Option-implied expectations in commodity markets and monetary policy

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Abstract

In this paper we estimate the dynamic interactions between option-implied variance and skewness in agricultural commodity markets and monetary policy. Using a structural vector autoregressive (SVAR) framework, we find that an expansionary (contractionary) monetary policy upwardly (downwardly) revises commodity markets' expectations about the price and volatility path of agricultural products. On the other hand, our empirical analysis reveals that monetary policy does not have a systematic and timely response to sudden changes in option implied expectations of commodity investors. In addition, we provide empirical evidence showing the robust forecasting power of agricultural option-implied information on monetary policy with R^2 values reaching almost 52%.

Key words: Monetary Policy, Implied Variance and Skewness, Agricultural Commodities

JEL classification: E44, E52, G12, Q14

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1. Introduction

Empirical and theoretical studies have shown that monetary policy is an important determinant of commodity prices (see, for example, Frankel, 1986; Frankel and Rose, 2010). Frankel (2013) argues that the lax monetary policy of the Fed during the recent period (2003-2013) was an important factor that contributed significantly to the rapid rise in almost all commodity prices. He provides a subtle economic interpretation of the factors that induce the negative statistical relationship between interest rates and commodity prices. Low interest rates increase the demand or decrease the supply of storable commodities because low interest rates decrease the incentive for extraction today versus tomorrow (real options effect), they decrease the cost of carrying inventories and lead to a portfolio rebalancing from bonds towards commodity markets.

The general consensus in the literature is that an expansionary (contractionary) monetary policy stance is usually associated with high (low) commodity prices. Anzuini, Lombardi and Pagano (2013) use a standard VAR analysis and examine the impact of US monetary policy shocks on commodity prices. They find that an expansionary monetary policy shock increases modestly commodities prices. Gubler and Hertweck (2013) provide empirical evidence that an expansionary monetary in US induces a persistent increase in commodity prices. Gospodinov and Jamali (2013) use commodity futures data and find that US expansionary monetary policy surprises tend to increase commodity prices. However, they document that the sensitivity to monetary shocks varies significantly across different commodity groups. Gordon and Rowenhorst (2006) show that commodities is the asset class which acts as the most efficient hedge against both the expected and the unexpected component of inflation, and Frankel and Hardouvelis (1985) find that when inflation expectations are upwardly revised (expansionary monetary policy), “investors to protect themselves will shift out of money and into commodities, thus driving up current commodity prices”. In addition, we identify in the literature the reverse channel of causality, according to which commodity prices are early warning signals of changes in monetary policy and of future inflationary pressures (Awokuse and Yang, 2003; Bhar and Hamori, 2008; Frankel, 2008; Cody and Mills, 1991; Garner, 1989; Gospodinov and Ng, 2013).

In this paper we take the current research one step further by linking US monetary policy not with commodity prices, but with the option-implied expectations about the future distribution of commodity prices. We focus on option implied variance and option implied skewness extracted from the agricultural (maize, wheat and soybeans) commodity derivative market. We use implied variance as an ex-ante measure of investor's expectations about the future variance of agricultural commodity prices. However, investor's expectations extracted from the options market may embed both risk aversion and objective expectations about future variance. To address this issue, in the empirical analysis we also decompose the implied variance into an objective expectation about future variance and a residual called variance risk premium which proxies for risk aversion. Option implied skewness is used as an ex-ante measure which quantifies expectations about the future price path of commodity prices. For example, Han (2008) finds that in the S&P 500 equity option market implied skewness is highly positively correlated with market sentiment. In our empirical analysis we view a positive implied skewness as a signal that reveals a bullish market and we consider a negative implied skewness as a signal that reveals a bearish commodity market.[1]

Our empirical investigation is motivated by studies that identify the crucial importance of the 'risk taking channel of monetary policy' (Andrian and Shin, 2008; Borio and Lowe, 2002; Borio and Zhu, 2012; Mishkin and White, 2002; Rajan, 2006). Our study is methodologically most closely related to the work of Bekaert, Hoerova and Lo Duca (2013) who study structural interdependencies between monetary policy and option-implied measures of risk aversion and volatility in the S&P 500 equity option market. In the empirical analysis we use a structural vector autoregressive (SVAR) framework to search for dynamic interactions between expectations about future variance and skewness in agricultural commodity markets and monetary policy. The stance of monetary policy is proxied by the Fed funds rate or other alternative measures like the real interest rate, the short-term US-Treasury Bill and the state of inflation expectations. [2] To the best of our knowledge, this is the first study which examines the dynamic interactions between commodity option-implied variance and skewness and monetary policy.

We find that unlike stock markets for which Bernanke and Kuttner (2005) and Bekaert, Hoerova and Lo Duca (2013) find that a lax monetary policy decreases risk aversion and option implied variance in the short to medium run (after about 6 months), in agricultural commodity markets an expansionary (contractionary) monetary policy increases (decreases) implied variance and skewness of agricultural

[1] When option-implied skewness increases, option writers increase the likelihood of future increase in the price of the underlying asset (calls are more expensive relative to puts) and vice-versa. For more details see Bakhsi, Kapadia and Madan (2003) and Rehman and Vilkov (2012).

[2] Bernanke (2007): "Undoubtedly, the state of inflation expectations greatly influences actual inflation and thus the central bank's ability to achieve price stability."

commodity markets in the short to medium run (after 4-7 months). In other words, we empirically verify that expectations in commodity markets have an opposite reaction to monetary shocks compared with those in the stock-market. We find that the degree of ‘bullishness’ (option-implied skewness) of agricultural markets is more sensitive to monetary shocks compared to implied variance.

Our main findings do not change when instead of the Fed funds rate we use other widely accepted alternative measures of the monetary policy stance, like the real interest rate, the 3-month US-Treasury Bill rate and the state of short-term inflation expectations. Our empirical analysis reveals that a positive one standard deviation shock in implied variance has sometimes a very sluggish effect on monetary policy in some of the VAR identification schemes. We do not find any statistically significant effects from implied skewness to monetary policy. Overall, our results indicate that there is no systematic response of monetary authorities to a sudden change in commodity market expectations. While the monetary authority reacts to a highly risk averse and volatile stock-market by lowering interest rates (see Bekaert, Hoerova and Lo Duca (2013), David and Veronesi (2014)), we empirically show that an analogous systematic relationship does not exist in agricultural commodity markets.[3]

Furthermore, following the approach of Bekaert, Hoerova and Lo Duca (2013), we also estimate a multivariate VAR in which we control for business cycles and we decompose option-implied variance into economic uncertainty (expected realized variance of commodity prices) and a residual called variance risk premium which

[3] Our VAR models show that the monetary policy responses to a positive shock to option-implied expectations and to risk aversion are sluggish, not persistently negative or positive and in many cases statistically insignificant. These empirical results show that monetary authorities do not (at least for the time-being) systematically intervene in order to calm down a turbulent commodity market.

proxies for risk aversion.[4] We find that option-implied expectations respond instantly (after 2-4 months) to monetary shocks with the responses remaining statistically significant for many months after the initial shock. These results show that monetary policy is able to affect commodity market expectations irrespective of the phase of the business cycle. When we decompose the option-implied variance to its two components we find that the risk aversion component has an instant and statistically significant positive response to negative monetary policy shocks in maize and soybeans markets. In the wheat market the economic uncertainty component instead of the risk aversion is more sensitive monetary policy shocks. Our findings implicitly reveal that monetary authorities, despite being able to affect commodity price trends (Bessler, 1984; Frankel and Hardouvelis, 1985; Pindyck and Rotemberg, 1990; Hua, 1998) they can also control the (option-implied) expectations of agricultural commodity investors, which is an indirect (but feasible) way to control the actual price and volatility path in commodity markets. The latter can be achieved under a flexible inflation targeting regime which allows the short-term targeting of other variables besides inflation.[5]

In the last part of the empirical analysis we examine if agricultural option implied variance and skewness are robust predictors of the future monetary policy stance. We find a negative and statistically significant relationship between option-implied variance and skewness and future (from one month up to two years) monetary policy

[4] Option-implied variance incorporates both economic uncertainty and risk aversion. Variance Risk Premium (VRP) is a more reliable measure of risk aversion, since it represents the compensation demanded by investors in order to bear variance risk (see Bliss and Panigirtzoglou, 2004; Carr and Wu, 2009).

[5] Under flexible inflation targeting regime the central bank has a predetermined inflation level as its primary long-run target, while on the other hand has enough flexibility to target other variables besides inflation in the short run in order to achieve a better trade-off between output and price stabilization. Bernanke and Gertler (1999) mention that "the main advantage of flexible inflation targeting is that it provides a unified framework both for making monetary policy in normal times, and for preventing and ameliorating the effects of financial crises."

stance. Our results remain robust when we control for macroeconomic fundamentals and stock market volatility (VIX). The predictive regressions employed in the empirical analysis do not suffer from endogeneity problems. The forecasting power of implied variance and skewness is not a consequence of the Feds systematic response to changes in expectations of option commodity market participants, since there exists no empirical evidence supporting the latter. The SVAR analysis reveals a sluggish, non-systematic (not always negative) and in many cases statistically insignificant response of monetary policy to shocks in option-implied variance and skewness. Following the results and the claims of Woodford (1994), we conclude that agricultural commodity option markets are able to give valuable information about the future path of monetary policy. The reason behind this option-implied macroeconomic informational content lies in the contemporaneous linkages between interest rates and real agricultural commodity prices (Calvo (2008), Frankel, 2008; Frankel and Rose, 2010; Frankel, 2013) according to which low real interest rates (lax monetary policy) lead to high real agricultural commodity prices. When for example commodity option writers (correctly) anticipate an upward trend in future interest rates, they give higher probability to a fall in commodity prices instead of rise, a fact which makes more negative the skewness of option-implied risk neutral distributions.

The remainder of the paper is structured as follows. In Section 2, we describe the analytical methodology for computing model-free option-implied variance and skewness and we describe the data. In Section 3 we present some descriptive statistics and we analyze the results of our VAR models and the results of our predictive regressions of implied variance and skewness on monetary policy. Section 4 provides various robustness to our empirical results. Finally, Section 5 concludes and presents some policy implications and suggestions for further research.

2. Methodology and Data

2.1 Model-Free Option-Implied Variance and Skewness

We compute the model-free version of option implied variance and skewness using the method of Bakhsi, Kapadia and Madan (2003). Under the risk-neutral probability measure Q, the analytical formulas for conditional risk neutral moments are given in the equations (1), (2) below:

$$VAR = E_t^Q(\mathrm{R}^2) - [E_t^Q(\mathrm{R})]^2 \quad (1)$$

$$SKEW = \frac{E_t^Q(R^3) - 3E_t^Q(R)E_t^Q(R^2) + 2[E_t^Q(R)]^3}{VAR^{3/2}} \quad (2)$$

In accordance with Bakshi, Kapadia and Madan (2003), we define the "*Quad*" and "*Cubic*" contracts as follows: [6]

$$Quad = e^{-r(T-t)} E_t^Q(R^2) \quad (3)$$

$$Cubic = e^{-r(T-t)} E_t^Q(R^3) \quad (4)$$

In the equations (3) and (4), r is the risk-free interest rate (3-month US-Treasury Bill), t is the trading date and T is the expiration date of a given contract and consequently $T-t$ defines time to maturity. If we substitute the "*Quad"* and "*Cubic"* expressions given in equations (3), (4) into equations (1), (2), we get the model-free version of option implied variance (IV) and implied skewness (IS) given below :

[6] If we define with R the logarithmic returns of the underlying asset with price S_t [$R=\ln((S_{t+1}/\ln(S_t))$], then a *Quad* (or volatility) contract is a theoretical contract with risk neutral quadratic expected return-payoff $E_t^Q(R^2)$ and a *Cubic* contract is a contract with risk neutral cubic expected return-payoff $E_t^Q(R^3)$. Bakhsi, Kapadia and Madan (2003) prove that quadratic and cubic expected risk neutral returns are continuous functions of Out of the Money (OTM) call and put option prices.

$$IV = e^{r(T-t)}Quad - [E_t^Q(R)]^2 \tag{5}$$

$$IS = \frac{e^{r(T-t)}Cubic - 3E_t^Q(R)e^{r(T-t)}Quad + 2[E_t^Q(R)]^3}{IV^{3/2}} \tag{6}$$

Furthermore, Bakhsi, Kapadia and Madan (2003) show that under the risk-neutral pricing measure Q, the *Quad* and *Cubic* contracts can be expressed as continuous functions of out-of-the-money European calls $C(t,T,K)$ and out-of-the-money European puts $P(t,T,K)$ in the form given below :

$$Quad = \int_F^\infty \frac{2\left(1 - \ln\left[\frac{K}{F}\right]\right)}{K^2} C(t,T,K)\,dK + \int_0^F \frac{2\left(1 + \ln\left[\frac{F}{K}\right]\right)}{K^2} P(t,T,K)\,dK \tag{7}$$

$$Cubic = \int_F^\infty \frac{6\ln\left(\frac{K}{F}\right) - 3\ln\left(\frac{K}{F}\right)^2}{K^2} C(t,T,K)\,dK - \int_0^F \frac{6\ln\left(\frac{F}{K}\right) + 3\ln\left(\frac{F}{K}\right)^2}{K^2} P(t,T,K)\,dK \tag{8}$$

Where K is the strike price of the option contract, F is the price of the underlying futures contract, t is the trading date and T is the expiration date of the option contract. In addition, Bakhsi, Kapadia and Madan (2003) prove that the expected conditional risk-neutral return $E_t^Q(R)$ can be approximated by the following expression:

$$E_t^Q(R) = e^{r(T-t)} - 1 - \frac{e^{r(T-t)}}{2}Quad - \frac{e^{r(T-t)}}{6}Cubic \tag{9}$$

Knowing the analytical forms of *Quad* and *Cubic* contracts from equations (7) and (8), and the approximating quantity of conditional risk neutral expected returns $E_t^Q(R)$

from equation (9), we can compute by using numerical integration the model-free implied variance and skewness given in equations (5) and (6).

2.2 Commodity Futures and Options Data

We obtain end-of-month option and futures data for maize, wheat and soybeans from the Chicago Board of Trade (CBOT). The options and futures data for maize, wheat and soybeans cover the period from January 1990 to December 2011. From our data sample we eliminate call options with moneyness level less than 80% $(K/F < 0.8)$ and call options with moneyness level greater than 120% $(K/F > 1.2)$. We then use the Black (1976) model in order to compute implied volatilities for our selected option contracts. Following Jiang and Tian (2005) and Chang, Christoffersen, Jacobs and Vainberg (2012), we use the cubic spline method in order to interpolate-extrapolate these implied volatilities for each maturity across all the selected moneyness levels. We construct a fine grid of 1001 moneyness levels with a band ranging between 50% and 300%, and for these moneyness levels we create a (corresponding) grid of 1001 implied volatilities. In order to get more reliable information from the grid of 1001 the moneyness -implied volatility pairs, we do not make any interpolation - extrapolation when the number of options for a given trading day and a given maturity date is less than four.

Using the Black (1976) formula for commodity option prices, we convert these 1001 implied volatilities into option prices. We take as out-of-the-money put options those with moneyness level smaller than 100% (K/F <1), and as out-of-the-money call options those with moneyness level larger than 100% (K/F >1). We use numerical trapezoidal integration to compute the *Quad* and *Cubic* contracts in (7) and (8) and to compute expected conditional risk neutral returns in (9). We then use the prices of *Quad* and *Cubic* contracts and the conditional risk neutral returns $E_t^Q(R)$, in order to compute IV and IS in (5), (6). Following Wang, Fausti and Quasmi (2012), we construct the constant two-month (60-day) model-free implied variance and skewness time series using the following linear interpolation formula:

$$MFIV_{60} = \left(T_1 MFIV_1 \frac{T_2 - T_{60}}{T_2 - T_1} + T_2 MFIV_2 \frac{T_{60} - T_1}{T_2 - T_1} \right) \times \frac{T_{365}}{T_{60}} \tag{10}$$

IV_1 is the option-implied variance with maturity closest to 60 days, but less than 60 days, and IV_2 is the option-implied variance with maturity closest to 60 days but more than or equal to 60 days. T_1 and T_2 are time to expiration for IV_1 and IV_2, with $T_1 < 60$ and $T_2 \geq 60$. T_{365} and T_{60} are the 365 and 60 day intervals respectively. We follow the same interpolation method for the construction of the model free option-implied skewness.

We also compute the 2-month realized variance of maize, wheat and soybean futures prices. The maturity of commodity futures has to be the same with commodity options written on them. Thus, we choose commodity futures which have approximately a constant 2-month maturity. Realized variance is calculated using daily closing prices of the nearby futures contract to get the best possible approximation of a fixed maturity of 60 days. If the nearby contract has less than 60 days to expiration, we replace it with the next deferred contract which always has more than (or equal to) 60 days to expiration, since expiration dates on commodity futures are 1st of March, May, July, September and December.

2.3 Macroeconomic and Stock Market Data

We obtain monthly data for the Consumer Price Index (CPI), US unemployment rate, real wages, Industrial Production Index (IPI) and the Fed fund rate (FFR) from Federal Reserve Bank of Saint Louis. We obtain monthly short-term (with 1 year horizon) inflation expectations data from the Federal Reserve Bank of Cleveland. We construct the time series for the short-term real interest rate as the Fed funds rate minus the rate of inflation. Short-term (3-month) US Treasury-Bill data are downloaded from DataStream. We construct monthly overlapping data of 2-month growth of Industrial Production Index, real wages and CPI. All macroeconomic data have monthly frequencies and cover the period from January 1990 through December 2011. We obtain end-of-month data for the VIX index from Chicago Board Options Exchange (CBOE). The VIX index has a fixed maturity of 30 days and it is constructed by using the cross section of out-of-the-money call and put options on the S&P 500 index.

3. Empirical results

3.1 Descriptive statistics

Table 1 reports the descriptive statistics for the realized variance (RV), implied variance (IV) and implied skewness (IS) in the maize, wheat and soybean market. Wheat has the highest average realized and implied variance and soybean has the highest average implied skewness. Maize is on average the most negatively skewed. Table 1 also presents the Augmented Dickey-Fuller (ADF) and the Philips-Perron (PP) test statistics. In each test the null hypothesis is that the time series variable has a unit root. The hypothesis of a unit root is rejected for all variables under consideration.

[Insert Table 1 Here]

Figure 1 plots the contemporaneous movements in the time series of the Fed fund rate and the implied skewness of maize, wheat and soybeans market during the period under investigation (1990-2011) and Figure 2 plot the contemporaneous movements between implied variance and the Fed fund rate. From Figures 1 and 2 we observe that a low (high) level of the Fed fund rate is associated with a high (low) implied skewness and high (low) implied variance. We additionally observe that after 2002 implied skewness turns from negative to positive in all three commodities under investigation, with the Fed fund rate reaching very low levels during the same period (monetary easing era).

[Insert Figure 1 Here]

[Insert Figure 2 Here]

3.2 Granger Causality

We begin our empirical analysis with the results from Granger causality tests between monetary policy and option implied variance and skewness. The test is conducted with unrestricted bivariate VAR models which contain as endogenous variables the monetary policy stance and the option-implied variance or skewness of agricultural commodity markets. More specifically, we estimate a VAR of the form $Y_t = [FFR_t \ IV_t]$ or $Y_t = [FFR_t \ IS_t]$, where *FFR* is the monthly Fed funds rate and represents the monetary policy stance, *IV* is the monthly option-implied variance from maize, wheat or the soybeans markets and *IS* is the implied skewness from maize, wheat or soybeans markets. The results are reported in Table (2).

[Insert Table 2 Here]

Granger causality tests in Table 2 indicate that the Fed fund rate causes the implied skewness in all markets under consideration (maize, grain and soyabens) while the reverse effect is insignificant. The Fed fund rate causes the implied variance in the maize markets, and the implied variance in all markets has a significant effect on the Fed funds rate. These preliminary tests indicate a significant directional effect from monetary policy to implied skewness and some mixed bi-directional effects in the case of implied variance.

3.3 Structural VARs

We follow the approach of Bekaert, Hoerova and Lo Duca (2013) and we estimate structural bivariate VAR models of the form $Y_t = [FFR_t \ IV_t]$, or $Y_t = [\mathrm{FFR}_t \ \mathrm{IS}_t]$. In the VAR specification we place monetary policy first and implied variance or implied skewness second in order to capture the fact that monetary authorities respond more sluggishly to market-oriented shocks while on the other hand, asset markets in general are more sensitive to monetary shocks. We run our bivariate SVARs using long-run and short-run restrictions. For an N variable VAR, we need N(N-1)/2 restrictions in order to be identified. Thus, for our bivariate SVARs, it is necessary to impose 1 restriction for their exact identification.

<u>Short-run restriction</u>

We run bivariate SVARs using a short-run restriction, according to which expectations about future volatility or skewness in commodity markets do not have a contemporaneous (short-run) effect in monetary policy. In other words, we assume that monetary authorities have a sluggish response to changes in option-implied expectations of commodity markets (The empirical evidence we provide later are in favor of this argument-assumption). The bivariate SVAR with the short-run restriction is the following:

$$\mathrm{B}_t Y_t = \gamma_0 + A Y_{t-1} + \varepsilon_t \tag{11}$$

Y_t is the matrix with the variables $Y_t = [FFR_t \ IV_t]$ or $Y_t = [\mathrm{FFR}_t \ \ \mathrm{IS}_t]$, γ_0 is a 2x1 vector with constants $(\gamma_0 = [\gamma_{01} \ \gamma_{02}])$, B is a 2x2 full-rank matrix which determines the endogeneity of the variables in our system and ε_t is the matrix with the independent structural shocks in our system $(E(\varepsilon_t \ \varepsilon_t') = I)$. Lastly, A is the 2x2 short-run (feedback) response matrix in which we impose the short-run restriction according to which implied variance or implied skewness do not have a short-run effect on monetary policy. Our short-run restriction on the feedback matrix A is the following:

$$A = \begin{bmatrix} a_{11} & 0 \\ a_{12} & a_{22} \end{bmatrix} \tag{12}$$

<u>Long-run restriction</u>

Our long-run restriction has to do with the relevant literature on money neutrality (see Barro (1977), Barro (1978), Lucas (1972), Lucas (1976), Bernanke and Mihov (1998)). We restrict monetary policy to have a zero effect on option-implied expectations in the long-run.[7] Following Blanchard and Quah (1989), the SVAR model with long-run restriction has the following long-run response matrix:

$$C = \left(I - B^{-1}A\right)^{-1} B^{-1} \tag{13}$$

[7] According to Barro (1977, 1978) and Lucas (1972, 1976) money cannot affect real variables in the long-run because only unanticipated monetary shocks matter for the real economy. In the long-run, every change in monetary policy becomes anticipated by market participants.

Matrices A and B are already described in equation (12). We assume that monetary policy has no real effects on option-implied expectations in the long-run by placing the long-run restriction $(c_{21} = 0)$ in the long-run response matrix C of the structural VAR of equation (12) of our bivariate SVAR as follows:

$$C = \begin{bmatrix} c_{11} & \mathrm{c}_{12} \\ 0 & \mathrm{c}_{22} \end{bmatrix} \tag{14}$$

The coefficient $c_{21} = 0$ restricts monetary policy to have no real effect on implied variance in the long-run. Additionally, we choose the optimal lag-length of our bivariate VARs by following the Akaike lag-length selection criterion[8].

We base our results on structural-form Impulse response functions (IRFs, thereafter) for which we compute the 95% bootstrapped confidence intervals based on 1000 replications. We also estimate the IRFs from the unrestricted (reduced-form) bivariate VAR model. The results are reported in Table 3. Panel A reports the results from bivariate structural and reduced-form VARs with endogenous variables the Fed funds rate (FFR) and the implied variance (IV) and Panel B the results with the Fed funds rate (FFR) and implied skewness (IS). We present how many months the Impulse Response Functions (IRFs) generated by a negative one standard deviation shock in FFR or a positive one standard deviation shock in IV/IS remain statistically significant within the 95% confidence interval. Figure 3 plots the graphs of the IRFs for the case

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[8] When we choose the lag-length using the Schwarz (SBIC) criterion we obtain similar conclusions as those we present when using the Akaike criterion. The Schwarz criterion, compared to the Akaike criterion selects more parsimonious VARs.

of FFR and IV (IV is measured in percentages) and Figure 4 plots the graphs of the IRFs for the case of FFR and IS.

[Insert Table 3 Here]

[Insert Figure 3 Here]

[Insert Figure 4 Here]

Several interesting conclusions emerge from observing the results regarding the empirical behavior of IRFs. Table 3 shows that a negative monetary shock has a significant positive effect in IV and IS in all markets considered (maize, wheat and soybeans). Both IV and IS display a fast response (after 4-8 months) to monetary policy shocks. Monetary policy shocks have a more long lasting impact on implied skewness compared to the impact on implied variance.

From Figure 3 we observe that a negative shock in the Fed funds rate (in the model with the short-run restriction) increases the implied variance of maize markets about 54.2 basis points after 7 months, increases the implied variance of wheat markets by 41.2 basis points after 3 months and increases implied variance of soybeans markets by 43.2 basis points after 7 months. These responses remain positive and statistically significant for many months after the initial monetary shock. For example, the IRFs of maize implied variance to a negative monetary shock remain statistically significant for 17 months (from the 8^{th} month till the 25^{th} month after the initial monetary shock) in the reduced form VAR, for 2 months (from the 8^{th} month till the 10^{th} month) in the SVAR with short-run restrictions and 15 months (from the 10^{th} month till the 25^{th} month) in the SVAR with long-run restrictions.

Implied skewness has also an almost immediate and persistent response to monetary policy shocks under all our VAR identification schemes. For example, from Figure 4 we see that a negative shock in the Fed fund rate increases the implied skewness of soybeans markets by 0.062 after 6 months. From Table 3 we see that this effect remains statistically significant from lag 6 up and till lag 32 in the model with the short-run restriction, and from lags 6-10 and 18-34 in the model with the long-run restriction. The monetary policy effects on the bullishness (implied skewness) of maize and wheat markets are much more intensive and long-lasting compared to the monetary effects on implied variance discussed previously. Our results indicate that the impact of monetary shocks on implied skewness is much greater compared to the impact on implied variance. In all the commodity markets we investigate and in all of our VAR identification schemes, implied skewness is being increased by a great amount in response to sudden shifts in monetary policy. This means that monetary authorities have the ability (under a flexible inflation targeting regime (see Bernanke and Gertler (1999)) to turn commodity option markets from bearish to bullish and vice-versa. In the section with the robustness tests we provide some additional empirical results which strengthen furthermore our claims about the ability of monetary authorities to turn commodity markets from bearish to bullish and vice-versa.

Our results are exactly opposite of those obtained by Bernanke and Kuttner (2005) and Bekaert, Hoerova and Lo Duca (2013) for the stock-market since they find that an expansionary monetary policy reduces uncertainty in equity markets. The economic interpretation behind this contradiction is that while in equity markets volatility and prices are negatively correlated (leverage effect), in commodity markets (and especially the storable ones), volatility and prices are positively correlated. As a result, an expansionary monetary policy (low interest rates) while raising equity and commodity market prices it does exactly the opposite to the volatility (risk) of these prices due to the opposite sign in the volatility-price correlation in the former ones compared to the latter ones. Thus, commodity investors revise upwards their expectations about volatility risk after observing a negative interest rate shock (expansionary policy), while equity investors revise downwards their expectations about volatility risk after observing the same shock. When studying the reverse channel of causality, we find that the responses of the Fed funds rate to positive variance shocks are sluggish and in most cases statistically insignificant. For example, for Table 3 we see that the monetary authority response is statistically significant 19 months after the initial shock in the best case. This fact implicitly reveals that monetary authorities, despite they systematically intervene in order to calm down equity markets by lowering interest rates, do not react in a systematic manner to a nervous and turbulent agricultural commodity market.

We also estimate multivariate VAR models in which we control for the business cycles. More specifically, our VAR ordering is the following:

$$Z_t = [FFR_t \ IPI_t \ IV_t \ IS_t] \tag{15}$$

We continue to place macroeconomic variables first and commodity market variables last in our VAR ordering selection due to the more sluggish response of the former compared to the latter ones. *FFR* is again the Fed funds rate, *IPI* is the growth in industrial production index, *IV* is the implied variance and *IS* is the implied skewness. We choose our lag-lengh in each of our multivariate VAR models using again the

Akaike criterion. According to the Akaike criterion, the 4-factor VAR for maize has 13 lags, the VAR model for wheat has 6 lags and the model for the soybeans has 4 lags. Our multivariable reduced-form VAR model is the following:

$$Z_t = \delta_0 + KZ_{t-1} + D\varepsilon_t \qquad (16)$$

Where K denotes $B^{-1}A$ and D denotes A^{-1} (A is the short-run feedback matrix of the structural VAR, according to equations (11) and (12)).

We base again our analysis on the structural form IRFs for the multivariable 4-factor reduced form VAR models for which we estimate the Bootstrapped standard errors using 1000 repetitions. Table 4 reports the months for which the IRFs between the monetary policy (Fed funds rate) and the option-implied expectations are statistically significant.

[Insert Table 4 here]

From Table 4 we see that our results remain robust to the inclusion of business cycles variables since implied skewness and variance respond instantly to monetary policy shocks with the responses being statistically significant. In more detail, we can see that the option-implied skewness responds instantly (after 4-5 months in all commodity markets under investigation) to an expansionary monetary policy shock. Table 4 also shows that in all markets considered there is some sluggish response of monetary policy to implied variance shocks. We do not find any statistically significant responses of monetary policy to shocks-sudden shifts in the expectations of commodity investors embedded in implied skewness. This fact strengthens furthermore our initial claims according to which the monetary authority (unlike what it does in times of stock-market turbulence-see Ribobon and Sack (2003)) does not show any intention to manage the expectations in these markets.

3.4 Forecasting monetary policy with option-implied moments

In this section we examine the predictive power of option-implied expectations on monetary policy. We provide empirical evidence showing that option-implied variance and skewness of maize, wheat and soybeans markets are robust predictors of the monetary policy stance. Table 5 shows the results of our predictive regressions when we regress the Fed funds rate on lagged values of option-implied variance and skewness, with the forecasting horizon ranging from 1 month up to 24 months ahead. Table 6 shows the results of our predictive regressions when we use implied variance and skewness and control for macroeconomic and stock-market factors in order to forecast the monthly Fed funds rate.

[Insert Table 5 Here]

[Insert Table 6 Here]

From Tables 5 and 6 we see that implied variance and skewness are robust predictors of the monetary policy stance. Implied skewness and implied variance have the highest predicative power in the wheat market with an R^2=45% for a 6-month forecasting horizon. For the 6-month forecasting horizon in the soybeans market the R^2=36% and in the maize market the R^2=29%. Even when we control for macroeconomic fundamentals like the inflation rate and the term spread (slope of the yield curve) the statistical results remain robust. We find R^2 values as high as 45% (6-month forecasting horizon) when we regress wheat implied variance and skewness on the Fed funds rate. The R^2 values remain high when we use maize or soybeans implied variance and skewness as predictors of the Fed fund rate. Implied variance and skewness coefficients are all negative and statistically significant. These results are in line with those of David and Veronesi (2014) who find that in equity markets, the put/call ratio (a variable which also measures the degree of bullishness in option markets) of At-The-Money (ATM) index options has a sustained impact and a robust forecasting power on future monetary policy, since it can forecast the path of the short-term US-Treasury Bill for up to eight quarters. Our results may look alike with those of David and Veronesi (2014), but this happens for structurally different reasons. While the Fed systematically reacts to "periods of high VIX levels" (Bekaert, Hoerova and Lo Duca (2013)), we neither find (in the relevant literature) nor provide empirical evidence showing the same for commodity markets. In contrast, our empirical analysis shows that the Fed does not react systematically to periods of increased uncertainty and bullishness in commodity markets and that the implied skewness (bullishness) does not Granger cause the Fed funds rate. This is why we strongly support that our predictive regressions do not suffer from endogeneity problems: because the information from the commodity derivative market is not taken into consideration by central banks.[9] This means that the information embedded in the commodity derivative market is useful for predicting the future short-term level of the monetary policy stance.

In addition, the regression results of Table 5 show that option-implied moments are robust predictors of monetary policy for both short and long-term forecasting horizons.

[9] Woodford (1994) supports the view that the indicators of monetary policy which enter in a statistically significant way into predictive regressions are not so significant after all, if they have already become a policy objective. In case an economic or financial variable is not a systematic policy target of monetary authorities and enters significantly into forecasting regressions of the monetary policy stance (like the Fed funds rate), then it can act as a monetary policy indicator.

For example, we get statistically significant coefficients of the lagged option-implied variance and skewness even when we forecast monetary policy 12 and 24 months ahead, with the R^2 values remaining as high as those of the short-term horizon forecasting regressions. When for example we forecast the monetary policy using maize option-implied variance and skewness, we find that R^2 values range from 26.9% (when we forecast the monetary policy 1 month ahead) to 20% (when we forecast the monetary policy 24 months ahead). This means that the forecasting power of commodity option-markets only slightly deteriorates when we decide to lengthen the forecasting horizon. In other words, we empirically verify that commodity option markets correctly anticipate and, according to Woodford (1994) they are valuable "non-standard indicators" of the monetary policy stance since they enter significantly into all of our forecasting regression models.

4. Robustness

In this section we conduct a series of robustness tests to test further the validity of the results presented in the previous sections.

4.1 Alternative measures of the monetary policy stance

First, we study the empirical link between option implied variance and skewness and alternative measures of the monetary policy stance, like the real interest rate, the 3-month US Treasury Bill and the state of inflation expectations. We use SVAR analysis with short-sun and long-run restrictions and the results are presented in Table 7 and Table 8. The tables present how many months the Impulse Response Functions (IRFs) generated by a negative one standard deviation shock in monetary policy or a positive one standard deviation shock in IV/IS remain statistically significant within the 95%

bootstrapped confidence interval. The empirical results are broadly in line with results obtained with the Federal fund rate as a proxy for the monetary policy stance. They indicate again that a negative monetary shock has a significant positive effect in IV in all markets considered (maize, wheat and soybeans). We don't find a statistically significant relationship only in the case of soybeans when the real interest rate is used as a proxy for monetary stance. Table 8 reports the results for the implied skewness. The results are statistically stronger and indicate that a negative monetary shock has a significant positive effect in IS in all markets considered (maize, wheat and soybeans) irrespective of the proxy used for the monetary policy stance.

[Insert Table 7 Here]

[Insert Table 8 Here]

4.2 Economic uncertainty and Risk Aversion

We also estimate a 5-factor VAR model following the approach of Bekaert, Hoerova and Lo Duca (2013), in which, besides controlling for business cycles, we decompose option-implied variance into economic uncertainty and a residual called variance risk premium which proxies for risk aversion. Economic uncertainty is defined as the expected realized variance of agricultural commodity futures prices. We compute the 2-month realized variance of maize, whet and soybean futures prices using the methodology described in section 2.2.

The variance risk premium represents the compensation demanded by investors for bearing variance risk and it is defined as the difference between realized variance and implied variance (IV_t). According to Bliss and Panigirtzoglou (2004) and Carr and Wu

(2009) it is a reliable measure of risk aversion in financial markets. More specifically, following Carr and Wu (2009) we define the variance risk premium as the difference between the P-measure expected variance and the Q–measure expected variance, using the following formula:

$$VRP\left(t,T\right)=E_t^P(RV\left(t,T\right)-E_t^Q(RV\left(t,T\right) \tag{17}$$

where, in our framework, $E_t^P(RV(t,T)$ is the expected realized variance RV_t and $E_t^Q(RV(t,T)$ is the implied variance IV_t. T is the time to maturity for option contracts and underlying futures contracts, which in our case is equal to 2 months. Risk aversion increases when the VRP decreases (becomes more negative).

We follow a similar approach to Bekaert, Hoerova and Lo Duca (2013) to find the best predictor $E_t^P(RV(t,T)$ of realized variance. More specifically, we run predictive regressions in order to get the best (conditional on market information) forecast for the realized variance for a given month. In order to make the best forecast about future realized variance we use as predictors the realized variance, the implied variance and the implied skewness of the previous month. We run the following regression for the maize, wheat and soybeans:

$$RV_t = b_0 + b_1 RV_{t-1} + b_2 IV_{t-1} + b_3 SKEW_{t-1} + \varepsilon_t \tag{18}$$

We then use the predicted (fitted) values from the above regression model as the measure of economic uncertainty (UC) in commodity markets.

Our 5-factor VAR model is the following:

$$Z_t = [FFR_t \ IPI_t \ \mathrm{UC}_t \ VRP_t \ MFIS_t] \quad (19)$$

where, *FFR* is again the Fed funds rate, *IPI* is the growth in industrial production index, *UC* is the proxy for economic uncertainty and *VRP* is the Variance Risk Premium and *MFIS* is the implied skewness. The results for the IRFs are reported in Table 9.

[Insert Table 9 Here]

From the results of table 9 we observe that when we decompose the risk neutral variance into economic uncertainty and risk aversion (variance risk premium) the risk aversion component has a more instant and statistically significant response to monetary policy shocks in maize and soybeans markets. In more detail, a negative one standard deviation shock in the Fed funds rate decreases the variance risk premium (thus, increases risk aversion) in maize and soybeans markets and the response is statistically significant from 5 till 22 months after the initial monetary shock in maize markets and from 3 to 17 months after the initial monetary shock in soybeans markets. These results indicate that the risk aversion component of implied variance has a statistically significant response to monetary policy shocks. Unlike the maize and soybeans market, in the wheat market the economic uncertainty instead of the risk aversion component is affected by monetary policy shocks. According to our 5-factor VAR model, monetary policy does systematically respond only in the case of increasing economic uncertainty in wheat markets. In the other two commodity markets the response of both uncertainty and risk aversion to monetary shocks is either sluggish or insignificant. Lastly, our results on the monetary effect on the implied skewness remain unaltered in the 5-factor VAR model in all three commodity markets.

4.3 Forecasting regressions with alternative measures of the monetary policy stance

Lastly, we present results from forecasting regressions presented in section 4.5 in which we use (instead of the fed funds rate) the alternative measures of the monetary policy stance. Tables 10, 11 and 12 below report the relevant results when we use inflation expectations, the 3-month US-Treasury Bill and the real interest rate as alternative measures of the monetary policy stance.

[Insert Table 10 Here]

[Insert Table 11 Here]

[Insert Table 12 Here]

The results indicate that implied skewness and implied variance imbed valuable information for forecasting future inflation expectations, treasury yields and real interest rates. In all case considered the estimates are negative and statistically significant.

5. Conclusions

In this paper we examine the dynamic links between option-implied expectations in agricultural commodity markets and monetary policy. We find that a lax monetary policy has a significant positive effect in implied variance and implied skewness in the maize, wheat and soybeans derivative markets. The impact of monetary shocks on implied skewness is much greater compared to the impact on implied variance. Our empirical results are in sharp contrast to those obtained by Bernanke and Kuttner

(2005) and Bekaert, Hoerova and Lo Duca (2013) who find that an expansionary monetary policy reduces uncertainty in equity markets. Commodity investors revise upwards their expectations about volatility risk after observing a negative interest rate shock (expansionary policy), while equity investors revise downwards their expectations about volatility risk after observing the same shock. We also provide empirical evidence showing the robust forecasting power of implied variance and skewness on monetary policy with R^2 values reaching almost 52%. Following Woodford (1994), these option-implied moments could be used as "non-standard indicators" of the monetary policy stance.

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Table 1: Maize-Wheat-Soybeans Descriptive Statistics

This table shows descriptive statistics of Realized Variance (RV), Implied Variance (IV) and Implied Skewness (IS). The data have a monthly frequency. The table presents also the Augmented Dickey-Fuller (ADF) and the Philips-Perron (PP) test statistics for each one of the variables. In each test the null hypothesis is that the time series variable has a unit root. Lags in ADF tests are chosen by the Swartz information criterion. The sample period for maize, wheat and soybeans data is from January 1990 to December 2011.

	Maize		
	RV	IV	IS
Mean	0.064	0.069	-0.104
Median	0.043	0.054	0.065
Maximum	0.365	0.237	1.071
Minimum	0.004	0.015	-2.214
Stand. Dev	0.058	0.044	0.632
Skewness	2.410	1.260	-1.206
Kurtosis	10.937	4.569	4.086
ADF test	-5.933	-4.677	-2.091
PP test	-10.410	-6.131	-8.748
	Wheat		
	RV	IV	IS
Mean	0.075	0.073	0.018
Median	0.059	0.057	0.091
Maximum	0.324	0.348	0.820
Minimum	0.008	0.014	-2.305
Stand. Dev	0.057	0.051	0.423
Skewness	1.887	2.117	-1.957
Kurtosis	6.963	9.098	10.135
ADF test	-2.965	-1.985	-3.222
PP test	-9.063	-4.870	-8.405
	Soybeans		
	RV	IV	IS
Mean	0.053	0.069	0.029
Median	0.037	0.048	0.124
Maximum	0.277	0.403	1.299
Minimum	0.003	0.011	-2.53
Stand. Dev	0.047	0.060	0.615
Skewness	2.334	2.639	-1.431
Kurtosis	9.1480	12.488	6.2581
ADF test	-6.335	-2.820	-6.638
PP test	-8.726	-7.721	-8.242

Table 2: Granger causality tests between monetary policy and option-implied moments
This table shows the results of the Granger causality tests between monetary policy and option-implied variance and skewness of commodity markets under investigation. The tests refer to the bivariate VAR models which include the Fed funds rate and option-implied variance and the Fed funds rate and option-implied skewness ([FFR IV], [FFR IS]). The optimal lag-length in these bivariate VAR models has been chosen using the Akaike critetion. The null hypothesis is that the Independent variable does not Granger cause the Dependent variable. With * , ** and *** we reject the null hypothesis of no causality at the 10%, 5% and 1% level respectively.

Dependent variable	Independent variable	chi-square	p-value
Fed funds rate**	Maize implied variance	22.37	0.033
Fed funds rate***	Wheat implied variance	23.06	0.002
Fed funds rate**	Soybeans implied variance	12.56	0.013
Fed funds rate	Maize implied skewness	11.47	0.488
Fed funds rate	Wheat implied skewness	14.99	0.183
Fed funds rate	Soybeans implied skewness	5.05	0.653
Maize implied variance***	Fed funds rate	30.31	0.002
Wheat implied variance	Fed funds rate	9.95	0.191
Soybeans implied variance	Fed funds rate	5.14	0.273
Maize implied skewness*	Fed funds rate	19.46	0.078
Wheat implied skewness***	Fed funds rate	27.07	0.005
Soybeans implied skewness***	Fed funds rate	29.93	0.0001

Table 3. Statistical significance of IRFs between monetary policy and implied variance/implied skewness

This table summarizes the results of bivariate structural and reduced-form VARs with endogenous variables the Fed funds rate (FFR) and the risk neutral implied variance (IV) in Panel A and the Fed funds rate (FFR) and implied skewness (IS) in Panel B. We present how many months the Impulse Response Functions (IRFs) generated by a negative shock in FFR or a positive shock in IV/IS remain statistically significant within the 95% confidence interval. We compute the Bootstrapped standard errors of the estimated IRFs using 1000 replications. The column "sign" indicates the sign of the statistically significant IRFs.

Panel A

	Impulse MP, response Maize IV		Impulse Maize IV, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Fed Fund Rate				
-reduced-form	+	8-25	-	30-42
-structural short-run	+	7, 8-10		--
-structural long-run	+	3, 7-8, 10-25	-	38-58

	Impulse MP, response Wheat IV		Impulse Wheat IV, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Fed Fund Rate				
-reduced-form	+	1-3	-	20-41
-structural short-run	+	1, 3		--
-structural long-run	+	3	-	19-44

	Impulse MP, response Soybeans IV		Impulse Soybeans IV, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Fed Fund Rate				
-reduced form	+	4-15		9-21
-structural short-run	+	4-5, 7-14		--
-structural long-run	+	--	-	4-39

Panel B

	Impulse MP, response Maize IS		Impulse Maize IS, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Fed Fund Rate				
-reduced-form	+	6-35		--
-structural short-run	+	7, 10, 19-23		--
-structural long-run	+	7, 10, 18-22		--

	Impulse MP, response Wheat IS		Impulse Wheat IS, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Fed Fund Rate				
-reduced-form	+	4-40		--
-structural short-run	+	2-5, 7, 9-28	+	2-3
-structural long-run	+	20-25		--

	Impulse MP, response Soybeans IS		Impulse Soybeans IS, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Fed Fund Rate				
-reduced-form	+	8-33		--
-structural short-run	+	6-32		--

-structural long-run	+	6-10, 18-34	-	1-31

Table 4. Statistical significance of IRFs between monetary policy and option-implied expectations of commodity markets (4-factor VAR model)

This table summarizes the results for the IRFs between monetary policy and option-implied expectations when we estimate a 4-factor VAR model presented in section 3.3. These IRFs are estimated for our 4-factor reduced-form VAR models with endogenous variables the monthly level of the Fed funds rate (FFR), the growth of the Industrial Production Index (IPI), the implied variance (IV) and the implied skewness (IS) of maize, wheat and soybeans markets. We present the IRFs of commodity markets to a negative monetary shock and the IRFs of monetary policy to a positive shock in commodity markets. More specifically, we present how many months the Impulse Response Functions (IRFs) remain statistically significant within the 95% bootstrapped confidence interval. Thus, we estimate for the three commodity markets a multivariate VAR model of the form: Y_1 = [FFR IPI IV IS]. We compute the Bootstrapped standard errors of the estimated IRFs using 1000 replications. Panel A shows the results for the IRFs for the implied variance (IV)-monetary policy (Fed funds rate) pair and Panel B shows the results for the IRFs for the implied skewness (IS)-monetary policy (Fed funds rate) pair for maize, wheat and soybeans markets. The column "sign" indicates the sign of the statistically significant IRFs.

Panel A

	Impulse FFR- Response IV		Impulse IV, response FFR	
	sign	significant from-to (month)	sign	significant from-to (month)
-Maize	+	7-11	-	29-36
-Wheat	+	1-9	-	24-45
-Soybeans	+	3-18	-	24-34

Panel B

	Impulse FFR- Response IS		Impulse IS, response FFR	
	sign	significant from-to (month)	sign	significant from-to (month)
-Maize	+	8-11		-
-Wheat	+	4-31		-
-Soybeans	+	5-33		-

Table 5: Forecasting monetary policy (Fed funds rate) with option-implied variance and skewness for long and short-term forecasting horizons

This table shows time-series regressions on monthly monetary policy stance (Fed funds rate), using as explanatory variables lagged values of option-implied variance and skewness for maize, wheat and soybeans futures respectively. In Panels A, B, C we run our predictive regressions on the Fed funds rate (FFR) using lagged values of maize, wheat and soybeans option-implied variance and skewness respectively. Our forecasting horizon ranges from 1 to 24 months. IV is option-implied variance, IS is option-implied skewness and FFR is the Fed funds rate. The t-statistics reported in the relevant columns are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) estimator. We forecast the future monetary policy stance k months ahead (k=1, 3, 6, 12, 24) according to the following regression model:

$$FFR_t = b_0 + b_1 IV_{t-k} + b_2 IS_{t-k} + \varepsilon_t$$

A: Maize

Horizon (k)	bo	t-stat(b_0)	b_1	t-stat(b_1)	b_2	t-stat(b_2)	% Adj. R^2
1m	0.048	11.34	-0.191	-3.368	-0.008	-2.873	26.9
3m	0.048	11.33	-0.193	-3.717	-0.008	-2.699	27.4
6m	0.048	11.39	-0.197	-3.848	-0.007	-2.435	29.1
12m	0.047	11.03	-0.200	-3.930	-0.004	-1.437	26.2
24m	0.048	12.02	-0.240	-5.016	-0.0004	-0.186	20.0

B: Wheat

Horizon (k)	bo	t-stat(b_0)	b_1	t-stat(b_1)	b_2	t-stat(b_2)	% Adj. R^2
1m	0.049	14.02	-0.175	-4.051	-0.024	-6.405	44.6
3m	0.049	14.24	-0.183	-4.567	-0.021	-5.386	43.8
6m	0.050	15.58	-0.202	-6.509	-0.018	-4.565	45.0
12m	0.049	14.88	-0.212	-7.163	-0.011	-2.623	39.3
24m	0.049	13.26	-0.239	-6.336	-0.001	-0.427	25.9

C: Soybeans

Horizon (k)	bo	t-stat(b_0)	b_1	t-stat(b_1)	b_2	t-stat(b_2)	% Adj. R^2
1m	0.047	14.37	-0.167	-4.135	-0.010	-3.981	33.9
3m	0.047	14.77	-0.173	-5.261	-0.010	-4.313	35.1
6m	0.047	15.00	-0.179	-6.283	-0.008	-3.980	36.0
12m	0.045	14.41	-0.170	-6.408	-0.004	-2.472	30.8
24m	0.043	12.45	-0.157	-5.095	-0.001	-0.437	14.5

Table 6: Forecasting monetary policy (Fed funds rate) with option-implied variance and skewness when controlling for macroeconomic fundamentals and stock-market risk aversion

This table shows time-series regressions on monthly Fed funds rate (FFR), using as explanatory variables lagged values of option-implied variance and skewness for maize, wheat and soybeans futures respectively. In Panel A we run our predictive regressions on the FFR one month ahead while in panel B we present the regression results when we run the same predictive regressions using a 3-month forecasting horizon. IV is option-implied variance, IS is option-implied skewness, I is the yearly overlapping inflation rate for each month, IPI is the yearly return in the industrial production index, SLOPE is the yield difference between the 10-year US-government bond and the 3-month US-TBill and VIX is the logarithm of the VIX index. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) estimator.

$$FFR_t = b_0 + b_1 IV_{t-1} + b_2 IS_{t-1} + b_3 VIX_{t-1} + b_4 I_{t-1} + b_5 IPI_{t-1} + b_6 SLOPE_{t-1} + \varepsilon_t$$

Panel A: k=1

		Maize	Wheat	Soybeans
Constant	Coef.	0.067	0.065	0.063
	t-stat	(3.949)	(4.662)	(3.951)
Implied Variance	Coef.	-0.139	-0.156	-0.130
	t-stat	(-2.894)	(-4.607)	(-5.042)
Implied Skewness	Coef.	-0.006	-0.170	-0.006
	t-stat	(-3.260)	(-5.219)	(-3.696)
VIX index	Coef.	-0.013	-0.007	-0.013
	t-stat	(-1.208)	(-0.831)	(-1.224)
Inflation	Coef.	0.417	0.323	0.505
	t-stat	(2.802)	(2.913)	(4.090)
Industrial Production	Coef.	0.011	0.008	-0.001
	t-stat	(0.223)	(0.211)	(-0.035)
Term spread (slope)	Coef.	-1.249	-1.208	-1.106
	t-stat	(-8.072)	(-9.893)	(-7.794)
% R^2 adjusted		62.5	73.5	65.1

Panel B: k=3

		Maize	Wheat	Soybeans
Constant	Coef.	0.068	0.067	0.066
	t-stat	(4.778)	(5.803)	(4.741)
Implied Variance	Coef.	-0.124	-0.149	-0.127
	t-stat	(-2.531)	(-4.634)	(-5.316)
Implied Skewness	Coef.	-0.006	-0.016	-0.005
	t-stat	(-3.181)	(-4.624)	(-5.342)
VIX index	Coef.	-0.015	-0.009	-0.015
	t-stat	(-1.589)	(-1.209)	(-1.528)
Inflation	Coef.	0.338	0.248	0.421
	t-stat	(2.206)	(2.227)	(3.255)
Industrial Production	Coef.	0.055	0.047	0.037
	t-stat	(1.022)	(1.144)	(0.750)
Term spread (slope)	Coef.	-1.169	-1.136	-1.039
	t-stat	(-7.207)	(-8.633)	(-7.090)
% R^2 adjusted		61.7	71.8	64.6

Table 7. Statistical significance of IRFs between alternative measures of monetary policy and implied variance

This table summarizes the results of our bivariate structural and reduced-form VARs with endogenous variables alternative proxies for the monetary policy stance (monthly level of expected inflation, the 3-month US-Tbill and the real interest rate) and the implied variance (IV) of agricultural commodity markets. More specifically, we present how many months the Impulse Response Functions (IRFs) remain statistically significant within the 95% confidence interval. We compute the Bootstrapped standard errors of the estimated IRFs using 1000 replications. Panel A shows the results when we use maize IV, panel B for wheat IV and panel C for soybeans IV. The column sign indicates the sign of the statistically significant IRFs. The column "sign" indicates the sign of the statistically significant IRFs.

Panel A

	Impulse EI, response Maize IV		Impulse Maize IV, response EI	
	sign	significant from-to (month)	sign	significant from-to (month)
Expected Inflation				
-reduced form	+	2-18	-	2-12
-structural short-run	+	2-31		--
-structural long-run	+	8-48	-	1-29
US-Treasury Bill				
-reduced form	+	3-23	-	21-45
-structural short-run	+	8-10, 19, 22	-	21-56
-structural long-run	+	8, 10, 19	-	19-53
Real Interest Rate				
-reduced-form	+	3-8	-	6-31
-structural short-run	+	9-11		--
-structural long-run	+	3, 23-38	-	3-29

Panel B

	Impulse EI, response Wheat IV		Impulse Wheat IV, response EI	
	sign	significant from-to (month)	sign	significant from-to (month)
Expected Inflation				
-reduced-form	+	2-17	-	2-14
-structural short-run	+	1-3		--
-structural long-run	+	4	-	6-56
US-Treasury Bill				
-reduced-form	+	2-18	-	6-43
-structural short-run	+	1, 4-5, 7-11		--
-structural long-run		--	-	24-39
Real Interest Rate				
-reduced form	+	9-11	-	3-15
-structural short-run		--		--
-structural long-run		--		--

Table 7 -Continued

Panel C

	Impulse EI, response Soybeans IV		Impulse Soybeans IV, response EI	
	sign	significant from-to (month)	sign	significant from-to (month)
Expected Inflation				
-reduced-form	+	6-19	-	17-28
-structural short-run	+	2-20		--
-structural long-run	+	1, 4	-	1-32
US-Treasury Bill				
-reduced-form	+	5-30	-	16-30
-structural short-run	+	3, 7-21		--
-structural long-run	+	15-23	-	1, 4-32
Real Interest Rate				
-reduced form		--	-	3-25
-structural short-run		--	-	7-29
-structural long-run		--	-	7-34

Table 8. Statistical significance of IRFs between alternative measures of monetary policy and implied skewness

This table summarizes the results of our bivariate structural and reduced-form VARs with endogenous variables alternative proxies for the monetary policy stance (monthly level of expected inflation, the 3-month US-Tbill and the real interest rate) and the implied skewness (IS) of agricultural commodity markets. More specifically, we present how many months the Impulse Response Functions (IRFs) remain statistically significant within the 95% confidence interval. We compute the Bootstrapped standard errors of the estimated IRFs using 1000 replications. Panel A shows the results when we use maize IS, panel B for wheat IS and panel C for soybeans IS. The column sign indicates the sign of the statistically significant IRFs. The column "sign" indicates the sign of the statistically significant IRFs.

Panel A

	Impulse MP, response Maize IS		Impulse Maize IS, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Expected Inflation				
-reduced-form	+	2-18		--
-structural short-run	+	2-24		--
-structural long-run	+	4-39	-	1-22
US-Treasury Bill				
-reduced-form	+	5-38		--
-structural short-run	+	8-10, 19-22		--
-structural long-run	+	19-21	-	26-30
Real Interest Rate				
-reduced-form	+	2-10	+	1-2
-structural short-run	+	1		--
-structural long-run		--		--

Panel B

	Impulse MP, response Wheat IS		Impulse Wheat IS, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Expected Inflation				
-reduced-form	+	1-18		--
-structural short-run	+	2-29		--
-structural long-run	+	6-45	-	1-25
US-Treasury Bill				
-reduced-form	+	3-44		--
-structural short-run	+	4, 7-37		--
-structural long-run	+	13-36	-	1-30
Real Interest Rate				
-reduced-form	+	3-14	-	3-15
-structural short-run	+	3-28		--
-structural long-run	+	1-3, 5-44	-	1-24

Table 8 -Continued

Panel C

	Impulse MP, response Soybeans IS		Impulse Soybeans IS, response MP	
	sign	significant from-to (month)	sign	significant from-to (month)
Expected Inflation				
-reduced-form	+	4-18		--
-structural short-run	+	3-24		--
-structural long-run	+	6-46	-	1-25
US-Treasury Bill				
-reduced-form	+	6-41		--
-structural short-run	+	7-9, 15-32		--
-structural long-run	+	7-9, 19-21	-	1-31
Real Interest Rate				
-reduced-form	+	2-12		--
-structural short-run	+	3-28		--
-structural long-run	+	5-44	-	1-24

Table 9. Statistical significance of IRFs between monetary policy and economic uncertainty-risk aversion of commodity markets

This table summarizes the results for the IRS between monetary policy and economic uncertainty-risk aversion (variance risk premium. These IRFs are estimated for our 5-factor reduced-form VAR models with endogenous variables the monthly level of the Fed funds rate (FFR), the growth of the Industrial Production Index (IPI), the economic uncertainty (UC), the variance risk premium (VRP) and the implied skewness (IS) of maize, wheat and soybeans markets. We present the IRFs of commodity markets to a negative monetary shock and the IRFs of monetary policy to a positive shock in commodity markets. More specifically, we present how many months the Impulse Response Functions (IRFs) remain statistically significant within the 95% bootstrapped confidence interval. Thus, we estimate for the three commodity markets a multivariate VAR model of the form: Y_1 = [FFR IPI UC VRP IS]. We compute the Bootstrapped standard errors of the estimated IRFs using 1000 replications. Panel A shows the results for the IRFs for the economic uncertainty (UC)-monetary policy (Fed funds rate) pair, Panel B shows the results for the IRFs for the variance risk premium (RV)-monetary policy (Fed funds rate) pair and panel C shows the results for the IRFs for the risk neutral skewness (IS)-monetary policy (Fed funds rate) pair for maize, wheat and soybeans markets. The column "sign" indicates the sign of the statistically significant IRFs.

Panel A

	Impulse FFR- Response UC		Impulse UC, response FFR	
	sign	significant from-to (month)	sign	significant from-to (month)
-Maize	+	8-20		-
-Wheat	+	1-21	-	1-43
-Soybeans		-		-

Panel B

	Impulse FFR- Response VRP		Impulse VRP, response FFR	
	sign	significant from-to (month)	sign	significant from-to (month)
-Maize	-	5-22		-
-Wheat	-	1	+	21-37
-Soybeans	-	3-17	+	9-49

Panel C

	Impulse FFR- Response IS		Impulse IS, response FFR	
	sign	significant from-to (month)	sign	significant from-to (month)
-Maize	+	7-40		-
-Wheat	+	4-41		-
-Soybeans	+	7-29		-

Table 10: Forecasting inflation expectations with option-implied moments when controlling for macroeconomic fundamentals and stock-market risk aversion

This table shows time-series regressions on inflation expectations (EI), using as explanatory variables lagged values of option-implied variance and skewness for maize, wheat and soybeans markets, respectively. In Panel A we run our predictive regressions on the inflation expectations one month ahead while in panel B we present the regression results when we run the same predictive regressions using a 3-month forecasting horizon. IV is option-implied variance, IS is option-implied skewness, I is yearly overlapping inflation rate for each month, IPI is the yearly overlapping return in the industrial production index, SLOPE is the yield difference between the 10-year US-government bond and the 3-month US-TBill and VIX is the log of the VIX index. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) estimator.

$$EI_t = b_0 + b_1 IV_{t-k} + b_2 IS_{t-k} + b_3 VIX_{t-k} + b_4 I_{t-k} + b_5 IPI_{t-k} + b_6 SLOPE_{t-k} + \varepsilon_t$$

Panel A: k=1

		Maize	Wheat	Soybeans
Constant	Coef.	0.034	0.033	0.033
	t-stat	(4.506)	(5.270)	(4.703)
Implied Variance	Coef.	-0.055	-0.062	-0.049
	t-stat	(-3.571)	(-4.523)	(-5.721)
Implied Skewness	Coef.	-0.002	-0.005	-0.002
	t-stat	(-2.802)	(-5.544)	(-3.729)
VIX index	Coef.	-0.008	-0.006	-0.009
	t-stat	(-1.894)	(-1.658)	(-2.016)
Inflation	Coef.	0.259	0.229	0.290
	t-stat	(3.749)	(3.943)	(4.931)
Industrial Production	Coef.	0.003	0.001	-0.001
	t-stat	(0.152)	(0.063)	(-0.064)
Term spread (slope)	Coef.	-0.021	-0.008	0.036
	t-stat	(-0.339)	(-0.166)	(0.637)
% R^2 adjusted		54.2	65.2	58.0

Panel B: k=3

		Maize	Wheat	Soybeans
Constant	Coef.	0.037	0.036	0.036
	t-stat	(5.311)	(5.946)	(5.436)
Implied Variance	Coef.	-0.051	-0.055	-0.044
	t-stat	(-2.863)	(-2.886)	(-3.918)
Implied Skewness	Coef.	-0.002	-0.005	-0.002
	t-stat	(-3.100)	(-4.043)	(-3.719)
VIX index	Coef.	-0.009	-0.007	-0.010
	t-stat	(-2.334)	(-2.099)	(-2.422)
Inflation	Coef.	0.184	0.158	0.216
	t-stat	(2.229)	(2.204)	(2.936)
Industrial Production	Coef.	0.005	0.004	0.002
	t-stat	(0.270)	(0.227)	(0.108)
Term spread (slope)	Coef.	-0.057	-0.044	-0.004
	t-stat	(-0.861)	(-0.760)	(-0.068)
% R^2 adjusted		44.8	53.1	46.1

Table 11: Forecasting the short-term US-Treasury Bill with option-implied moments when controlling for macroeconomic fundamentals and stock-market risk aversion

This table shows time-series regressions on monthly US-Treasury Bill of 3-month maturity, using as explanatory variables lagged values of option-implied variance and skewness for maize, wheat and soybeans markets, respectively. In Panel A we run our predictive regressions on US-Tbill one month ahead while in panel B we present the regression results when we run the same predictive regressions using a 3-month forecasting horizon. IV is option-implied variance, IS is option-implied skewness, I is yearly overlapping inflation rate for each month, IPI is the yearly overlapping return in the industrial production index, SLOPE is the yield difference between the 10-year US-government bond and the 3-month US-TBill and VIX is the VIX index. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) estimator.

$$USTbill_t = b_0 + b_1 IV_{t-k} + b_2 IS_{t-k} + b_3 VIX_{t-k} + b_4 I_{t-k} + b_5 IPI_{t-k} + b_6 SLOPE_{t-k} + \varepsilon_t$$

Panel A: k=1

		Maize	Wheat	Soybeans
Constant	Coef.	0.069	0.067	0.066
	t-stat	(4.549)	(5.511)	(4.615)
Implied Variance	Coef.	-0.136	-0.157	-0.133
	t-stat	(-2.972)	(-5.275)	(-5.911)
Implied Skewness	Coef.	-0.006	-0.016	-0.006
	t-stat	(-3.237)	(-5.364)	(-3.678)
VIX index	Coef.	-0.017	-0.012	-0.018
	t-stat	(-1.817)	(-1.487)	(-1.773)
Inflation	Coef.	0.357	0.265	0.444
	t-stat	(2.471)	(2.601)	(3.772)
Industrial Production	Coef.	0.013	0.007	-0.002
	t-stat	(0.267)	(0.210)	(-0.055)
Term spread (slope)	Coef.	-1.075	-1.038	-0.937
	t-stat	(-7.188)	(-8.846)	(-6.869)
% R^2 adjusted		60.6	72.9	64.2

Panel B: k=3

		Maize	Wheat	Soybeans
Constant	Coef.	0.068	0.067	0.065
	t-stat	(5.166)	(6.322)	(5.114)
Implied Variance	Coef.	-0.124	-0.150	-0.127
	t-stat	(-2.619)	(-4.927)	(-5.591)
Implied Skewness	Coef.	-0.006	-0.015	-0.005
	t-stat	(-3.226)	(-4.806)	(-3.520)
VIX index	Coef.	-0.018	-0.012	-0.018
	t-stat	(-2.032)	(-1.681)	(-1.914)
Inflation	Coef.	0.297	0.210	0.380
	t-stat	(2.016)	(2.024)	(3.115)
Industrial Production	Coef.	0.050	0.042	0.033
	t-stat	(0.995)	(1.080)	(0.701)
Term spread (slope)	Coef.	-0.981	-0.952	-0.855
	t-stat	(-6.114)	(-7.285)	(-5.862)
% R^2 adjusted		59.1	70.3	62.3

Table 12: Forecasting the real interest rate with option-implied moments when controlling for macroeconomic fundamentals and stock-market risk aversion

This table shows time-series regressions on monthly real interest rate (RIR), using as explanatory variables lagged values of option-implied variance and skewness for maize, wheat and soybeans markets, respectively. In Panel A we run our predictive regressions on the real interest rate one month ahead while in panel B we present the regression results when we run the same predictive regressions using a 3-month forecasting horizon. IV is option-implied variance, IS is option-implied skewness, I is yearly overlapping inflation rate for each month, IPI is the yearly overlapping return in the industrial production index, SLOPE is the yield difference between the 10-year US-government bond and the 3-month US-TBill and VIX is the VIX index. The t-statistics reported in parentheses are corrected for autocorrelation and heteroscedasticity using the Newey-West (1987) estimator.

$$RIR_t = b_0 + b_1 IV_{t-k} + b_2 IS_{t-k} + b_3 VIX_{t-k} + b_4 I_{t-k} + b_5 IPI_{t-k} + b_6 SLOPE_{t-k} + \varepsilon_t$$

Panel A: k=1

		Maize	**Wheat**	**Soybeans**
Constant	Coef.	0.058	0.056	0.055
	t-stat	(3.415)	(3.893)	(3.328)
Implied Variance	Coef.	-0.144	-0.158	-0.133
	t-stat	(-2.793)	(-4.947)	(-4.869)
Implied Skewness	Coef.	-0.006	-0.016	-0.006
	t-stat	(-3.119)	(-5.016)	(-3.376)
VIX index	Coef.	-0.008	-0.002	-0.008
	t-stat	(-0.736)	(-0.292)	(-0.742)
Inflation	Coef.	-0.491	-0.582	-0.399
	t-stat	(-3.502)	(-5.657)	(-3.145)
Industrial Production	Coef.	-0.001	-0.004	-0.014
	t-stat	(-0.034)	(-0.117)	(-0.291)
Term spread (slope)	Coef.	-1.231	-1.190	-1.089
	t-stat	(-7.710)	(-9.355)	(-7.593)
% R^2 adjusted		46.4	60.7	49.7

Panel B: k=3

		Maize	**Wheat**	**Soybeans**
Constant	Coef.	0.048	0.047	0.044
	t-stat	(2.920)	(3.287)	(2.832)
Implied Variance	Coef.	-0.168	-0.152	-0.134
	t-stat	(-2.164)	(-4.254)	(-4.632)
Implied Skewness	Coef.	-0.006	-0.015	-0.005
	t-stat	(-2.677)	(-4.339)	(-2.644)
VIX index	Coef.	-0.006	-0.001	-0.006
	t-stat	(-0.578)	(-0.128)	(-0.496)
Inflation	Coef.	-0.310	-0.403	-0.226
	t-stat	(-2.107)	(-3.152)	(-1.758)
Industrial Production	Coef.	0.010	0.002	-0.009
	t-stat	(0.156)	(0.145)	(-0.142)
Term spread (slope)	Coef.	-1.111	-1.079	-0.991
	t-stat	(-6.140)	(-7.409)	(-6.313)
% R^2 adjusted		36.3	50.8	41.3

Figure 1. Contemporaneous movements of the Fed funds rate and implied skewness

This graph plots the contemporaneous time series movements of the time series of maize, wheat and soybeans option-implied skewness and the Fed funds rate. The data cover the period from January 1990 to December 2011.

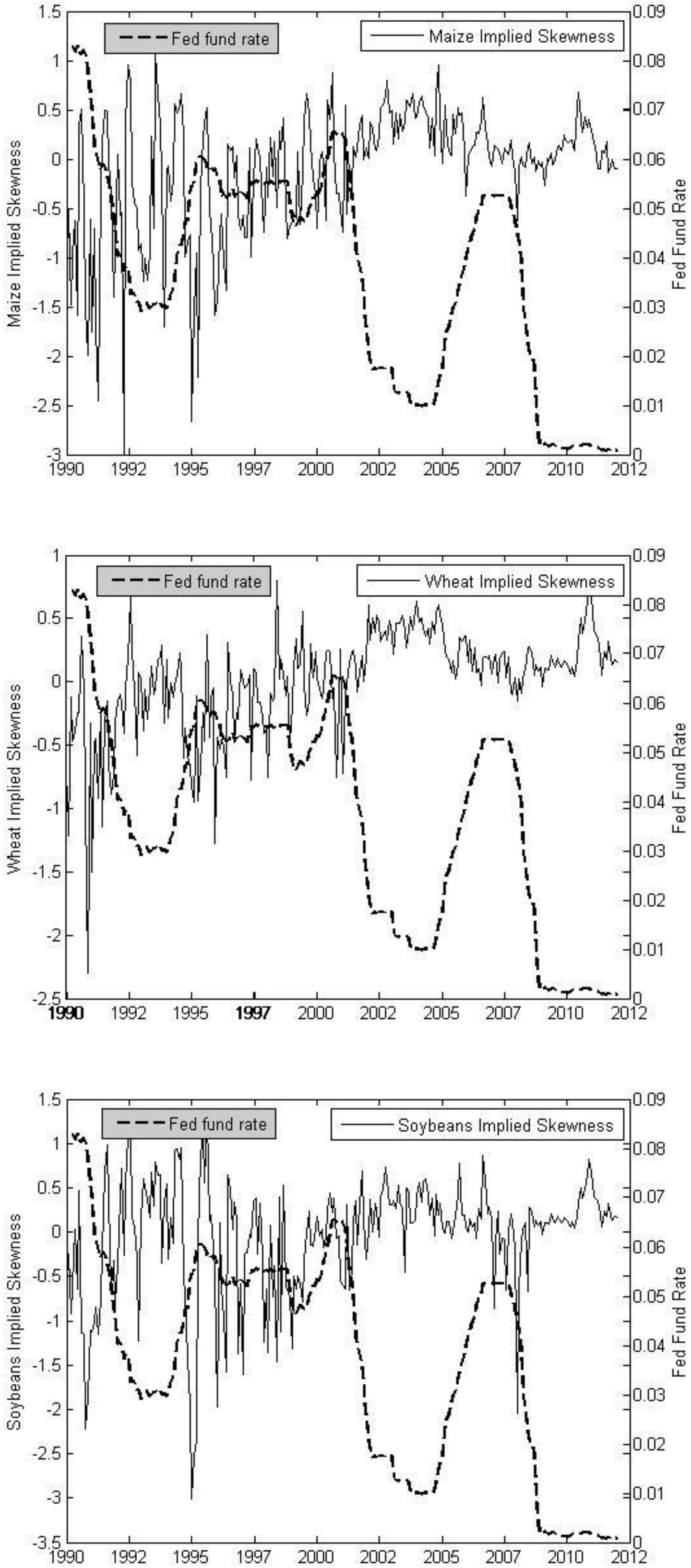


Figure 2. Contemporaneous movements of the Fed funds rate and implied variance

This graph plots the contemporaneous time series movements of the time series of maize, wheat and soybeans option-implied variance and the Fed funds rate. The data cover the period from January 1990 to December 2011.

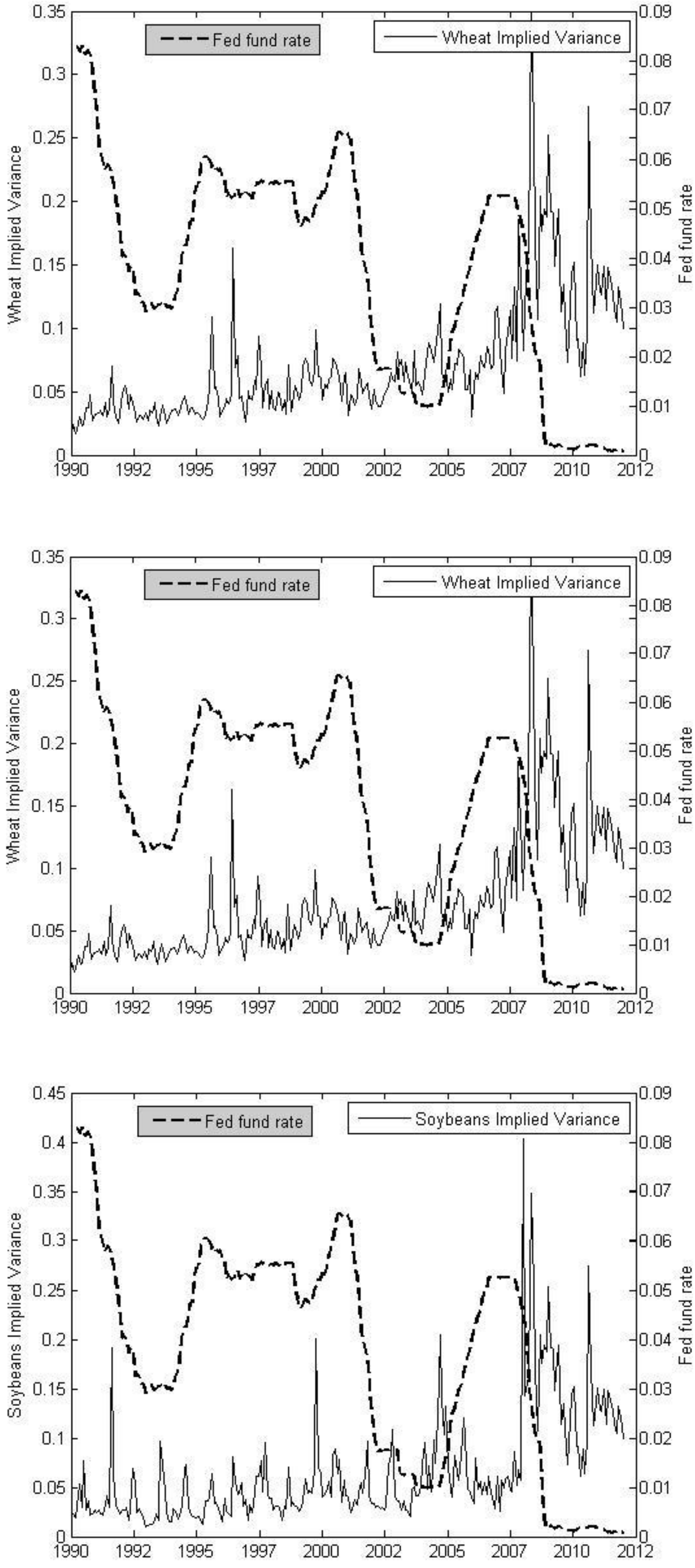
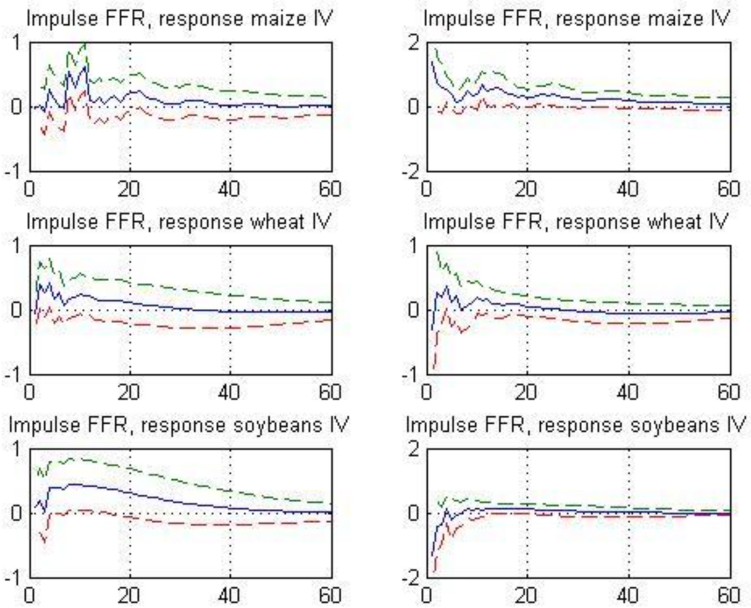


Figure 3. Structural form IRFs between monetary policy (Fed funds rate) and implied variance

This graph shows the structural Impulse Response Functions (IRFs) of the bivariate structural VARs of the form $Y_t=[FFR_t\ IV_t]$, where FFR is the monthly Fed funds rate and IV is the monthly implied variance of maize, wheat and soybeans markets, respectively. Panel A shows the responses of implied variance to a negative one standard deviation shock to the Fed funds rate, while Panel B shows the responses of the Fed funds rate to a positive shock implied variance of agricultural commodity markets. Both the IRFs of the FFR and the implied variance (IV) of agricultural markets are expressed in percentages (divided by 100). The left column of each Panel shows the responses of the models with the short-run restriction while the right column shows the responses of the models with the long-run restriction. The dashed lines show the 95% bootstrapped confidence intervals.

PANEL A

Short-run restriction | Long-run restriction



PANEL B

Short-run restriction | Long-run restriction

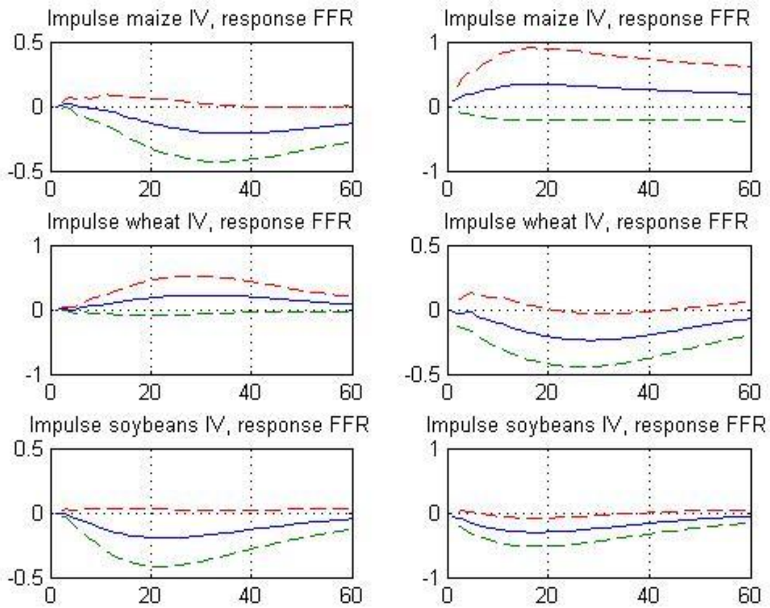
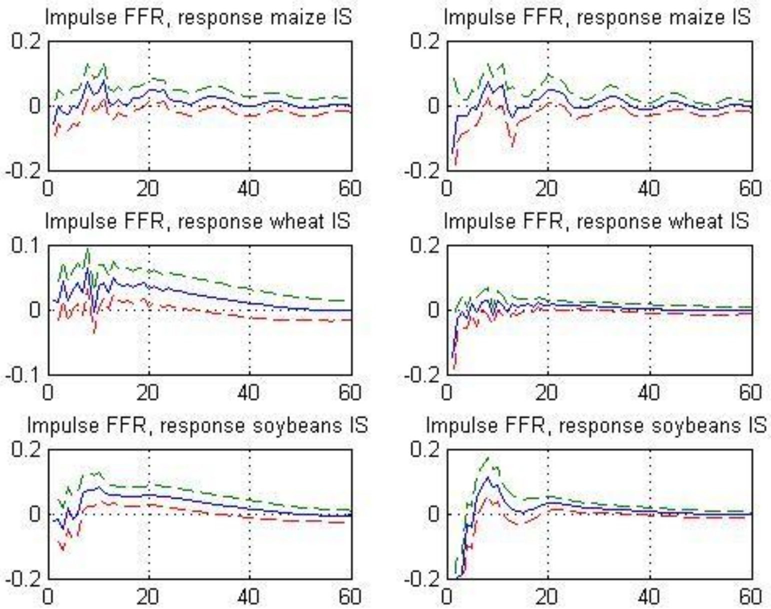


Figure 4. Structural form IRFs between monetary policy (Fed funds rate) and the implied skewness

This graph shows the structural Impulse Response Functions (IRFs) of the bivariate structural VARs of the form Y_t=[FFR_t IS_t], where FFR is the monthly Fed funds rate and IS is the monthly implied skewness of maize, wheat and soybeans markets, respectively. Panel A shows the responses of implied skewness to a negative one standard deviation shock to the Fed funds rate, while Panel B shows the responses of the Fed funds rate to a positive shock to implied skewness. The IRFs of FFR presented in Panel B are expressed in percentages (divided by 100), while for the impulse responses of implied skewness (IS) it was not necessary to do an analogous transformation. The dashed lines show the 95% bootstrapped confidence intervals. The left column of each panel shows the responses of the models with the short-run restriction while the right column shows the responses of the models with the long-run restriction.

PANEL A

Short-run restriction | Long-run restriction



PANEL B

Short-run restriction | Long-run restriction