VOLATILITY SPILLOVERS BETWEEN CRUDE OIL PRICES AND US DOLLAR TO EURO EXCHANGE RATES*

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Abstract

The surge in oil prices in recent years has been raising questions on its implications for global imbalances and needs of policy adjustments. The slowdown in US economy has added to exacerbate these imbalances. According to press records the situation in the first half of 2008 can be characterized as follows: Oil prices went through the roof, while the US dollar came to a record low against the euro. The OPEC was facing criticism of adjusting prices to the weakness of the dollar and tightening supplies in spite of an increasing world demand, while blaming record prices on speculative oil trading. Populist proposals to price oil in currencies other than the US dollar were being renewed by radical members.

In which way does such economic and political turmoil bear on oil price and currency exchange rate interaction? Even though crude oil prices and US dollar exchange rates are somehow linked, the correlation of price changes is almost zero. This is because the link between them is in terms of volatility spillovers rather than in terms of co-movements of returns. We investigate the joint volatility performance of US dollar to euro exchange rates and of the benchmark crude West Texas Intermediate. We apply a novel bivariate asymmetric quadratic GARCH model which enables us to analyse the pattern of volatility spillovers. Our findings give rise to interpretations in terms of certain characteristics of speculative activity.

Key words: crude oil price fluctuations, US dollar to euro exchange rate, bivariate asymmetric quadratic GARCH, volatility spillover

1 Introduction

1.1 Background

The first stock trading day in 2008 was the day when oil prices briefly hit the $100-a-barrel level for the first time in history. In February 2008, oil prices definitely went through the roof, while

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the USD fell to a record low against the euro. Soaring prices were widely cited as being driven by the slide of dollar, growing worries over inflation and a prolonged US financial crisis, apart from concerns on strong demand and supply tigthening.[1]

How are the surge in oil prices and the slide in the dollar linked?

The sustained rise in oil prices in recent years has been mooting its implications for global imbalances and on whether or which policy adjustments would promote petrodollar recycling. Oil-exporting and emerging market countries are considered to have grown major players on the current account imbalance scene, holding "the key to oil and dollar moves". [2]

On the one hand, it was argued[3] that a "twin peg" of currency and domestic oil prices in emerging economies has propelled exceptional export-oriented domestic growth for years. Accordingly large current account surpluses and foreign exchange reserves have resulted in a liquidity boom, the alleged "main source of oil demand growth and price appreciation in the past four years". More recently, the US financial crisis and aggressive US interest rate cuts have "led to a deterioration in the US economic position" and as a result has helped to weaken the dollar and accelerate these "twin peg" imbalances.

On the other hand, "crude oil prices are higher than in the past partly to compensate for a weaker dollar", the OPEC said, when a peak of crude prices had coincided with a record low of the dollar before.[4] In the first half of 2008, the OPEC was facing persistent criticism of adjusting prices and tightening supplies in spite of a strong world demand growth. Populist proposals to price oil in currencies other than the USD were being renewed by radical members. The cartel's policy was said "to ensure oil price volatility"[5]

The OPEC uses to restate that supplies were adequate and that record prices were related to speculative oil trading, the weakness of the dollar and the US subprime mortgage market turmoil. Chakib Khelil, president of the cartel, went as far as to say: "The prices are high due to the recession in the United States and the economic crisis, which has touched several countries, a situation that has an effect on the value of the dollar. Each time the dollar falls 1 per cent, the price of the barrel rises by $4 and of course vice versa."[6]

In what way does this economic and political turmoil bear on oil price and currency exchange rate interaction? Is there any interaction in terms of correlation of oil price and exchange rate fluctuations? What is the role of volatility spillovers in this connection? We will study interactions by fitting a bivariate stochastic time series model to empirical data of the benchmark crude West Texas Intermediate (WTI) prices and USD to euro exchange rates.

1.2 Data

The present study requires WTI price series as well as USD/euro exchange rate series. We use data beginning in January 1995 and ending in May 2008. Daily quotes of WTI crude oil spot prices were obtained from the Energy Information Administration of the US Government[7], while daily USD/euro exchange rates were taken from the European Central Bank[8]. We substituted USD/DEM exchange rates (suitably converted) for the period of time prior to January 1999.

[1] FT, 2008-02-27
[2] FT, 2007-10-15, 2008-01-10
[3] FT, 2008-01-10
[4] FT, 2007-09-14
[5] FT, 2008-01-30
[6] FT, 2008-04-28
[7] http://eia.doe.gov/; last accessed 2008-05-30.
[8] http://www.ecb.int, last accessed 2008-05-30.

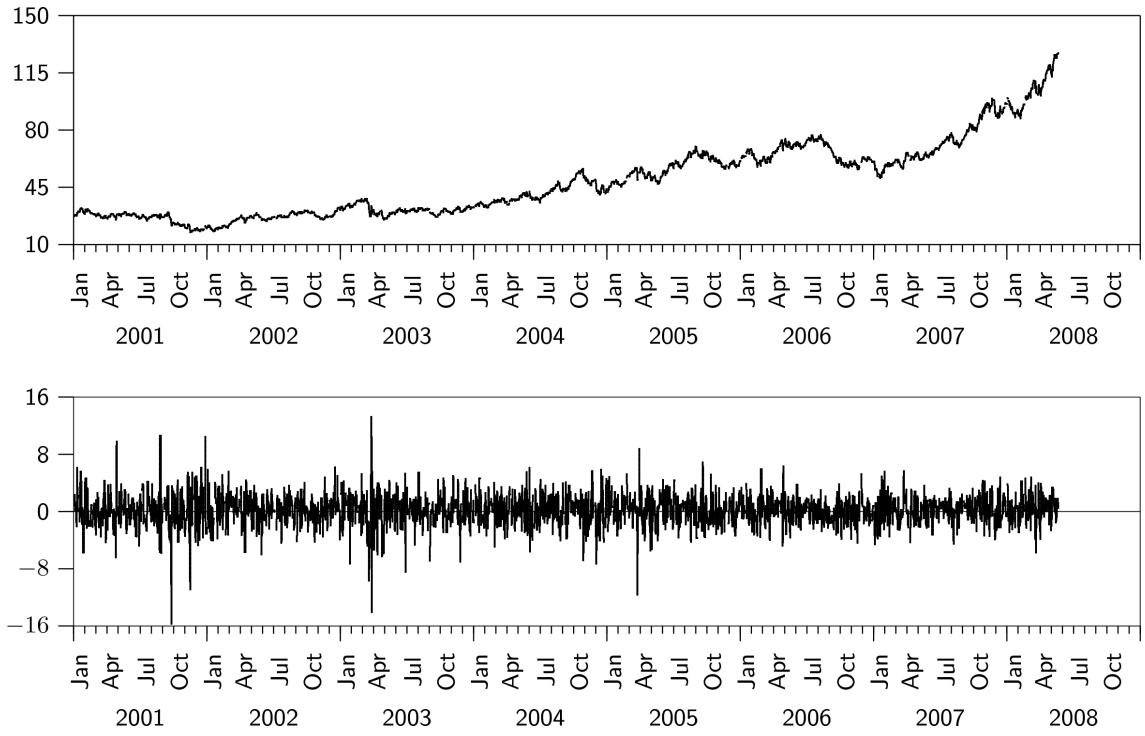

Figure 1: WTI prices: level series and daily returns

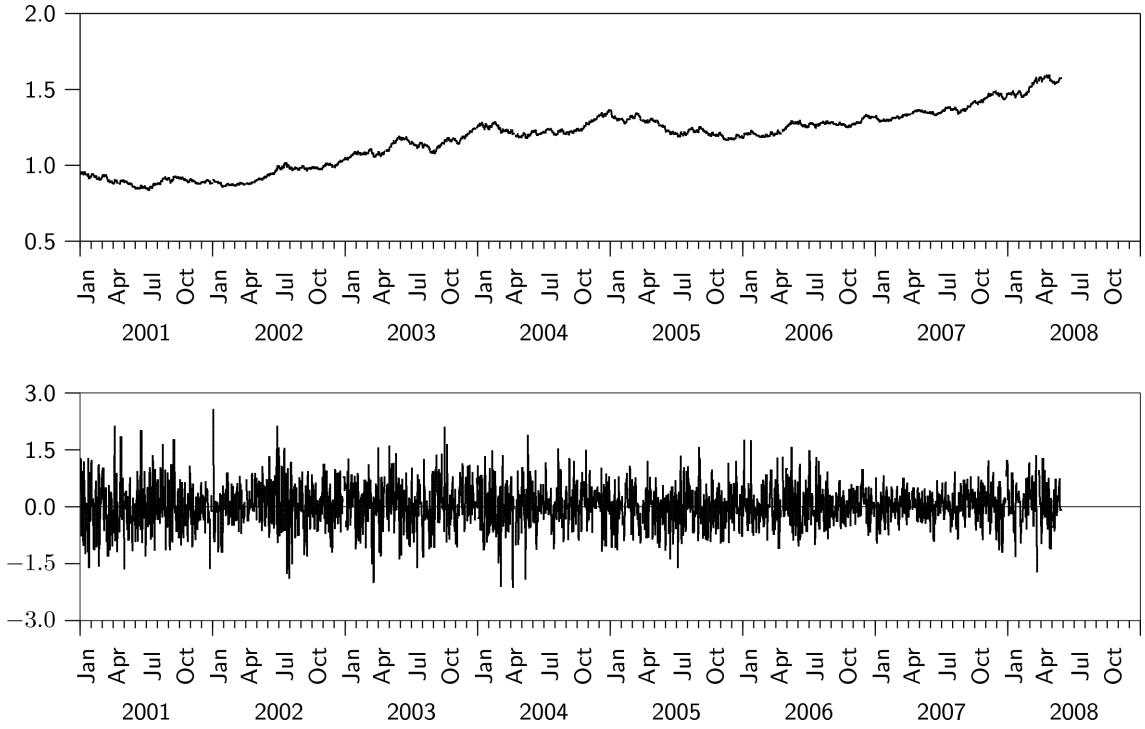

Figure 2: USD/euro exchange rates: level series and daily returns

Our analysis uses bivariate return (price change) series, computed as simple returns in percent. Data from 2001-01-02 through 2008-05-20 (1906 data points) constitute the empirical basis for fitting models for daily price changes, while data from 1995-01-03 through 2008-05-20 (699 data points) were used to fit weekly models, where weekly returns were computed as price changes from Tuesday to Tuesday.

The level series and daily returns of WTI prices and USD/euro exchange rates are depicted in Figures 1 and 2.

1.3 Is there any Interaction in Terms of Correlation?

Are the rise in oil prices and the slide in the dollar related in terms of correlation of returns? We restrict our answer to the series of daily data.

The daily level series in Figures 1 and 2 may give the impression of co-movements. But there is no evidence for the hypothesis of a simple unidirectional interaction: The average correlation of price changes in the entire time period considered is close to zero. Time-dependent correlations within rolling windows of size 20 (50) days are depicted in Figure 3. The correlation ceiling appears to be higher with decreasing window size. However, short-period correlations reveal frequent sign fluctuations. Therefore, even though crude oil prices and USD exchange rates appear somehow linked in terms of time-dependent correlation, a translation into a general pattern is not feasible. Our hypothesis is that the link between crude oil prices and USD exchange rates is rather in terms of volatility spillovers than in terms of co-movements.

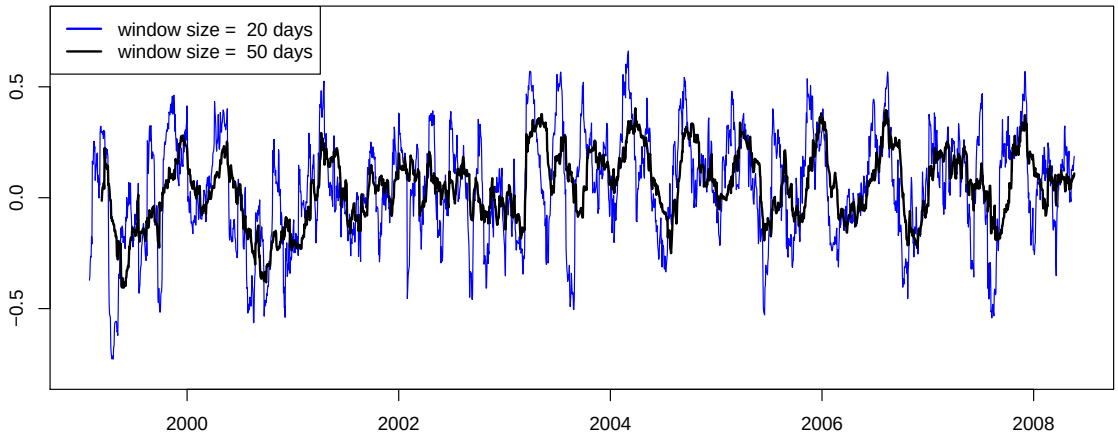

Figure 3: Rolling correlations of daily returns

1.4 Goals of This Paper

Do oil price and currency exchange rate volatilities spill over? If so, in which way? In this paper, we investigate the joint volatility performance of WTI crude oil price changes and USD/euro exchange rate fluctuations in a daily and weekly time spacing. We shall examine whether the following hypotheses can be supported by evidence:

- USD/euro exchange rate fluctuations impact on WTI prices in terms of volatility spillovers.
- There is asymmetry in the sense that the impact is more pronounced for "bad news", by which we mean: The USD is weakening.

To study the conditional volatility of a series of returns is the general purpose of GARCH models. The classical GARCH process is a univariate process displaying a certain form of heteroscedasticity: Tomorrow's volatility (standard deviation) is conditional on information (news) available today, and on its past performance; see Engle [4], Bollerslev [2], and also Tsay [10]. Glosten, Jaganathan, and Runkle [3] intoduced the GJR-GARCH process to allow for positive and negative news having different impacts on volatility. Univariate news impact on volatility was studied systematically by Engle and Ng [6].

Because we want to investigate the joint behaviour of WTI and USD price fluctuations, we need a bivariate model. Attempts to generalize GARCH models to more than one time series include the BEKK model of Engle and Kroner [5]; see also Bauwens, Laurent and Rombouts [1]. An extension of this model which is capable of allowing for asymmetry in news impact is the bivariate asymmetric quadratic GARCH model of Schmidbauer [9]. This approach enables us to analyse the pattern of volatility spillovers between WTI and USD price changes including possible differences between between positive and negative news.

All computations were carried out in R [8]. — This paper is organized as follows. Section 2 introduces the bivariate asymmetric quadratic GARCH model which we use in our study. How we proceed to fit data and empirical findings for daily and weekly data are provided in Section 3. Finally, Section 4 gives a summary and some conclusions.

2 Methodology: A Bivariate Asymmetric Quadratic GARCH Model

The goal of the present study is to investigate the interaction of crude oil price price changes and USD/euro exchange rate fluctuations in terms of volatility, and in particular to ascertain possible asymmetry in this interaction, as manifest in the impact of news (past returns) on the future bivariate return distribution.

The following model suits our purposes:

$$\epsilon_t = \mathtt{H}_t^{-1/2} \cdot \nu_t, \tag{1}$$

where (ν_t) is a bivariate Gaussian white noise process with $\mathrm{cov}(\nu_t) = \mathtt{I}$ (the 2×2 unity matrix) and

$$\mathtt{H}_t \;=\; \mathtt{C}'\mathtt{C} \;+\; \mathtt{A}'\epsilon_{t-1}\epsilon'_{t-1}\mathtt{A} \;+\; \mathtt{B}'\mathtt{H}_{t-1}\mathtt{B} \;+\; S_w(\epsilon_{t-1}) \cdot \Gamma'\epsilon_{t-1}\epsilon'_{t-1}\Gamma \tag{2}$$

with parameter matrices $\mathtt{C} = (c_{ij})$ $(c_{21} = 0)$, $\mathtt{A} = (a_{ij})$, $\mathtt{B} = (b_{ij})$, $\Gamma = (\gamma_{ij})$ $(i, j = 1, 2)$. S_w is a weight function which is defined as

$$S_w(e_1, e_2) = 0.5 - \frac{\cos(\frac{\pi}{4} + w) \cdot e_1 + \sin(\frac{\pi}{4} + w) \cdot e_2}{2\sqrt{e_1^2 + e_2^2}}, \text{ if } e_1^2 + e_2^2 \neq 0, \text{ and } = 0 \text{ otherwise.} \tag{3}$$

The parameter w in the weight function S_w determines the angle for which the (mean-corrected) return vector (e_1, e_2) leads to an excess impact on next period's volatility. For details of the construction of S_w, see Schmidbauer [9]. We call the model defined by (1), (2), and (3) the baqGARCH (bivariate asymmatric quadratic GARCH) model. This model can be seen as a generalization of the BEKK model (see Engle and Kroner [5]) to allow for asymmetry in the volatility specification; the BEKK model is similar but has no S_w term. It can also be seen as

an extension of the GJR model (Glosten, Jaganathan, and Runkle [3]) to two dimensions. The matrix $\mathtt{H}_t$ is the conditional covariance matrix of ϵ_t, given $\epsilon_{t-1}, \epsilon_{t-2} \ldots$.

A model for a bivariate series of price changes, with returns on WTI crude oil as first and returns on the USD w.r.t. the euro as second component, is

$$X_t = M + \epsilon_t, \tag{4}$$

where M is the long-run mean. (No vector autoregressive specification is needed in place of M, since the return series do not display significant autocorrelation.)

News impact on volatility can then be studied in the baqGARCH model by letting the conditional volatility matrix $\mathtt{H} = (h_{ij})$ depend on $x = (x_1, x_2)$:

$$x \mapsto \mathtt{H}(x) \;=\; \mathtt{C}'\mathtt{C} \;+\; \mathtt{A}'xx'\mathtt{A} \;+\; \mathtt{B}'\Sigma\mathtt{B} \;+\; S_w(x) \cdot \Gamma' xx' \Gamma, \tag{5}$$

where Σ is the unconditional covariance matrix of the process. Section 4 below presents contour lines of the functions

$$x \mapsto h_{11}(x), \quad x \mapsto h_{22}(x), \quad x \mapsto h_{12}(x)/\sqrt{h_{11}(x)h_{22}(x)}, \tag{6}$$

allowing for the following interpretations:

The function...	represents the news impact on the next day's (week's) conditional...
$h_{11}(x)$	variance of returns on WTI prices
$h_{22}(x)$	variance of returns on USD/euro exchange rates
$h_{12}(x)/\sqrt{h_{11}(x)h_{22}(x)}$	correlation of returns

3 Empirical Findings

The interaction between WTI crude oil prices and the USD/euro exchange rate can now be studied by fitting a baqGARCH model to the data described in section 2. The first step is to identify a symmetric model structure (with the matrix Γ set equal to zero) and to estimate its parameter matrices. Subsequently we search for an asymmetric model which can beat the symmetric model in terms of the AIC. None of the models presented below leave significant autocorrelation in the series of (squared) residuals; all of them contain only significant parameters. We treat the case of daily and weekly price changes separately, because their way of interaction may depend on time spacing.

3.1 Daily Returns

Constraining the model class to symmetric setups (i.e., a BEKK model), a model with $\mathtt{A}$ and $\mathtt{B}$ being diagonal matrices was identified as suitable to model the bivariate series of daily returns. The parameter matrices of the fitted model are (the t values are shown in parentheses):

$$\mathtt{C} = \begin{pmatrix} 1.015 & 0.043 \\ (5.812) & (4.967) \\ 0.000 & 0.000 \\ (-) & (-) \end{pmatrix} \quad \mathtt{A} = \begin{pmatrix} 0.323 & 0.000 \\ (9.282) & (-) \\ 0.000 & 0.139 \\ (-) & (9.866) \end{pmatrix} \quad \mathtt{B} = \begin{pmatrix} -0.831 & 0.000 \\ (-16.009) & (-) \\ 0.000 & 0.987 \\ (-) & (419.278) \end{pmatrix}$$

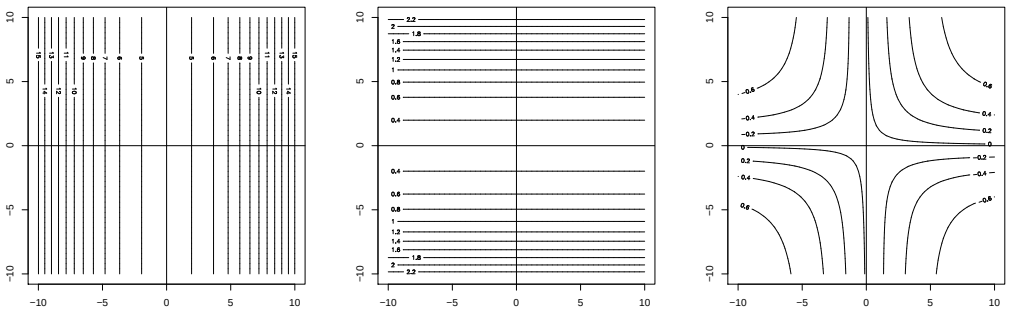

Figure 4: News impact functions, daily returns, symmetric model

The AIC value is 5797.0. Contour lines of the news impact functions are displayed in Figure 4.

The values on the horizontal (vertical) axis are yesterday's returns on WTI prices (yesterday's price change of the euro, measured in USD, respectively), and shown are the contour lines of today's variance of WTI price changes, today's variance of the change in the USD/euro exchange rate, and today's correlation of returns (from left to right), each conditional on yesterday's price change. The positive part of the horizontal axis indicates a price increase in WTI crude oil; the positive part of the vertical axis indicates a weaker USD in the sense that the price of a euro increased from the day before yesterday to yesterday. The characteristic appearance of the variance news impact function (vertical and horizontal lines, respectively) stems from the special form of $\mathtt{A}$. The shape implies that today's conditional variance does not discriminate between price increases and decreases, and neither series has a direct impact on the other's volatility. Furthermore, news impact on the correlation is indirect via the variances, not direct via the covariance.

There is a baqGARCH model which beats the symmetric model w.r.t. the AIC. Its parameter matrices are:

$$\mathtt{C} = \begin{pmatrix} 1.026 & 0.049 \\ (6.643) & (4.666) \\ 0.000 & 0.000 \\ (-) & (-) \end{pmatrix} \quad \mathtt{A} = \begin{pmatrix} -0.148 & 0.000 \\ (-2.061) & (-) \\ 0.000 & -0.146 \\ (-) & (-6.258) \end{pmatrix} \quad \mathtt{B} = \begin{pmatrix} -0.819 & 0.000 \\ (-16.149) & (-) \\ 0.000 & 0.982 \\ (-) & (278.654) \end{pmatrix}$$

$$\Gamma = \begin{pmatrix} 0.450 & 0.000 \\ (7.375) & (-) \\ 0.000 & -0.111 \\ (-) & (-2.483) \end{pmatrix} \quad \begin{matrix} w = -1.2004 \\ (-2.959) \end{matrix}$$

The AIC value of this model is 5780.3. The asymmetric model rejects the null hypothesis that there is no asymmetric interaction between daily crude oil price changes and daily USD/euro exchange rate fluctuations, because w as well as the parameters in Γ are significantly different from zero. In addition, the news inpact functions (see Figure 5) reveal the nature of asymmetry prevalent in the interaction of returns.

In particular, today's volatilities no longer appear independent of yesterday's returns on the other series, as was found in the symmetric setup (left and center plot in Figure 4). The volatility of WTI prices (left plot in Figure 5) increases, if the USD got weaker. Furthermore, it discriminates between yesterday's increases and decreases of prices; decreases imply higher volatility. Today's volatility of USD/euro exchange rates (center plot in Figure 5) slightly decreases, if WTI got more expensive.

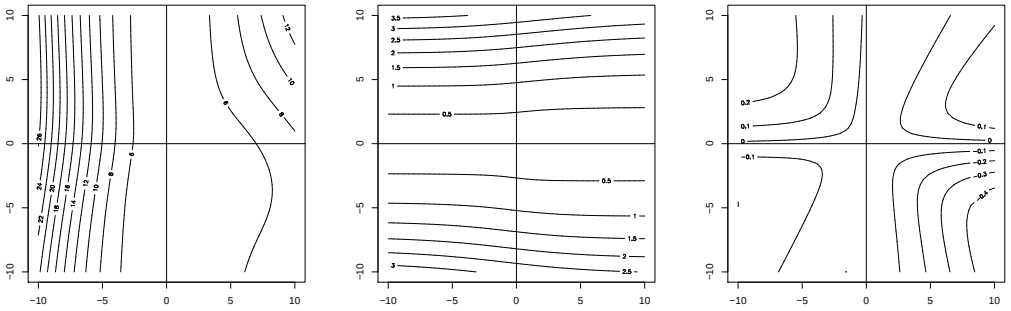

Figure 5: News impact functions, daily returns, asymmetric model

The news impact function for the conditional correlation in the symmetric model (right plot in Figure 4) insinuated that returns are expected to be highly correlated after a day with a massive WTI price increase and weaker USD, indicating a possible hedging strategy. A glance at the corresponding news impact function for the asymmetric model (right plot in Figure 5) dashes the hope for a simple hedging strategy. Conditional correlation of returns is positive (negative) if the USD weakened (strengthened). The amount of increase in correlation is most pronounced in situations when both WTI and the USD got more expensive.

3.2 Weekly Returns

For weekly data, the parameter matrices of the fitted BEKK model are:

$$\mathtt{C} = \begin{pmatrix} 0.651 & 0.154 \\ (4.825) & (2.143) \\ 0.000 & 0.220 \\ (-) & (2.937) \end{pmatrix} \quad \mathtt{A} = \begin{pmatrix} 0.078 & 0.000 \\ (2.002) & (-) \\ -0.233 & 0.240 \\ (-2.807) & (6.739) \end{pmatrix} \quad \mathtt{B} = \begin{pmatrix} 0.987 & 0.000 \\ (223.622) & (-) \\ 0.000 & 0.949 \\ (-) & (65.173) \end{pmatrix}$$

Because the asymmetric setup does not reject the null hypothesis that there is no asymmetric interaction between weekly crude oil price changes and weekly USD/euro exchange rate fluctuations, we will skip the part of the baqGARCH model.

The contour lines of the news impact functions of this week's conditional variance of WTI price changes, this week's conditional variance of USD/euro exchange rate changes, and this week's conditional correlation of returns are shown in Figure 6 (from left to right). The values on the horizontal (vertical) axis are past week's returns on WTI prices (past week's price change of the euro, measured in USD, respectively).

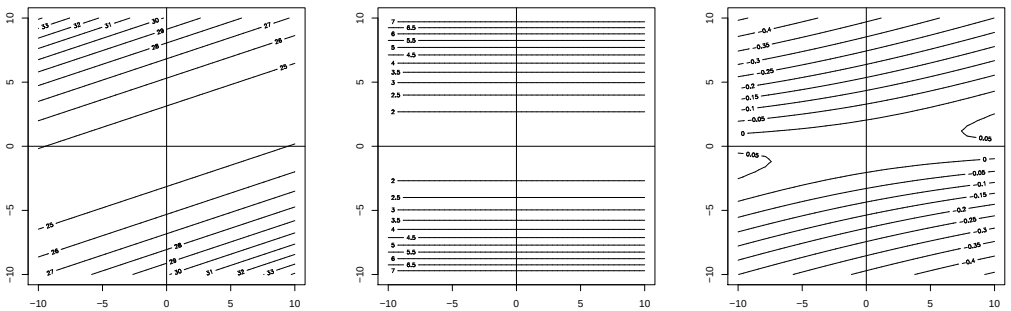

Figure 6: News impact functions, weekly returns, symmetric model

While an impact on the volatility of USD/euro exchange rates (center plot in Figure 6) appears to come from news on the USD only, the impact function for WTI prices (left plot in Figure 6) shows volatility spillovers according to a combined news pattern. An increase in WTI volatility is most pronounced if both oil and the USD got more expensive, and there is a symmetric effect, if both prices eased. Concerning conditional correlation of weekly returns (right plot in Figure 6), the effect of news about USD exchange rate fluctuations appears much higher than of news about WTI price changes. Weeks of large WTI price gains (losses) imply an increase in the amount of negative correlation only in combination with an USD that strengthened (weakened).

4 Summary and Conclusions

Our goal was to investigate joint volatility behaviour of WTI price changes and USD to euro exchange rate fluctuations, in particular to ascertain possible volatility spillovers. The empirical basis of the study consisted of time series of daily closing quotes, from which we computed daily and weekly returns.

We applied a novel bivariate asymmetric quadratic GARCH model which provided news impact functions to measure the volatilities and correlation of returns on WTI prices and USD/euro exchange rates, conditional on news (past returns).

We found evidence for volatility spillovers for daily and as well as for weekly price series.

In the case of weekly time spacing, there is strong impact of USD news on WTI price volatility. The steepest ascent of volatility occurs when oil price decreased (increased) and the USD got weaker (stronger). Economically, this can be interpreted as the result of an increase in trading volume in crude oil, which entails excess price volatility for the next week. There is a corresponding pronounced impact of USD fluctuation news concerning conditional correlation of returns.

In the daily time spacing, the effect of USD news appears much less pronouncedly, though asymmetric: "Bad news" of a weakening USD appears to be more influential than news of a rise in its value. This phenomenon can be explained by short-term occurences of hysteria in speculative activity, seizing investors who "pour money into commodities following deepening fears about the weakness of the US dollar."[9] It remains undetected in a symmetric setup of the bivariate GARCH model. The asymmetric news impact on correlation of daily returns dashes hopes for a simple hedging strategy of WTI and USD reserves.

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