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Commodity Price Volatility and Monetary Policy Uncertainty: A GARCH Estimation

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Commodities are on the move. In July of this year commodity prices reached near-record highs. Then, almost as quickly as they rose, commodity markets collapsed and prices fell to levels not seen in over a year. Until this collapse, commodities had enjoyed a bull market since late 2001, with the last two years witnessing the most significant rise in commodity prices in almost two decades. The staggering gains of commodities in 2007 and 2008, led by dramatic increases in energy and gold prices, seemed out of place given the softening economy and the collapsing housing market. A contentious debate began among consumers immediately pointed to speculation, the age-old scapegoat of rising prices.

However, the erratic behavior of commodities suggests larger macroeconomic forces are at play. All asset classes, including bond, stock and foreign exchange markets are susceptible to macroeconomic and monetary policy forces. Commodities are no exception. Since the oil embargo of the 1970s, which saw both commodity prices and inflation rise exponentially, economists have debated on the dynamics of commodity prices and monetary policy. Over the last twenty years, the FOMC of the Federal Reserve board has implemented a number of different practices meant to increase the transparency of monetary policy. This increased transparency is witnessed through reductions in the prediction errors of federal funds futures contracts. The interrelationship between the fed monetary policy uncertainties and commodity price movements is the primary focus of this study. Additionally, this paper will analyze the way monetary forces alter the volatility of commodities prices. It will question whether uncertainties in interest rates spur price movements of both gold and an index of primary commodities. Ultimately, the study finds that monetary policy uncertainties, as measured by the prediction error of the federal funds futures price, are a significant predictor of price volatility in gold and contribute the futures price level for the commodity index. The argument will be prefaced by a review of the relevant literature followed by the specific research question, reasoning, methodology and empirical results.

I. Literature Review

Generally, the literature has approached the relationship between commodity price fluctuations and macroeconomic forces from two directions: commodity price movements as an indication of inflation and thus a useful tool for monetary policy creation, and monetary policy as a causal factor in price volatility. Literature regarding the former has largely centered on the effectiveness of commodity prices to predict inflation. Evaluations of the latter have explored the likelihood of an existing causal dynamic between monetary policy and commodity price fluctuations. These analyses have varied in methodology, evolving from cointegration and vector autoregression models to the application of more recently developed Generalized Autoregressive conditional heteroskedasticity (GARCH) models. Both sides attempt to explain the movement of commodity prices and define the hazy relationship existing between monetary policy and commodity prices. While this literature review will focus on monetary policy as a contributory element of commodity price volatility, a complete picture of the relationship cannot be drawn without a discussion of the relationship between commodity prices and inflation.

Traditionally, commodity prices have been considered too volatile to play a significant role in monetary policy decision-making. However, several studies argue that commodity prices may be an early indicator of the health of the economy because they are continually auctioned in standardized markets with efficient information (Marquis and Cunningham, 1990; Cody and Mills, 1991). Thus, many authors share the common hypothesis that commodity prices help explain the future trajectory of macroeconomic variables, including the inflation rate. Early studies employed traditional Granger Causality tests to explain the relationship between price movements and inflation rates (Bessler, 1984). However, Granger tests can indicate only whether a significant relationship exists between variables, without further providing a characterization of it; Moreover, bivariate tests only evaluate pairs of variables and so may produce misleading results. As a result, cointegration and error correction models were introduced to correct for the nonstationarity of monetary and price variables. These typically involved either bivariate or multivariate VAR models. Bivarate VAR models usually measured the interaction between CPI and commodity prices. However, bivariate VAR models failed to produce significant results because they did not account for other factors affecting inflation (Furlong and Ingentio 1996).

Employing a multivariate VAR model over the period 1959 to 1987, Cody and Mills (1991) found that commodity prices are an early indicator of the state of the economy and that the Federal Reserve typically does not respond to commodity price movements. More recent literature by Awokuse and Yang (2002) rebukes Cody and Mills' final argument. Using a more sophisticated five variable VAR(k) model (where k indicates lag length) and a modified Wald test, Awokuse and Yang test for different restrictions on the parameters of the VAR(k) model. They concur that commodity prices help predict changing macroeconomic variables but argue that for the period 1975-2001, the Federal Reserve did respond to commodity prices. Differences in the latter argument may be attributed to the contrasting time periods and use of slightly different model specifications.

Both Awokuse and Yang and Cody and Mills evaluate variables across long spans of time, failing to accommodate for the individual impacts of different time periods. Furlong and Ingentio take this into consideration by evaluating sub-periods in time in addition to the longer set. They find that non-oil commodity prices were most statistically significant at predicting inflation in the 1970s and 1980s, but were not as reliable in the 1990s. Furlong and Ingentio conclude that the models of commodity prices predicted future inflation most accurately when "the effects of factors affecting inflation that were reflected first in the tightness in labor markets and the foreign exchange rate of the dollar, while they performed poorly when they did not" (Furlong and Ingentio 1996). They attribute their opposing results in the different sub-periods to changes in the types of shocks affecting commodity prices in the economy.

Furlong and Ingentio point to the decline of commodities as an inflationary hedge as a possible contributor in the shifting role of commodities in the 1980s and 1990s, although they acknowledge it is a weak argument on its own. Historically, primary commodities are unreliable inflationary hedges (Furlong and Ingentio 1996). Thus, commodity futures indexes are typically used to hedge against prices movements and not against inflation. The shining exception is gold, which is somewhat of an anomaly among commodities because of its historical use in monetary policy and money supply. Unlike many commodities it is durable, transportable and universally accepted as a store of value. Therefore, its underlying worth is inherently trusted. Worthington and Pahlavani (2007) found a stable, long-term relationship between the inflation rate and the price of gold. Using a cointegration model that allowed for structural changes in the U.S. gold market in 1972 and 1973 and the acceleration of inflation in 1978 and

1979, they concluded that gold prices and inflation move together, thus, finding gold to be a reliable hedge against inflation.

The interplay between commodity prices and inflation rates contributes significantly to the discussion of the relationship between monetary policy and price volatility. However, the policy implications are limited to whether or not the Federal Reserve should react to changing commodity prices. Conversely, evaluating monetary policy as a driving factor of commodity price volatility helps define the impact of the Fed's decision over time. The causal connection between monetary policy and commodity price volatility is more nuanced and complicated than the connection between price movements and inflation. While supply and demand forces should theoretically drive commodity prices, interest rates also play an important role in determining storage costs and, therefore, total commodity supply. High interest rates increase storage costs, making it more advantageous for suppliers to sell goods on the market rather then hold them in storage. Additionally, assets such as bonds become more attractive than commodity contracts. Therefore, rising interest rates should cause commodity prices to fall (Bond 1984, Frankel 2006 and Hess 2008).

Unfortunately, the actual analysis is more complicated than the theoretical argument. Frankel and Hadouvelis (1985) emphasize that only in a purely monetarist view will prices react immediately to money growth or the expectation of future money growth. The earliest empirical studies of the interplay between commodity prices and interest rates analyzed the sensitivity of commodity prices to money market shocks (Bond 1984, Frankel and Hardouvelis 1985). Frankel and Hardouvelis study how commodity prices reacted to weekly money supply announcements in order to "assess the degree of market credibility that the Fed has in its commitment to money growth targets" (426). They focused on how both expectations of money growth and actual money growth shaped commodity prices from 1980-82. Similarly, Bond (1984) focused on how expectations of supply and interest rates shocks shape futures markets. He found that shocks expected to be transitory produced smaller responses from spot and futures markets as well as smaller deviations in their respective prices. While these studies elaborate on the role of expectations of money growth and commodity price volatility, they fail to draw historical causal conclusions on the relationship.

Similar to the empirical work on the relationship between commodity prices and inflation, much of the literature employs cointegration to determine if a long-run relationship between commodity prices and levels of monetary variables exists (Hua 1998, Swaray 2008). The key element in these hypotheses is the belief in a long-run relationship, as cointegration models assume that even if two variables are non-stationary, a stationary linear combination of variables exists (Vogelvang). These variables have a relationship in the long-run even if that relationship may not be evident in a shorter time-frame. Hua (1998) finds that economic activities and the real effective exchange rate of the dollar have significantly "affected the real non-oil primary commodity prices in both long-run and short-run terms." He also finds commodity prices are vulnerable to interest rate shocks. Swaray (2007) also employs a cointegration test, coupled with an error correction model to demonstrate how fluctuations in monetary variables produce commodity price shocks. He found that fluctuations in business cycles and macroeconomic variables, including oil prices, have a significant impact on non-fuel primary commodities. While these studies evaluate the long-term relationship between commodity prices and monetary variables, they fail to explain the characteristics of the volatility itself. Understanding if macroeconomic and monetary variables create price volatility is a crucial determinant of a causal nature between the two. Cointegration and vector autoregressions are useful forecasting tools but fall short of explaining causes of volatility.

The GARCH model attempts to fill this void. In a typical ordinary least squares model the variance on the error term should be evenly distributed throughout the data. This assumption, called homoskedasticity, is contrasted with heteroskedasticity, in which the variance on the error term is not consistent over time. Robust OLS regressions will correct for heteroskedasticity; however, a GARCH model "treat[s] heteroskedasticity as a variance to be modeled" (Engle 2001). Many types of time series data do not have heteroskedastic errors, so allowing for heteroskedasticity did not appear necessary. However, a great deal of financial data contains heteroskedastic errors resulting from varying risks associated with differing time periods. Thus, "the expected value of the magnitude of error terms at some times is greater than at others" (Engle 2001). By analyzing heteroskedastic error terms, the GARCH model estimates causal factors in volatility.

Therefore, the GARCH model has emerged as a primary tool to estimate causes of commodity price volatility. Hammoudeh and Yuan (2008) employ multiple variations of the GARCH model to examine the "characteristics of the volatility behavior of strategic [metal] commodities in the presence of positive interest rate shocks and changes in short term interest rates" (609). Using the GARCH, EGARCH and CGARCH models, he is able to analyze the impact of past shocks, the effects of "good and bad news" on volatility and the effect of transitory and persistent volatilities in the short and long-runs. He finds that both past shocks and past volatilities predict future volatilities, with past volatilities predicting with slightly more strength. Furthermore, rising interest rates have a dulling effect on price volatility suggesting that monetary policy may be used to calm commodity markets. Finally, Hammoudeh and Yuan found that gold, and silver to some extent, are not sensitive to bad news making it a good hedge against crises, wars and high inflation. Thus, we see an extension on the earlier literature finding gold a sufficient hedge against inflation.

Absent from all the literature is a discussion on characteristics of volatility associated with uncertainties in monetary policy. In an efficient market with widely available information, expectations of changes in interest rates will immediately be factored into prices at any given time. Changes in federal funds rates that were already expected would, therefore, not have a large impact on prices. However, unexpected monetary policy shocks could have significant impacts on market movements. Commodity futures prices are based on the expectations of a variety of macroeconomic variables that directly affect the price of the good. Therefore, realistic and reliable expectations regarding the direction of future monetary policy should result in less volatile commodity markets. The predictability of interest rate and monetary policy decisions has increased greatly in the last twenty years. The Greenspan era of the Federal Reserve ushered in a new era of transparency that altered the way FOMC decisions were reported to the public. Due to these changes, interest rates were highly predictable by the late nineties and uncertainty surrounding monetary policy was minimal. Do increased uncertainties regarding interest rates alter the volatility of the commodities market? Specifically have they affected the volatility of gold, the commodity most closely linked to the money supply and considered a reliable hedge against inflation? Using the methodology employed by Hammoudeh and Yuan, I will attempt to find a causal relationship between expected future interest rates and commodity price volatility, both for primary commodities and gold.

II. Quantifying Monetary Policy Uncertainty

Undoubtedly, the most difficult aspect of operationalizing this hypothesis involves quantifying the markets' uncertainty regarding the trajectory of the federal funds rate. As stated earlier, predictability of monetary policy is closely related to the transparency of FOMC actions and decisions. Indeed, Federal Reserve Chairman Ben Bernanke embraced the importance of a more transparent FOMC in a speech in 2007:

A considerable amount of evidence indicates that central bank transparency increases the effectiveness of monetary policy and enhances economic and financial performance in several ways…if practitioners in financial markets gain a better understanding of how policy is likely to respond to incoming information, asset prices and bond yields will tend to respond to economic data in ways that further the central bank's policy objectives.

FOMC transparency has increased greatly over the past two decades and understanding its evolution is paramount to any analysis of monetary policy predictability. Carlson et al. (2006) note the difference between the markets' reaction to policy tightening in 1994 against similar policy moves in 2004 to illustrate how FOMC transparency has altered monetary policy predictability. In 1994, bond markets' inability to anticipate FOMC policy changes led to uncertainty among traders and volatility in the markets. In contrast, market volatility remained low after policy tightening in 2004 as market participants appeared to anticipate changes better. Carlson et al. credit this change in market reaction to a number of policy changes made during the Greenspan era. The following table summarizes the critical monetary policy changes that have significantly altered the transparency of the FOMC.

Table 1: Policy Changes regarding FOMC decision-making

Date	Policy action
August 1989	Policy change dictates that the target federal funds rate must be a multiple of 25 basis points. Previously, the FOMC made changes of any degree, leading to uncertainty regarding their next move.
Feb. 1994	This FOMC meeting was the first instance that the Committee released a press statement describing its policy. In the past the market had to deduce the committee's move by monitoring the Fed's open market operations.
May/Dec. 1999	In May, for the first time, the FOMC released a press statement that included a "policy bias," indicating that the fed was leaning toward an increase or decrease but had not yet changed the target. In December, they replaced the policy bias with "balance of risks" language to summarize its outlook for the economy.
Aug. 2003	This meeting marked the first time the Committee included "forward-looking" language suggesting the probable direction of the target fed funds rate in its press statement.

As William Poole stated in 2005, the purpose of these changes was “to increase the transparency of policy, improve accountability, and provide better information to market participants about the future direction of policy.” (Poole 2005) These changes have significantly altered the way the FOMC communicates with the public regarding the current fed funds rate as well as near-term policy decisions.

However, these policy changes alone are not enough to gauge the predictability of the federal funds market. They provide the framework to understand the context of the federal funds market and the significant events which have shaped its transformation, but to gauge interrelationships between commodity prices and monetary policy a quantitative measure is needed to assess the expectations of future FOMC decisions at a given time. The emergence of the federal funds futures market in October of 1988 changed the way in which markets predict FOMC decisions. Like the federal funds market, futures contracts in federal funds are traded continuously during the day until the contract matures at the end of its settlement month. Its settlement price is based on the average effective funds rates during its settlement month. Not surprisingly, federal funds futures contracts quickly became a way to gauge the markets’ anticipation of near-term fed funds rates. In many ways, a fed funds futures contracts represents a bet on future target federal funds rates (Poole 2005). Today, these futures contracts begin trading 24 months before their settlement date; however, their value is not typically considered relevant or reliable beyond the four or five-month-ahead contract.

A number of scholars have explored monetary policy uncertainty and the ability of fed funds futures to predict policy changes. In general, these authors have reached a consensus that futures contracts in fed funds rate are valuable indicators of market expectations (Krueger and Kuttner 1996, Kuttner 2001). Similarly, much of this literature assesses whether or not fed funds futures contracts can be considered an accurate and reliable predictor of the trajectory of Federal Reserve policy. Indeed, Hamilton (2007) illustrates the ability of fed funds futures contracts to predict interest rate movements by analyzing the time-series properties of daily changes in fed funds futures prices for contracts expiring in a one to three month horizon. He finds that this is particularly true in recent years, suggesting that the policy changes instituted by the FOMC in the 1990s and early 2000s have had a positive impact on market predictability. Carlson et al (2006) similarly defend this argument by analyzing the prediction errors of fed funds futures contracts. They find noticeable differences in the prediction errors from futures contracts expiring before 1994 and contracts existing after 1994, with even smaller errors dominating the era after 1999. However, they do note that smaller error predictions may “also reflect the end of unanticipated deflation, possible market deepening over the period, or a decline in the risk period” (3). They also acknowledge that errors grow in the recession periods regardless of the year. Nevertheless, their conclusions, coupled with the results of Hamilton (2007) and Kuttner (2001), establish a strong hypothesis that fed funds futures contracts are useful indicators of market expectations of fed funds rates. Thus, the prediction error of the futures contract provides the best way to gauge monetary policy uncertainty.

III. Theoretical considerations

Commodity futures are essentially tools used by businesses and financial investors to hedge against risks of uncertain future price changes and/or profit from expected increases or decreases in commodity prices. Because returns to commodity futures are inherently risky, basic economic theory suggests that their prices will contain a risk premium that compensates investors for the extra risks they take by investing in risky rather than safe financial assets. It also suggests that factors that increase the uncertainty of futures returns would increase the extent to which their prices fluctuate, that is, their volatility.

The main route by which monetary policy is usually thought of as influencing commodity futures prices is interest rates. A basic proposition is that increases in short-term interest rates tend to drive down commodity prices because they raise the costs of storing the commodities themselves (Fama and French 1987). This leads to a prediction of a negative relationship between futures prices and the Federal Funds rate. However, uncertainty regarding monetary policy would also be expected to affect the risk premium associated with commodity futures. To the extent that financial market participants have clear expectations of likely changes in monetary policy over the term of the futures contract, we would expect the risk premium built into the futures price to be relatively low, while more uncertain expectations for changes in rates would push the risk premium up (Micu 2005). Finally, the extent of uncertainty about policy may also boost the volatility of futures prices. Especially among financial-market participants whose motives for investing in futures are largely speculative, uncertainty about possible changes in rates may foster more frequent buying and selling in response to incoming news, causing prices to swing by a wider margin over a given period of time.

IV. Econometric Approach

This study utilizes a GARCH model to estimate how past volatility and variance in prices influence the variance in the current term. GARCH models were introduced by Bollerslev in 1986 as an extension of autoregressive regressive conditional heteroskedasticity (ARCH) models developed by Engle (1982). Engle postulates that ARCH disturbances exist if variance errors in the model tend to occur in clusters. These heteroskedastic errors are commonly found in speculative and financial markets which tend to be highly volatile. In ARCH models, the mean and the variance equations are conditional on past errors. Thus, the residuals of past terms estimate the mean and variance of the current term. The GARCH model extends Engle's ARCH estimation by augmenting the variance equation to include the forecast variance from the previous term. The information regarding volatility observed in the last period as measured by the lagged squared residuals is the equation's ARCH term while the GARCH term represents lagged variance forecasts.

Previous work (Hammoudeh and Yuan 2008) demonstrates the time-varying volatility of commodity prices and implies the need for a GARCH estimation model. This study hopes to gauge how changes in monetary policy uncertainty affect both the levels of commodity prices and their volatilities. Thus, this GARCH model will be a function of relevant measures of monetary policy captured by a set of variables, Z1t…Zkt. Additionally, the mean and variance of Yit will be influenced by combinations of exogenous variables, X1t…Xkt. Thus, the GARCH model postulates the level of the futures price and its volatility, respectively, as follows:

$$Y_{it} = b_0 + dY_{t-1} + \sum_{i=1}^{k} b_i X_{it-k} + \sum_{i-1}^{j} c_i Z_{it-j} + \varepsilon_t$$

$$\sigma^2{}_{it} = \omega_0 + \sum_{i=1}^{l} \alpha_l \varepsilon^2{}_{t-l} + \sum_{i=1}^{m} \beta_i \sigma^2{}_{it-m} + \sum_{i=1}^{k} h_i Z_{t-k} + \sum_{i=1}^{j} g_i X_{it-j}$$

Here, the model becomes an ARCH specification if the β's and h's equal zero. The information regarding volatility observed in the last period as measured by the lagged squared residuals is the equation's ARCH term while the GARCH term represents lagged variance forecasts. A GARCH equation is typically modeled as GARCH (p,q) where each letter denoted the number of lags on their respective terms. Bollerslev (1986) found the GARCH model to equal and, in some ways, improve the prediction value of an ARCH model using less lags.

In this study, a GARCH (1,1) model is employed for both dependent variables. A higher order GARCH (p,q) model would be necessary if ARCH effects remained in the model after the estimation. Higher-order GARCH (p,q) models allow for a wider range of autocorrelations in the volatility processes (Brockwell 2005). If residual tests depict remaining time series trends in the estimation, then a higher order GARCH may be needed.

This study is primarily concerned with the daily movements of two measures of commodity futures prices, the CRB/Reuters commodities index and gold prices, which serve as the dependent variables. Historically, gold serves an important hedge against inflation and, therefore, it is expected to be especially sensitive to changes in monetary-policy variables. The CRB/Reuters index is constructed of 28 diverse commodities, from agricultural commodities, such as hogs, to industrial goods. As such, it captures broad commodity price trends and may be used as a proxy to measure how commodities more generally respond to uncertainties in the monetary-policy environment. Futures prices are utilized because they are generally considered more volatile than spot prices in that they respond quickly to information and are more sensitive to speculation.

The variables tested as regressors in the econometric analysis were chosen based off the regressors employed by Hammoudeh and Yuan. They found that oil shocks and the lagged dependent variable are the significant predictors of that commodity price volatility. As an extension of Hammoudeh and Yuan's study, these variables will be utilized and augmented by the residual of the prediction error and the target federal funds rate. The oil price is utilized to measure the reaction of the commodities to oil shocks, which tend to pass-through onto other goods (Baffes 2007).[1] Oil is lagged because as Hammoudeh and Yuan (2008) states, "It has been shown that oil prices have a greater speed of adjustment to equilibrium than other commodities (Hammoudeh and Yuan 2007). Oil is more sensitive to special events such as refinery outages, cold snaps, hurricanes, and geopolitical events in the oil producing countries than the other commodities" (611). The study also utilizes the daily target federal funds rate (TAR) to ascertain if the target itself and not just the prediction error, affects futures prices

[1] In order to preserve the continuity of the GARCH model, missing data for oil prices and the CRB index because of holidays was generated by obtaining the average from the days immediately surrounding the gap. We preserve the integrity of the time series characteristics as this occurred approximately four times per year over 20 years.

Finally, the residual of the prediction error (ERR) of the daily fed funds futures contract is included to measure the effect of monetary policy uncertainty. Daily average prediction errors were obtained by calculating the prediction errors from the contracts expiring in the 1-to-3-month time horizon. That is, prediction errors for the month of June were obtained by calculating the prediction error for each day in the June, July and August contracts. The prediction error is defined as the absolute value of the difference between the futures contract price on day x and the target federal funds rate on the last day of the delivery month. The errors over this three-month time horizon were then averaged. In this instance, averaging the errors on each contract did not eliminate the time aspect of the prediction value, in that the error regularly falls as the end of the month approaches. If the hypothesis of Carlson et al. (2006) is right, then we should still observe lower average prediction errors after 1999 and higher averages in the period before 1994. (In fact, this pattern occurs in the data, as shown in Appendix A, Figure A3). The average summarizes the prediction error for 30, 60 and 90 days ahead of the expiration of the contract, instead of just focusing on month-to-month errors, which typically predict well.

The residuals on the errors were obtained by coding each date for its place in the month (numbers descended from 31 to 0). Thus, each date denotes the number of days left in the month. This allowed for an OLS regression to predict the residuals for the absolute errors based on the number of days remaining in the month. To avoid the cancelling of positive and negative residuals, the square of the residuals is used. These residuals help to standardize the prediction of the fed funds futures error by using the number of days left in a month as a predictor of this error. Thus, the residual of the regression is the difference between the observed dependent variable (ERR) and the predicted dependent variable based on the number of days remaining in a given month.

The empirical analysis used daily data from November 18, 1988 to December 31, 2006, where the beginning of the analysis is dictated by the introduction of fed funds futures contracts and the end is chosen to exclude the unprecedented turmoil in financial and commodities markets that began in 2007. Table 1 summarizes the data sources, variable definitions and give descriptive statistics for GOLD, OIL, CRB, TAR, ERR and RES2. Unit root tests on all variables indicated the presence of unit roots in the log levels of all the commodity price measures, but no unit roots in the monetary policy measures (see Appendix A2). However, first differences of the commodity price measures were stationary, so these variables were incorporated into the analysis using log-difference form. The statistics show a high level of kurtosis for all the variables except the fed funds target, indicating the possibility of time varying volatilities in the dependent variable and the necessity of an ARCH or GARCH approach.

The necessity of a GARCH model is confirmed by examining for remaining ARCH effects on the individual series and on the GARCH estimation. Ljung-Box Q-statistics tested for the presence of white noise in the constant and the trend on DLOIL, DLCRB and DLGOLD. The presence of white noise would suggest ARCH processes are present in the data. Likewise, tests on the residual of the estimation also indicate if trends remain in the data. In this case, the presence of white noise among the residuals suggests that the ARCH effects have been sufficiently captured by the model. This study utilized the ARCH-LM test, Correlogram of the Q-statistic, histogram of the residual and visual plot of the standardized residual to test for remaining ARCH effects. The results from the ARCH effects tests for both DLCRB and DLGOLD did not reveal any remaining significant ARCH effects. None of the tests revealed any significant remaining ARCH effects. Indeed, figures 2 and 3 show the plots of standardized residuals for gold and the CRB index, respectively. The figures show a significant amount of white noise throughout the sample set, implying a correct estimation of the GARCH model. These tests, coupled with the stochastic characteristics of the commodity variables and their high level of kurtosis, indicate the appropriateness of the GARCH model and its ability to capture the time-varying volatility of commodity prices.

V. Results

Capturing monetary policy uncertainties on the levels and variances of commodity prices involved creating estimations that analyzed the influences of both non-policy and policy variables on the dependent variables. Although the residual of the prediction error serves as the estimation's measure of monetary policy uncertainty, the inclusion of non-policy variables augments the model by estimating the influences of oil price changes and the dependent variable's previous term. The interaction of the non-policy variables with the monetary policy variables on commodity prices creates a model that appropriately measures significant influences to the volatility and levels of gold and the CRB/Reuters Index. Accordingly, the lagged dependent variable and the lagged oil price shocked are regressed as non-policy variables while the residual of the prediction error of the fed funds futures rate and the target federal funds rate are included as monetary policy variables. Table 2 presents the results of the estimations on both gold and the CRB/Reuters index. Full regression estimations are available in Appendix A and Appendix B for gold and the CRB/Reuters index, respectively. Although not all significant, these variables produced models with minimal remaining ARCH effects, suggesting that they best captured the ARCH processes present in the data.

The empirical results of the GARCH model offer important insights into the behavior of commodity prices and their interaction with monetary policy uncertainties. In general, the study finds that the GARCH model is a good measure of the persistent volatility present in gold prices. Additionally, past volatilities and errors are significant determinants of the variance of the futures price and past prices are a significant determinant of the expected price. However, a more nuanced analysis shows how monetary policy influences prices levels and volatilities. The residual of the prediction error on the fed funds futures contract is not significant in the mean equation but is significant at the five percent level in the variance equation. This suggests that uncertainties surrounding monetary policy contribute significantly to the volatility of the gold price, but do not necessarily help predict the current futures' price of gold. Higher uncertainty regarding monetary policy does not bid up the price of gold future but increases the arc of the price swing.

Table 2: GARCH (1,1)- Determinants of commodities futures prices

	Gold		CRB	
Variable	Mean	Variance	Mean	Variance
Constant	.000523** (2.650)	4.06E-07* (1.899)	0.000357* (1.979)	5.89E-07** (3.305)
Dep. Var (-1)	-0.040* (4.45)		0.074** (4.75)	
Oil Shock	0.005+ (1.714)	5.29E-05** (2.67)	4.47E-05 (0.013)	8.25E-06 (0.753)
Fed target	-0.0001** (-3.28)	-4.40E-08 (-1.22)	-4.20E-05 (-1.222)	-1.94E-08 (-0.959)
Residual of Error	0.002 (.959)	4.53E-06* (2.12)	-0.002985+ (-1.765)	-6.34E-07 (-0.621)
ARCH term		0.045** (8.42)		0.049** (8.39)
GARCH term		0.95** (188)		0.937** (117.11)
LL	16589.214		17849.12	
DW	1.948		2.078	
F-stat	.42		.423	
AIC	-7.08		-7.55	

Notes: T-statistics in parenthesis, errors modeled using Generalized Error Distribution (GED)
*+ significant at 10% level, * significant at 5% level, ** significant at 1% level*

The significance of the residual as a measure of monetary policy uncertainty suggests that on a broader scale the volatility of gold prices responds to macroeconomic shifts. For instance, recessionary periods typically experience higher rates of monetary policy uncertainty because investors and traders cannot always predict the depth or length of the recessions. Due to its role as a financial safe haven, investors are known to rush toward gold during recessions, causing prices to move (Hammoudeh and Yuan 2008). Thus increased monetary policy uncertainties would be expected to contribute to price movements during recessions. Likewise, because the prediction error of the fed funds futures rate has improved over the past two decades and the models shows increased errors causing increased volatility, we can deduce that monetary policy could be expected to have contributed to a reduction in fluctuations in gold futures market. Although this GARCH model does not find monetary policy uncertainties to predict gold futures prices well, it does model the prediction error as a determinant in the volatility of gold. Therefore, uncertainties in monetary policy are an important element in understanding movements in gold futures markets.

Likewise, oil shocks are positive at the ten percent level for the mean equation and the one percent level in the variance equation. Thus, it can be deduced that movements in oil prices create more volatile gold markets but may not have the same strength in raising the current term price. Although oil shocks may pass-through onto gold prices, they are a more compelling determinant of the variance in gold prices. Oil shocks are closely related to rising headline inflation (Baffes 2007). Given gold's role as an inflation hedge, it is not surprising that greater volatility in oil causes a growth in the variance of gold prices. From this model we can deduce that a price shock on oil will cause investors to hedge inflation, thus moving the price of gold. Additionally, we can logically conclude that oil shocks may affect gold prices and, like monetary policy uncertainties, significantly increase the volatility of gold futures prices.

For the CRB index, the model finds that past volatilities, as measured by the GARCH term, and passed shocks on volatility, measured by the lagged residuals of the ARCH term, have the largest effect on the variance of the CRB index. The estimation for the CRB/Reuters index differs significantly from the model for gold in that the residual of the error is not significant in the variance and is significant in the mean. There are a number of possibilities that may explain this occurrence. The commodities listed on the CRB/Reuters index have inherently different attributes and characteristics than gold; its basket of goods contains agricultural, industrial and energy commodities. Furthermore, these goods are less connected to the financial markets than gold. Monetary policy is created to directly influence financial lending and assets that are less connected with these instruments experience the effects of monetary policy through changes in storage cost or changes in money supply and availability of credit. In varying degrees, these types of commodities are more vulnerable to supply and demand shocks that may have a greater influence on price volatility. Seasonality in agricultural commodities will also affect supply and demand, causing the price to move. Therefore, we can reasonably expect the CRB/Reuters price index to behave differently than gold.

In this model, increased uncertainties in monetary policy had an effect on the price levels of the commodities listed in the CRB/Reuters price index. However, they did not significantly affect the variance of the prices. The GARCH model estimates that increased uncertainties lower the price levels on the futures index. By extension, we would then expect decreased uncertainties to increase the price level of commodities. Thus, the model predicts that greater certainty in monetary policy may actually increase speculation in commodity futures. If traders have reasonable expectations of the trajectory monetary policy of they may have greater confidence in the outlook of commodity futures and the stability of commodity markets, causing them to invest. This conclusion is especially intriguing given the steady rise in commodity prices after 2001 and this period's low monetary policy uncertainties. Anecdotally, this theory also adds an interesting dimension to the recent plunge in commodity prices, which has occurred concurrent to high levels of monetary policy uncertainty.

When estimated against the CRB/Reuters index, the non-policy variables exhibited different characteristics and prediction ability from the results in the gold model. Contrary to the GARCH estimation for gold, oil shocks played almost no role in the determination of either the mean term or the variance term. This is likely because the continuous CRB index contains crude oil, so the shock was already factored in by the lagged DLCRB. Additionally, an increase on the dependent variable does predict an increase on estimation of the current price levels. The past prices of the commodity index may be a better predictor of how oil shocks influence commodities, since energy shocks will have an immediate effect on the CRB/Reuters index prices.

VI. Conclusion

This study measures the affect monetary policy uncertainty had on commodity price movements since the introduction of the federal funds futures market in 1988. Similar studies had examined the effects of interest rate shocks on commodity prices or, conversely, the influence of fed funds futures movements on financial assets. However, the literature lacked a comprehensive analysis of the relationship between commodity prices and federal funds prediction error. This study attempted to fill this hole in the literature by analyzing the predictive capabilities of the federal funds futures error on the price movements and volatility of gold and the CRB/Reuters index. Ultimately, the study found that uncertainties regarding monetary policy increase volatility in gold futures markets. Conversely, a reduction in monetary policy uncertainties may cause an increase in speculation and an uptick in prices for primary commodities.

The results have important implications for commodity and financial traders. Modeling the determinants of gold volatility is important for traders who may interact with financial derivatives whose underlying assets are gold (Hammoudeh and Yuan 1988). Furthermore, it offers greater insight as to how gold prices move in response to macroeconomic events, including crises and recessions. Because the model predicts increased volatilities during periods of monetary policy uncertainty, market actors may be better prepared to deal with these periods of increased price variance in the future. As such, the risk hedging process is smoothed. The results for the CRB/Reuters index imply that increased abilities of fed funds futures contracts to predict future target interest rates has led to increased commodity prices. This affects commodity traders who may be able to form better expectations of the direction of the commodity prices if the direction of monetary policy is more certain.

Additionally, the results have important implications for monetary policymakers. The estimation shows that prediction errors for the fed funds futures contracts significantly affect the behavior of commodity prices. Thus, increased transparency in the last twenty years has dampened volatilities on gold prices. However, better expectations of monetary may have also contributed to rising commodity prices. The monetary policymaker needs to be cognizant of the effects this financial instrument has on non-financial markets and how these consequences reverberate through the economy.

There is still much room for investigation within the topic of monetary policy uncertainty, especially as it pertains to market volatility. It is an exciting field with important implications for options and futures traders, as well as policymakers. The importance of providing smooth monetary policy cannot be understated. Analyzing monetary policy as it affects commodity prices helps to create a better understanding of the impact financial tools have on consumer and durable goods.

VII. References

Awokuse, Tituse and Jian Yang. 2002 "The informational role of commodity prices in formulating monetary policy: a reexamination." *Economics Letters* 79 pp. 219-224

Baffes, John. 2007. "Oil Spills on Other Commodities." World Bank Policy Research Working Paper.

Bernanke, Ben. "Federal Reserve Communications" Speech at the Cato Institute 25th Annual Monetary Conference, Washington, D.C. 11/14/2007

Bollerslev, T. (1986) "Generalized Autoregression Conditional Heteroskedasticity," *Journal of Econometrics* 31, pp. 307-327

Carlson et al. (2006) "FOMC Communications and the Predictability of Near-Term Policy Decisions." Federal Reserve Bank of Cleveland.

Cody, Brian J., and Leonard Mills. 1991. "Role of Commodity Prices in Formulating Monetary Policy." *Review of Economics and Statistics* 73, pp. 358–365.

Engle , Robert. 1982 "Autoregressive conditional heteroskedasticity with estimates of the variance of United Kingdom inflation." *Econometrica* 50, pp. 987-1000

Engle, Robert. 2001. "GARCH 101 The Use of ARCH/GARCH Models in Applied Econometrics." *Journal of Economic Perspectives* 15 (4) pp. 157-168

Fama, Eugene F. and Kenneth R. French. 1987 "Commodity Futures Prices: Some Evidence on Forecast Power, Premiums, and the Theory of Storage" *The Journal of Business* 60, No. 1 pp. 55-73

Frankel, J.A. 2006. "The effect of monetary policy on real commodity prices." NBER working paper.

Frankel and Hardouvelis. 1985. "Commodity Prices, Money Surprises and Fed Credibility." *Journal of Money, Credit and Banking*. 17 (4), pp. 425-438

Furlong, Fred and Robert Ingentio. 1996 "Commodity prices and Inflation." *FRBSF Economic Review* 2 p. 35-47

Hamilton, James D. 2007. "Assessing Monetary Policy Effects Using Daily Fed Funds Futures Contracts," NBER Working Papers 13569, National Bureau of Economic Research, Inc.

Hammoudeh, Shawkat and Yuan Yuan. 2008 "Metal Volatility in the Presence of Oil and Interest Rate Shocks." *Energy Economics* 30, 606-620

Hess, Dieter et al. 2008. "How do Commodity Futures Respond to Macroeconomic news?" *Financial Market Portfolio Management*. 22, pp. 127-146

Hua, P., 1998. On Primary Commodity Prices: The Impact of Macroeconomic/Monetary Shocks. *Journal of Policy Modeling* 20, 767–790.

Krueger Joel T. & Kenneth N. Kuttner, 1995. "The Fed funds futures rate as a predictor of Federal Reserve policy," Working Paper Series, Macroeconomic Issues 95-4, Federal Reserve Bank of Chicago.

Kuttner, Kenneth N. 2001 "Monetary policy surprises and interest rates: Evidence from the Fed funds futures market" *Journal of Monetary Economics.* 47 (3) 523-544

Marquis, M. H., and S. D. Cunningham. 1990. "Is There a Role for Commodity Prices in the Design of Monetary Policy? Some Empirical Evidence." *Southern Economic Journal* 57 (2) pp. 394–412.

Micu, Marian. 2005 "Declining risk premia in the crude oil futures market." *BIS Quarterly Review.*

Pindyck, R.S., Rotemberg, J.J., 1990. "The Excess Co-movement of Commodity Prices." *Economic Journal* 100, 1173–1189.

Poole William. "How Predictable is Fed Policy?" Speech at the St Louis Federal Reserve. 10/04/2005

Swaray, Raymond. 2008 "Macroeconomic Determinants of Non-fuel Commodity Prices Movements." *Journal of Applied Business Research 24* (1) 11-16

VIII. Appendix A

A1. Descriptive Statistics

	Gold*	Oil*	Residual Error	ofFed FundsTarget Rate	CRB/Reuters Price Index*
Mean	8.85E-05	0.000319	0.016916	4.627950	0.000109
Median	0.000000	0.000920	0.005463	5.000000	0.000196
Maximum	0.088872	0.188677	0.643864	9.812500	0.081538
Minimum	-0.077327	-0.406396	1.94E-11	1.000000	-0.075853
Std. Dev.	0.008844	0.024271	0.043299	2.151642	0.005976
Skewness	-0.225497	-1.298478	6.181270	0.185964	0.025694
Kurtosis	13.40621	24.99212	55.63627	2.665268	16.32252
Jarque-Bera	21359.49	96547.00	575546.3	49.29271	34943.79
Probability	0.000000	0.000000	0.000000	0.000000	0.000000

Sum	0.418219	1.507947	79.92812	21867.06	0.514860
Sum Sq. Dev.	0.369478	2.782821	8.856731	21870.05	0.168698
Observations	4725	4725	4725	4725	4725
Source	International Monetary Fund	Energy Information Administration	International Monetary Fund	St. Louis Federal Reserve Bank	Commodity Research Bureau

*Descriptive Statistics on first difference of the log

A2. Unit root tests for predictors and dependent variables

Variable	Augmented Dickey Fuller	Phillips-Perron
Gold	I(1)	I(1)
CRB Index	I(1)	I(1)
Oil	I(1)	I(1)
Residual of Fed funds futures prediction error	I(0)	I(0)
Prediction error	I(0)	I(0)
Target federal funds rate	I(0)	I(0)

A3. Residual of Fed Funds Futures contract overtime