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# Volatility of Commodity Futures Prices

# and Market-Implied Inflation Expectations

by Lucjan T. Orlowski [1)*]

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This study examines intricate interplay between crude oil, copper and gold futures prices, and market-implied inflation expectations that are proxied by the breakeven inflation derived from the 5-year US Treasury Note yields. We perform the Bai-Perron multiple breakpoint tests, Bayesian VAR with impulse response functions and GARCH with GED parameterization tests on daily data for the sample period January 3, 2003 – March 26, 2015. The results show a strong causal impact of shocks in the breakeven inflation on West Texas Intermediate and Brent crude oil as well as copper futures prices, albeit to varied degrees during the examined sample period. At times of low market risk and highly liquid markets West Texas Intermediate and copper futures prices move in tandem with the 5-year breakeven inflation. Prices of Brent and gold futures move in the opposite direction to the market-implied inflation.

**Keywords:** commodity futures prices; breakeven inflation; Bayesian VAR; Bai-Perron multiple breakpoint regression; GARCH

**JEL Classification: C58, G13.**

This version: September 2017

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## I. Introduction

We aim to investigate the interplay between changes in selected commodity futures prices and market-implied inflation expectations proxied by the breakeven inflation (BEI). We apply the 5-year BEI rate, which represents a measure of expected inflation derived from 5-year Treasury Constant Maturity Securities and 5-year Treasury Inflation-Protected Constant Maturity Securities (TIPS). In essence, the 5-year BEI indicates the expected inflation over the next 5-year period by bond market participants.

We subscribe to the general notion that the market-implied inflation expectations have a pronounced impact on commodity futures prices, albeit to varied degrees and directions depending on the specific commodity and market risk conditions. We do not presume a reverse causality, i.e. an impact of changes in commodity futures prices on the market-implied inflation expectations.

There is an extensive body of literature examining the relationship between commodity prices and financial variables, mainly exchange rates, interest rates and equity prices. Among others, Blanchard/Gali (2007) discuss significant differences in reactions of oil prices to the macroeconomic fundamentals between the 1970s and 2000s. Lizardo/Mollick (2010) show that crude oil prices significantly and continuously explain changes in the US dollar (USD) exchange rate. Reboredo (2012), Ding/Vo (2012) and Fratzscher et al. (2014) argue that such causal impact becomes stronger at times of financial crises. Sari et al. (2012) provide evidence of pronounced short-run responses of metal futures prices and weaker reactions of oil prices to the USD exchange rate. Balcilar et al. (2017) focus on asynchronous co-movements between shocks in

S&P 500 equity prices and West Texas Intermediate (WTI) oil prices, arguing that stocks are driven mainly by permanent shocks, while oil prices are subject to both permanent and temporary disturbances. Investigating patterns of signal diffusion among different financial markets, Narayan et al. (2017) provide evidence of cross-market pricing transmission from gold, to bonds, to oil and subsequently to inflation, based on long-term (1950-2015) monthly data. Examining similar market reactions during the post-financial crisis period Batten et al. (2017) show that equity prices have moved in tandem with oil prices, particularly in Asian markets.

Nevertheless, the interplay between futures prices and inflation expectations has been addressed rather sparsely. Most of the empirical literature on this subject is based on lower frequency, monthly data and inflation expectations based on headline or core inflation measures. The novel aspect of our approach is the application of high frequency daily financial data (one-month futures settlement prices) and the BEI-based inflation expectations measure. We have chosen two energy and two metal futures that are most frequently addressed in the empirical literature and market reports as being presumably tied to key financial variables including inflation expectations. Our four selected commodity futures include Brent and WTI crude oil, copper and gold. Our daily database includes 3074 observations for futures prices and the 5-year BEI during the January 3, 2003 – March 26, 2015 sample period. The starting point of our sample period coincides with the earliest availability of data for the 5-year BEI. We have also tested the longer-term, 10-year BEI and decided not to use it in our paper, as its rather smooth trajectory over the long-range expectations horizon weakens the connection with daily changes in commodity futures prices. Moreover, long-term inflation expectations embedded in the 10-year BEI are mainly affected by central banks' credibility and overall ability to control inflation, while medium-term expectations reflected by the 5-year BEI carry information about market news and forecasts (Gürkaynak et al., 2010; Cunningham et al., 2010; Strohsal/Winckelmann, 2015).

In addition to testing time responses, we examine the varied degrees of responses of individual futures prices to BEI. We perform the stationary ordinary least-squares (OLS) regression, subsequently augmented with the Bai-Perron multiple breakpoint (MBP) tests that enable us to analyze the intricate interplay of our variables at different sub-periods and varied financial stability conditions. We also conduct the conditional volatility testing of these relationships by employing the generalized autoregressive conditional heteroscedasticity GARCH(p,q) tests with the general error distribution (GED) parameterization, which allows us to estimate the degree of leptokurtosis (i.e. tail risks) in the conditional volatility series.

Based on the prior available empirical research and market reports that we review in the literature section of our paper, we initially assume that inflation expectations have a pronounced positive impact on crude oil and copper futures prices, and a weaker positive impact on gold prices. We further assume that the causal reactions between the breakeven inflation and futures prices are seemingly different at normal (tranquil) versus turbulent market periods. We hypothesize that at times of financial distress the interactions between inflation expectations and commodity futures become weakened, somewhat suppressed by higher market risk.

Section II provides a brief survey of pertinent literature. In Section III, we identify and discuss the specific variables and describe our database. We believe that prior to devising an appropriate model and performing its empirical testing, we ought to analyze causal reactions and impulse responses between shocks in commodity futures prices and shocks in BEI. These mutual responses are shown and analyzed in Section IV.  Our baseline analytical model is presented and tested with a stationary OLS in Section V. Subsequently, in Section VI we conduct a MBP regression to detect structural breaks from data. In Section VII we perform the GARCH conditional volatility analysis. Section VIII summarizes our key findings.

## II. Literature Overview

The literature examining the relationship between commodity futures prices and various economic and financial variables is quite extensive. However, most of these studies address linkages between gold and oil futures prices on the one side, and interest rates and exchange rates on the other. The association of futures prices with market-implied inflation expectations is sparsely analyzed. In particular, only the most recent studies consider market-implied inflation expectations based on break-even inflation measure that is derived on the basis of Treasury Inflation-Protected Securities (TIPS) first introduced by the US Treasury only in 1997. The consistent BEI data have become available as of 2003.

The early dominant view was that BEI-based inflation expectations measure was less accurate in predicting inflation than inflation expectations derived more directly from real and nominal yield curves, particularly at turbulent market periods as argued by Adrian and Wu (2009). They attributed this inaccuracy to the markets for TIPS being considerably less liquid than those for nominal on-the-run Treasuries. However, as argued by Söderlind (2011), BEI is gaining traction among monetary policy-makers and security investors as an accurate predictor of expected inflation. It is because changes in BEI are not only caused by the expected inflation but can also be affected by shifts in inflation risk and liquidity risk premium.

Several studies point out to a discernible impact of oil shocks on short- and long-term inflation expectations embedded in yields of U.S. Treasury securities. Among others, Celasun et al. (2012) suggest that "oil price shocks have a statistically significant, albeit economically small impact on longer-term inflation expectations". They further argue that this relationship has become stronger in the aftermath of the 2008 financial crisis - the intensity of which they attribute to heightened inflation uncertainty and to the expansionary monetary policy. A stronger correlation between changes in futures prices and inflation expectations at times of financial distress is also shown by Lumsdaine (2009). This co-movement is particularly discernible for shorter-term inflation expectations as measured by shorter maturity BEI. As argued by Lumsdaine (2009), changes in oil futures prices have a greater influence on near-term than on longer-term inflation expectations.

While the interplay between futures prices and market-implied inflation expectations has been analyzed more recently (Celasun et al., 2012), the relationship between futures prices and lower-frequency inflation measures based on headline and core inflation indexes has been widely discussed in the literature before. An earlier study by Blanchard and Gali (2007) shows that the response of inflation expectations to the shocks in oil prices significantly decreased during the 1973-2005 sample period. They attribute this decrease to the declining share of crude oil and related products in both global consumption and production. They also point out a decrease in real wage rigidities and the improved credibility of monetary policy as plausible causes for these dynamic changes. Their conclusions are questioned by Bhardwaj et al. (2015) who provide evidence that prices of commodities are increasingly positively correlated with inflation, while a correlation between prices of stocks and bonds with inflation is considerably weaker.

In a similar vein to Blanchard and Gali, Clark and Terry (2009) show a diminishing response of the economy-wide headline and core inflation to shocks in crude oil prices. They argue that this weakening relationship is caused by a decreased responsiveness of monetary policy to energy inflation, a reduction in the consumption of oil, a reduction in real wage rigidity and, in general, the beneficial effects of a low-inflation environment. Their results shall be interpreted with caution, since their empirical exercise covers the period ending by the second quarter of 2008 and does not account for the post-recession trends in the relationship between oil prices and inflation expectations.

In a broader scope of research, there is evidence that changes in inflation expectations, along with changes in other macroeconomic fundamentals and market risk indicators (such as CBOE VIX volatility index) are significantly related to changes in crude oil prices. Among others, Chiang et al. (2014) find that oil price risk is significantly related to changes in the rate of inflation, among other tested macroeconomic factors including stock market volatility, industrial production and GDP growth, and unemployment changes. There is also evidence that higher market risk perceptions reflected by the elevated VIX tends to suppress commodity futures returns. Gozgor et al. (2016) show that the negative causal relationship between market risk and commodity futures returns is particularly pronounced for corn and soybean futures.

There is a consensus in the literature that crude oil prices are very sensitive to changes in financial asset prices. Pass-through effects of changes in financial asset prices onto oil prices are carried via exchange rates. Among others, Zhang (2013), Fratzscher, et al. (2014) and Orlowski (2016) point out that there is a significant causality between oil price and the US dollar exchange rate in both directions. Fratzscher, et al. (2014) show an inversely related response of the exchange rate to shocks in oil prices, as well as the transmission of the exchange rate shocks into oil prices. They further show the negative correlation between oil prices and the US Dollar exchange rate since the early 2000s, particularly during the recent financial crisis.

There is a general belief in the literature that the pass-through effects of oil prices into the USD value in key international currencies depend on the disruptions in the supply of crude oil and on the volatility of oil demand caused by global economic shocks. Allegret et al. (2015) highlight the impact of shocks in oil demand on exchange rates. They downplay the supply-side pass-through process claiming that the impact of supply shocks on the volatility of oil prices as well as the exchange rates is marginal. Based on their examined 1988-2003 sample period they claim that the real currency appreciation effects caused by the demand-driven rise in oil prices are only confined to some currencies. They also point to the role of endogenous structural changes in the oil market and macroeconomic policies as important driving forces behind the adjustments of real exchange rates to oil price shocks.

A noteworthy contribution to understanding uncertainty of commodity prices is made by Joëts et al. (2015). They assume that commodity price uncertainty is endogenous with respect to macroeconomic activity. In particular, the 2007-08 period of heightened oil price uncertainty resulted from global business cycle and macroeconomic uncertainty. However, the increased price uncertainty has not been necessarily accompanied by high volatility in oil prices. This leads them to conclude that the oil price uncertainty is linked to predictability rather than to price volatility. Just like oil, copper prices are very sensitive to macroeconomic uncertainty since copper is widely used for industrial purposes and its price often serves as an indicator of global economic development. Regarding gold, its response to macroeconomic uncertainty is more transient. During economic downturns, while inflation decreases, the gold price tends to overshoot as it is normally used as a hedge by investors.

With respect to inflation expectations, Ranson (2014) and Narayan et al. (2017) consider gold as a leading indicator of CPI-based inflation. They argue that other commodities are correlated with gold but respond with different time-lags. While lagging behind gold, other commodity prices perform in advance of inflation.

In sum, the literature examining the link between commodity prices and inflation focuses predominantly on the headline or core inflation captured by low frequency data. We focus on market-implied inflation expectations proxied by the daily BEI data series[1]. As markets for Treasury Inflation-Protected Securities have matured, longer BEI-based inflation expectations data series are available. The improved BEI predictability of future inflation has motivated us to better capture the dynamic, changeable responses of commodity futures prices to changes in inflation, both in normal and stressful market times.

## III. Variables and Data

We investigate the relationship and specific interactions between the four selected commodity futures prices and market-implied inflation expectations proxied by BEI. Our database includes 3074 observations during January 3, 2003 - March 26, 2015 sample period. We use Bloomberg daily one-month settlement prices data for Brent and WTI crude oil, copper and gold. We use the 5-year BEI data available from the Federal Reserve Bank of St. Louis' Economic Data (FRED). All data series are entered in their first differences, as they are all non-stationary at their levels as indicated by our preliminary conducted Augmented Dickey-Fuller unit root tests (not displayed in the paper).

[1] The market-implied inflation expectations have a number of advantages over survey-based inflation indicators. They are derived from asset prices and available daily; they are based on real money quotes; they reveal expectations of numerous market participants and across a wide range of forecast horizons (Cunningham et al., 2010).

We employ a range of econometric methods for empirical testing. As a first step, we intend to learn about causal interactions between BEI and the selected futures prices, along with their optimal lag structure. This information is essential for a proper design of our model reflecting association between commodity futures and market implied inflation expectations. In order to examine causal interactions and optimal lags, we employ the structural Bayesian vector autoregression (BVAR) model. Its lag structure is optimized by minimizing the Akaike information criterion. In conjunction with the obtained BVAR system, we estimate accumulated impulse response functions that show the cumulative dissemination of shocks between the tested variables over the period of eight days. Based on the impulse response functions, we propose a model reflecting bi-variate relationship between the selected futures prices as dependent variables and BEI as a common regressor. The model is first tested with the stationary OLS regression and subsequently with the Bai-Perron MBP regression. The obtained breakpoints enable us to shows significantly different functional relationships between futures prices and BEI during the obtained sub-periods.

We close our analysis by focusing on the conditional volatility dynamics in the investigated bivariate relationships between the selected futures prices and market-implied inflation expectations. We employ the GARCH(p,1) model with GED parameterization for this purpose. In our preliminary tests, we have attempted to use higher-order GARCH variance q terms. However, the optimized GARCH p and q orders with the minimum Akaike Information Criterion (AIC) have led us to choose the GARCH(p,1) specification. The inclusion of GED parameters has consistently proven to be valid, as all the tested data series have displayed some degree of leptokurtosis (tail risks) shown by the obtained GED coefficients all being less than 2.

## IV. Causal Interactions between Breakeven Inflation and Futures Prices

In order to properly design our analytical model reflecting co-movements between commodity futures prices and BEI we begin with the analysis of optimized causal reactions between these variables. For this purpose, we employ a BVAR system estimation for the set of daily data of futures prices and the 5-year breakeven inflation. We choose 5 lagged terms in the BVAR system, is implied by a minimized SIC.

From the BVAR(5) system, we derive impulse response functions that show diffusion of lagged responses of individual variables to a Cholesky one-standard-deviation shock in each of these variables. In Figure 1, we show accumulated responses of BEI to shocks in each of the commodity futures prices in the upper four graphs, as well as the accumulated responses of futures prices to a shock in BEI in the lower four graphs. In the case of gold (the lower left-side graph), we have chosen the change in the log in the Hodrick-Prescott (H-P) trend in its futures price, as the inclusion of the de-trended data series with a cyclical noise component in preliminary tests did not show any significant reactions. In the remaining cases, we use changes in logs of futures prices in response to daily changes in BEI. The accumulated impulse responses shown in the bottom row are for WTI, copper and Brent crude oil from the left to the right graphs respectively.

….. insert Figure 1 around here …..

There is clear evidence that changes in BEI do not respond to shocks in any of the commodity futures prices, as shown by the four upper graphs in Figure 1. Our VAR exercise does not confirm findings expressed in the literature among others by Engemann, et al. (2011)

and Ranson (2014) of prevalent pass-through effects of commodity futures prices into inflation expectations. Evidently, based on our high-frequency data analysis, reactions in financial markets differ from the pass-through effects in the real economy.

The opposite causal reactions between commodity futures prices and BEI are pronounced. There is a mild, positive response of the (H-P) trend in gold futures to a shock in BEI. The accumulated response is not instantaneous as it takes at least four to seven days to become discernible. More importantly, our analysis shows a strong negative response of WTI crude oil futures prices to a shock in BEI. Specifically, a positive one-standard deviation shock in BEI tends to drive down WTI futures price. This response is rather immediate and it tends to accumulate over the displayed eight-day response period. There is also a negative response of the Brent crude oil price to a shock in BEI, but the magnitude of this response is much weaker and less immediate than that for WTI. In contrast, the response of copper futures price to a shock in BEI is positive and strong.

Our BVAR and impulse response analysis leads us to believe that the negative response of crude oil futures to shocks in BEI may stem from implications of a weaker demand for oil induced by a surge in the expected inflation. In the case of copper, a positive shock in BEI seems to induce a stronger demand for this metal that is extensively used in the industrial sector. In sum, the obtained causal reactions prompt us to devise an analytical model that would examine changes in futures prices in response to changes in BEI.

## V. A Baseline Model with Financial Crisis Effects

Following the above finding of BEI affecting futures prices, we propose a baseline model specified as:

$$\Delta \log FP_t = \beta_0 + \beta_1 \Delta \pi_t^* + \mu_t \quad (1)$$

where $FP_t$ is the futures' price for an individual commodity, $\pi_t^*$ is 5-year BEI and $\mu_t$ is the error term.

We further test the argument that there is a pronounced impact of turbulent market (high market risk) periods on the functional relationship between inflation expectations and commodity prices (Blanchard/Gali, 2007; Allegret, et al., 2015; Bhardwaj, et al., 2015). To test its validity for market-implied inflation expectations, we include a turbulent market dummy variable $TMD_t$, along with its interactive variable with BEI in our model:

$$\Delta \log FP_t = \beta_0 + \beta_1 \Delta \pi_t^* + \beta_2 TMD_t + \beta_3 (TMD_t * \Delta \pi_t^*) + \mu_t^{'} \quad (2)$$

The $TMD_t$ variable is obtained by performing a Bai-Perron threshold test of L+1 vs. L sequentially determined thresholds, for the daily series of CBOE VIX market volatility index for the longest available period of March 31, 1983 – March 26, 2015. While performing the threshold test on VIX, we have allowed a maximum of one threshold and error distributions to differ at the obtained two levels. The test has generated a VIX threshold of 23.89, thus our $TMD_t$ dummy variable assumes the value of 1 at turbulent market days of VIX exceeding this level and 0 for the tranquil market days of VIX being equal or below this threshold. The stationary OLS estimations of Eqs. 1 and 2 are shown in Table 1. The OLS estimation of our baseline model (Eq.1) suggests that there is a strong, direct relationship between changes in the

5-year BEI and changes in WTI oil as well as copper futures prices, which is roughly consistent with the findings of Celasun, et al. (2012), Rudarakanchana (2014) and Bhardwaj, et al. (2015). The OLS estimation shows no significant relationship between changes in BEI and the Brent crude oil as well as gold futures prices.

….. insert Table 1 around here …..

The inclusion of the $TMD_t$ variable (Eq. 2) has a meaningful impact on the relationship between the breakeven inflation and the WTI oil price. As proven by the positive sign of $\hat{\beta}_1$ and the negative sign of the interactive term coefficient $\hat{\beta}_3$ , changes in WTI futures prices move in tandem with changes in BEI at normal market periods, but they move against each other at times of financial distress. This leads us to believe that increases in BEI drive up WTI futures prices at normal market periods, but they are significantly associated with declining WTI prices at turbulent market times. Perhaps more realistically, the stressful market conditions, particularly the financial crisis episodes may entail a combination of lower inflation expectations but elevated commodity futures prices due to capital flows to futures markets, as also confirmed by Chiang, et al., (2015). In addition, there is a strong direct relationship between BEI and copper futures prices estimated in the OLS regression. However, at times of financial distress copper futures prices fall significantly (as implied by the negative sign of the estimated $\hat{\beta}_2$ coefficient), although their interaction with BEI (the $\hat{\beta}_3$ term) is not significant.

In sum, we detect a statistically significant positive impact of market-implied inflation expectations on the WTI crude oil and copper futures prices, and no discernible impact on gold or Brent crude oil futures. Nevertheless, the obtained direct relationship is time-sensitive; it is subject to major reversals during the periods of financial distress and other conditions affecting futures markets.

## VI. Breakeven Regression: Discernible Phases

Further insights into the issue of time-sensitivity in the relationship between market-implied inflation expectations and commodity futures prices can be detected through the application of the Bai-Perron regression with structural breaks[2]. To ensure comparability of the obtained structural breaks and phases for the four tested commodities we apply a fixed number of four sequentially determined breaks to each commodity series. We optimize the common number of breaks by finding minimum values of the Akaike information criterion. Our tests allow for a heterogeneous error distribution across breaks. Standard errors and covariance are heteroscedasticity and autocorrelation consistent (HAC) through the application of the Newey-West fixed bandwidth. We employ a trimming factor of 15 percent and use the 0.05 significance level. The results of our Bai-Perron multiple breakpoint tests are shown in Table 2.

….. insert Table 2 around here …..

The application of four breaks for each of the selected futures price series allows us to identify five discernible phases in the functional relationships between changes in BEI and changes in logs of the four selected futures prices. As shown in Table 2, the timing of detected breaks in the tested series of the four commodity futures is quite different. The results for the WTI futures price series show their positive co-movement with the 5-year BEI during the entire sample

[2] The Bai-Perron structural break test allows for detecting parametric instability and extracting unexpected breaks in the time series regression. For a technical description of this testing procedure see Bai/Perron (2003).

period, with the notable exception of Phase III (covering the April 4, 2007 – February 9, 2009 sub-period), which reflects the early stage of the global financial crisis. The crisis resolution policies enacted during Phases IV and V seem to restore a positive, statistically significant relationship between WTI prices and 5-year BEI. In consistency with the obtained result in Table 1, during Phase III that runs from the onset through the peak of the financial crisis (April 4, 2007 – February 9, 2009) this relationship becomes considerably weaker.

The pattern of interactions between Brent oil futures prices and BEI is very different. There is a significant inverse relationship observed during the sub-periods captured by Phases II and IV in contrast to the positive co-movement between BEI and WTI prices in the same phases. The most pronounced difference in the interactions of WTI and Brent oil futures with BEI is observed in Phase IV that roughly corresponds with the timing of the crisis resolution policies. In hindsight, the patterns of interactions between the two crude oil futures prices with the 5-year BEI differ considerably across the entire sample period. There is a prevalent positive co-movement between WTI and BEI, and generally a negative association between Brent and BEI.

The results in Table 2 show also a discernible positive relationship between copper futures prices and 5-year BEI, but only in Phases II and IV, which roughly correspond with the periods of economic recovery. This result underscores the commonly agreed upon notion of a strong association between copper prices and the real economy rather than the financial market variables (Joëts et al., 2015). In contrast to the copper futures, the relationship between gold prices and BEI is predominantly inverse, although it is statistically significant only in Phase IV corresponding with the early stage of the crisis resolution policies.

In sum, perhaps the most compelling result of our analysis is the strong, positive relationship between BEI and WTI during both the pre- and post-crisis periods. This functional relationship becomes much weaker during the turbulent market period corresponding with the peak of the financial crisis.

Thus far, our analysis has focused on the association between changes in BEI and changes in commodity futures prices. As we have indicated in the literature review section, a great deal of empirical research has been devoted to the volatility analysis or to risk embedded in the functional relationships between the tested variables. In order to contribute to the discussion on volatility dynamics, we conclude our study by performing GARCH conditional volatility tests on the relationships between BEI and commodity futures prices.

## VII. Conditional Volatility Analysis

The GARCH(p,1) model allows for examining volatility dynamics in the investigated relationships between the commodity futures prices and the market-implied inflation expectations. In our version of GARCH tests, we employ GED parameterization that allows to account for the degree of leptokurtosis in the examined data series. The distribution is leptokurtic, i.e. it displays heavy tails if the estimated GED parameter is less than 2 and closer to 0[3]. Our GARCH(p,1)-GED model consists of two equations. The underlying conditional mean equation is specified as:

[3] For an empirical investigation of tail risks in different types of financial markets using GED parameterization see for instance Orlowski (2012).

$$\Delta \log FP_{\Phi/t-1} = \beta_0 + \beta_1 \Delta \pi^{*}_{\Phi/t-1} + \varepsilon_t \tag{3}$$

Eq. 3 reflects changes in the log of daily futures prices based on the available information set denoted by $FP_{\Phi/t-1}$ as a function of changes in the 5-year BEI denoted by $\pi^{*}_{\phi/t-1}$. The conditional variance equation (Eq.4) is a function of the squared lagged residuals (p-order ARCH terms) and the one-day lagged squared variance[4]:

$$\sigma_t^2 = \gamma_0 + \gamma_{11}\varepsilon_{t-1}^2 + ... + \gamma_{1p}\varepsilon_{t-p}^2 + \gamma_2\sigma_{t-1}^2 \tag{4}$$

Restrictions on $\gamma$ parameters that reflect our initial hypothetical assumptions can be specified as: $\gamma_0 \rangle 0$, $\gamma_{11} + ... + \gamma_{1p} \geq 0$, $\gamma_2 \geq 0$, $\gamma_{11} + ... + \gamma_{1p} + \gamma_2 \langle 1$. A positive sum of $\gamma_{1p}$ would reflect a pronounced positive impact of ARCH-type shocks, a positive $\gamma_2$ would indicate persistency in volatility, and the sum of ARCH and GARCH parameters lower than the unity would imply an exponentially decreasing variance over time, i.e. an overall volatility compression.

In our empirical tests, the orders of ARCH terms have been optimized by minimizing the AIC. The GARCH(p,1)-GED estimation results are shown in Table 3.

….. insert Table 3 around here …..

Estimations of the conditional mean equation broadly reiterate the functional relationships that we have obtained in our OLS estimations. Most importantly, changes in WTI

[4] We have used higher-order GARCH terms in the preliminary testing that are all insignificant. Therefore we choose only the first-order GARCH terms in the estimation outcomes shown in Table 3.

and copper futures prices are directly related to changes in BEI, as implied by positive, significant $\hat{\beta}_1$ coefficients. This direct relationship is stronger and more significant for WTI than for copper futures. Unlike in the OLS estimation, the inverse relationship between changes in Brent crude oil futures and the market-implied inflation expectations is significant in GARCH tests.

The results of the estimated conditional volatility equation suggest that Brent and copper conditional volatility equations have high-order ARCH-type shocks, indicating unstable patterns in diffusion of unexpected shocks in volatility. In contrast, diffusion of unexpected volatility shocks for WTI is rather orderly, as determined by a lower, third-order ARCH terms. In all four cases, the conditional volatility is highly persistent, as implied by GARCH coefficients being close to one. Pronounced tail risks are detected in all four estimated series (GED parameters being less than 2).

While the test results for WTI, copper and Brent futures are rather robust, changes in gold prices seem unrelated to changes in BEI. The GARCH(p,1)-GED test estimation for gold seems spurious, due to non-zero constant terms (implying mean reversion), as well as the log likelihood being negative and AIC being too high.

In sum, the results of GARCH tests confirm our previous findings that the patterns and the directions of reactions of the examined futures to changes in the market-implied inflation expectations are not uniform. Our tests verify that the association between changes in WTI futures prices and BEI is the most robust. Its conditional volatility patterns are the most stable and predictable.

## VIII. Concluding Remarks

This study analyzes the complex, idiosyncratic interactions between the commodity futures prices and the market-implied inflation expectations. These interactions vary across the analyzed commodities and depend on market risk conditions. Our empirical tests show that WTI and Brent oil futures prices decline in response to positive shocks in the 5-year breakeven inflation. Copper prices respond positively to the same shocks, while gold futures response is positive but not pronounced. The market-implied inflation expectations do not seem affected by shocks in the commodity futures prices.

The most meaningful finding of our empirical exercise is a strong positive response of the WTI futures prices to changes in the market-implied inflation expectations. WTI and the 5-year BEI move in the same direction at normal market periods, but in opposite directions at turbulent market times. The apparent price divergence at times of financial distress suggests that inflation expectations tend to decline with lower interest rates, while WTI futures prices may be still increasing.

The results of the multiple breakpoint tests suggest a positive relationship between WTI and the 5-year BEI, with the exception of the period coinciding with the peak of the financial crisis. In contrast, Brent futures are positively related to BEI only at the peak of the crisis, but inversely during the run-up to and the aftermath of the crisis. Copper futures are directly related to BEI but only in Phases II and IV. Gold prices are inversely related to BEI during the run-up to the crisis and the immediate post-crisis periods.

We also find that volatility dynamics of all examined series is highly persistent and subject to pronounced tail risks, as implied by the estimated GARCH coefficients being all close to unity and GED parameters significantly less than 2.

Considering the diversity in responses of various futures prices to changes in BEI, further research is needed on the stability and changeable patterns of these relationships. The pattern reversals are likely to depend on changes in the exchange rates and their volatility, or the exchange rate risk (as discussed by Fratzscher et al., 2014). They may be also related to changes in monetary policy and the liquidity and interest rate risks, among other factors. These functional relationships deserve a further in-depth investigation as longer data series become available.

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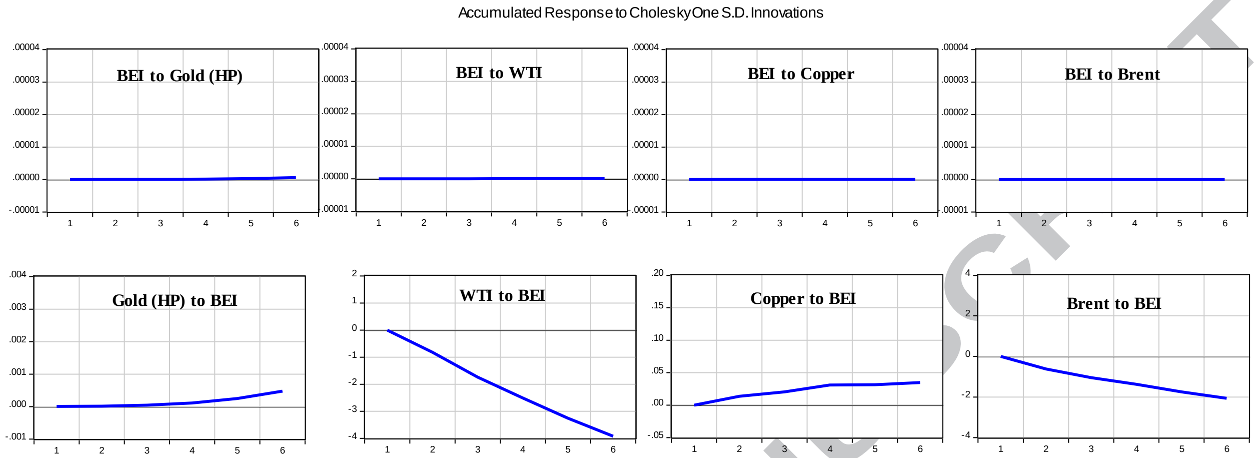
**Figure 1:** Accumulated impulse responses between daily changes in 5-year BEI and futures prices.




Notes: accumulated responses of changes in the 5-year breakeven inflation to changes in logs of futures prices are shown in the upper-row graphs. Lower-row graphs show the accumulated responses of changes in gold, WTI, copper and Brent futures prices (from the left to the right respectively) to a one-standard deviation shock in the 5Y breakeven inflation. BVAR includes 5 lagged terms. Sample period: January 3, 2003 – March 26, 2015 (3074 daily observations).

Source: own estimation based on Bloomberg and FRB St. Louis FRED data.

**Table 1:** Estimation representations of Eqs.1 and 2.

| Dependent variables↓ $\Delta \log$ in: | Equation 1 | | | Equation 2 | | | | |
|---|---|---|---|---|---|---|---|---|
| | $\hat{\beta}_0$ | $\hat{\beta}_1$ | Diagnostic statistics | $\hat{\beta}_0$ | $\hat{\beta}_1$ | $\hat{\beta}_2$ | $\hat{\beta}_3$ | Diagnostic statistics |
| Gold | 0.001* (1.74) | -0.005 (-1.39) | $\bar{R}^2$ 0.001 AIC -5.94 DW 2.06 | 0.001 (1.22) | -0.007 (-1.03) | 0.001 (0.93) | 0.003 (0.34) | $\bar{R}^2$ 0.001 AIC -5.94 DW 2.06 |
| WTI | 0.001 (0.37) | 0.088*** (12.93) | $\bar{R}^2$ 0.051 AIC -4.82 DW 2.11 | 0.001 (0.99) | 0.177*** (14.22) | -0.002* (-1.86) | -0.126*** (-8.53) | $\bar{R}^2$ 0.074 AIC -4.84 DW 2.13 |
| Brent | 0.001 (0.72) | -0.010 (-1.52) | $\bar{R}^2$ 0.004 AIC -4.87 DW 2.14 | 0.001 (0.39) | -0.017 (-1.36) | 0.001 (0.56) | 0.009 (0.64) | $\bar{R}^2$ 0.001 AIC -4.87 DW 2.14 |
| Copper | 0.001 (1.19) | 0.028*** (4.38) | $\bar{R}^2$ 0.006 AIC -4.94 DW 2.26 | 0.001** (1.95) | 0.012* (1.75) | -0.002** (-1.91) | 0.010 (0.70) | $\bar{R}^2$ 0.008 AIC -4.94 DW 2.26 |

Notes: Dependent variables: changes in logs (returns) of 1M futures settlement prices. Independent variable: the change in 5Y breakeven inflation. AIC = Akaike information criterion, DW = Durbin-Watson statistics, t-statistics are in parentheses, *** denotes significance at 1%, ** at 5%, * at 10%. Sample period: January 3, 2003 – March 26, 2015 (3074 observations).

Data Source: Bloomberg, FRB of St. Louis FRED.

**Table 2:** Phases in the relationship between five-year breakeven inflation and commodity futures settlement prices: the Bai-Perron multiple breakpoint regression estimation of Eq. 1.

Dependent variables: changes in logs of one-month commodity futures daily settlement prices
Independent variable: changes in 5-year BEI
Sample period: January 3, 2003 – March 26, 2015 (3074 observations)

| Dependent var., Δlogs of → Phases based on breakpoints ↓ | **West Texas Intermediate** | **Brent** | **Copper** | **Gold** |
|---|---|---|---|---|
| Phase I | 01/03/2003-11/04/2004<br>$\hat{\beta}_0$ = 0.001 (0.73)<br>**$\hat{\beta}_1$ *100 = 6.171** (2.38)** | 01/03/2003-11/04/2004<br>$\hat{\beta}_0$ = 0.001(1.40)<br>$\hat{\beta}_1$ *100 = 0.123 (0.05) | 01/03/2003-05/26/2006<br>$\hat{\beta}_0$ = 0.002 (3.73)<br>$\hat{\beta}_1$ *100 = -0.588 (-0.40) | 01/03/2003-05/16/2005<br>$\hat{\beta}_0$ = 0.001(0.53)<br>$\hat{\beta}_1$ *100 = 0.741 (0.74) |
| Phase II | 11/05/04-04/03/07<br>$\hat{\beta}_0$ = 0.001 (0.69)<br>**$\hat{\beta}_1$ *100 = 27.808*** (12.17)** | 11/05/04-11/10/06<br>$\hat{\beta}_0$ = 0.001(0.37)<br>**$\hat{\beta}_1$ *100 = -8.193*** (-2.49)** | 05/30/06-03/06/09<br>$\hat{\beta}_0$ = -0.001(-1.49)<br>**$\hat{\beta}_1$ *100 = 4.013*** (3.23)** | 05/17/05-04/11/07<br>$\hat{\beta}_0$ = 0.001(1.81)<br>**$\hat{\beta}_1$ *100 = -3.480* (-1.71)** |
| Phase III | 04/04/07-02/09/09<br>$\hat{\beta}_0$ =- 0.001 (-0.69)<br>$\hat{\beta}_1$ *100 = 2.023 (0.42) | 11/13/06-11/17/08<br>$\hat{\beta}_0$ =- 0.001(-0.32)<br>**$\hat{\beta}_1$ *100 = 6.394** (2.04)** | 03/09/09-02/10/11<br>$\hat{\beta}_0$ =0.002(2.76)<br>$\hat{\beta}_1$ *100 = -0.838 (-0.44) | 04/12/07-08/24/09<br>$\hat{\beta}_0$ = 0.001 (0.80)<br>$\hat{\beta}_1$ *100 = -0.104 (-0.18) |
| Phase IV | 02/10/09-08/16/12<br>$\hat{\beta}_0$ = 0.001 (1.30)<br>**$\hat{\beta}_1$ *100 = 23.770*** (11.53)** | 11/18/08-03/25/11<br>$\hat{\beta}_0$ = 0.001(2.45)<br>**$\hat{\beta}_1$ *100 = -2.362*** (-2.33)** | 02/11/11-04/10/13<br>$\hat{\beta}_0$ = -0.001 (-0.70)<br>$\hat{\beta}_1$ *100 = 1.206 (0.76) | 08/25/09-09/22/11<br>$\hat{\beta}_0$ = 0.001 (2.25)<br>**$\hat{\beta}_1$ *100 = -5.163*** (-3.71)** |
| Phase V | 08/17/12-03/26/15<br>$\hat{\beta}_0$ = -0.001 (-1.47)<br>**$\hat{\beta}_1$ *100 = 12.634*** (5.25)** | 03/28/11-03/26/15<br>$\hat{\beta}_0$ = -0.001(-1.52)<br>$\hat{\beta}_1$ *100 = -2.402 (-1.52) | 04/11/13-03/26/15<br>$\hat{\beta}_0$ = -0.001 (-0.47)<br>**$\hat{\beta}_1$ *100 = 3.725*** (2.36)** | 09/23/11-03/26/15<br>$\hat{\beta}_0$ = -0.001 (-1.02)<br>$\hat{\beta}_1$ *100 = 0.687 (0.70) |
| Diagnostic stats:<br>F-statistics<br>Log likelihood<br>AIC<br>DW | <br>42.98<br>7505.27<br>-4.877<br>2.14 | <br>4.24<br>7500.38<br>-4.873<br>2.18 | <br>5.05<br>7604.15<br>-4.941<br>2.27 | <br>3.05<br>9143.34<br>-5.942<br>2.05 |

Notes: Bai-Perron multiple breakpoint regressions with a fixed number of 4 sequentially determined breaks. The number of breaks is obtained by a minimum Akaike information criterion (AIC). Standard errors and covariances are Newey-West heteroscedasticity and autocorrelation consistent (HAC). The tests allow for heterogeneous error distribution across breaks. DW is Durbin Watson statistics. Z-statistics are in parentheses. *** denotes significance at 1%, ** at 5% and * at 10%.

Source: as in Table 1.

**Table 3: Estimation representations of GARCH(p,1)-GED conditional volatility tests - Eqs. 3 and 4.**

| | Gold | WTI | Brent | Copper |
|---|---|---|---|---|
| *Conditional mean equations:* | | | | |
| $\hat{\beta}_0$ | 0.322*** (3.07) | 0.001* (1.66) | 0.001* (1.80) | 0.001** (1.92) |
| $\hat{\beta}_1$ | -0.558 (-0.19) | 0.161*** (26.54) | -0.014** (2.05) | 0.014*** (2.58) |
| *Conditional Variance equations:* | | | | |
| Constant term | 0.089 | 0.000*** | 0.000** | 0.000*** |
| ARCH(1) | 0.062*** | 0.056** | 0.069*** | 0.096*** |
| ARCH(2) | NA | 0.043 | -0.009 | 0.011 |
| ARCH(3) | NA | -0.050* | -0.047 | 0.001 |
| ARCH(4) | NA | NA | 0.047 | -0.078*** |
| ARCH(5) | NA | NA | -0.035* | NA |
| ARCH(6) | NA | NA | 0.044** | NA |
| GARCH(1) | 0.942*** | 0.944*** | 0.929*** | 0.968*** |
| GED parameter | 1.346*** | 1.536*** | 1.433*** | 1.305*** |
| Diagnostic stats.: | | | | |
| Log Likelihood | -11236 | 7923.2 | 7973.3 | 8119.8 |
| AIC | 7.314 | -5.150 | -5.180 | -5.277 |
| DW | 2.07 | 2.08 | 2.14 | 2.26 |

Notes: as in Table 1. Z-statistics are in parentheses.

Source: as in Table 1.

Volatility of Commodity Futures Prices and Market-Implied Inflation Expectations

Highlights:

- Interplay between crude oil, copper and gold futures and breakeven inflation is examined
- Bai-Perron multiple breakpoint, BVAR, GARCH-GED tests are employed
- WTI and Brent oil futures prices decline in response to positive shocks in 5Y breakeven inflation
- WTI and copper prices display positive co-movement with breakeven inflation, but not during the peak of the recent crisis
- Gold prices and breakeven inflation are inversely related during the run-up to the crisis and its aftermath