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Unconventional Monetary Policy and Asset Price Risk

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Abstract

We examine the effects of unconventional monetary policy (UMP) events in the United States on asset price risk using risk-neutral density functions estimated from options prices. Based on an event study including a key exchange rate, an equity index, and five commodities, we find that "tail risk" diminishes in the immediate aftermath of UMP events, particularly downside left tail risk. We also find that QE1 and QE3 had stronger effects than QE2. We conclude that UMP events that serve to ease policies can help to bolster market confidence in times of high uncertainty.

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I. INTRODUCTION

Unconventional monetary policies have become an important part of the policy toolkit in the aftermath of the 2008–09 global financial crisis. But there is much uncertainty about the effects of these policies, including on asset prices. Their use has also been controversial, raising suspicions that they contribute to spillovers that may be damaging for other countries, notably by distorting exchange rates and other asset prices. In one high profile example, newspaper headlines have warned that such policies are contributing to higher food commodity prices, with adverse effects on food importing countries and the poor.[2] The key channel for such distortions, some argue, is through incentives to engage in "excessive speculation." This is defined in different ways, including an amount of speculation beyond that which is necessary or normal relative to hedging needs, as measured by Working's T (Irwin and Sanders, 2010) or "sudden or unreasonable fluctuations or unwarranted changes in the price of [a] commodity" (CFTC). Whatever the definition, such activity is often linked to speculative bubbles, in which asset prices rise above the asset's fundamental value as defined by future payoffs under rational expectations. The recent crisis has shown that the probability of policy interest rates hitting the zero lower bound is much higher than we thought which means that furthering our understanding of the effects of unconventional monetary policies, including possibly harmful side-effects, remains an important task.

The consensus so far is that there is little evidence that such policies cause significant short-term changes in "risk asset" prices (see section II.B). These are defined as assets whose prices tend to decline as measures of broad market uncertainty increase, at least over the short run. We extend this analysis and assess the effect of unconventional monetary policy events (henceforth UMPs) in the United States—including important speeches by Federal Reserve officials and public statements released after Federal Open Market Committee meetings—on the distribution of asset price risk. Our focus on U.S. policies does not imply that the policies of other countries or regions do not affect asset prices, but recognizes the importance of U.S. policies for global economic and financial conditions. The questions that we ask in this paper include: do UMPs raise or reduce uncertainty about the outlook for risk asset prices; are the effects symmetric, by affecting upside and downside risks; and does "excessive speculation" increase following a UMP event. Answering these questions, we believe, provides an important and innovative contribution to this rapidly growing literature.

To answer these questions, we use an event study methodology to test the null hypothesis that UMPs have no effect on the distribution of asset price risk. To do this, we estimate risk-neutral density functions (henceforth RNDs) from options prices of the euro – U.S. dollar exchange rate, the S&P500 equity index, and the prices of five commodities: gold, crude oil, natural gas, corn, and soybeans. We fit a weighted average log-normal distribution to the data, subject to important arbitrage constraints, for the 20 days immediately preceding a UMP event and for one test date after the event. On the basis of these fitted density functions and focusing on measures of tail risk and the implied volatilities of liquid at-the-money options contracts, we conduct hypothesis tests and assess whether, and

[2] An example is the article "US Accused of Forcing Up World Food Prices," *Guardian*, November 5, 2010.

how, asset price risk has changed. Formally testing whether UMPs trigger excessive speculation, as defined above, is difficult, mainly because it is not possible to pin down fundamental values with precision. At the same time, its presence would surely be reflected in prices or RNDs or both. If UMPs are indeed a cause of such behavior, it is likely that one would find evidence of investor positioning for very large price gains, including by purchasing deep out-of-the-money call options; that is, contracts for which the exercise price was significantly above the current price of the underlying asset. (Note that this would likely be a necessary, but perhaps not sufficient, condition for excessive speculation). In turn, this would lead to a strong positive skew in the RND.

The plan of the paper is as follows. In Section II, we outline the theory that identifies the linkages between commodity pricing and monetary policy. In Section III, we describe the theoretical and empirical methodology. Section IV provides and overview of the data we use. Section V presents the key results, while in Section VI we offer our interpretation. Section VII provides brief concluding remarks.

II. Unconventional Monetary Policy and Asset Prices

This section more fully defines what we consider to be UMP, briefly reviews the channels through which it may affect asset prices, and highlights some of the key empirical findings to date.

A. Defining Unconventional Monetary Policies

Non-standard measures taken by the U.S. Federal Reserve since the onset of the crisis can be classified as: lending to financial institutions; providing liquidity to important credit markets; and large-scale asset purchase programs (LSAPs). The first two measures may be viewed as consistent with the central bank's role as lender of the last resort. In large part, they aim at preventing a fire sale of assets triggered by vanishing liquidity. In contrast, the LSAPs targeted a reduction of interest rates along the term structure to stimulate economic activity.

There are four channels through which UMP can affect asset prices. First is the portfolio balance channel. Central bank purchases of a Treasury security should alter the relative valuation of other imperfectly substitutable assets (including commodities) and increase the demand for them. Second, the signaling channel, as unconventional measures are thought to predict lower policy rates in the future. Third, a confidence channel which may work to offset the signaling effect. In other words, the announcement of unconventional measures may be viewed by markets as indicating that economic and financial prospects are worse than currently priced in. Some studies suggest that such measures serve to boost confidence in economic prospects (e.g., Joyce and others, 2010 and Wright, 2011). Fourth, unconventional measures may enhance market liquidity and reduce risk premia (e.g., Gagnon et al, 2010).

There may be additional channels for commodity prices, including through other financial variables, particularly interest rates and exchange rates—both variables likely affected by UMPs. For example, Frankel (2008) describes a number of channels through which lower real interest rates should lead to higher commodity prices. A depreciating U.S.

dollar should similarly lead to higher commodity prices, including due to changes in demand related to shifting purchasing power parities and changes in supply from suppliers whose costs are in different (non-U.S. dollar) currencies. This suggests that events that change broader financial conditions, including interest rates and exchange rates, should also affect commodity prices.

B. Recent Empirical Findings

Most studies find that UMPs that ease policy (both announcements and operations) serve to reduce interest rates and depreciate the exchange rate of the domestic country. In particular, an emerging body of evidence indicates that U.S. asset purchase announcements lowered Treasury yields and depreciated the U.S. dollar, particularly over short horizons (such as one day)—see Gagnon and others (2010), Neeley (2010), Glick and Leduc (2011, 2013), Szczerbowics (2011), and Rosa (2013). Similar results have been found for the United Kingdom with respect to gilt yields and sterling by Joyce and others (2010) and Glick and Leduc (2011).

Fratzscher, Lo Duca, and Straub (2012) find that UMPs have had large effects on portfolio decisions and cross-border capital flows, although there are important differences between announcements and operational events. In particular, actual purchases led to higher capital inflows to emerging market investment funds, developments typically associated with rising commodity prices.

There are fewer empirical studies covering the effects of UMPs on commodity and equity prices. Using event study methodology, Kozicki, Santor and Suchanek (2011) find no consistent evidence that U.S. LSAP announcements contributed to increases in commodity prices. The authors looked at 17 commodity futures prices within a 2–3 day window surrounding an announcement date and concluded that the abnormal returns of commodity prices were not statistically different from zero. Their study also documented an appreciation of currencies of commodity-exporting countries against the U.S. dollar and a rise in their stock market indices following LSAP announcements, especially in 2008–09. Glick and Leduc (2011) conclude that LSAP announcements by the Federal Reserve and the Bank of England generally led to declines in commodity prices, especially during the first phase of these operations in 2008–09. Positive monetary policy surprises in the U.S. led to larger declines in commodity prices, particularly energy prices, than in the U.K. The authors use regression analysis using daily S&P Goldman Sachs Commodity Indices and their sub-indices based on spot (or nearest futures) prices. Bayoumi and Bui (2011) use event-study methodology to conclude that U.S. QE1 announcements had a stronger initial impact on financial conditions, including commodity prices and U.S. and foreign equities, than QE2 announcements, but the effects of the latter on commodity prices—oil and non-oil— and equity indices were generally not statistically significant. The effects of QE1 on commodity and equity prices were significant and negative, especially for the post-Lehman sample period.

Other recent studies examine the impact of both conventional and unconventional monetary policy surprises on asset prices. Glick and Leduc (2013) examine the response of the U.S. dollar to the Fed's monetary policy announcements using intra-day data and find a significant depreciation of the U.S. dollar following both conventional and unconventional policy surprises. Their paper documents that the magnitude of U.S. dollar depreciation declines from LSAP1 through LSAP3, and that the U.S. dollar depreciation effect is highest against the euro. Among the few studies that go beyond price levels and examine higher moments of the price distribution is Bekaert, Hoerova, and Lo Duca (2010). They use sub-components of the VIX (one that reflects actual expected stock market volatility and a residual that reflects risk aversion) to test the effects of monetary policy on stock market risk employing a simple VAR method. Their study finds that accommodative monetary policy decreases risk aversion (increases risk appetite) in the stock market after about nine months, while its effects on market uncertainty are similar but weaker. Rosa (2013) uses event-study approach to measure the effect of monetary policy surprises on intra-day energy prices and finds that FOMC asset purchase announcements have significant effects on both levels and volatility of energy futures prices, mainly through the exchange-rate channel. He finds a negative relationship between unanticipated LSAP announcements and oil price futures.

III. Methodology

We provide a brief exposition of the theory and our empirical strategy, both of which draw on Cheng (2010). To give some intuition, consider a call (put) option that provides the owner with the option, but not the obligation, to purchase (sell) some "underlying" asset at a specified price at a specified future date. A potential purchaser would decide whether or not to buy this option based on its expected payoff, one key component of which is the probability that the price of the asset will indeed be higher (lower) than the exercise price (and be "in-the-money") at the time of expiry. If not, the option will expire worthless ("out-of-the-money"). In fact, a call (put) option should embed the probabilities of all the different prices above (below) the exercise price. Standard asset price theory lets us consider an option as a probability-weighted average of all possible payoffs. As these embedded probabilities change, so will the expected payoff and current price of the option. Our aim is to map observable changes in option prices to changes in the underlying probabilities, controlling for all other factors that influence option prices, including the underlying price and risk-free interest rates. One factor we cannot control for, however, is a shift in risk preference and, as a result, we assume "risk neutrality."

To obtain a picture of the entire probability distribution we need more than one option. This is because differences in risk preferences might imply a different set of risk-neutral probabilities embedded in each option price. From a set of options on the same asset, with identical expiries but different exercise prices, it is possible to recover an estimate of the probability density function that best fits current market prices. This can be achieved by a number of methods, but one approach is to fit a lognormal distribution (which we assume is a realistic form for the density function) to actual market data. By using a weighted mixture of lognormal distributions, this method is able to capture important features of the density function, particularly the fatness of the tails (kurtosis) and the extent to which it is asymmetric (skew). Once we have an estimated density function, we can calculate various statistics, relying more on cumulative densities (e.g., the 5th or 95th percentile price) rather than typical summary statistics (such as the mean and the variance) given the non-normal characteristics of the final estimate.

A. Theory of Risk Neutral Distributions

We use well-known asset pricing relationships to derive the risk distribution of commodity prices. In particular, we assume that the price of a long position in a risky asset can be expressed as:

$$P_0 = \exp(-r\tau)\int_{-\infty}^{\infty} Z_\tau(\theta) f^N(\theta)\,d\theta \equiv \exp(-r\tau)E^N\{Z_\tau\}. \tag{1}$$

In (1), P_0 is the price of the futures contract in period 0, r is the risk-free interest rate over the horizon τ, Z_τ is the payoff contingent on state θ to the asset in period $\tau > 0$, and $f^N(\theta)$ is the risk-neutral probability density function. In other words, the current price is the present value probability-weighted average over the possible range of payoffs in some future period. The risk neutral distribution (henceforth RND) incorporates the market's collective objective probability density function on prices $f(\theta)$ together with investors' intertemporal rate of marginal substitution that results from the standard Euler condition. This is often written as:

$$M_\tau(\theta) \equiv \exp(-\rho\tau)\frac{U'(C_\tau(\theta))}{U'(C_0)}. \tag{2}$$

In (2), ρ is the investor's subjective discount rate and U'(C) is the marginal utility of consumption. Unfortunately, investor preferences as described by (2) are not directly observable and we are forced to work with $f^N(\theta)$.

Cox and Ross (1976) showed that the price of a European-style call option can be written in a similar fashion to (1) as:

$$C(X,\tau) = \max(S_\tau - X, 0) = \exp(-r\tau)\int_X^{\infty}(S_\tau - X)\, f^N(S_\tau)\,dS_\tau. \tag{3}$$

In (3), C is the price of the call option, X is the exercise price, S_τ is the price of the underlying asset (e.g., a commodity futures contract) at expiration in period τ, and $f^N(S_\tau)$ is the RND for all possible prices of the underlying (with the distribution truncated at X). Differentiating (3) with respect to X (and making use of Leibnitz' rule) obtains:

$$C'(X,\tau) = -\exp(-r\tau)\int_X^{\infty} f^N(S_\tau)\,dS_\tau. \tag{4}$$

Differentiating (4) again with respect to X obtains:

$$C''(X,\tau) = \exp(-r\tau) f^N(X) . \tag{5}$$

(5) can then be used to estimate the entire RND for the underlying asset payoffs. In the case of a commodity futures contract, the payoff is simply the price that prevails upon expiration and hence (5) can be used to estimate the probability distribution function of prices at some future period.

B. Estimation of Risk Neutral Distributions

A number of methods have been proposed to recover the RND. We follow Cheng (2010) and Bahra (1997) and assume a specific log-normal functional form for the RND. In particular, we assume that $f^N(S_\tau)$ is the weighted average of N-component lognormal density functions with weights ω_i indexed by i:

$$f^N(S_\tau) = \sum_{i=1}^{N} \left[\omega_i L(\alpha_i, \beta_i; S_\tau) \right] . \tag{6}$$

Two parameters govern the lognormal distributions. The first is α_i which is derived from the stochastic differential equation for the log of the price of the underlying S:

$$\alpha_i = \ln S_0 + \left(\mu_i - \tfrac{1}{2}\sigma_i^2 \right) \tau . \tag{7}$$

In (7), μ can be interpreted as the drift term and σ as the volatility, for instance from a Brownian motion process. However, as Melick and Thomas (1997) point out, assuming a functional form for the terminal distribution does not impose any restrictions on the stochastic process of the underlying asset price. The second is β_i which is the volatility of the underlying over the horizon τ:

$$\beta_i = \sigma_i \sqrt{\tau} . \tag{8}$$

The parameters α_i, β_i, and ω_i for all i are to be estimated. Following Cheng (2010) and recognizing that α_i and β_i can be uniquely identified by μ_i and σ_i we focus our attention on these latter parameters with a ready economic interpretation. We can write the fitted call and put prices using these distributions as:

$$\hat{C}_j = \exp(-r\tau) \int_{X_j}^{\infty} \left(S_\tau - X_j \right) \left[\sum_{i=1}^{N} \omega_i L(\alpha_i, \beta_i; S_\tau) \right] dS_\tau . \tag{9}$$

$$\hat{P}_j = \exp(-r\tau) \int_{X_j}^{\infty} \left(X_j - S_\tau \right) \left[\sum_{i=1}^{K} \omega_i L(\alpha_i, \beta_i; S_\tau) \right] dS_\tau . \tag{10}$$

In the absence of arbitrage, it must be true that the current spot price is equal to the futures price discounted by the risk-free interest rate (and in the case of commodities, the convenience yield) which we have denoted by μ. This can be written as:

$$F_\tau = S_0 \exp\left(\mu\tau\right). \tag{11}$$

The problem is then to choose a set of parameters ($\mu_{1,} \mu_{2,\ldots,} \mu_N$), ($\sigma_{1,} \sigma_{2,\ldots,} \sigma_N$), and ($\omega_{1,} \omega_{2,\ldots,} \omega_N$) to minimize the distance between fitted and actual options prices subject to the constraint that the no arbitrage condition holds and that the weights on the lognormal mixtures sum to unity:

$$\min \sum_{j=1}^{K} \left[C\left(X_j, \tau\right) - \hat{C}_j\left(\mu, \sigma, \omega\right) \right]^2 + \sum_{l=1}^{L} \left[P\left(X_j, \tau\right) - \hat{P}_j\left(\mu, \sigma, \omega\right) \right]^2 \tag{12}$$

subject to:

$$F_\tau = S_0 \sum_{i=1}^{N} \omega_i \exp\left(\mu_i \tau\right) \qquad \text{and} \qquad \sum_{i=1}^{N} \omega_i = 1 \qquad \text{where} \qquad \omega_i \geq 0 \forall i \tag{13}$$

$C(X_j, \tau)$ and $P(X_j, \tau)$ in (12) are observed prices for call and put options, respectively, with an exercise price X_j and expiration date τ.

Our starting values for the search algorithm are $\mu \approx 0$ and $\sigma = \sigma^{IV}$ (implied volatility of the at-the-money option—see below for details). We imposed restrictions on the parameters similar to Cheng (2010) and in most cases these facilitated stability in the search process. However, we were also forced to loosen the restrictions due to a failure to converge in some cases, particularly for less liquid contracts where the prices of deep out-of-the-money (OTM) options were particularly volatile. (These are options for which the strike price is significantly different from the prevailing price of the underlying asset.) We used four lognormal mixtures, initially equally-weighted such that $\omega_1 = \ldots = \omega_4$.

From the fitted density functions we recovered variables that reflect "tail risk," or the positive and negative price changes expected with a 5 percent probability (while still assuming risk neutrality). Specifically, this is measured as the log distance between the 5th percentile price and the mean (futures) price for the left tail (or downside risk) and the log distance between the 95th percentile price and the mean price for the right tail (or upside risk).

C. Event Study Methodology

We use event studies and statistical tests to determine whether we can reject the null hypothesis that UMP events have no impact on the asset price distribution statistics we obtain from the estimation procedure described above. In all cases, our test date is the day following the event (denoted as t+1) since in many cases, markets were close or approaching the close before the event occurred. For example, FOMC decisions are typically announced at 11:30am or 1:15pm Central time while corn and soybean contract trading closes at 2:00pm Central time.

The first test is Patell's (1976) aggregated *t*-test where we compare at-the-money (ATM) implied volatility and the left and right tails (measured by log distance) of the fitted RND at time *t*+1 to the sample mean for these variables for the preceding 20 days (i.e., *t*-1, *t*-2, …, *t*-20). This control sample period (or estimation window) is chosen as a balance between adequate size and a need to ensure that the tendency for RNDs to converge to the underlying spot price over time does not dominate. For example, the RND should in most cases become increasingly leptokurtic as the probability of large price changes declines as a function of time to expiry. At a residual maturity of about 3 months and a 20 day control sample, we can reject the null hypothesis that these variables (ATM implied volatility and the 5^{th} and 95^{th} percentile tails) are nonstationary at the 1 percent level on the basis of standard panel unit root tests. Specifically, where *m* is the sample size (i.e., the number of non-overlapping events for a particular asset *i*) our *t*-test statistic is:

$$\frac{1}{\sqrt{m}}\sum_{j=1}^{m}\frac{x_{ij,t+1}-\mu_{ij,t-1}}{\sqrt{\mathrm{var}_{t-1}(x_{ij})}}\sim T_{n-1} \tag{14}$$

In (14), for any asset *i* and event *j*, $x_{ij,t+1}$ denotes the value of the variable at the test date *t*+1 and $\mu_{ij,t-1}$ and var_{t-1} denotes the sample mean of the process $\{x\}$ calculated using the estimation window at date *t*-1. We complement this with another test of significance that does not rely on the assumption of normality of the variable *x*. This is the small sample ranking test suggested by Corrado (2010):

$$\frac{4.91}{\sqrt{m}}\sum_{j=1}^{m}\left[u_{ij}^{0.14}-\left(1-u_{ij}\right)^{0.14}\right]\sim N(0,1)$$

where (15)

$$u_{ij}=\frac{h_{ij}}{n_{ij}+2}$$

In (15), h_{ij} denotes the rank of the variable *i* during event *j* on the test date *t*+1 and n_j denotes the control period sample size (which equals 20 in our case).

A third test takes account of the clustering or overlaps in the event windows. Some of our tests assess the effect of the same event on a range of assets, introducing cross-asset correlations on the test date and violating the assumptions of independence upon which the t-test and rank test are based. To deal with clustering, we estimate a fixed-effects panel regression in which for each asset *i* and event *j* within the panel (membership of which will vary depending on the test) the variable x_{ij} is the endogenous variable and a constant and dummy variable are the explanatory variables. The dummy variable *d* takes a value of 0 for the 20 days before the test date (i.e., *t-20,t*-19,…, *t*-1) and a value of 1 on the test date (*t*+1).

$$x_{ij,s} = k_{ij} + \gamma d + \varepsilon_s \tag{16}$$

The t statistic for the common coefficient γ is the test statistic for the significance of UMP event. The regression is estimated using ordinary least squares and t statistics are calculated using panel corrected cross section SUR-robust standard errors.

A final test extends the regression analysis to take some account of initial conditions. Specifically, we allow for the response of the distribution to the UMP event to be conditioned on the gap between the VIX at period *t*-1 for each event *j* and its mean value at *t*-1 for all 14 events. We use the VIX rather than asset-specific indicators as it provides a measure of broad uncertainty that will typically be unaffected by market-specific initial conditions, such as the risk of a supply shock in a particular commodity market. The intuition is that during periods of very high uncertainty, the effect of UMP events may be larger. We measure initial conditions by interacting the event dummy variable *d* with the gap between the endogenous variable *x* and its mean value for that asset during the 20 days preceding all 14 UMP events.

$$x_{ij,s} = k_{ij} + \gamma_1 d + \gamma_2 d\left(\mathrm{VIX}_{j,t-1} - \overline{\mathrm{VIX}}_{t-1}\right) + \varepsilon_s \tag{17}$$

In (17) the coefficient γ_2 measures the impact of initial conditions.

IV. Data

A. Financial Data

Our sample includes the EUR/USD exchange rate, the S&P500 equity index, gold, crude oil, natural gas, corn, and soybeans. Options prices for these assets and commodities at a daily frequency were sourced from Thomson Reuters Datastream and checked against a more limited sample of data from the relevant options exchange directly. We worked with a horizon of three months, which means that we identified contracts with an expiration date closest to three months ahead of each monetary policy event date. This choice reflected a trade-off that allowed for a sufficiently long horizon to allow for the incorporation of significant uncertainty but also short enough to ensure a sufficient trading liquidity, which can decline sharply as expiration dates lengthen.

For each event, we used about seven call and put options with strike prices centered around the ATM option strike price on the date of the event. Strike price increments were determined by the price characteristics of each contract. We identified the spot price as the current cash price. For commodities, this was for physical delivery with similar specifications as the futures contract (differences were mainly in terms of delivery point) as published by the U.S. Departments of Agriculture and Energy or the London Bullion Market (see Table 1 for contract specifications). The risk-free interest rate used was the 3-month yield from the zero coupon U.S. Treasury curve.

B. Monetary Policy Events

We use what has become the standard event dating for UMP events in the literature classified as QE1, QE2, and QE3, where QE denotes quantitative easing. In all cases, these events are verbal or written communications, rather than actual monetary operations (see Table 2).

V. Results and Discussion

A. Results

We find strong evidence that UMP events in the United States trigger significant realignments of risk perception in financial markets when we consider all 14 UMP events between 2008 and 2012. Figure 1 presents estimates for the coefficient γ on the event dummy variable d in equation (17) along with confidence intervals calculated using robust standard errors. Results for food and energy commodities, all commodities, and non-commodities (equities and the exchange rate) are presented separately in Panel 1.

For the full sample, we are able to reject the null hypothesis of no change in the log distance between the futures price and, separately, both the left- and right-hand tails of the distribution. This implies that, following a UMP event that serves to ease policies, asset price distributions shrink at the tails, moving closer to the prevailing futures prices, pointing to reductions in both upside and downside tail risks. In contrast, there is no significant impact on at-the-money implied volatility. In other words, the effect is much stronger on the perceived probabilities of very large prices movements than it is on smaller changes in prices. These results are broadly consistent across the various sub-groups, with the absolute impact on tail risks larger for commodities than for equities and exchange rates. The dispersion of commodity distributions, measured by log distance, is typically much larger than that for major equity indices and exchange rates. To give a sense of magnitudes, the average shift in the left tail (downside risk) for the S&P500 would be about 4 percentage points, reducing the log distance to the mean from (approximately) 25 percent to 21 percent.

The effects are mainly asymmetric, with the left tail shifting towards the mean by more than the right tail. This suggests that the decline in price tail risk is larger for downside risks relative to upside risks. This finding was consistent across all assets with the exception of the EUR/USD exchange rate for which the narrowing of the distribution was symmetric. At the same time, we find that the impact on price levels is not statistically significant, a finding consistent with earlier studies (these results are not shown). This implies a "mean preserving" shift in the distribution in which the asymmetric shifts in tail risk are being offset by shifts closer to the shoulders of the distribution.

Considering each asset individually, the decline in left and right tail risk following UMP events is statistically significant for almost all the assets in our sample on the basis of Patell's t-test and the rank test (see Appendix, Figure 5). Note that wheat is shown below but is excluded from the aggregate tests because we found the out-of-the-money options to be relatively illiquid and possibly unreflective of investor perceptions. Implied volatility typically declines across assets but the fall is statistically significant only for gold and then only for one test.

Estimating regression (16) for all assets over QE1, QE2, and QE3 events separately, and again focusing on the value of the event dummy coefficient γ, indicates that the first and most recent stages of the QE program shifted perceptions of risk more than the middle stage (QE2) as shown by Panel 2. In tests encompassing all assets, we find statistically significant and larger inward shifts of the tails of the price distributions during QE1 and QE3. In contrast, inward shifts following QE2 events were smaller and not significant. It is not clear whether this was due to a greater "surprise element" or the nature of the operations was perceived differently by markets.

Initial conditions appear to affect the impact of UMP events, based on the results from the estimation of (17). The event dummy coefficient γ_1 is quantitatively similar to its counterpart (γ) in (16). The event dummy interacted with the VIX gap γ_2 is statistically significant only for the right tail and serves to amplify the effect of a UMP event. As an example, consider the VIX gap during event 1 which, as defined above, was 31.6 (i.e., the VIX was 31.6 index points higher at t-1 for event 1 compared to the average at t-1 for all 14 events). With an estimated coefficient γ_2 of -0.07, this suggests that the initial condition contributed to about 2 percentage points of the inward shift of the right tail (see Panel 3).

B. Discussion

The overarching conclusion from our analysis is that "tail risk," defined in this paper as the price change expected with a 5 percent probability, declines in the immediate aftermath of an event that serves to ease monetary policy through unconventional means. This is strong evidence supporting the view that policymakers achieved one of their objectives when embarking on UMP, namely a reduction in market uncertainty that could contribute to an easing in financial conditions.

An important result is that the effect of UMP is much larger on the tails of the distribution than the mean. In other words, the implied volatility that prices the option changes much more for options that are deeply in or out-of-the-money. Volatility "smiles" are often perceived to reflect risk aversion, with investors willing to pay a premium to insure against extreme market outcomes, as well as objective beliefs regarding price outcomes. Unfortunately, it is not possible for current technology to identify whether shifts in the RND are due to investor beliefs of risk aversion. At the same time, it is likely that both are linked in the sense that as investors become more confident that an extreme price event can be avoided so risk aversion will decline. Our conclusion is that UMP, at least during the crisis and post-crisis period, exerted its most important effect in significantly lowering the probability of extreme outcomes. This surely marks the recent phase of UMP as distinct from regular monetary policy actions and signals one possible extension of this research.

One puzzle emerging from the results is that both downside and upside risks are significantly affected, albeit with some asymmetry that caused larger shifts in the left tail of the RND. A reasonable prior, conditional on the result that UMP easing events reduce market uncertainty, is that the effect would be much larger on the left tail. This would be consistent with more accommodative monetary policy that eases financial conditions, which would reduce the probability of disruptive financial market dislocation or deteriorating economic growth. In turn, this would likely lower the probability of large declines in "risky" asset prices with cyclical characteristic, including commodities and equities. All else equal, this would also shift the mean of the distribution to the right and imply a rise in the underlying asset price. As previous research has found, this has not happened following UMP easing events since 2008.

That both tails shift inward naturally reflects changes in the supply and demand of deep out-of-the-money options. One possible explanation is that many market participants positioned for large price changes that may result from macro events prefer to assume symmetric exposure, for example through a long strangle strategy. This would involve purchasing deep out-of-the-money calls and puts at strike prices that are significantly above and below the prevailing price of the underlying. This would be an interesting extension of this research.

One conclusion we draw is that there is no evidence for "excess speculation" in the short run after a UMP event as it is defined in Section I. Such speculation is typically thought to be consistent with a rise in prices, in part driven by the expectation of future large price gains that are not linked to fundamentals. From the perspective of a RND, this would surely be represented by large rightward shift in the mean of the distribution driven by a significant rise in right tail or upside risk. We find the opposite effect, that right tail risk declines and the shift in the distribution is, in fact, "mean preserving."

C. Case Study: Federal Reserve Announcement of the TALF Facility

This section provides a brief case study of the first event in our sample, which was an important milestone in the UMP program. This event took place on November 25, 2008 at 8:15 am EST, with the Federal Reserve and the Department of the Treasury unveiling their plan to create the Term Asset-Backed Securities Loan Facility (TALF) and purchase direct obligations and mortgage-backed securities of housing-related GSEs.

Between the day before (t-1) and the day after (t+1) the event, futures prices were mixed and at-the-money implied volatility broadly declined (see Table 3). The 5^{th} percentile and 95^{th} percentile tails of the RND shifted in towards the (futures price), indicating that markets had priced-in lower tail risks shortly after the announcement. The one exception in this case is natural gas, the right tail for which shifted in on the day of the event (t) but subsequently widened the day after the event (t+1). This shift was likely influenced by the release of EIA's *Natural Gas Monthly* on November 26 (day after the UMP event).

Looking at the effect of the announcement over the 10-day horizon, as shown in Table 4, we can see that over time prices eased across commodities, but picked up for equities and exchange rates. The outcomes for energy commodities were strongly affected by the EIA *Short-Term Energy Outlook* released on December 9, 2008 (10 days after the UMP event), which projected the first decline in global annual oil demand since 1983 and caused a drop in oil spot and futures prices as well as an upswing in volatility (oil VIX). Meanwhile, implied volatilities declined for non-energy commodities and exchange rates, and the tails of the price distribution shrank, especially on the right-hand side. Of course, causality must be interpreted with caution, as there in no practical way to separate the effects of other price-moving events from those of UMP announcements.

Looking at the probability density functions around the event date, the decline in price risk is even more evident: on the day of the event price distributions narrowed down both from the right and from the left for oil, corn, and soybeans, implying lower price volatility. This effect was amplified over time, with price probability distributions narrowing for all the assets in our sample ten days after the event. Notably, the right tail of the RND (implying price increases) became significantly thinner (see Panel 4).

To conclude, the TALF announcement contributed to a broad and substantial reduction in tail risks, particularly of the left tail. The effects vary for each event and across commodities, but it is consistent with what we saw across events on average.

VI. Conclusion

In this paper, we examine the effects of unconventional monetary policy (UMP) events in the United States on asset price risk using risk-neutral density functions estimated from options prices. Based on an event study including a key exchange rate, an equity index, and four commodities, we find that "tail risk" diminishes in the immediate aftermath of UMP events, particularly downside left tail risk. We also find that QE1 and QE3 had stronger effects than QE2. We conclude that UMP events that serve to ease policies can help to bolster market confidence in times of high uncertainty.

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APPENDIX: TABLES

Table 1. Spot Delivery and Derivative Contract Specifications

Asset	Exchange	Contract	Physical Characteristics	Months Traded	Contract Size	Pricing Unit
S&P 500 Index	Chicago Mercantile Exchange	Futures	Capitalization-weighted index of 500 stocks	Mar, Jun, Sep, Dec	$250 x S&P 500 futures price	U.S. dollars per contract
		Options		Mar, Jun, Sep, Dec	One S&P 500 futures contract	
		Spot	Capitalization-weighted index of 500 stocks			U.S. dollars per contract
EURUSD	LIFFE Amex exchange (Amsterdam)	Futures	Euro/U.S. dollar rate set by EuroFX at 1 pm Amsterdam time	Mar, Jun, Sep, Dec	20,000 EUR	U.S. dollars per 100 euro
		Options		Mar, Jun, Sep, Dec	One EUR/USD futures contract	
		Spot	Euro/U.S. dollar rate set by EuroFX at 1 pm Amsterdam time			U.S. dollars per 100 euro
Gold	Chicago Mercantile Exchange	Futures	Gold (a minimum of 995 fineness)	Current calendar month; the next two calendar months; any Feb, Apr, Aug, and Oct falling within a 23-month period; and any Jun and Dec falling within a 72-month period beginning with the current month.	100 troy ounces	U.S. dollars per troy ounce
		Options			One COMEX Gold futures contract	
		Spot	Gold (a minimum of 995 fineness)			U.S. dollars per troy ounce
Oil	New York Mercantile Exchange	Futures	Light sweet crude oil	Consecutive months are listed for the current year and the next five years; in addition, the Jun and Dec contract months are listed beyond the sixth year.	1,000 barrels	U.S. dollars per barrel
		Options			One crude oil futures contract of 1,000 barrels	
		Spot	Light sweet crude oil			U.S. dollars per barrel
Natural Gas	New York Mercantile Exchange	Futures	Natural gas delivered at Henry Hub, LA	Consecutive months for the current year plus the next twelve full calendar years.	10,000 MMBtu	U.S. dollars per MMBtu
		Options		Consecutive months for the current year plus the next three full calendar years.	One crude oil futures contract of 1,000 barrels	
		Spot	Natural gas delivered at Henry Hub, LA			U.S. dollars per MMBtu
Corn	Chicago Mercantile Exchange	Futures	Yellow corn grade #2	Mar, May, Jul, Sep, Dec	5,000 bushels (127 MT)	U.S. cents per bushel
		Options		Mar, May, Jul, Sep, Dec. The monthly option contract exercises into the nearby futures contract.	One corn futures contract (of a specified month) of 5,000 bushels	
		Spot	Yellow corn grade #2			U.S. cents per bushel
Soybeans	Chicago Mercantile Exchange	Futures	Yellow soybean grade #2	Jan, Mar, May, Jul, Aug, Sep, Nov.	5,000 bushels (136 MT)	U.S. cents per bushel
		Options		Jan, Mar, May, Jul, Aug, Sep, Nov. The monthly option contract exercises into the nearby futures contract.	One soybean futures contract (of a specified month) of 5,000 bushels	
		Spot	Yellow soybean grade #2			U.S. cents per bushel

Sources: United States Department of Energy; United States Department of Agriculture; Chicago Mercantile Exchange; New York Mercantile Exchange; NYSE/ Euronext; LIFFE Amex Exchange; London Bullion Market; and Bloomberg, L.P.

Table 2. Monetary Policy Event Dates, November 2008 to September 2012

No.	Phase	Date	Description	Announcement
1	QE 1	11/25/2008	Initial LSAP announcement	Fed announces purchases of $100 billion in GSE debt and up to $500 billion in MBS.
2		12/1/2008	Bernanke Speech	Chairman Bernanke mentions that the Fed could purchase long-term Treasuries.
3		12/16/2008	FOMC Statement	FOMC statement first mentions possible purchase of long-term Treasuries.
4		1/28/2009	FOMC Statement	FOMC statement says that it is ready to expand agency debt and MBS purchases, as well as to purchase long-term Treasuries.
5		3/18/2009	FOMC Statement	FOMC will purchase an additional $750 billion in agency MBS, to increase its purchases of agency debt by $100 billion, and $300 billion in long-term Treasuries.
6		8/12/2009	FOMC Statement	Fed will purchase a total of up to $1.25 trillion of agency MBS and up to $200 billion of agency debt by end-2009. Also, the Fed is in the process of buying $300 billion of Treasury securities.
7		9/23/2009	FOMC Statement	Fed's purchases of $300 billion of Treasury securities will be completed by the end of October 2009.
8		11/4/2009	FOMC Statement	The amount of agency debt to be purchased by the Fed reduced to $175 billion. MBS and agency debt purchases are to be completed by end-2010Q1.
9	QE 2	8/10/2010	FOMC Statement	Fed will keep constant its holdings of securities at their current level by reinvesting principal payments from agency debt and agency MBS in longer-term Treasury securities. FOMC will continue to roll over the Fed's holdings of Treasury securities as they mature.
10		8/27/2010	Bernanke Speech, Jackson Hole	Chairman Bernanke names "conducting additional purchases of longer-term securities" as a tool, "is prepared to provide additional monetary accommodation through unconventional measures ..."
11		10/15/2010	Bernanke Speech, Boston	Chairman Bernanke states the Fed will continue keeping interest rates low and mentions further quantitative easing.
12		11/3/2010	FOMC Statement	Fed intends to purchase a further $600 billion of longer-term Treasury securities by the end of 2011Q2, a pace of about $75 billion per month.
13	QE 3	8/31/2012	Bernanke Speech, Jackson Hole	Chairman Bernanke hints at QE3: "The Federal Reserve will provide additional policy accommodation as needed to promote a stronger economic recovery and sustained improvement in labor market conditions in a context of price stability."
14		9/13/2012	FOMC Statement	The Fed will purchase additional agency MBS at a pace of $40 billion per month.

Sources: Kozicki, Santor and Suchanek (2011); and the Board of Governors of the Federal Reserve System of the United States.

Table 3. Change Over the Event Date 1/

	Oil	Natural Gas	Gold	S&P500	EURUSD	Corn	Soybeans
Futures price (percent)	0.6	0.5	-1.1	4.5	0.2	0.0	0.3
Implied volatility (percentage points)	-0.6	1.8	-1.4	-4.5	-0.3	0.0	-0.7
VaR, 5% (percent)	3.0	-1.2	5.9	44.6	0.8	0.8	1.0
VaR, 95% (percent)	-0.5	1.5	-6.3	-15.6	-0.1	-0.5	-0.1

1/ From the day preceding the event to the day following the event.
Sources: Datastream; and authors' calculations.

Table 4. Change 10 Days After the Event Date 1/

	Oil	Natural Gas	Gold	S&P500	EURUSD	Corn	Soybeans
Futures price (percent)	-15.8	-16.8	-5.6	5.0	0.3	-11.7	-8.2
Implied volatility (percentage points)	29.6	12.5	-4.8	0.7	-1.6	-9.3	-3.2
VaR, 5% (percent)	-40.1	-25.1	5.4	41.9	3.2	7.3	-2.9
VaR, 95% (percent)	-5.2	-11.6	-13.6	-13.9	-2.0	-22.4	-12.1

1/ Compared to the day preceding the event.
Sources: Datastream; and authors' calculations.

APPENDIX FIGURES

Panel 1. Estimated UMP Impact Coefficients and 95 Percent Confidence Intervals, 2008–12

Figure 1. All Assets and All Events

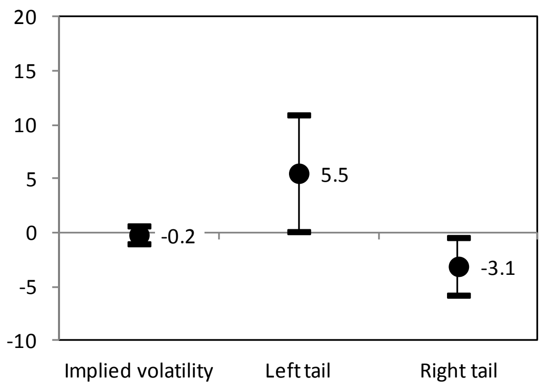


Figure 2. Food and Energy and All Events

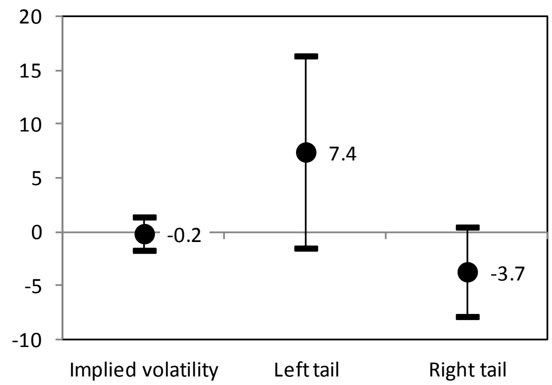


Figure 3. Commodities and All Events

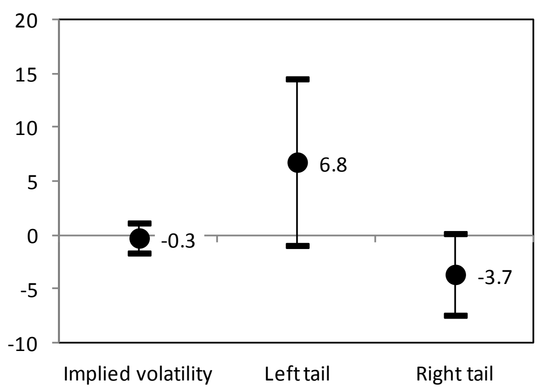
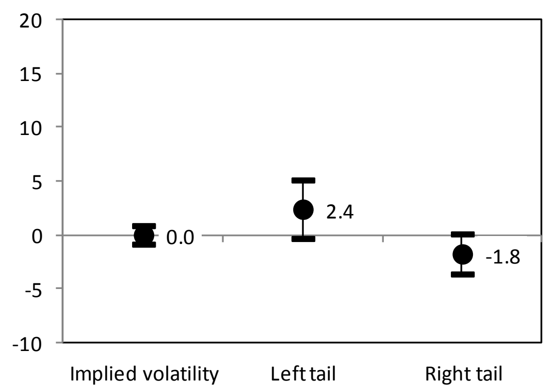
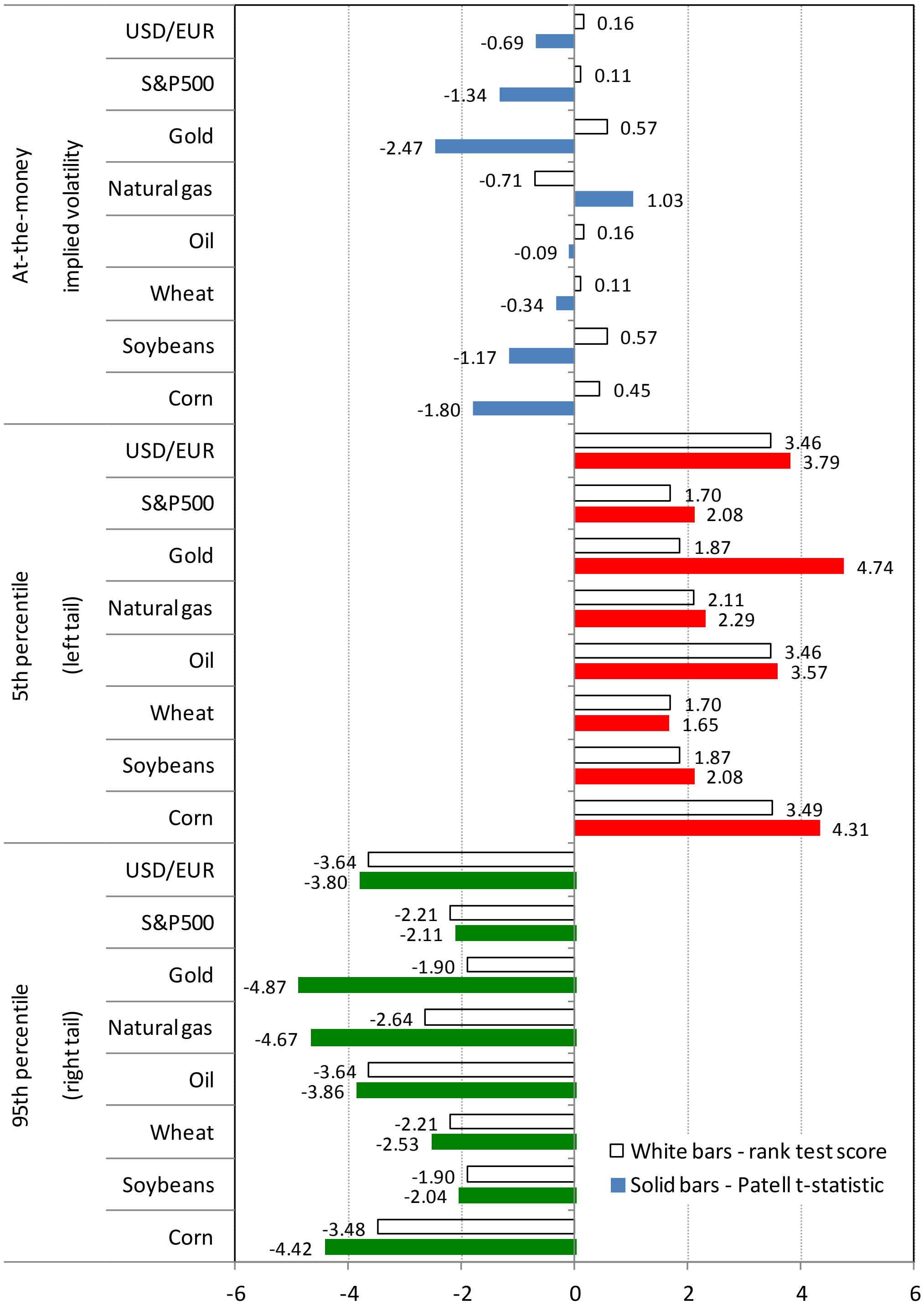


Figure 4. Non-Commodities and All Events



Source: Authors' calculations.

Figure 5. Patell Test and Rank Test t-statistics, All Asset over Events



Source: Authors' calculations.

Panel 2. Estimated UMP Impact Coefficients and 95 Percent Confidence Intervals by UMP Phase: QE1, QE2, and QE3

Figure 6. All Assets and All Events

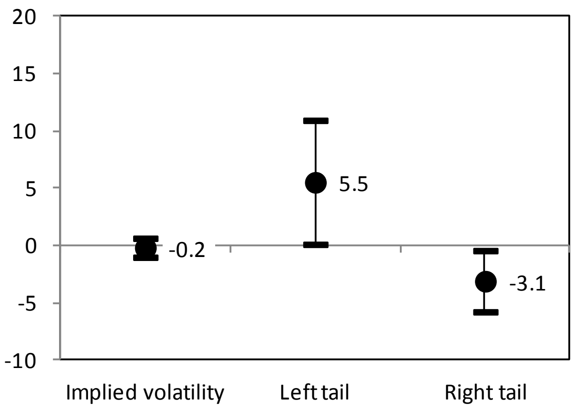


Figure 7. All Assets and QE1 Events

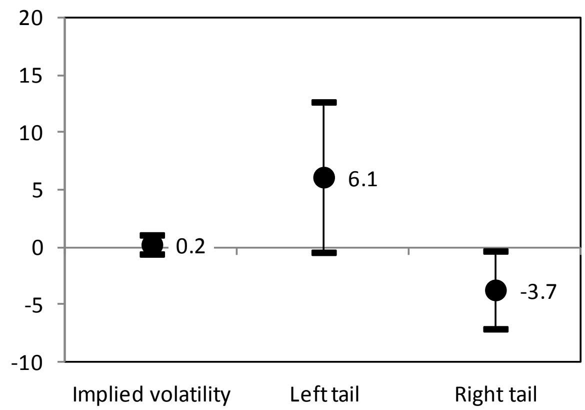


Figure 8. All Assets and QE2 Events

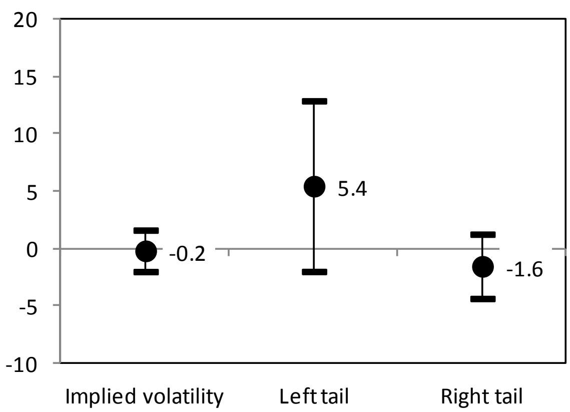
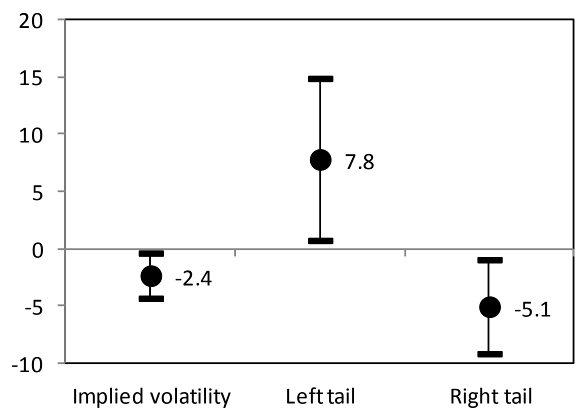


Figure 9. All Assets and QE3 Events



Source: Authors' calculations.

Panel 3. Estimated UMP Impact Coefficients Including Initial Conditions and 95 Percent Confidence Intervals

Figure 10. Impact Coefficient on Event Dummy

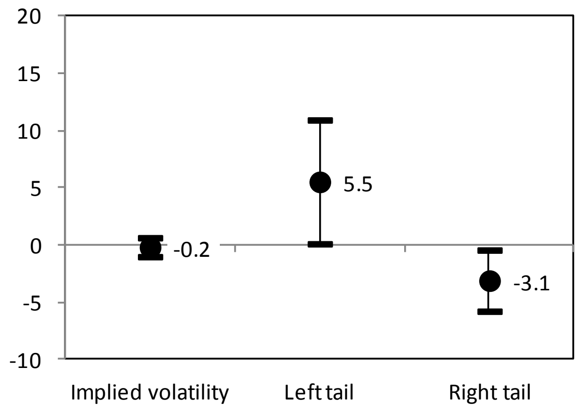
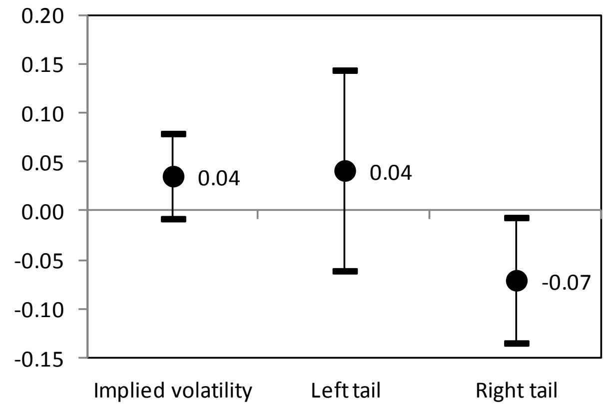


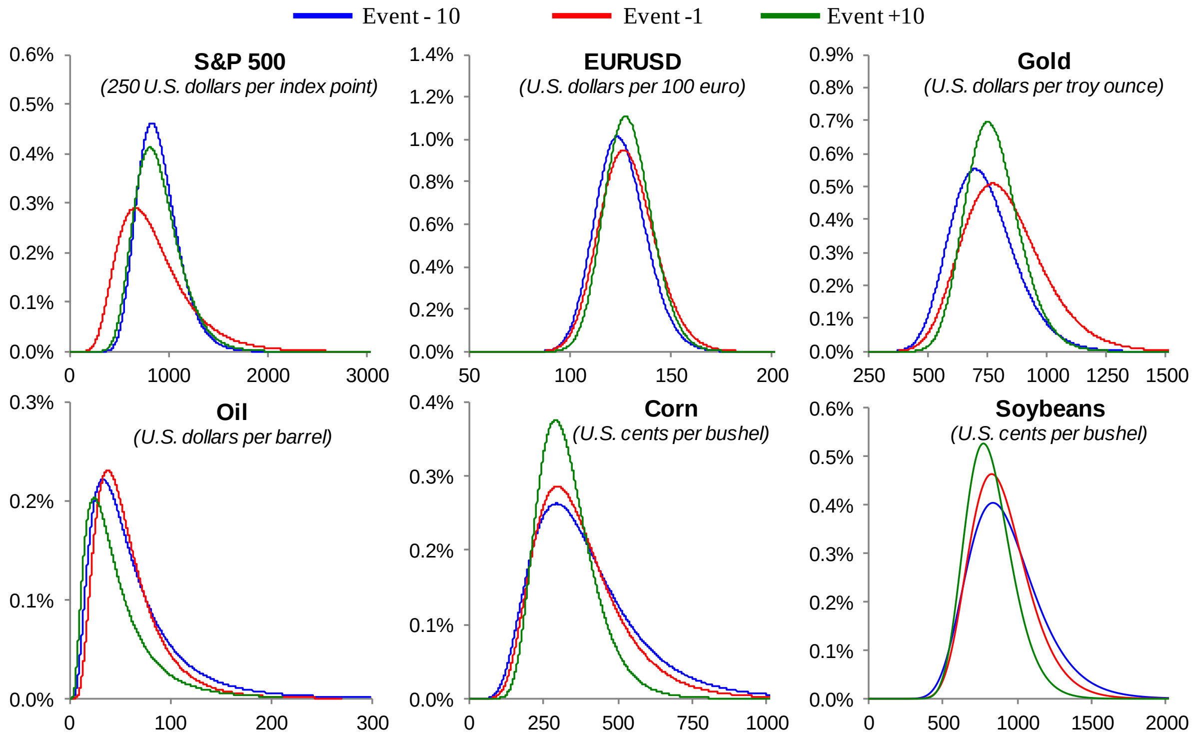
Figure 11. Impact Coefficient on Initial Condition



Source: Authors' calculations.

Panel 4. Probability Density Functions for Selected Assets: Event 1

(Price on the x-axis; probability on the y-axis)



Sources: Datastream; and authors' calculations.