of risk-neutral probabilities of a 20% decline in S&P500 index, implied by 1-month and 3-month index options. Vertical lines refer to announcement days regarding the Federal Reserve's UMP containing news on forward guidance about future short-term rates or Fed asset purchases programs.



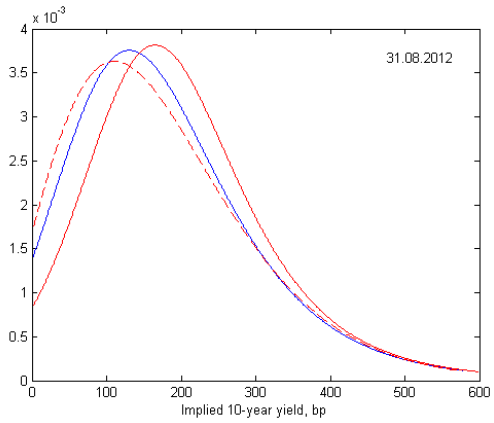
(a) Fed funds target lowered to 0-0.25*bp*, longer-term Treasury securities purchases considered



(b) Low Fed funds rate at least until mid-2013



(c) Low Fed funds rate at least until late 2014



(d) Bernanke Jackson Hole speech on merits of UMP

Figure 3. Swaption-implied probability densities of forward 10-year swap rates around selected announcement dates. The RNPDs are constructed from the implied volatilities of swaptions with 2-year expiries and a 10-year swap tenor. The Figure shows RNPDs at market close one day before the announcement, the announcement day itself, and ten business days afterwards.

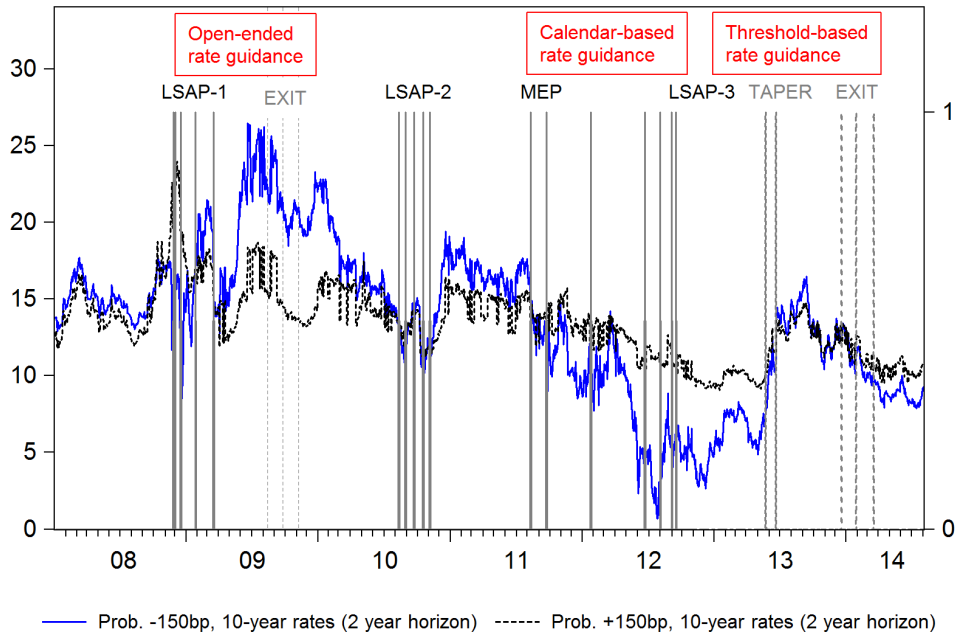


Figure 4. This graph depicts the time-variation of risk-neutral probabilities of a 150*bp* rise and 150*bp* drop in 10-year rates, implied by the prices of swaptions with two years to maturity and a 10-year swap tenor. Vertical lines refer to announcement days regarding the Federal Reserve's UMP containing news on forward guidance about future short-term rates or Fed asset purchases programs.

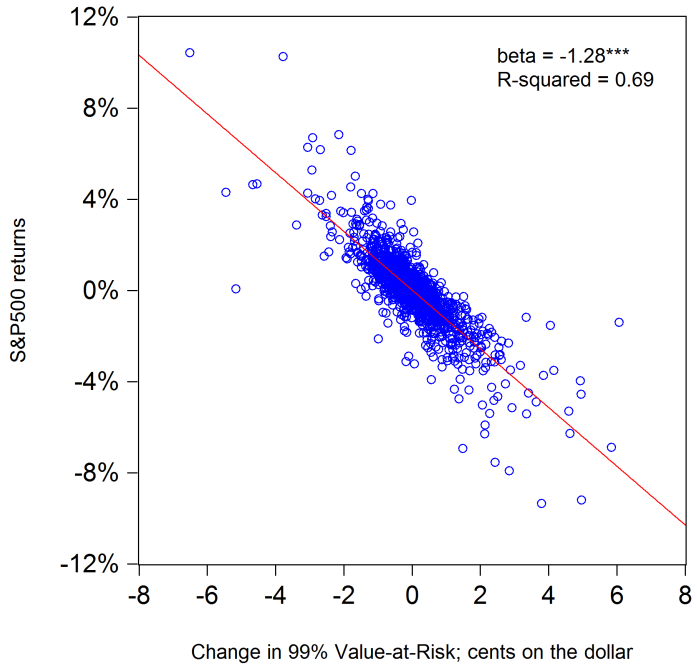
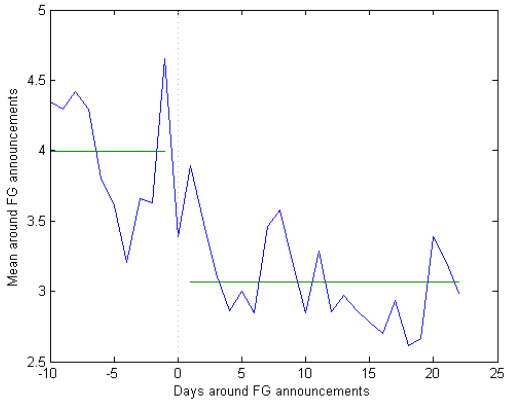
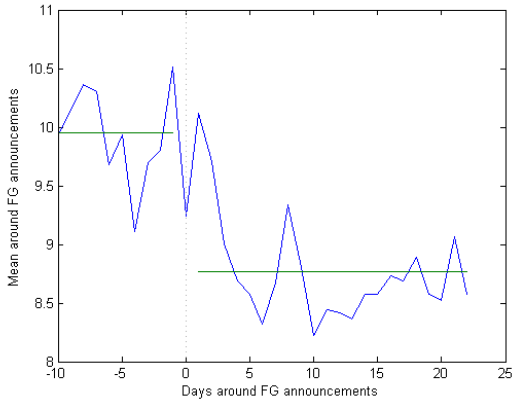


Figure 5. Scatter plot of stock market versus changes in 99% Value-at-Risk (VaR); VaR deduced from the daily RNPDs constructed from 1-month S&P500 index options. Business day frequency, 2 January 2008 to 21 October 2014 sample period.

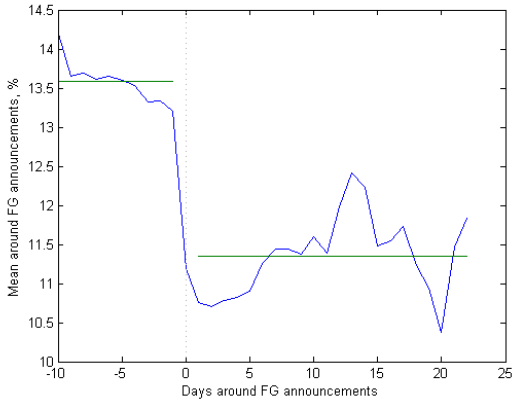


(a) Prob. 20% stock market decline over 1-month

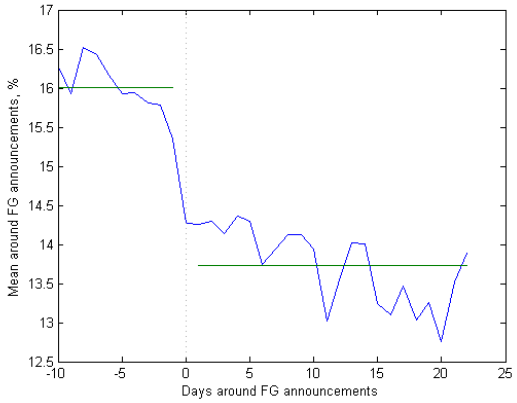


(b) Prob. 20% stock market decline over 3-months

Figure 6. Mean probability of a 20% drop in stock prices around forward guidance announcement dates (averaged across events). The risk indicator is based on risk-neutral probability densities constructed from 1-month and 3-month S&P500 index options.



(a) Prob. 150*bp* rate drop



(b) Prob. 150*bp* rate rise

Figure 7. Mean probability of a 150*bp* drop and 150*bp* rise in 10-year rates around forward guidance announcement dates (averaged across events). The risk indicator is based on the implied probability densities, derived from the prices of swaptions with two years to expiry and a 10-year swap tenor.