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VOLATILITY WITH LONG-TERM ECONOMIC AND  
FINANCIAL VARIABLES**

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# Modeling and Forecasting Commodity Market Volatility with Long-term Economic and Financial Variables<sup>☆</sup>

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## Abstract

This paper investigates the time-varying volatility patterns of some major commodities as well as the potential factors that drive their long-term volatility component. For this purpose, we make use of a recently proposed GARCH-MIDAS approach which typically allows us to examine the role of economic and financial variables of different frequencies. Using commodity futures for Crude Oil (WTI and Brent), Gold, Silver and Platinum as well as a commodity index, our results show the necessity of disentangling the short-term and long-term components in modeling and forecasting commodity volatility. They also indicate that the long-term volatility of most commodity futures is significantly driven by the level of the global real economic activity as well as the changes in consumer sentiment, industrial production, and economic policy uncertainty. However, the forecasting results are not alike across commodity futures as no single model fits all commodities.

*Keywords:* Commodity futures, GARCH, Long-term volatility, Macroeconomic effects, Mixed data sampling.

*JEL:* C58, G17, Q02

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## 1. Introduction

Earlier studies on commodity markets have shown that commodity futures can be a valuable source of diversification benefits for investors and portfolio managers, given their distinct risk-return characteristics as compared to traditional assets like bonds and stocks. Bodie & Rosansky (1980) note, for example, that their benchmark portfolio of commodity futures performs as well as the portfolio of common stocks in terms of average returns over the period 1950-1976. More importantly, a diversified portfolio of 60% stocks and 40% commodity futures leads to a return variability reduction of about one-third relative to the 100% stock portfolio, while having the same level of return. The hedging ability against inflation is another interesting feature of commodity futures (Lucey et al., 2017). Similarly, Lintner (1983) finds that the variability of portfolios of stocks and bonds is consistently lower when they are combined with managed commodity futures. More recent studies such as Gorton & Rouwenhorst (2006), Arouri et al. (2011), Narayan et al. (2013), and Klein (2017) also find evidence to confirm this diversifying potential of commodity futures through the use of various datasets and evaluation methods. The specific drivers of commodity returns as well as their low correlations with stocks and bonds can thus be viewed as the key factors that explain the increasing role of commodity futures in portfolio investments and diversification strategies (Domanski & Heath, 2007, Dwyer et al., 2011, Bekiros et al., 2017).

With the intensification of their financialization since 2004, commodity markets are exposed to some structural changes in the distributional characteristics of returns and dependence with other asset classes. Commodity futures returns now behave more like stock returns, and their correlation with stocks has become positive and increased in recent years, particularly after the collapse of Lehman Brothers (Büyüksahin & Robe, 2011, Daskalaki & Skiadopoulos, 2011, Tang & Xiong, 2012, Büyüksahin & Robe, 2014, Adams & Glück, 2015). As a result of this increasing equity-like behavior, researchers find evidence of lower diversification benefits associated with the inclusion of commodity futures in diversified portfolios and a higher level of their shock transmission and volatility spillovers with stocks (Baur & McDermott, 2010, Filis et al., 2011, Narayan & Sharma, 2011, Daskalaki & Skiadopoulos, 2011, Silvennoinen & Thorp, 2013).

The large fluctuations of commodity prices over recent years have also generated concerns for macroeconomic stability and overall economic performance. The standard deviation of the IMF all commodity price index over the 2005M1-2017M6 is 36.45%. The same price index also reached the highest value of 220.03 index points in July 2008 (base index of 100 points in 2005), or an increase of 120%. Since the information about volatility is a critical input for portfolio design, risk management and policy decisions (i.e., the volatility directly affects the cross-asset correlation and portfolio's risk level), an important strand of the commodity finance literature has devoted attention to commodity volatility modeling and the identification of its determinants. A general consensus from the majority of past studies is that main volatility drivers tend to differ across different classes

of commodities.

For instance, Daskalaki et al. (2014) attempt to identify common factors for the pricing of commodities. They conclude that neither macroeconomic, equity-related, nor commodity-specific factors can explain the pricing over all commodity classes. Batten et al. (2010) analyze the macroeconomic drivers of monthly precious metal volatility and document that monetary (e.g., inflation) and financial (e.g., S&P 500 returns) variables can explain the volatility block wise, but their results do not hold for Silver. Moreover, the drivers of volatility within the group of precious metals are not alike. Silvennoinen & Thorp (2013) analyze the correlation of commodities and find lagged VIX to have positive impact on weekly energy volatility, but no impact on precious metals.

Regarding the energy market volatility, Pindyck (2004) document that macroeconomic variables such as treasury bill yields or effective exchange-weighted dollar rate do not affect oil price volatility using weekly data. Kilian & Vega (2011) find evidence that WTI oil price returns are not sensitive to macroeconomic news. Karali & Ramirez (2014) use macroeconomic variables, political and weather events to identify drivers of crude oil, heating oil, and natural gas futures volatility. Their results indicate that only crude oil's volatility increases following political, financial, and natural events, whereas macroeconomic variables have no significant impact on oil price volatility. A recent study by Yin (2016) shows that economic policy uncertainty spills over to oil price spot and futures volatility.

Nevertheless, several studies empirically uncover common volatility links among commodity classes. The work of Verma (2012) shows, for example, negative influence of sentiment on the volatility of energy and precious metal futures. Considering a sample of agricultural, energy, and metal commodities, Karali & Power (2013) find evidence of significant influences of inflation and industrial production on commodity markets long-term volatility. Smales (2017) documents that the volatility of commodity markets, represented by the Commodity Research Bureau Index and the S&P Goldman Sachs Commodity Index, react to both the U.S. and Chinese macroeconomic news including the U.S. employment and economic output as well as the purchasing intentions of Chinese manufacturers. Lastly, Prokopczuk et al. (2017) investigate the co-movement of commodity market volatility and economic uncertainty via regression with realized volatility and find that certain macroeconomic and financial variables (i.e., the inflation volatility, the VIX, the default return spread and the TED spread) drive the monthly commodity volatility. The authors suggest to scrutinize the issue further through the framework proposed by Engle et al. (2013) which combines Generalized Autoregressive Heteroskedasticity (GARCH, Engle, 1982, Bollerslev, 1986) models with the Mixed Data Sampling (MIDAS, Ghysels et al., 2004, 2007) technique. This combination particularly allows one to use macroeconomic variables, usually available at monthly or quarterly frequency, as explanatory variables of daily volatility.

The GARCH-MIDAS model has been mostly used to examine the macroeconomic effects of

equity (Asgharian et al., 2013, Conrad & Loch, 2015, Opschoor et al., 2014) and bond markets (Nieto et al., 2015). Some studies have also employed this methodology to examine the volatility in commodity markets. Dönmez & Magrini (2013) investigate possible drivers of long-term volatility of agricultural commodities (wheat, corn, and soybean). For oil prices, Yin & Zhou (2016) and Pan et al. (2017) use GARCH-MIDAS with demand and supply shocks as explanatory variables for the volatility. Conrad et al. (2014) use macroeconomic variables to explain the dynamic correlations of stock markets and oil prices. Regarding commodities, Wei et al. (2017) and Fang et al. (2018) show that the economic policy uncertainty is positively associated with WTI spot returns and Gold futures variance and improves forecasts. Moreover, Liu et al. (2018) use news implied volatility indices to explain the long-term volatility of commodities. The authors present evidence that stock market related news affect energy and non-energy commodities. However, news on financial intermediaries are only associated with non-energy commodities.

Our paper contributes to the literature on modeling and forecasting the volatility of commodity markets for portfolio and risk management purposes to the extent that investors and portfolio managers would need accurate volatility to construct diversified portfolio including commodity assets. Going a step further, we particularly focus on the modeling and predictive ability of the GARCH-MIDAS model, while taking into account the potential macro-economic drivers of commodity volatility.

Using data of four economically-important commodity futures (Crude Oil, Gold, Silver, and Platinum) as well as a rich set of economic and financial variables (e.g., industrial production, consumer sentiment, economic uncertainty, implied volatility, and global real economic activity), we find that the growth rate of industrial production and consumer sentiment decreases volatility of commodity futures. Moreover, our analysis suggests that rising economic policy uncertainty and global real economic activity increase the long-term commodity volatility. When examining the usefulness of GARCH-MIDAS to forecast the volatility of commodity futures, we reveal that the inclusion of macroeconomic and financial variables in the volatility models improve the volatility forecast, especially on longer time horizons such as 5- or 20-days ahead prediction. However, no single model appears to be the best-suited specification for all commodity futures we consider. Hence, in the light of our empirical findings, investors would have to pay a close watch on the trends in industrial production, consumer sentiment, economic policy uncertainty, and global economic activities before making any tactical portfolio rebalancing related to commodity futures.

The remainder of the paper is structured as follows. In Section 2, we introduce our econometric framework. Section 3 presents our dataset. Section 4 reports and discusses the empirical results. Section 5 concludes the paper.

## 2. Methodology

### 2.1. Spline-GARCH

The Spline-GARCH by Engle & Rangel (2008) is a multiplicative alternative to the additive Component GARCH (Engle & Lee, 1999). The model allows one to disentangle the high and low frequency parts of conditional volatility. The long-term volatility  $\sqrt{\tau_t}$  is described by a non-parametric spline. Engle & Rangel (2008) suggest to divide the sample in equidistant knots  $k$ . The Spline-GARCH can be formulated as follows:

$$r_t = \mu + z_t \sqrt{\tau_t g_t} \quad \text{with } z_t \sim t_\nu(0, 1) \text{ i.i.d.}, \quad (1)$$

$$g_t = (1 - \alpha - \beta) + \alpha \left( \frac{\varepsilon_{t-1}^2}{\tau_{t-1}} \right) + \beta g_{t-1}, \quad (2)$$

$$\tau_t = c \exp \left( \omega_0 \frac{t}{T} + \sum_{i=1}^k \omega_i \max \left( \frac{t - t_i}{T}, 0 \right)^2 \right), \quad (3)$$

where  $\mathbb{V}[r_t | \Omega_{t-1}] = \tau_t g_t$  with  $\Omega_{t-1}$  as the information set at time  $t - 1$  containing all past returns  $r_t$  and residuals  $\varepsilon_t = (r_t - \mu)$ . The innovation  $z_t$  is an i.i.d. random variable from a Student's  $t$  distribution with  $\nu$  degrees of freedom. The parameter  $\mu$  describes the unconditional mean of the return series. The process  $\sqrt{g_t}$  describes the high frequency part of the conditional volatility with the well known GARCH dynamics. To maintain non-negativity and weakly stationarity  $\alpha, \beta \geq 0$  and  $\alpha + \beta < 1$ . Engle & Rangel (2008) suggest to identify the optimal choice of knots by using an information criterion such as Bayesian Information Criterion (BIC). However, we follow the approach of Walther et al. (2017), who choose the number and positions of knots by means of the Iterative Cumulative Sums of Squares (ICSS) variant of Sansó et al. (2004).

### 2.2. GARCH-MIDAS

Based on the Spline-GARCH, the GARCH-MIDAS model is introduced by Engle et al. (2013). It incorporates a long-term volatility component  $\tau_q$  to a simple GARCH model (Bollerslev, 1986). Thus, the conditional volatility of  $r_t$  partly depends on a macroeconomic variable  $X$  with  $K$  lags.

$$r_{t,q} = \mu + z_{t,q} \sqrt{\tau_q g_{t,q}} \quad \text{with } z_{t,q} \sim t_\nu(0, 1) \text{ i.i.d.}, \quad (4)$$

$$g_{t,q} = (1 - \alpha - \beta) + \alpha \left( \frac{\varepsilon_{t-1,q}^2}{\tau_q} \right) + \beta g_{t-1,q}, \quad (5)$$

$$\tau_q = \exp \left( m + \theta \sum_{k=1}^K \varphi_k(\omega_1, \omega_2) X_{q-k} \right), \quad (6)$$

$$\varphi_k(\omega_1, \omega_2) = \frac{(k/(K+1))^{\omega_1-1} (1-k/(K+1))^{\omega_2-1}}{\sum_{j=1}^K (j/(K+1))^{\omega_1-1} (1-j/(K+1))^{\omega_2-1}}. \quad (7)$$

The constraints  $\alpha, \beta \geq 0$  and  $\alpha + \beta < 1$  have to hold in order to maintain the non-negativity and stationarity of the high-frequency part  $g_t$ . For a further discussion on stationarity and ergodicity, see Wang & Ghysels (2015). The Beta-weighting scheme  $\varphi_k(\omega_1, \omega_2)$  is introduced to MIDAS by Ghysels et al. (2007). Dependent on the parameters  $\omega_1, \omega_2 > 1$ , the Beta scheme can depict increasing, decreasing, or hump-shaped weights, which sum up to unity.<sup>1</sup> Engle et al. (2013) also offer the possibility to use an exponential scheme, which is not as flexible as the Beta-function based scheme. Furthermore, Baumeister et al. (2014) consider unrestricted and equally-weighted schemes. Due to the exponential character of the low-frequency part  $\tau_q$ , no additional restrictions for non-negativity are required. In our specification,  $\tau_q$  stays constant for a quarter of a year  $q$ , which is associated with time  $t$ . Note that if we do not include a macroeconomic variable  $X$ , the long-term variance is  $\tau_q = \exp(m)$  and the model degenerates to a simple GARCH representation.

For the  $T + 1$  prediction of GARCH-MIDAS, we estimate the parameters from the in-sample period up to  $T$  and the last quarter  $Q$  and calculate the forecast as follows:

$$\hat{h}_{T+1} = \mathbb{E}[\tau_Q g_{T+1,Q} | \Omega_T] = \tau_Q \mathbb{E}[g_{T+1,Q} | \Omega_T] \quad (8)$$

$$= \tau_Q \left( (1 - \alpha - \beta) + \alpha \left( \frac{\varepsilon_{T,Q}^2}{\tau_Q} \right) + \beta g_{T,Q} \right). \quad (9)$$

The multi-step prediction  $T + h$  is conducted by recursively substituting the unknown variance forecast until time  $T$ :

$$\hat{h}_{T+h} = \tau_Q \left( (1 - \alpha - \beta) \sum_{i=0}^h (\alpha + \beta)^i + (\alpha + \beta)^h g_{T,Q} \right). \quad (10)$$

This technique of recursive substitution is criticized by Ederington & Guan (2010) for keeping the same weights for all forecast horizons. Admittedly, the short-term component of the GARCH-MIDAS model is prone to this critique. However, the long-term component is the estimate for longer horizons. Thus, the dissipating weights of the short-term component can be neglected for longer horizons. Another possible critique may be that we apply quarterly macroeconomic variables for short-term forecast of 1-day or 5-days ahead. Nonetheless, the latest observation of a macroeconomic variable will influence the overall volatility level and thus also affect near-term forecasts.

At the empirical level, we first estimate the three baseline models (i.e., the simple GARCH, the Spline-GARCH, and the GARCH-MIDAS accommodating each of the financial and macroeconomic variables) over different sub-samples corresponding to different dynamics of commodity prices. We then compare the forecasting performance of these models over an out-of-sample

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<sup>1</sup>Here, we use the scheme presented in Conrad & Loch (2015).

period.<sup>2</sup>

### 3. Data

We consider, in this paper, the most important commodity futures in the real economy, which are traded in the New York Mercantile Exchange (NYMEX) and the Commodity Exchange (COMEX) and are commonly investigated in commodity finance literature. We include the WTI crude oil index (RCLC1)<sup>3</sup>, the Brent crude oil index (LLCCS00), Gold (NGCCS00), Silver (NSLCS00), and Platinum (NPDCS00).<sup>4</sup> In addition, we take the S&P Goldman Sachs Commodity Index (GSCI) into consideration, which collected from Datastream as well. For all price and index series we use the daily prices over the period from 1 January 1996 to 31 December 2015, and calculate the daily logarithmic returns as  $r_t = 100 \cdot (\log(P_t/P_{t-1}))$ .

For the set of macroeconomic variables which will be used as potential drivers of the long-term commodity volatility, we consider the Product Price Index (*PPI*), the Industrial Production (*IP*), the University of Michigan Consumer Sentiment (*SENTI*), the overall Economic Policy Uncertainty Index (*EPUI*)<sup>5</sup>, the Effective Exchange Rate for the United States (*EERUS*) from the Bank of International Settlement, the bond market volatility index (*MOVE*), the S&P500 volatility index (*VIX*), the 3-month Treasury Bill rate (*TB3M*), the TED spread (*TED*), and the global real economic activity (*GREA*) from Kilian (2009)<sup>6</sup>. The latter is constructed by adjusting the prices of dry bulk cargo rates for various commodities. Given the data availability from 1 January 1992 to 1 October 2015, we calculate 95 quarterly growth rates as  $X_q^M = 100 \cdot (P_q/P_{q-1} - 1)$  for each series, except the *GREA*, for Apr 1st 1992-Oct 1st 2015.<sup>7</sup> For the *GREA*, we choose to use the variable in levels, since it is already deflated and linearly detrended by construction. We subdivided the full sample into three periods: (I) 1996-2005, (II) 2006-2015, and the full sample (III) 1996-2015. Table 1 reports the descriptive statistics and some preliminary tests on all time series.

[include Table 1 about here]

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<sup>2</sup>All calculations are exercised in MatLab R2017b. In addition, we are thankful to Kevin Sheppard for providing his MFE MatLab toolbox from which we used some functions including the Model Confidence Set. The toolbox is available from [https://www.kevinsheppard.com/MFE\\_Toolbox](https://www.kevinsheppard.com/MFE_Toolbox).

<sup>3</sup>The price series is retrieved from [https://www.eia.gov/dnav/pet/pet\\_pri\\_fut\\_s1\\_d.htm](https://www.eia.gov/dnav/pet/pet_pri_fut_s1_d.htm).

<sup>4</sup>Except for WTI, all price series are retrieved from Thompson Reuters Datastream. The price series are continuous futures series which roll over to the nearest contract at the first day of the month (Roll method Type 0).

<sup>5</sup>The data is obtained from <http://www.policyuncertainty.com/>.

<sup>6</sup>We are grateful to Lutz Kilian for kindly providing the data for the global real economic activity with recent updates on his personal webpage <http://www-personal.umich.edu/~lkilian/paperlinks.html>.

<sup>7</sup>We choose this time window, because the VIX is only available starting 1990. Choosing 1992 as a starting year allows us 1) have the necessary  $K = 16$  quarters lag, i.e. four years, for the GARCH-MIDAS model and 2) to calculate proxies for the variance of all macroeconomic variables which includes a year of time lag.

We find that all time series are stationary, given the results of the Augmented Dickey-Fuller (ADF) test. Only for *GREA* in the first sample, the ADF test does not reject the hypothesis of a unit root in the sample. Moreover, the daily log-returns of the commodities exhibit high auto-correlation of squared returns at 12 lags (ARCH test), which suggests the use of GARCH models.

In addition to the growth rates of the macroeconomic variables, we also include the quarterly realized variance of the commodities, defined as

$$X_q^{RV} = \sum_{i=1}^{66} r_{t-i,q}^2. \quad (11)$$

Moreover, we use the quarterly variance of the growth rates of the macroeconomic variables  $X_q^{MV}$  as explanatory variable for the long-term volatility. We estimate the variance of the quarterly macroeconomic variables in a similar fashion as in Schwert (1989). In a first step, we filter the quarterly growth rates with a fourth-order Auto-Regressive model and four quarterly dummy variables to account for seasonal effects of the growth series:

$$X_q^M = \sum_{i=1}^4 \phi_i X_{q-i}^M + \sum_{i=1}^4 \eta_i D_i + \varepsilon_q. \quad (12)$$

In a second step, the filtered quarterly observations,  $\varepsilon_q$ , are squared and used as an estimator for the quarterly variance of the macroeconomic variables:

$$X_q^{MV} = \varepsilon_q^2. \quad (13)$$

#### 4. Results and Discussions

We now turn to our results. We divide this section into three parts. In the first subsection, we estimate three GARCH models: the simple GARCH, the Spline-GARCH, and the GARCH-MIDAS-*RV* to examine whether including a time-varying long-term component can better explain the commodity volatility.

In the subsequent subsection, we estimate a total of 20 different models for each commodity, i.e. we use separately the quarterly growth rates and the quarterly variances of all explanatory macroeconomic and financial variables in our sample in combination with GARCH-MIDAS. Focusing on a single variable in the GARCH-MIDAS model allows us to conclude significance and direction of impact of the explanatory variables.

Lastly, we employ the GARCH-MIDAS models with quarterly growth rates of the macroeconomic and financial drivers, the simple GARCH model, as well as the GARCH-MIDAS-*RV* and the Spline-GARCH to forecast the volatility of our five commodities under investigation. Thus, a

total of 13 models is incorporated to predict the 1-day, 1-week, and 1-month ahead volatility.

#### 4.1. Long-term Volatility Patterns

We start our analysis by examining the parameter estimations of the simple GARCH, the Spline-GARCH, and the GARCH-MIDAS-RV models with Student's  $t$  distribution for the period from 2 January 1996 to 31 December 2015. The estimation of these models allows to straightforwardly assess whether it is economically meaningful to decompose the commodity return volatility into high and low frequencies. Note that the GARCH-MIDAS-RV has the quarterly realized variance of each commodity return as an explanatory variable of its long-term volatility.

[include Table 2 about here]

The estimation results are given in Tab. 2. As expected, the GARCH-MIDAS-RV model, which incorporates the quarterly realized variance of commodity returns, yields the best goodness-of-fit (i.e., lowest BIC) for all commodities under consideration, except for Platinum where the Spline-GARCH is the best-suited model. In all cases, the simple GARCH model has the worst fit, given its low Log-Likelihood (LL). For the Spline-GARCH model, the knots are identified by means of the ICSS approach and the results show five structural breakpoints for WTI and Brent oil indices, six for Gold, Silver and GSCI, and only one breakpoint for Platinum.

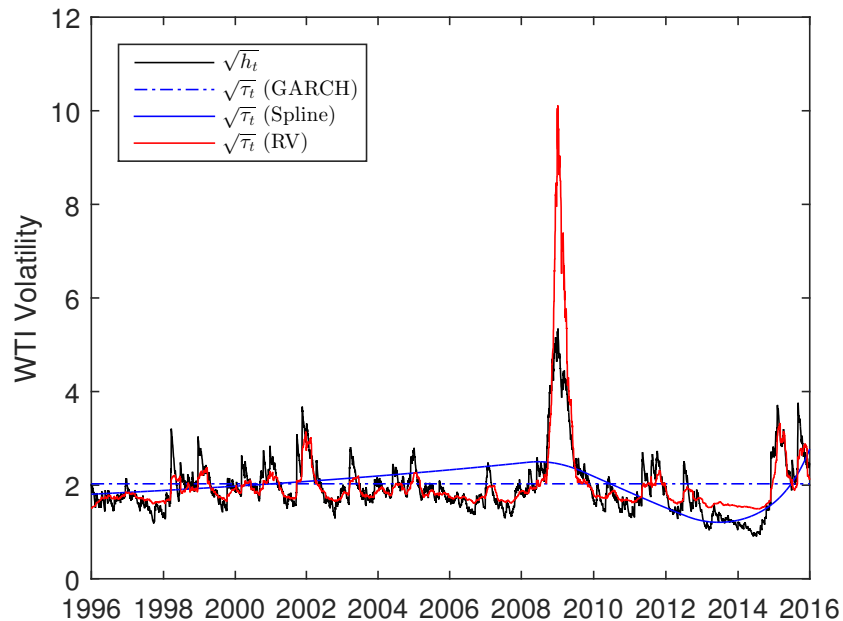


Figure 1: Volatility ( $\sqrt{h_t}$ ) and long-term volatility ( $\sqrt{\tau_t}$ ) of WTI oil price returns with GARCH, Spline-GARCH, and GARCH-MIDAS-RV for the period 1996-2015.

Tab. 2 also indicates that the short-term dynamics (i.e.  $\alpha$  and  $\beta$ ) of the three models are highly significant and very similar with relatively close values. This finding thus suggests that the differences in statistical fit (LL) and goodness-of-fit (BIC) rather arise from the long-term volatility component. Engle et al. (2013) use a variance ratio to determine the explanatory value of the long-term volatility. The measure  $VR = \frac{\mathbb{V}(\log \tau_t)}{\mathbb{V}(\log h_t)}$  describes the proportion of variance of the logarithmic long-term volatility and the variance of the logarithmic conditional volatility. For each GARCH-based specification, we use the estimated conditional variance  $\hat{h}_t$  of the simple GARCH model as base.<sup>8</sup> For the remaining models, we see that the long-term component of the Spline-GARCH and the GARCH-MIDAS-RV explains the fluctuation of the variance in a range between 21% and 96%. As an illustration, we depict, in Fig. 1, the long-term components of each model for the WTI crude oil volatility. The long-term volatility pattern provided by the GARCH-MIDAS-RV follows closely the conditional volatility dynamics.

#### 4.2. Drivers of Long-term Volatility

We now turn to present and discuss the results from the GARCH-MIDAS regressions over the three different sample periods for each commodity, whereby the long-term volatility component is modeled as a function of each of the financial and macroeconomic variables.

Before we present the regression analysis, we further test the legitimacy of a time-varying long-term component by means of a recently proposed regression-based misspecification test. To test the null hypothesis of a constant long-term component (simple GARCH), Conrad & Schienle (2018) suggest to run the following linear regression model:

$$\log RV_q = a_0 + a_1 X_{q-1} + \rho \log RV_{q-1} + \xi_q, \quad (14)$$

where  $RV_q$  is the quarterly realized variance based on the daily, standardized residuals from the simple GARCH model.  $X_{q-1}$  is the lagged, quarterly macroeconomic variable. The idea behind the test is that the realized variance should not be predictable. Hence, if  $a_1$  is statistically different from zero, we can reject the null hypothesis of a constant long-term component. Our results show, that for all five commodities at least two variables are able to predict the realized variance. Thus, some variables might not be appropriate to predict  $RV$ , but it appears the simple GARCH model with constant long-term component is not correctly specified.<sup>9</sup>

Since a time-varying long-term component seems reasonable, we proceed with the GARCH-MIDAS insample regression. This analysis allows us to identify the drivers of shocks or swings in the long-term volatility component. Without loss of generality, we solely concentrate on the

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<sup>8</sup>Note that the simple GARCH has an VR of zero. Since its long-term component is constant over time, the variance of the constant logarithmic long-term component is zero.

<sup>9</sup>The complete regression results are given in the Appendix in Table 6.

interpretation of the MIDAS parameters  $\theta$ ,  $\omega_1$ , and  $\omega_2$ . The results are given in Tab. 3, where we summarize the sign of the statistically significant parameter  $\theta$ .<sup>10</sup>

[include Table 3 about here]

The results for the WTI crude oil indicate that the quarterly growth rates of all macroeconomic variables have significant effects on the WTI long-term volatility in at least one out of the three periods we consider, except *PPI* and *TB3M*. In particular, the consumer sentiment (*SENTI*) consistently has a negative and significant impact in all three periods. Hence, when consumer sentiment rises the oil price volatility tends to decrease, which may suggest that the economy is in its stable state. As expected, the economic policy uncertainty (*EPUI*), the effective exchange rate for the United States (*EERUS*), and the global real economic activity (*GREA*) drive up the long-term oil price volatility. The effect of the quarterly variance of the growth rates of macroeconomic variables is however not exactly similar as the *PPI* and *TB3M* variables have now significant impacts. Also, the impact of the variance of the *SENTI* variable on long-term oil price volatility over the full period is positive. A close look at the *SENTI* variable shows that for the full period, we estimate the parameters  $\hat{\theta} = -0.2359$ ,  $\hat{\omega}_1 = 1.7843$ , and  $\hat{\omega}_2 = 2.8450$ . Hence, for a 1% increase of *SENTI* one quarter before, the long-term WTI volatility decreases by  $\exp(-0.2359 \cdot 0.0549) - 1 = -0.0129$  or -1.29%. The highest impact is due to changes in the consumer sentiment five quarters before, i.e. a 1% increase in consumer sentiment decreases the long-term volatility in five quarters by  $\exp(-0.2359 \cdot 0.1094) - 1 = -0.0258$  or -2.58%. Figure 2 shows the full lag structure for all three sample periods and how it changed from the first to the second decade of the whole sample. In the second sample period, the impact of *SENTI* is even bigger than for the full sample. As to the variance of the 3-month treasury bill rate, it negatively influences the long-term WTI volatility for all three sample periods. Thus, the U.S. oil price volatility decreases due to interest rate variability. This finding complements the observations of Barsky & Kilian (2002), who document that oil price increases (decreases) were preceded by low (high) interest rates.

The European Brent oil volatility shows similar patterns like its U.S. counterpart. Especially for the second period and the full sample, we observe that the *GREA* level is positively associated with the long-term oil price volatility. Hence, positive values in the global real economic activity index lead to higher oil price fluctuations. Kilian (2009) builds the index based on dry bulk ship cargo rates. These rates increase in times of high economic activity due to the fact that high demand meets an relatively inelastic supply curve. Thus, a positive index points towards a demand shock and an increased trading volume of commodities in general, which leads to their higher volatility. Analogously, if the *GREA* has a negative index, the markets cool down given the lower demand,

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<sup>10</sup>The complete regression results are given in the Appendix in Tables 7-24.

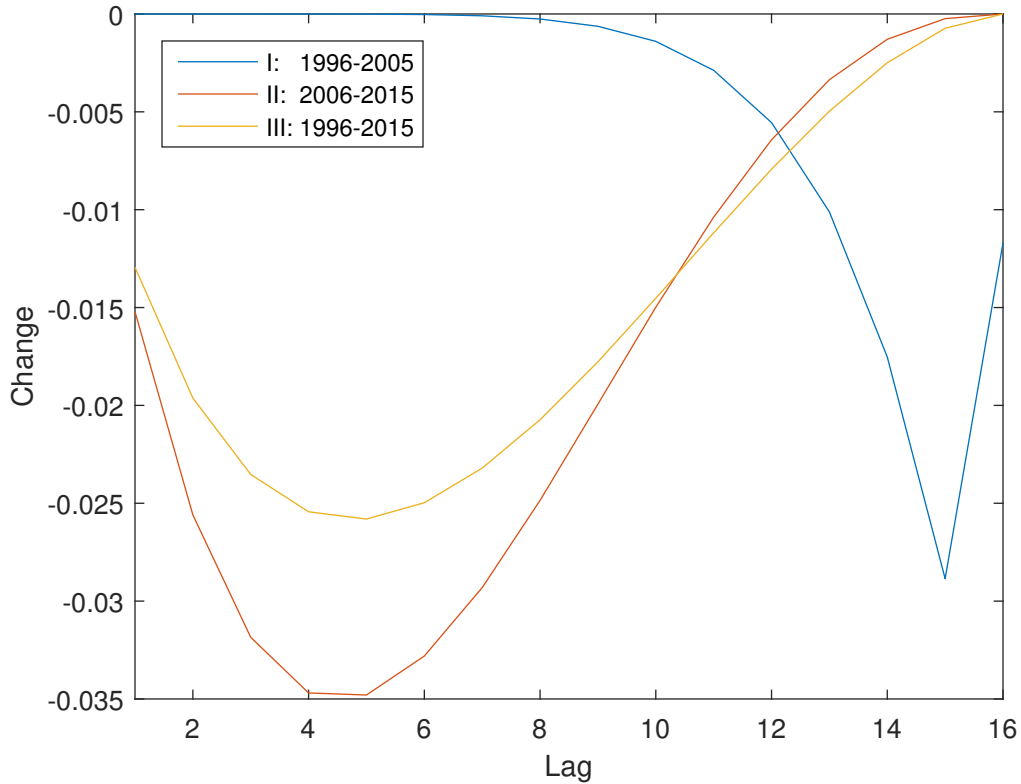


Figure 2: Change of the conditional variance of WTI due to the impact of consumer sentiment (*SENTI*) for quarterly lags up to  $K = 16$ .

and oil prices stabilize (less volatility). We find the *GREA* to be significant for all commodities in the second sub-sample. Figure 3 shows the effects of the lagged *GREA* levels on the long-term volatility of the two oil indices and the three metals. While the long-term volatility of the WTI and Brent is influenced by the *GREA* index from its first lag onwards, the metal volatility only reacts five quarters after and their highest reaction is observed at the seventh lag. Interestingly, we find that Brent reacts one quarter quicker to demand shocks than WTI, which could be explained by the fact that the Brent oil price is used as the benchmark for two-thirds of the world's oil trades.

For the long-term volatility of Gold and Silver, we find a negative effect of the *IP* variable. Industrial production generally reflects the state of the U.S. economy. Thus, an increase in the *IP* growth rates will decrease the long-term metal volatility. This is because Gold and Silver are often used for hedge and/or safe-haven purposes during turbulent periods (Baur & Lucey, 2010) and are not invested extensively when the economy performs well. We also find that the *EPUI* growth rates positively affect Gold's and Platinum's volatility whatever the sub-samples, but it is not the case for Silver. This finding suggests that increases in the economic policy uncertainty leads to different expectations by investors. Hence, we can support the results of Fang et al. (2018) and Wei et al.

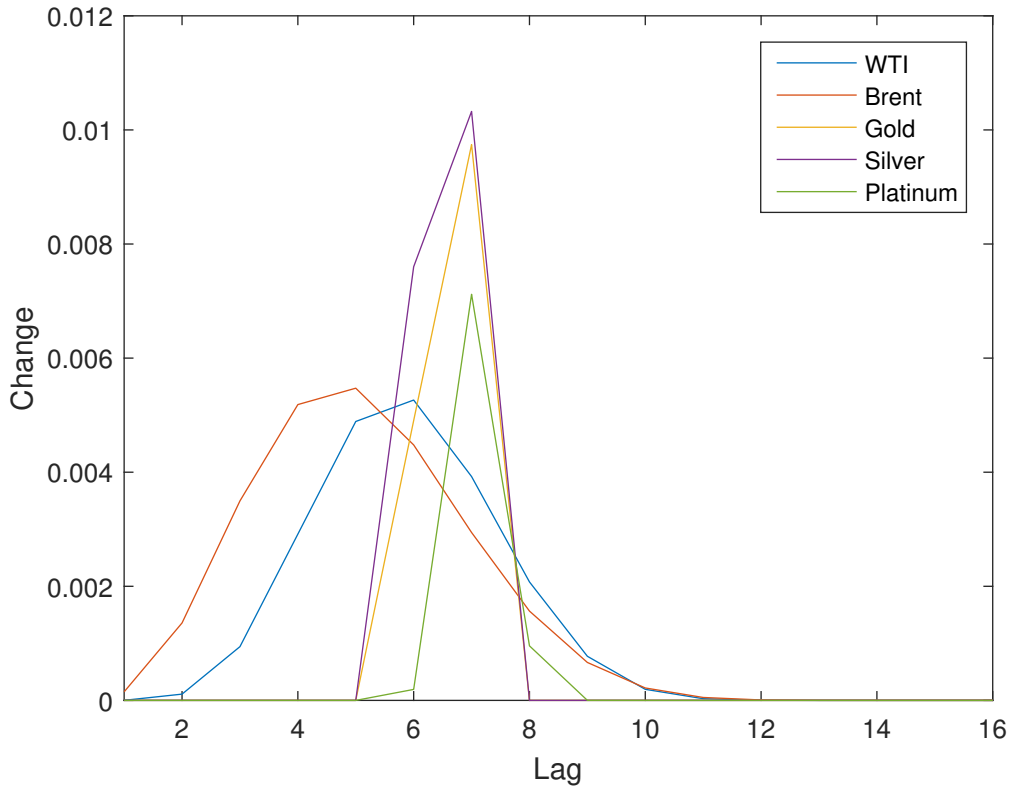


Figure 3: Change of the long-term conditional volatility of WTI, Brent, Gold, Silver, and Platinum due to the impact of global real economic activity (*GREA*) index for quarterly lags up to  $K = 16$ . The period spans from 2006-2015.

(2017), which show the importance of *EPUI* for Gold and WTI, respectively.

To summarize, our findings show that the growth rates of the industrial production (*IP*) and consumer sentiment (*SENTI*) negatively influence the long-term commodity volatility regardless of subsample periods and commodities, whenever the associated coefficients are statistically significant. The same result is reported in Karali & Power (2013) where changes in the industrial production are negatively associated with crude oil and Gold. There is also a positive link between the growth rate of *EPUI* and the level of *GREA* with the long-term commodity volatility. Except for *EPUI*, we can confirm these results for the GSCI. The impact of the variance of macroeconomic variables, albeit significant, is however not consistent across commodities or subsamples. We only find the variance of *SENTI* (+) and *PPI* (+) to be consistent with only one exception each. Both variables confirm the assumption, that uncertainty about sentiment and inflation impacts prices, which is the idea behind the standard ARCH model (Engle, 1982).

### 4.3. Forecasting Commodity Volatility

Whether the GARCH-MIDAS specifications with financial and macroeconomic variables are helpful for forecasting commodity volatility is of great interest to investors and portfolio managers. This subsection compares their predictive ability with the one of the simple GARCH, the Spline-GARCH, and the GARCH-MIDAS-RV models.<sup>11</sup> We choose an out-of-sample period of four years from 3 January 2012 to 30 December 2015 (i.e.  $M = 1005$  observations), with an expanding training window starting from 2 January 1996. Three loss functions are used to compare the forecasting performance of the different models and model specifications. They are described as follows:

$$\begin{aligned} \text{RMSE} &= \frac{1}{M} \sqrt{\sum_{i=1}^M \left( \hat{h}_i - (r_i - \hat{\mu}_i)^2 \right)}, \\ \text{MAE} &= \frac{1}{M} \sum_{i=1}^M \left| \hat{h}_i - (r_i - \hat{\mu}_i)^2 \right|, \\ \text{QLIKE} &= \frac{1}{M} \sum_{i=1}^M \left( \log \hat{h}_i + \frac{(r_i - \hat{\mu}_i)^2}{\hat{h}_i} \right), \end{aligned}$$

where  $\hat{h}_i$  is the forecasted conditional variance and the squared residual  $(r_i - \hat{\mu}_i)^2$  is the proxy for the actual variance at time  $i$  in the out-of-sample set  $i = 1, \dots, M$ .

Moreover, following Hansen et al. (2011), we employ the Model Confidence Set (MCS) with 10% level of significance to identify the best forecasting models and to avoid the problem of data snooping.

[include Table 4 about here]

The results of the variance forecast are given in Tab. 4. For oil price returns (WTI and Brent), the Spline-GARCH yields the best variance prediction performance and is present in the MCS of almost all loss functions over all horizons. All GARCH-MIDAS models with macroeconomic and financial variables have relatively equal performance in forecasting the oil price volatility with respect to the RMSE criterion over 1- or 5-days ahead. For the other loss functions, only the GARCH-MIDAS-*GREA* model joins the Spline-GARCH in the MCS, while the GARCH-MIDAS-*VIX* model for the Brent oil is also included in the MCS with respect to the QLIKE. Putting together with the findings in subsection 4.2, the *GREA* is not only suitable for explaining the in-sample volatility, but also a promising candidate to conduct forecasts of long-term oil price volatility.

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<sup>11</sup>Due to the fact that we do not find consistent patterns for the variance of these variables, we use the growth rates of the macroeconomic and financial variables only.

The results for Gold show that all competing models belong to the set of equally well-performing models at the 1-day ahead forecast horizon with respect to the RMSE and at the 5- and 20-days ahead forecast horizon with respect to QLIKE. Only the GARCH-MIDAS-*TB3M* model is present in all MCS regardless of time horizons and loss functions. This is a little bit surprising in our study, because (a) it is not significant in all in-sample estimations and (b) the direction of effects is not consistent. Its predictive power seems to suggest that it contains information about the long-term volatility which is used as a tendency for the short-term forecasts. For instance, a rising tendency in the *TB3M* could signal stock market booms and thus more stable Gold prices in the long-run because Gold will be less used in hedging and diversification strategies.

For Silver, the RMSE and QLIKE loss functions indicate that almost all GARCH-MIDAS models with financial and macroeconomic variables, the GARCH, and the GARCH-MIDAS-*RV* have equal performance at the three forecasting horizons under consideration. The MAE, on the other hand, only identifies four out of 13 models with superior performance. The inclusion of *SENTI*, *EPUI*, and *MOVE* variables into the GARCH-MIDAS models results in lower MAE for 5- and 20-days than the other specifications. Having realized volatility as explanatory variable for the long-term volatility shows better performance for 1- and 5-days ahead forecasts.

The long-term volatility of Platinum appears to be harder to predict. We find the same macroeconomic variables as for Silver to be included in the MCS. While the GARCH-MIDAS-*SENTI* and GARCH-MIDAS-*MOVE* models (also simple GARCH) show good performance for 5- and 20-days horizons, the GARCH-MIDAS-*EPUI* and GARCH-MIDAS-*RV* belong to the MCS for 1-day ahead prediction.

The variance of the commodity index GSCI is relatively well predicted by all explanatory variables. Only the MAE indicates that the Spline-GARCH maybe favourable.

The results from the variance forecasting show that no single GARCH-MIDAS specification is able to predict the volatility better than the others, and this result holds across all commodities. Especially, the use of the *TED* to predict commodity volatility is not recommended. From 54 tests (three horizons, three loss functions, and six commodities), it is only included in 15 MCS. On the contrary, the GARCH-MIDAS model using the *GREA* level appears to have 29 inclusions.

In addition to the volatility forecast, we evaluate the Value-at-Risk (VaR) forecast performance of the models. For this purpose, we use the multivariate unconditional coverage test of Pérignon & Smith (2008) to jointly test the coverage of  $p = 95\%$ ,  $97.5\%$ , and  $99\%$  VaRs. The idea of the test is based on the hit ratio test of Kupiec (1995), which compares the empirically observed VaR exceedance with the theoretical one. Since the test by Kupiec (1995) only compares one coverage ratio at a time, the extension of Pérignon & Smith (2008) allows us to scrutinize the performance of a specific VaR forecast at three different coverage ratios jointly. We define the coverage as the ratio of VaR violations to the number of out-of-sample observations. The backtest compares this

number to the theoretical coverage, e.g. for a 95% VaR the theoretical coverage is 5%.

Based on the GARCH models, we estimate the VaR as follows:

$$\widehat{\text{VaR}}_{t,p} = \hat{\mu}_t + \sqrt{\hat{h}_t} F_{1-p}^{-1}(\hat{\nu}), \quad (15)$$

where  $F_{1-p}^{-1}(\nu)$  is the  $(1 - p)$ -quantile function of the Student- $t$  distribution with  $\nu$  degrees of freedom.<sup>12</sup>

[include Table 5 about here]

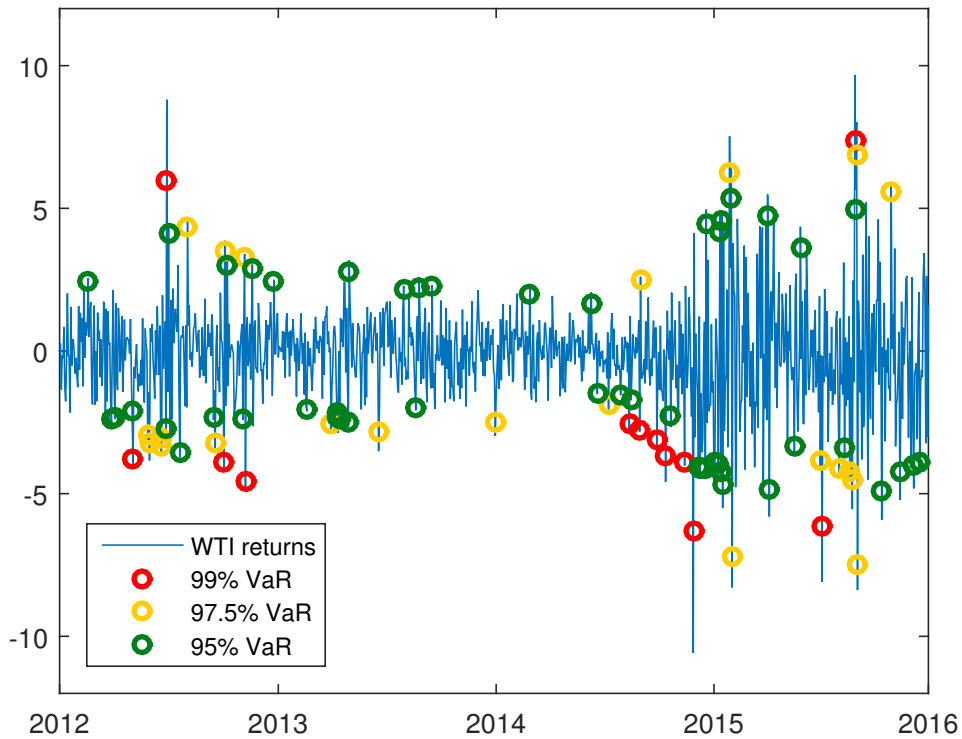


Figure 4: Value-at-Risk forecast for WTI 2012-2015 with GARCH-MIDAS-SENTI.

The results of the VaR backtest in Table 5 can be summarized as follows. First, for the WTI and Brent crude oil as well as for GSCI, almost all models pass the VaR test from a long trading

<sup>12</sup>In addition, we calculate the Expected Shortfall (ES) for our commodities. The ES is the expected value of the returns which are lower than the estimated VaR. We use the ES backtest by Acerbi & Szekely (2014), which evaluates the number and the size of exceedances jointly. We incorporate a level of confidence of 97.5%, which is the usual level under the Basel requirements Basel Committee on Banking Supervision (2016). For the sake of brevity, our results are presented in the Appendix Tab. 25. Basically, the ES results confirm the impression of the VaR backtest.

position, but fail when the short trading perspective is evaluated. For the GSCI, the result may partly be explained due to the fact that a large share of the index includes crude oil. Second, the test rejects more models on the long trading positions for Gold and Silver. Finally, except for some models at 5-days ahead VaR forecast for long trading positions, all forecasting models for Platinum fail to obtain satisfactory results. Figure 4 demonstrates the VaR forecast for WTI with GARCH-MIDAS-*SENTI*, which has the least rejections over all VaR tests conducted (17 out of 36). On the short trading positions, i.e. traders being susceptible to earn positive returns, the GARCH-MIDAS model with the sentiment index as an explanatory variable is rejected by the backtest due to the fact that the predictions are too conservative. For example, the 95% VaR forecast which is supposed to have a coverage of 5% only yields 2.69% (27 exceptions). The 97.5% VaR only has 0.90% (9 exceptions) and the 99% VaR only has a coverage of 0.02% (2 exceptions), where 2.5% and 1% are required, respectively.<sup>13</sup> Since the model fails to provide a sufficient estimate of the VaR at any quantile, it is rejected by the Pérignon & Smith (2008) test. Models that yield too conservative VaR estimates are costly in terms of capital requirements of banks or VaR-limits of traders. However, as mentioned above, the VaR estimates for the long trading position pass the test. Here, the coverage of the 95% VaR is 5.57% (56 exceptions).

In order to check for robustness of our in-sample and out-of-sample results, we check for several different settings of our models. First, we change the number of lags  $K$ , i.e. how many past quarters information of macroeconomic variables are used. Second, we use logarithmic differences of the macroeconomic variables instead of growth rates. Third, we attempt to incorporate the first principal component of all macroeconomic and financial variables. Fourth, instead of using the Student- $t$  distribution for the innovations  $z_t$ , we evaluated our results assuming a Normal distribution. Finally, we change the frequency of our explanatory variable, which we use at a quarterly rate, to monthly growth rates to explain the long-term volatility of daily commodity returns. For all mentioned robustness checks, the results remain qualitatively intact.

## 5. Conclusion

The motivation of this paper was to identify the potential drivers of the long-term volatility of commodity prices through the GARCH-MIDAS class model, at both modeling and forecasting levels. We conduct our empirical investigation in three steps including the in-sample estimation, the identification of the long-term commodity volatility drivers, and the out-of-sample volatility forecasting. In the first step, we show that disentangling long-term and short-term volatility of

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<sup>13</sup>The exceptions can be counted by the dots in Fig. 4. For the 95% VaR the sum of all yellow, green, and red dots is the number of exceptions for each trading position. For the 97.5% VaR, one has to sum the yellow and the red dots. For the 99% VaR, the number of exceptions is given by the sum of the red dots only.

commodity futures leads to a better in-sample fit by means of the Spline-GARCH and the GARCH-MIDAS models with commodity's realized volatility.

In the second step, we employ the GARCH-MIDAS framework to examine whether each of the financial and macroeconomic variables in our study matters for the long-term commodity volatility. We find that the long-term commodity volatility is negatively influenced by the growth rates of the consumer sentiment and the industrial production, but positively by the growth rate of the economic policy uncertainty and the level of the general real economic activity. We also investigate whether the variance of these financial and macroeconomic variables inhibits any information for the long-term commodity volatility, but we do not find any consistent results across commodity futures.

The last part of the paper uses the GARCH-MIDAS with financial and macroeconomic variables to forecast the volatility of commodities over the 1-, 5-, and 20-days ahead horizons. It is important to stress that the consistent results for in-sample estimations are not translated into forecasting performance. Thus, we find different best-suited models for each commodity. For example, the oil price volatility is best predicted with either Spline-GARCH or the GARCH-MIDAS-*GREA*. For Gold, the GARCH-MIDAS-*TB3M* is recommended for forecasting the volatility at the 1-, 5-, and 20-days ahead forecasts. For Silver and Platinum, we find the GARCH-MIDAS-*SENTI*, the GARCH-MIDAS-*EPUI*, the GARCH-MIDAS-*MOVE*, and the GARCH-MIDAS-*RV* to have equally well results. At the same time, our forecasting results show, from a risk management perspective, that the inclusion of financial and macroeconomic variables in the volatility models does not lead to better Value-at-Risk predictions than the simple GARCH model.

The findings of our paper can be improved by potentially considering the asymmetric effects of financial and macroeconomic variables. For instance, Verma (2012) and Bahloul & Bouri (2016) report volatility asymmetric responses in times of bullish and bearish markets. Moreover, the forecastability of GARCH-MIDAS models might be improved by model averaging.

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|  | <i>T</i> | Mean    | Min.     | Max.     | Stand.Dev. | Skewness | Kurtosis | LB(12)      | ARCH(12)    | ADF         |
|--|----------|---------|----------|----------|------------|----------|----------|-------------|-------------|-------------|
| Commodities (daily returns)                    |          |         |          |          |            |          |          |             |             |             |
| Jan 1st 1996-Dec 30th 2005                     |          |         |          |          |            |          |          |             |             |             |
| WTI  | 2501     | 0.0492  | -12.1607 | 11.6594  | 1.9820     | -0.2029  | 5.2754   | 15.7446     | 64.4502***  | -49.6648*** |
| Brent  | 2610     | 0.0448  | -14.4372 | 12.8982  | 2.2517     | -0.2308  | 5.4517   | 9.7797      | 50.7701***  | -52.9709*** |
| Gold   | 2610     | 0.0110  | -5.1049  | 8.8872   | 0.8800     | 0.6539   | 12.7778  | 17.1831     | 112.6825*** | -51.0886*** |
| Silver   | 2610     | 0.0205  | -11.8323 | 7.6612   | 1.4473     | -0.4294  | 8.3490   | 23.0132**   | 175.5339*** | -51.0985*** |
| Platinum                                       | 2610     | 0.0342  | -14.4173 | 18.6781  | 1.3806     | 1.1136   | 30.8952  | 30.6490***  | 12.0356     | -52.0306*** |
| GSCI   | 2610     | 0.0350  | -9.1695  | 6.5670   | 1.3058     | -0.1160  | 4.8398   | 9.4775      | 67.5175***  | -51.7882*** |
| Jan 2nd 2006-Dec 31st 2015                     |          |         |          |          |            |          |          |             |             |             |
| WTI  | 2514     | -0.0199 | -10.5782 | 12.1150  | 2.1369     | -0.1592  | 6.2928   | 21.3814**   | 452.5556*** | -53.5608*** |
| Brent  | 2609     | -0.0176 | -10.9455 | 12.7066  | 2.0985     | -0.0683  | 6.8232   | 51.0998***  | 592.7609*** | -54.3737*** |
| Gold   | 2609     | 0.0275  | -9.8206  | 8.6250   | 1.2635     | -0.3727  | 8.0461   | 27.4426***  | 130.4636*** | -51.0980*** |
| Silver   | 2609     | 0.0171  | -19.5185 | 12.3585  | 2.2741     | -0.8740  | 9.2652   | 14.8882     | 141.0550*** | -52.5413*** |
| Platinum                                       | 2609     | -0.0033 | -9.6033  | 16.0210  | 1.5176     | -0.0922  | 11.2790  | 15.7196     | 164.1283*** | -48.1499*** |
| GSCI   | 2609     | -0.0428 | -8.6486  | 7.2159   | 1.4950     | -0.3046  | 6.3860   | 20.0830*    | 477.3502*** | -53.0929*** |
| Jan 1st 1996-Dec 31st 2015                     |          |         |          |          |            |          |          |             |             |             |
| WTI  | 5015     | 0.0146  | -12.1607 | 12.1150  | 2.0612     | -0.1826  | 5.8927   | 17.6758     | 527.7097*** | -73.1878*** |
| Brent  | 5219     | 0.0136  | -14.4372 | 12.8982  | 2.1765     | -0.1553  | 6.0644   | 32.4483***  | 535.3568*** | -75.8587*** |
| Gold   | 5219     | 0.0193  | -9.8206  | 8.8872   | 1.0887     | -0.1107  | 10.0088  | 33.3773***  | 269.7001*** | -72.2897*** |
| Silver   | 5219     | 0.0188  | -19.5185 | 12.3585  | 1.9058     | -0.8372  | 10.7768  | 17.0178     | 341.2088*** | -73.7414*** |
| Platinum                                       | 5219     | 0.0154  | -14.4173 | 18.6781  | 1.4507     | 0.4234   | 19.4480  | 19.3300*    | 84.9298***  | -70.5618*** |
| GSCI   | 5219     | -0.0039 | -9.1695  | 7.2159   | 1.4040     | -0.2416  | 5.9329   | 16.2624     | 655.5203*** | -74.3136*** |
| Macroeconomic Variables (monthly growth rates) |          |         |          |          |            |          |          |             |             |             |
| Apr 1st 1992-Oct 1st 2005                      |          |         |          |          |            |          |          |             |             |             |
| <i>PPI</i>                                     | 55       | 0.6694  | -0.3376  | 2.0451   | 0.4754     | 0.6912   | 3.7751   | 318.2274*** | 50.1899***  | -3.6043***  |
| <i>IP</i>                                      | 55       | 0.8200  | -1.8292  | 2.8383   | 0.9645     | -0.3809  | 3.1006   | 35.2119***  | 14.3579     | -3.2424***  |
| <i>SENTI</i>                                   | 55       | 0.4590  | -23.1088 | 21.8281  | 7.6340     | 0.0805   | 4.2131   | 41.7492***  | 32.1541***  | -9.3907***  |
| <i>EPUI</i>                                    | 55       | 1.7363  | -38.8710 | 69.5293  | 22.3375    | 0.4208   | 3.1595   | 39.2926***  | 17.0294     | -11.0963*** |
| <i>EERUS</i>                                   | 55       | 0.0478  | -6.9507  | 6.1370   | 3.0024     | -0.2221  | 2.6952   | 21.6967**   | 17.2949     | -7.0971***  |
| <i>MOVE</i>                                    | 55       | 1.3843  | -29.3532 | 63.6364  | 18.5001    | 1.0442   | 4.1247   | 21.9241**   | 9.1196      | -10.0174*** |
| <i>VIX</i>                                     | 55       | 2.3680  | -40.3663 | 107.7626 | 28.2879    | 1.5510   | 5.8957   | 35.4489***  | 11.1852     | -10.2729*** |
| <i>TB3M</i>                                    | 55       | 1.0094  | -38.4615 | 41.4894  | 14.5236    | 0.1139   | 4.0666   | 87.7110***  | 33.2890***  | -3.5105***  |
| <i>TED</i>                                     | 55       | 6.2467  | -60.2941 | 86.1111  | 34.0892    | 0.4774   | 2.6466   | 31.6456***  | 33.4887***  | -8.9898***  |
| <i>GREA</i>                                    | 55       | -0.4675 | -31.9724 | 50.0013  | 20.8700    | 0.8223   | 3.0898   | 164.7693*** | 48.2137***  | -1.4067     |
| Apr 1st 2002-Oct 1st 2015                      |          |         |          |          |            |          |          |             |             |             |
| <i>PPI</i>                                     | 55       | 0.5419  | -2.5072  | 2.3931   | 0.9436     | -0.5981  | 4.1356   | 40.2087***  | 15.1128     | -5.9474***  |
| <i>IP</i>                                      | 55       | 0.2587  | -6.3991  | 2.2055   | 1.4753     | -2.5494  | 11.3393  | 45.8746***  | 32.7200***  | -3.2404***  |
| <i>SENTI</i>                                   | 55       | 0.3614  | -23.1088 | 23.3553  | 9.2580     | 0.1338   | 3.3880   | 33.7638***  | 5.9681      | -10.0613*** |
| <i>EPUI</i>                                    | 55       | 2.6112  | -45.3283 | 81.8613  | 25.4964    | 1.0549   | 4.3691   | 18.0936     | 11.2170     | -9.1542***  |
| <i>EERUS</i>                                   | 55       | -0.2340 | -7.9567  | 7.5602   | 3.5305     | 0.1185   | 2.6679   | 34.7111***  | 17.9774     | -5.5318***  |
| <i>MOVE</i>                                    | 55       | 0.8816  | -38.2632 | 74.1710  | 20.6668    | 1.4848   | 5.8719   | 8.3091      | 11.6003     | -8.3127***  |
| <i>VIX</i>                                     | 55       | 4.4193  | -45.5307 | 160.0484 | 34.2312    | 2.1021   | 9.7139   | 30.7492***  | 8.4924      | -6.8370***  |
| <i>TB3M</i>                                    | 55       | 0.8119  | -80.5970 | 166.6667 | 43.9323    | 1.7308   | 8.3431   | 12.7389     | 18.4377     | -6.4236***  |
| <i>TED</i>                                     | 55       | 10.6581 | -63.4146 | 246.1538 | 52.2457    | 2.2308   | 10.1778  | 18.6416*    | 13.1449     | -8.8564***  |
| <i>GREA</i>                                    | 55       | 14.6714 | -52.8075 | 64.3385  | 30.4095    | -0.3424  | 2.1175   | 155.1052*** | 49.8877***  | -2.1508**   |
| Apr 1st 1992-Oct 1st 2015                      |          |         |          |          |            |          |          |             |             |             |
| <i>PPI</i>                                     | 95       | 0.5767  | -2.5072  | 2.3931   | 0.7532     | -0.7862  | 6.0136   | 70.8559***  | 28.7945***  | -6.8992***  |
| <i>IP</i>                                      | 95       | 0.5351  | -6.3991  | 2.8383   | 1.3503     | -2.2119  | 11.4121  | 60.7998***  | 42.0781***  | -4.2607***  |
| <i>SENTI</i>                                   | 95       | 0.6426  | -23.1088 | 23.3553  | 8.3201     | 0.2527   | 3.7418   | 38.7771***  | 8.6220      | -12.9977*** |
| <i>EPUI</i>                                    | 95       | 2.7076  | -45.3283 | 81.8613  | 24.7079    | 0.8304   | 3.8843   | 25.0137**   | 12.1545     | -13.2026*** |
| <i>EERUS</i>                                   | 95       | 0.1405  | -7.9567  | 7.5602   | 3.2155     | -0.0054  | 2.7492   | 23.7173**   | 15.9138     | -8.0968***  |
| <i>MOVE</i>                                    | 95       | 1.8373  | -38.2632 | 74.1710  | 20.5543    | 1.1986   | 4.7469   | 14.3955     | 9.1704      | -12.0629*** |
| <i>VIX</i>                                     | 95       | 4.2099  | -45.5307 | 160.0484 | 32.1412    | 1.9710   | 8.8980   | 36.8007***  | 8.0812      | -12.6911*** |
| <i>TB3M</i>                                    | 95       | -0.0771 | -80.5970 | 166.6667 | 34.1781    | 2.1582   | 13.2354  | 18.4462     | 30.7764***  | -8.4102***  |
| <i>TED</i>                                     | 95       | 7.8327  | -63.4146 | 246.1538 | 45.9179    | 2.0660   | 10.5898  | 28.4977***  | 19.9667*    | -11.7807*** |
| <i>GREA</i>                                    | 95       | 4.8672  | -52.8075 | 64.3385  | 26.9702    | 0.3593   | 2.3448   | 309.0392*** | 81.8343***  | -2.8191***  |

Table 1: Descriptive statistics of commodity returns and growth rates of macroeconomic variables.

Note: Rejection of the respective hypothesis at 1%, 5% and 10% is marked by \*\*\*, \*\*, and \*, respectively. LB(12) and ARCH(12) are the Ljung-Box and ARCH test at 12 lags auto-correlation of returns and squared returns. ADF is the Augmented Dickey-Fuller test for stationarity.

| Commodity | Model     | knots | $\mu$     | $\alpha$  | $\beta$   | $\nu$     | LL     | BIC          | VR     |
|-----------|-----------|-------|-----------|-----------|-----------|-----------|--------|--------------|--------|
| WTI       | GARCH     | –     | 0.0439    | 0.0396*** | 0.9559*** | 8.2406*** | -10251 | 20545        | –      |
|           | Spline    | 5     | 0.0455    | 0.0398*** | 0.9478*** | 8.0593*** | -10240 | 20573        | 0.4983 |
|           | <i>RV</i> | –     | 0.0434*** | 0.0414*** | 0.9338*** | 8.9963*** | -10222 | <b>20513</b> | 0.7782 |
| Brent     | GARCH     | –     | 0.0391*   | 0.0413*** | 0.9560*** | 7.0635*** | -10893 | 21828        | –      |
|           | Spline    | 5     | 0.0409    | 0.0432*** | 0.9424*** | 6.9465*** | -10878 | 21851        | 0.5524 |
|           | <i>RV</i> | –     | 0.0398*   | 0.0425*** | 0.9437*** | 7.3761*** | -10869 | <b>21806</b> | 0.6319 |
| Gold      | GARCH     | –     | 0.0111    | 0.0399*** | 0.9578*** | 4.5391*** | -7000  | 14043        | –      |
|           | Spline    | 6     | 0.0092    | 0.0469*** | 0.9459*** | 3.9893*** | -6980  | 14063        | 0.7281 |
|           | <i>RV</i> | –     | 0.0126*   | 0.0467*** | 0.9443*** | 4.2017*** | -6973  | <b>14015</b> | 0.7653 |
| Silver    | GARCH     | –     | 0.0437*** | 0.0320*** | 0.9651*** | 4.0933*** | -9822  | 19686        | –      |
|           | Spline    | 6     | 0.0400*   | 0.0349*** | 0.9595*** | 3.7689*** | -9806  | 19716        | 0.9574 |
|           | <i>RV</i> | –     | 0.0458*** | 0.0408*** | 0.9397*** | 3.8973*** | -9798  | <b>19665</b> | 0.8059 |
| Platinum  | GARCH     | –     | 0.0330**  | 0.0518*** | 0.9388*** | 4.7068*** | -8460  | 16962        | –      |
|           | Spline    | 1     | 0.0307**  | 0.0535*** | 0.9344*** | 4.5654*** | -8450  | <b>16960</b> | 0.2618 |
|           | <i>RV</i> | –     | 0.0309**  | 0.0560*** | 0.9311*** | 4.6732*** | -8453  | 16975        | 0.2055 |
| GSCI      | GARCH     | –     | 0.0138    | 0.0355*** | 0.9388*** | 7.9946*** | -8633  | 17309        | –      |
|           | Spline    | 6     | 0.0141    | 0.0351*** | 0.9542*** | 7.8838*** | -8621  | 17345        | 0.6525 |
|           | <i>RV</i> | –     | 0.0138    | 0.0321**  | 0.9612*** | 8.3741*** | -8616  | <b>17301</b> | 0.4904 |

Table 2: Parameter estimation results of the GARCH, Spline-GARCH, and GARCH-MIDAS-*RV*: 2 January 1996 - 31 December 2015.

Note: The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively. LL is the Log-Likelihood and the BIC is the Bayesian Information Criterion. Numbers in bold face indicate the model with the best goodness-of-fit (lowest BIC). The variance ratio VR represents the proportion of long-term variance to total variance.

| Commodity<br>Period    | WTI |    |     | Brent |    |     | Gold |    |     | Silver |    |     | Platinum |    |     | GSCI |    |     |
|------------------------|-----|----|-----|-------|----|-----|------|----|-----|--------|----|-----|----------|----|-----|------|----|-----|
|                        | I   | II | III | I     | II | III | I    | II | III | I      | II | III | I        | II | III | I    | II | III |
| quarterly growth rates |     |    |     |       |    |     |      |    |     |        |    |     |          |    |     |      |    |     |
| <i>PPI</i>             |     |    |     |       |    | -   |      | +  | -   |        |    |     |          |    |     | +    |    | +   |
| <i>IP</i>              |     | -  |     |       | -  |     |      | -  | -   | -      |    |     |          |    |     |      |    |     |
| <i>SENTI</i>           | -   | -  | -   |       | -  | -   |      | -  | -   |        |    | -   |          |    |     |      | -  |     |
| <i>EPUI</i>            |     | +  |     |       | +  |     | +    | +  | +   |        |    | +   |          | +  |     |      |    |     |
| <i>EERUS</i>           | -   | +  |     |       | +  |     |      |    |     |        | -  | -   |          | +  |     | +    |    |     |
| <i>MOVE</i>            |     |    | +   |       | +  |     |      | -  |     |        | -  |     |          | +  |     |      | +  | +   |
| <i>VIX</i>             |     | -  | -   |       |    |     |      |    |     |        |    |     |          | +  |     | +    |    |     |
| <i>TB3M</i>            |     | -  |     |       | +  |     | -    | -  | +   |        |    | +   | -        |    |     |      |    | -   |
| <i>TED</i>             | -   |    | -   |       | +  | +   | -    | -  |     |        | -  | +   |          |    | +   |      |    |     |
| <i>GREA</i>            |     | +  | +   |       |    | +   | +    | +  | +   | +      | +  | +   |          | +  | +   | +    | +  | +   |
| quarterly variance     |     |    |     |       |    |     |      |    |     |        |    |     |          |    |     |      |    |     |
| <i>PPI</i>             | +   | +  |     |       | +  | +   |      | +  | +   | +      | +  | +   | +        |    |     |      | +  | +   |
| <i>IP</i>              | -   | +  |     |       | +  |     |      |    | +   | +      |    | +   |          |    |     |      |    | -   |
| <i>SENTI</i>           | -   | +  |     |       |    |     |      | +  | +   | +      |    | +   | +        |    |     |      |    | +   |
| <i>EPUI</i>            |     |    |     |       | +  |     | -    |    | +   |        | +  | -   | +        |    | +   | +    | +  |     |
| <i>EERUS</i>           |     | +  |     |       |    |     | -    |    | +   | +      |    | +   | +        |    | -   | -    | +  |     |
| <i>MOVE</i>            | -   |    | -   |       |    |     |      | -  |     |        |    | -   | -        |    |     | +    |    |     |
| <i>VIX</i>             |     | -  | -   |       | +  | -   | -    |    | +   |        | +  | -   |          |    | -   | -    |    | -   |
| <i>TB3M</i>            | -   | -  | -   |       | +  | -   | -    | -  | -   | +      |    |     | -        |    | +   |      | +  | -   |
| <i>TED</i>             | +   |    |     |       |    |     | -    | -  | +   | +      |    | +   | +        |    | +   |      | +  | -   |
| <i>GREA</i>            |     |    |     |       | +  |     |      |    |     | +      |    |     |          |    | +   |      |    |     |

Table 3: Regression results for GARCH-MIDAS model using macroeconomic and financial variables.

Note: The sign (+ or -) is given if the parameter  $\theta$  is statistically significant, i.e. p-value < 10%. Otherwise the field is left blank. The periods span from (I) 1996-2005, (II) 2006-2015, and (III) 1996-2015.

|          |         | PPI           | IP            | SENTI         | EPUI          | EERUS         | MOVE          | VIX           | TB3M          | TED           | GREA          | GARCH         | RV            | Spline        |
|----------|---------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| WTI      |         |               |               |               |               |               |               |               |               |               |               |               |               |               |
| RMSE     | 1-day   | <b>3.4620</b> | <b>3.4717</b> | <b>3.4609</b> | <b>3.4717</b> | <b>3.4561</b> | <b>3.4647</b> | <b>3.4679</b> | <b>3.4636</b> | <b>3.4588</b> | <b>3.4633</b> | <b>3.4587</b> | <b>3.4366</b> | <b>3.4466</b> |
|          | 5-days  | <b>3.6689</b> | 3.6779        | <b>3.6705</b> | <b>3.6582</b> | <b>3.6638</b> | <b>3.6692</b> | <b>3.6651</b> | <b>3.6967</b> | <b>3.6679</b> | <b>3.6604</b> | <b>3.6661</b> | 3.7518        | <b>3.6738</b> |
|          | 20-days | 3.7608        | 3.7893        | <b>3.7525</b> | <b>3.7457</b> | 3.7605        | 3.7603        | <b>3.7426</b> | 3.8008        | 3.7671        | <b>3.7372</b> | 3.7550        | 3.9878        | 3.7846        |
| MAE      | 1-day   | 0.7105        | 0.7173        | 0.6833        | 0.7054        | 0.7044        | 0.7090        | 0.7011        | 0.7157        | 0.7190        | 0.6906        | 0.7067        | 0.7220        | <b>0.6738</b> |
|          | 5-days  | 0.7670        | 0.7844        | 0.7410        | 0.7554        | 0.7631        | 0.7680        | 0.7546        | 0.7789        | 0.7789        | 0.7420        | 0.7628        | 0.8526        | <b>0.7293</b> |
|          | 20-days | 0.8466        | 0.8864        | 0.8217        | 0.8271        | 0.8489        | 0.8539        | 0.8251        | 0.8629        | 0.8673        | <b>0.8093</b> | 0.8405        | 1.0394        | <b>0.7966</b> |
| QLIKE    | 1-day   | 0.8807        | 0.8864        | 0.8304        | 0.8725        | 0.8753        | 0.8763        | 0.8637        | 0.8938        | 0.8943        | 0.8457        | 0.8745        | 0.9077        | <b>0.8461</b> |
|          | 5-days  | 0.9300        | 0.9475        | 0.8830        | 0.9165        | 0.9267        | 0.9294        | <b>0.9090</b> | 0.9465        | 0.9470        | <b>0.8894</b> | 0.9229        | 1.0410        | <b>0.8985</b> |
|          | 20-days | 1.0081        | 1.0532        | 0.9651        | 0.9838        | 1.0099        | 1.0159        | <b>0.9793</b> | 1.0258        | 1.0353        | <b>0.9554</b> | 0.9988        | 1.2578        | <b>0.9600</b> |
| Brent    |         |               |               |               |               |               |               |               |               |               |               |               |               |               |
| RMSE     | 1-day   | <b>3.0136</b> | <b>3.0106</b> | <b>3.0028</b> | <b>3.0022</b> | <b>3.0052</b> | <b>3.0112</b> | <b>3.0068</b> | <b>2.9924</b> | <b>2.9959</b> | <b>3.0038</b> | <b>3.0008</b> | <b>2.9952</b> | <b>3.0020</b> |
|          | 5-days  | <b>3.2042</b> | <b>3.2030</b> | <b>3.1999</b> | <b>3.1934</b> | <b>3.1989</b> | <b>3.2002</b> | <b>3.2020</b> | <b>3.2011</b> | <b>3.1962</b> | <b>3.1834</b> | <b>3.1963</b> | <b>3.2741</b> | <b>3.2395</b> |
|          | 20-days | 3.3086        | 3.3167        | 3.3050        | 3.2908        | 3.3114        | 3.3040        | 3.3033        | 3.3126        | 3.3044        | <b>3.2665</b> | 3.3017        | 3.5075        | 3.4219        |
| MAE      | 1-day   | 0.6585        | 0.6670        | 0.6525        | 0.6620        | 0.6656        | 0.6656        | 0.6631        | 0.6599        | 0.6667        | <b>0.6430</b> | 0.6606        | 0.6830        | <b>0.6461</b> |
|          | 5-days  | 0.7072        | 0.7198        | 0.7036        | 0.7109        | 0.7182        | 0.7167        | 0.7150        | 0.7158        | 0.7210        | <b>0.6866</b> | 0.7115        | 0.7837        | 0.7043        |
|          | 20-days | 0.7733        | 0.7960        | 0.7759        | 0.7751        | 0.7936        | 0.7852        | 0.7845        | 0.7886        | 0.7927        | <b>0.7442</b> | 0.7812        | 0.9387        | 0.7830        |
| QLIKE    | 1-day   | 0.8238        | 0.8408        | 0.8134        | 0.8335        | 0.8417        | 0.8392        | 0.8340        | 0.8415        | 0.8484        | 0.8007        | 0.8330        | 0.8747        | <b>0.8492</b> |
|          | 5-days  | 0.8637        | 0.8842        | 0.8558        | 0.8721        | 0.8851        | 0.8795        | 0.8760        | 0.8865        | 0.8914        | <b>0.8362</b> | 0.8739        | 0.9720        | <b>0.9067</b> |
|          | 20-days | 0.9217        | 0.9535        | 0.9200        | 0.9272        | 0.9534        | 0.9406        | 0.9386        | 0.9494        | 0.9578        | 0.8862        | 0.9356        | 1.1416        | <b>0.9776</b> |
| Gold     |         |               |               |               |               |               |               |               |               |               |               |               |               |               |
| RMSE     | 1-day   | <b>1.6349</b> | <b>1.6345</b> | <b>1.6286</b> | <b>1.6315</b> | <b>1.6332</b> | <b>1.6363</b> | <b>1.6335</b> | <b>1.6324</b> | <b>1.6350</b> | <b>1.6340</b> | <b>1.6359</b> | <b>1.6154</b> | <b>1.6206</b> |
|          | 5-days  | 1.7210        | 1.7189        | 1.7202        | 1.7187        | 1.7180        | 1.7207        | 1.7162        | <b>1.7149</b> | 1.7219        | 1.7183        | 1.7192        | 1.7351        | 1.7229        |
|          | 20-days | 1.7288        | 1.7304        | 1.7294        | 1.7274        | <b>1.7252</b> | 1.7284        | <b>1.7219</b> | <b>1.7236</b> | 1.7300        | 1.7271        | 1.7266        | 1.7618        | 1.7384        |
| MAE      | 1-day   | 0.2628        | 0.2593        | 0.2557        | 0.2566        | 0.2560        | 0.2597        | 0.2568        | <b>0.2519</b> | 0.2559        | 0.2576        | 0.2590        | 0.2640        | 0.2617        |
|          | 5-days  | 0.2775        | 0.2743        | 0.2702        | 0.2716        | 0.2693        | 0.2737        | 0.2701        | <b>0.2654</b> | 0.2712        | 0.2717        | 0.2725        | 0.2889        | 0.2837        |
|          | 20-days | 0.2902        | 0.2907        | 0.2824        | 0.2851        | 0.2810        | 0.2850        | 0.2816        | <b>0.2769</b> | 0.2829        | 0.2840        | 0.2834        | 0.3249        | 0.3110        |
| QLIKE    | 1-day   | 0.4122        | 0.4108        | 0.4093        | 0.4098        | 0.4087        | 0.4127        | 0.4061        | <b>0.4060</b> | 0.4105        | 0.4111        | 0.4113        | <b>0.4143</b> | 0.4079        |
|          | 5-days  | <b>0.4667</b> | <b>0.4639</b> | <b>0.4625</b> | <b>0.4628</b> | <b>0.4629</b> | <b>0.4680</b> | <b>0.4584</b> | <b>0.4598</b> | <b>0.4650</b> | <b>0.4661</b> | <b>0.4652</b> | <b>0.4719</b> | <b>0.4611</b> |
|          | 20-days | <b>0.4756</b> | <b>0.4787</b> | <b>0.4745</b> | <b>0.4712</b> | <b>0.4694</b> | <b>0.4759</b> | <b>0.4612</b> | <b>0.4727</b> | <b>0.4760</b> | <b>0.4767</b> | <b>0.4744</b> | <b>0.4948</b> | <b>0.4754</b> |
| Silver   |         |               |               |               |               |               |               |               |               |               |               |               |               |               |
| RMSE     | 1-day   | <b>3.4798</b> | <b>3.4808</b> | <b>3.4786</b> | <b>3.4844</b> | <b>3.4695</b> | <b>3.4722</b> | <b>3.4790</b> | <b>3.4746</b> | <b>3.4827</b> | <b>3.4593</b> | <b>3.4787</b> | <b>3.4671</b> | <b>3.4754</b> |
|          | 5-days  | <b>3.6118</b> | <b>3.6079</b> | <b>3.5963</b> | <b>3.6027</b> | <b>3.6112</b> | <b>3.6053</b> | <b>3.6117</b> | <b>3.6080</b> | 3.6355        | <b>3.5970</b> | <b>3.6056</b> | <b>3.6028</b> | 3.6394        |
|          | 20-days | <b>3.6370</b> | 3.6847        | <b>3.6231</b> | <b>3.6284</b> | <b>3.6349</b> | <b>3.6294</b> | <b>3.6414</b> | <b>3.6361</b> | 3.6705        | <b>3.6447</b> | <b>3.6312</b> | 3.6480        | 3.7435        |
| MAE      | 1-day   | 0.7748        | 0.7733        | 0.7640        | 0.7675        | 0.7710        | 0.7672        | 0.7721        | 0.7704        | 0.7822        | 0.7656        | 0.7724        | <b>0.7571</b> | 0.8025        |
|          | 5-days  | 0.8113        | 0.8145        | <b>0.7972</b> | <b>0.8008</b> | 0.8134        | <b>0.8022</b> | 0.8091        | 0.8064        | 0.8205        | 0.8117        | 0.8068        | <b>0.7988</b> | 0.8636        |
|          | 20-days | 0.8472        | 0.8769        | <b>0.8324</b> | <b>0.8327</b> | 0.8544        | <b>0.8369</b> | 0.8449        | 0.8437        | 0.8618        | 0.8800        | 0.8413        | 0.8531        | 0.9605        |
| QLIKE    | 1-day   | 0.8651        | <b>0.8624</b> | <b>0.8474</b> | <b>0.8546</b> | <b>0.8627</b> | <b>0.8543</b> | <b>0.8629</b> | <b>0.8610</b> | <b>0.8812</b> | <b>0.8547</b> | 0.8615        | <b>0.8418</b> | 0.9129        |
|          | 5-days  | <b>0.9121</b> | <b>0.9178</b> | <b>0.8902</b> | <b>0.8987</b> | <b>0.9137</b> | <b>0.9027</b> | <b>0.9086</b> | <b>0.9074</b> | <b>0.9290</b> | <b>0.9135</b> | <b>0.9071</b> | <b>0.8942</b> | <b>0.9852</b> |
|          | 20-days | <b>0.9499</b> | 0.9984        | <b>0.9299</b> | <b>0.9340</b> | <b>0.9569</b> | <b>0.9387</b> | <b>0.9469</b> | <b>0.9463</b> | 0.9720        | <b>0.9970</b> | <b>0.9461</b> | <b>0.9597</b> | 1.1089        |
| Platinum |         |               |               |               |               |               |               |               |               |               |               |               |               |               |
| RMSE     | 1-day   | 0.9786        | 0.9725        | 0.9751        | <b>0.9532</b> | 0.9836        | 0.9814        | 0.9907        | 0.9811        | 0.9838        | 0.9798        | 0.9822        | <b>0.9505</b> | 0.9954        |
|          | 5-days  | 1.0680        | 1.0511        | <b>1.0461</b> | 1.0604        | 1.0520        | <b>1.0451</b> | 1.0671        | 1.0523        | 1.0509        | <b>1.0484</b> | <b>1.0457</b> | 1.0609        | 1.0931        |
|          | 20-days | 1.1481        | 1.0992        | 1.0862        | 1.1429        | 1.0803        | <b>1.0706</b> | 1.1447        | 1.0889        | 1.0791        | 1.0842        | <b>1.0709</b> | 1.1617        | 1.2173        |
| MAE      | 1-day   | 0.2944        | 0.2810        | 0.2740        | <b>0.2718</b> | 0.2861        | 0.2814        | 0.2906        | 0.2803        | 0.2836        | 0.2796        | 0.2816        | <b>0.2712</b> | 0.3101        |
|          | 5-days  | 0.3368        | 0.3162        | <b>0.3048</b> | 0.3225        | 0.3154        | 0.3078        | 0.3273        | 0.3112        | 0.3115        | 0.3094        | 0.3084        | 0.3285        | 0.3582        |
|          | 20-days | 0.3976        | 0.3603        | <b>0.3394</b> | 0.3846        | 0.3482        | <b>0.3359</b> | 0.3828        | 0.3441        | 0.3412        | 0.3440        | <b>0.3373</b> | 0.4025        | 0.4368        |
| QLIKE    | 1-day   | 0.4903        | 0.4751        | 0.4683        | <b>0.4679</b> | 0.4791        | 0.4760        | 0.4876        | 0.4753        | 0.4776        | 0.4760        | 0.4754        | <b>0.4663</b> | 0.5087        |
|          | 5-days  | 0.5327        | <b>0.5110</b> | <b>0.5013</b> | 0.5192        | 0.5098        | <b>0.5043</b> | 0.5264        | 0.5075        | 0.5070        | <b>0.5081</b> | <b>0.5038</b> | 0.5237        | 0.5564        |
|          | 20-days | 0.6020        | 0.5583        | <b>0.5389</b> | 0.5906        | 0.5428        | <b>0.5317</b> | 0.5878        | 0.5422        | 0.5359        | 0.5433        | <b>0.5317</b> | 0.6092        | 0.6466        |
| GSCI     |         |               |               |               |               |               |               |               |               |               |               |               |               |               |
| RMSE     | 1-day   | <b>1.1906</b> | <b>1.1889</b> | <b>1.1854</b> | <b>1.1918</b> | <b>1.1892</b> | <b>1.1878</b> | <b>1.1857</b> | <b>1.1867</b> | <b>1.1898</b> | <b>1.1863</b> | <b>1.1877</b> | <b>1.1871</b> | <b>1.1876</b> |
|          | 5-days  | <b>1.2466</b> | <b>1.2481</b> | <b>1.2458</b> | <b>1.2478</b> | <b>1.2469</b> | <b>1.2466</b> | <b>1.2453</b> | <b>1.2512</b> | <b>1.2483</b> | <b>1.2430</b> | <b>1.2467</b> | 1.2619        | <b>1.2520</b> |
|          | 20-days | <b>1.2660</b> | 1.2749        | <b>1.2673</b> | <b>1.2655</b> | 1.2714        | <b>1.2640</b> | <b>1.2635</b> | 1.2725        | <b>1.2680</b> | <b>1.2606</b> | <b>1.2652</b> | 1.3184        | 1.2765        |
| MAE      | 1-day   | 0.2536        | 0.2578        | 0.2499        | 0.2565        | 0.2558        | 0.2560        | 0.2569        | 0.2592        | 0.2575        | 0.2505        | 0.2558        | 0.2593        | <b>0.2412</b> |
|          | 5-days  | 0.2695        | 0.2774        | 0.2680        | 0.2717        | 0.2742        | 0.2726        | 0.2741        | 0.2779        | 0.2737        | 0.2677        | 0.2724        | 0.2929        | <b>0.2606</b> |
|          | 20-days | 0.2926        | 0.3085        | 0.2974        | 0.2932        | 0.3031        | 0.2958        | 0.2976        | 0.3025        | 0.2965        | 0.2951        | 0.2953        | 0.3513        | <b>0.2841</b> |
| QLIKE    | 1-day   | 0.4201        | 0.4253        | 0.4158        | 0.4263        | 0.4215        | 0.4250        | 0.4242        | 0.4288        | 0.4260        | 0.4148        | 0.4240        | 0.4249        | <b>0.4277</b> |
|          | 5-days  | <b>0.4452</b> | <b>0.4525</b> | <b>0.4423</b> | <b>0.4508</b> | <b>0.4480</b> | <b>0.4504</b> | <b>0.4492</b> | <b>0.4562</b> | <b>0.4509</b> | <b>0.4398</b> | <b>0.4492</b> | 0.4634        | <b>0.4602</b> |
|          | 20-days | <b>0.4601</b> | 0.4754        | 0.4602        | <b>0.4647</b> | 0.4684        | <b>0.4650</b> | <b>0.4643</b> | <b>0.4729</b> | <b>0.4659</b> | <b>0.4553</b> | <b>0.4638</b> | 0.5147        | <b>0.4740</b> |

Table 4: Out-of-sample forecasting results tested with loss functions.

Note: We report RMSE, MAE, and QLIKE results from out-of-sample variance forecasting with 1-day, 5-day, and 20-days ahead horizons. Bold face values indicate models which are included in the Model Confidence Set  $M_{90\%}$  with 10% level of significance. The Model Confidence Set is constructed with 1 000 bootstraps with block length 2.

|          | PPI     | IP         | SENTI      | EPUI       | EERUS      | MOVE       | VIX        | TB3M       | TED        | GREX       | GARCH      | RV         | Spline     |
|----------|---------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| WTI      |         |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day   | 1.3291     | 1.1545     | 0.7991     | 1.6975     | 1.0796     | 2.8591     | 0.7387     | 3.8566     | 0.6516     | 1.3291     | 6.1798     | 14.5278*** |
|          | 5-days  | 2.4676     | 0.7679     | 3.4783     | 3.5441     | 1.6851     | 1.2782     | 1.0554     | 2.0651     | 1.0821     | 0.8176     | 2.9684     | 10.3501**  |
|          | 20-days | 0.6864     | 4.8842     | 1.4394     | 0.5415     | 0.5240     | 1.8007     | 1.5031     | 1.1241     | 3.9504     | 1.5194     | 7.3225*    | 3.9551     |
| short    | 1-day   | 20.9990*** | 22.2830*** | 17.8585*** | 22.2830*** | 20.5433*** | 17.8585*** | 25.5188*** | 22.2830*** | 16.1967*** | 22.2830*** | 26.8411*** | 11.8460*** |
|          | 5-days  | 19.7260*** | 19.7260*** | 16.2864*** | 19.7260*** | 22.6564*** | 15.2284*** | 18.2351*** | 20.5608*** | 14.4342*** | 19.7260*** | 24.5973*** | 3.8532     |
|          | 20-days | 21.8583*** | 23.4792*** | 16.3097*** | 20.9999*** | 17.9309*** | 16.6369*** | 25.2843*** | 24.8083*** | 15.4233*** | 23.4792*** | 37.0052*** | 9.5762*    |
| Brent    |         |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day   | 1.3212     | 1.9542     | 3.2275     | 2.5316     | 3.0767     | 3.4419     | 3.4419     | 3.4872     | 2.5772     | 2.9013     | 3.8418     | 13.2270*** |
|          | 5-days  | 0.5081     | 0.1887     | 0.8625     | 2.0491     | 0.5373     | 0.1447     | 1.1387     | 0.3684     | 1.3616     | 0.4033     | 2.4273     | 6.9526**   |
|          | 20-days | 0.1827     | 2.8120     | 0.2733     | 0.2733     | 0.0777     | 1.5195     | 1.4823     | 0.7019     | 1.7862     | 1.9348     | 8.5164**   | 13.6750**  |
| short    | 1-day   | 14.9398*** | 13.2542*** | 16.7118*** | 18.0098*** | 13.8808*** | 20.0969*** | 13.0955*** | 17.2960*** | 12.8030*** | 17.4813*** | 22.6950*** | 8.4746**   |
|          | 5-days  | 7.7895*    | 8.5757***  | 8.3241***  | 9.6155**   | 11.1006**  | 9.5324**   | 9.7748**   | 11.5843*** | 6.9029*    | 8.5757***  | 18.7983*** | 7.5898*    |
|          | 20-days | 7.0655*    | 11.8865*** | 8.3241***  | 10.5743**  | 13.1998*** | 8.7765**   | 11.8865*** | 14.7199*** | 7.0091*    | 11.8865*** | 23.9646*** | 8.1956**   |
| Gold     |         |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day   | 5.4212     | 7.4347*    | 6.5363*    | 5.8312     | 4.8550     | 7.1804*    | 8.5736**   | 5.1490     | 5.9782     | 5.8508     | 7.6761*    | 7.6761*    |
|          | 5-days  | 7.4729*    | 6.6538*    | 12.2202*** | 10.9482**  | 8.2508**   | 8.8531**   | 16.0478*** | 8.8893**   | 8.6701**   | 10.0241**  | 2.9920     | 4.2414     |
|          | 20-days | 3.1121     | 7.2493*    | 5.7318     | 6.6734*    | 5.7318     | 3.4979     | 8.8540**   | 7.2806*    | 6.6082*    | 7.0935*    | 2.4357     | 4.6911     |
| short    | 1-day   | 5.6325     | 6.8793*    | 7.8011*    | 9.0662**   | 8.2540**   | 7.6206*    | 9.0571**   | 8.5955**   | 8.2408**   | 9.1922**   | 5.8510     | 6.1055     |
|          | 5-days  | 5.1960     | 6.4311*    | 4.0094     | 3.2093     | 3.8040     | 3.8040     | 3.2804     | 3.0748     | 1.8667     | 3.0748     | 9.4037**   | 9.1922**   |
|          | 20-days | 1.6759     | 2.6478     | 2.9517     | 4.6223     | 4.7104     | 4.8257     | 4.0689     | 2.6671     | 4.2187     | 4.4200     | 4.1172     | 1.8214     |
| Silver   |         |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day   | 8.3506**   | 8.3717**   | 3.4444     | 9.6970**   | 11.9246*** | 5.3758     | 6.8155*    | 4.2605     | 7.0210*    | 5.6580     | 3.3027     | 10.0485**  |
|          | 5-days  | 10.1703**  | 8.8807**   | 5.8659     | 12.0897*** | 8.9491**   | 7.2200*    | 9.1486**   | 10.7235**  | 10.3623**  | 7.8693**   | 3.9186     | 7.7240*    |
|          | 20-days | 8.9082**   | 3.4429     | 7.7535*    | 7.7073*    | 6.7105*    | 8.4334**   | 7.2591*    | 6.3901*    | 5.8254     | 7.7535*    | 5.5627     | 4.4962     |
| short    | 1-day   | 6.0082     | 6.5006*    | 3.8869     | 5.1025     | 6.0082     | 3.1086     | 6.4065*    | 4.9452     | 5.5046     | 4.4973     | 5.2996     | 5.2704     |
|          | 5-days  | 3.4635     | 3.5168     | 2.1808     | 3.2898     | 3.6571     | 3.4419     | 3.8246     | 3.4766     | 2.2704     | 2.6531     | 2.5205     | 2.3807     |
|          | 20-days | 2.2842     | 2.5435     | 3.4147     | 0.8214     | 1.1282     | 1.8214     | 1.8214     | 2.7952     | 2.9651     | 1.8214     | 5.4773     | 5.9199     |
| Platinum |         |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day   | 19.9014*** | 19.6155*** | 21.0900*** | 27.8269*** | 13.9264*** | 8.5953**   | 15.5119*** | 14.8219*** | 13.3196*** | 16.6391*** | 24.4327*** | 15.3000*** |
|          | 5-days  | 3.8151     | 3.4504     | 6.7372*    | 1.9001     | 4.7311     | 1.1156     | 8.4307**   | 6.0150     | 5.9988     | 5.0833     | 1.8731     | 7.4687*    |
|          | 20-days | 17.8293*** | 8.0833*    | 5.7995     | 9.2022**   | 6.6313*    | 10.1528**  | 6.5700*    | 5.5198     | 4.3314     | 5.8722     | 13.4484*** | 17.2960*** |
| short    | 1-day   | 27.8042*** | 23.5669*** | 13.9304*** | 22.6623*** | 17.2109*** | 11.6623*** | 17.5100*** | 15.1069*** | 16.7712*** | 17.0085*** | 24.5270*** | 27.0605*** |
|          | 5-days  | 14.0903*** | 12.4601*** | 5.5615     | 7.2440*    | 15.3856*** | 9.5994**   | 10.6561**  | 11.1458**  | 8.2407**   | 9.5994**   | 12.4414*** | 17.8791*** |
|          | 20-days | 31.9399*** | 20.8183*** | 13.9301**  | 22.3735*** | 16.7704*** | 15.5485*** | 17.5100*** | 15.1058*** | 15.1807*** | 17.8012*** | 34.1885*** | 37.8763*   |
| GSCI     |         |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day   | 1.4158     | 0.8195     | 2.6487     | 1.3086     | 0.6172     | 2.0186     | 0.9560     | 0.7246     | 5.5553     | 1.6527     | 0.4558     | 2.6326     |
|          | 5-days  | 3.2518     | 1.9640     | 2.8505     | 3.1964     | 4.8702     | 3.7042     | 4.7722     | 3.4969     | 3.9438     | 3.7949     | 1.1036     | 9.7574**   |
|          | 20-days | 2.1576     | 6.8216*    | 4.8381     | 4.2624     | 5.9076     | 2.7729     | 5.8866     | 4.2624     | 3.9438     | 5.4887     | 8.4895**   | 4.0112     |
| short    | 1-day   | 15.3333*** | 17.7034*** | 12.3636*** | 15.3333*** | 16.9663*** | 18.2407*** | 17.7034*** | 16.9663*** | 13.0210*** | 17.7034*** | 21.5876*** | 9.5326**   |
|          | 5-days  | 12.5020*** | 15.5200*** | 12.5020*** | 12.8814*** | 15.2607*** | 17.0451**  | 15.6749**  | 14.2475**  | 10.7001**  | 15.7697*** | 21.1838*** | 6.4446*    |
|          | 20-days | 17.0474*** | 20.1984*** | 17.0474*** | 14.1518*** | 17.5953*** | 18.3818*** | 20.5407*** | 17.5953*** | 14.7650*** | 17.3125**  | 34.4316*** | 8.9230**   |

Table 5: Results for the Value-at-Risk with multivariate unconditional coverage test at 0.95%, 0.975%, and 0.99% confidence.

## Appendix A Misspecification Test Results

| Commodity    | WTI           | Brent         | Gold          | Silver        | Platinum      | GSCI          |
|--------------|---------------|---------------|---------------|---------------|---------------|---------------|
| <i>PPI</i>   | <b>0.0005</b> | <b>0.0233</b> | 0.9075        | <b>0.0925</b> | 0.9656        | <b>0.0602</b> |
| <i>IP</i>    | <b>0.0166</b> | <b>0.0283</b> | 0.2160        | 0.5425        | 0.1646        | <b>0.0116</b> |
| <i>SENTI</i> | 0.8144        | 0.3272        | 0.0732        | 0.1922        | <b>0.0862</b> | 0.1005        |
| <i>EPUI</i>  | <b>0.0114</b> | <b>0.0370</b> | 0.6813        | 0.5567        | 0.7283        | <b>0.0056</b> |
| <i>EERUS</i> | 0.1311        | <b>0.0958</b> | 0.5110        | 0.7992        | 0.6556        | 0.4134        |
| <i>MOVE</i>  | 0.1499        | 0.4188        | <b>0.0222</b> | <b>0.0092</b> | 0.1139        | <b>0.0905</b> |
| <i>VIX</i>   | <b>0.0055</b> | <b>0.0543</b> | <b>0.0011</b> | <b>0.0004</b> | <b>0.0544</b> | <b>0.0010</b> |
| <i>TB3M</i>  | <b>0.0316</b> | <b>0.0683</b> | 0.3664        | 0.3079        | 0.2420        | <b>0.0704</b> |
| <i>TED</i>   | 0.5037        | 0.5975        | 0.0632        | <b>0.0131</b> | <b>0.0213</b> | 0.4535        |
| <i>GREA</i>  | 0.9110        | 0.5901        | 0.5594        | 0.2826        | 0.6389        | 0.6366        |

Table 6: Test results from the regression-based misspecification test of Conrad & Schienle (2018). The values presented are p-values for the coefficient  $a_1$  in the regression Eq. 14. Bold faced figures are indicating p-values of 10% or less.

## Appendix B Estimation Results

|                        | $\mu$    | $\alpha$  | $\beta$   | $m$       | $\theta$  | $\omega_1$  | $\omega_2$ | $\nu$     | LogL     | BIC      | VR     |
|------------------------|----------|-----------|-----------|-----------|-----------|-------------|------------|-----------|----------|----------|--------|
| GARCH                  | 0.0662*  | 0.0235*** | 0.9610*** | 1.3442*** |           |             |            | 7.3371*** | -5173.52 | 10386.16 | -      |
| GARCH-RV               | 0.0598** | 0.0194    | 0.8188*** | 0.5098*** | 0.0030*** | 1.0081      | 84.7548*** | 8.5403*** | -5146.45 | 10355.50 | 2.0557 |
| quarterly growth rates |          |           |           |           |           |             |            |           |          |          |        |
| <i>PPI</i>             | 0.0656   | 0.0209    | 0.9639*** | 1.8656    | -0.8437   | 35.3324     | 6.7549     | 7.2906*** | -5170.66 | 10403.91 | 0.3950 |
| <i>IP</i>              | 0.0648   | 0.0217*** | 0.9635*** | 1.4700    | -0.1454   | 8.5688      | 1.0000**   | 7.2451*** | -5172.31 | 10407.21 | 0.2212 |
| <i>SENTI</i>           | 0.0688*  | 0.0217*** | 0.9591*** | 1.3908*** | -0.0790*  | 8.6486      | 1.0420***  | 7.3093*** | -5168.06 | 10398.71 | 0.6124 |
| <i>EPUI</i>            | 0.0661   | 0.0195*** | 0.9684*** | 1.3156*** | 0.0095    | 3.5530      | 29.4196    | 7.3811*** | -5172.11 | 10406.81 | 0.1431 |
| <i>EERUS</i>           | 0.0664*  | 0.0240*** | 0.9582*** | 1.3543*** | -0.0399*  | 29.8139     | 179.9190   | 7.3247*** | -5171.58 | 10405.76 | 0.1895 |
| <i>MOVE</i>            | 0.0676*  | 0.0237*** | 0.9608*** | 1.3562*** | -0.0131   | 17.9453*    | 50.4967*   | 7.3290*** | -5171.77 | 10406.14 | 0.1723 |
| <i>VIX</i>             | 0.0670*  | 0.0245*** | 0.9608*** | 1.3342*** | 0.0042    | 177.3029*** | 1.3560***  | 7.3441*** | -5172.47 | 10407.54 | 0.0851 |
| <i>TB3M</i>            | 0.0680*  | 0.0235*** | 0.9620*** | 1.3472*** | 0.0059    | 275.1401*   | 869.3456** | 7.2795*** | -5172.39 | 10407.38 | 0.1360 |
| <i>TED</i>             | 0.0662*  | 0.0229*** | 0.9627*** | 1.3544*** | -0.0024*  | 1.1083***   | 109.8121   | 7.3234*** | -5171.84 | 10406.27 | 0.1213 |
| <i>GREA</i>            | 0.0662*  | 0.0234*** | 0.9607*** | 1.3619*** | 0.0020    | 81.9892***  | 1.6231     | 7.3467*** | -5173.46 | 10409.51 | 0.0103 |
| quarterly variances    |          |           |           |           |           |             |            |           |          |          |        |
| <i>PPI</i>             | 0.0628*  | 0.0205*** | 0.9648*** | 0.9814*** | 1.9056**  | 3.1102      | 1.0974***  | 7.1587*** | -5169.76 | 10402.11 | 0.6266 |
| <i>IP</i>              | 0.0672*  | 0.0223*** | 0.9633*** | 1.4308*** | -0.1676*  | 45.9446     | 139.8659   | 7.4050*** | -5171.01 | 10404.62 | 0.2246 |
| <i>SENTI</i>           | 0.0668*  | 0.0235*** | 0.9605*** | 1.3846*** | -0.0986*  | 299.9747*** | 15.4201*   | 7.4282*** | -5172.26 | 10407.12 | 0.1032 |
| <i>EPUI</i>            | 0.0675** | 0.0234*** | 0.9615*** | 1.4068*** | -0.0744   | 425.8406    | 44.6619    | 7.3785*** | -5172.55 | 10407.70 | 0.0974 |
| <i>EERUS</i>           | 0.0655*  | 0.0216*** | 0.9647*** | 1.4587*** | -0.1252   | 3.8376      | 34.3449    | 7.2796*** | -5172.33 | 10407.25 | 0.1277 |
| <i>MOVE</i>            | 0.0684*  | 0.0212*** | 0.9629*** | 1.4320*** | -0.1210** | 141.2469**  | 488.3996** | 7.3892*** | -5169.77 | 10402.14 | 0.3607 |
| <i>VIX</i>             | 0.0702** | 0.0251*** | 0.9579*** | 1.4392*** | -0.1219   | 79.4647     | 11.1845    | 7.5197*** | -5169.94 | 10402.47 | 0.3623 |
| <i>TB3M</i>            | 0.0685** | 0.0220*** | 0.9635*** | 1.4031*** | -1.2953** | 159.0463    | 2.6100     | 7.4197*** | -5171.10 | 10404.79 | 0.2092 |
| <i>TED</i>             | 0.0657*  | 0.0226*** | 0.9635*** | 1.2421*** | 0.1478*   | 340.8063*** | 35.5891*** | 7.2947*** | -5171.88 | 10406.36 | 0.2044 |
| <i>GREA</i>            | 0.0655   | 0.0236*** | 0.9587*** | 1.0938*** | 0.8111    | 4.8713      | 2.4795     | 7.2785*** | -5172.75 | 10408.09 | 0.1398 |

Table 7: GARCH-MIDAS estimation results for WTI log returns 02 Jan 1996-30 Dec 2005 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

## Appendix C Expected Shortfall Results

|                        | $\mu$    | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$  | $\omega_2$  | $\nu$     | LogL      | BIC      | VR     |
|------------------------|----------|-----------|-----------|-----------|------------|-------------|-------------|-----------|-----------|----------|--------|
| GARCH                  | 0.0439*  | 0.0396*** | 0.9559*** | 1.4152*** |            |             |             | 8.2405*** | -10251.29 | 20545.18 | -      |
| GARCH-RV               | 0.0434*  | 0.0414*** | 0.9339*** | 0.7312*** | 0.0021***  | 1.0090**    | 83.9421***  | 8.9921*** | -10222.39 | 20512.94 | 0.7781 |
| quarterly growth rates |          |           |           |           |            |             |             |           |           |          |        |
| <i>PPI</i>             | 0.0437*  | 0.0389*** | 0.9569*** | 1.8931*** | -0.7933    | 9.6178      | 4.9566      | 8.3242*** | -10250.16 | 20568.48 | 0.0776 |
| <i>IP</i>              | 0.0435** | 0.0375*** | 0.9579*** | 1.4301*** | -0.0708    | 4.1419      | 171.0336*** | 8.2199*** | -10250.13 | 20568.42 | 0.0317 |
| <i>SENTI</i>           | 0.0442** | 0.0401*** | 0.9516*** | 1.4563*** | -0.2358*** | 1.7845***   | 2.8456      | 8.0824*** | -10246.60 | 20561.37 | 0.3746 |
| <i>EPUI</i>            | 0.0435   | 0.0364*** | 0.9586*** | 1.2572*** | 0.0487     | 1.4480      | 3.1990      | 8.2006*** | -10248.33 | 20564.82 | 0.1442 |
| <i>EERUS</i>           | 0.0447   | 0.0390*** | 0.9556*** | 1.4134*** | 0.2066     | 5.7845      | 1.8151      | 8.3647*** | -10247.79 | 20563.74 | 0.1930 |
| <i>MOVE</i>            | 0.0444*  | 0.0383*** | 0.9560*** | 1.3136*** | 0.0671**   | 1.2579***   | 2.1798***   | 8.2353*** | -10247.82 | 20563.80 | 0.2052 |
| <i>VIX</i>             | 0.0467** | 0.0375*** | 0.9572*** | 1.4137*** | -0.0086*   | 65.2652*    | 28.8864*    | 8.2042*** | -10246.86 | 20561.89 | 0.0553 |
| <i>TB3M</i>            | 0.0438*  | 0.0393*** | 0.9559*** | 1.4062*** | 0.0031     | 76.0193     | 15.7319     | 8.2363*** | -10250.24 | 20568.64 | 0.0190 |
| <i>TED</i>             | 0.0456*  | 0.0395*** | 0.9551*** | 1.6324*** | -0.0265*** | 6.5371***   | 4.4292***   | 8.3307*** | -10247.50 | 20563.16 | 0.2421 |
| <i>GREA</i>            | 0.0437   | 0.0379*** | 0.9559*** | 1.2659*** | 0.0143**   | 9.9051***   | 22.3021***  | 8.0910*** | -10246.79 | 20561.74 | 0.3782 |
| quarterly variances    |          |           |           |           |            |             |             |           |           |          |        |
| <i>PPI</i>             | 0.0451*  | 0.0394*** | 0.9560*** | 1.4468*** | -0.0543    | 431.0154*** | 472.4755*** | 8.2833*** | -10249.59 | 20567.33 | 0.0389 |
| <i>IP</i>              | 0.0440   | 0.0396*** | 0.9560*** | 1.4106*** | 0.0071     | 93.1714     | 1.4359      | 8.2432*** | -10251.24 | 20570.64 | 0.0007 |
| <i>SENTI</i>           | 0.0445** | 0.0393*** | 0.9549*** | 1.7079*** | -0.3954    | 4.5379*     | 5.3025*     | 8.3932*** | -10249.30 | 20566.77 | 0.1721 |
| <i>EPUI</i>            | 0.0443** | 0.0396*** | 0.9559*** | 1.3686*** | 0.0418     | 335.7813*** | 87.5495***  | 8.2424*** | -10249.84 | 20567.85 | 0.0147 |
| <i>EERUS</i>           | 0.0443   | 0.0414*** | 0.9523*** | 1.1746*** | 0.1875     | 2.5551      | 10.9575**   | 8.2579*** | -10250.37 | 20568.90 | 0.0660 |
| <i>MOVE</i>            | 0.0452** | 0.0393*** | 0.9544*** | 1.6285*** | -0.2314*** | 7.5151***   | 22.3919***  | 8.2475*** | -10246.80 | 20561.77 | 0.1758 |
| <i>VIX</i>             | 0.0462** | 0.0401*** | 0.9459*** | 1.7531*** | -0.3881*** | 10.6926     | 5.6186*     | 8.3157*** | -10239.45 | 20547.06 | 0.3613 |
| <i>TB3M</i>            | 0.0458** | 0.0392*** | 0.9487*** | 1.6150*** | -1.3559*** | 18.0971***  | 15.2119***  | 8.3524*** | -10240.50 | 20549.16 | 0.4255 |
| <i>TED</i>             | 0.0444** | 0.0394*** | 0.9564*** | 1.4066*** | 0.0099     | 182.2665    | 1.8471      | 8.2752*** | -10250.62 | 20569.40 | 0.0050 |
| <i>GREA</i>            | 0.0455** | 0.0395*** | 0.9556*** | 1.4450*** | -0.0413    | 312.8666*** | 371.7751*** | 8.3227*** | -10248.85 | 20565.86 | 0.0532 |

Table 8: GARCH-MIDAS estimation results for WTI log returns 02 Jan 1996-30 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$  | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$  | $\omega_2$  | $\nu$      | LogL     | BIC      | VR     |
|------------------------|--------|-----------|-----------|-----------|------------|-------------|-------------|------------|----------|----------|--------|
| GARCH                  | 0.0286 | 0.0546*** | 0.9411*** | 1.4195*** |            |             |             | 10.0821*** | -5066.68 | 10172.52 | -      |
| GARCH-RV               | 0.0279 | 0.0638*** | 0.9143*** | 0.7061*** | 0.0020***  | 1.0091      | 83.7974**   | 11.1036*** | -5053.22 | 10169.08 | 0.7126 |
| quarterly growth rates |        |           |           |           |            |             |             |            |          |          |        |
| <i>PPI</i>             | 0.0286 | 0.0533*** | 0.9429*** | 2.0460    | -1.0944    | 8.8428      | 4.9528      | 10.4109*** | -5065.72 | 10194.09 | 0.1252 |
| <i>IP</i>              | 0.0286 | 0.0504*** | 0.9456*** | 1.4944*** | -0.1145*   | 1.6841      | 163.7524    | 10.0182*** | -5065.10 | 10192.84 | 0.0642 |
| <i>SENTI</i>           | 0.0297 | 0.0585*** | 0.9293*** | 1.4222*** | -0.2857*** | 2.0030***   | 3.5371**    | 9.6653***  | -5063.88 | 10190.40 | 0.5146 |
| <i>EPUI</i>            | 0.0314 | 0.0532*** | 0.9410*** | 1.3063*** | 0.0544***  | 9.8069***   | 19.1486***  | 10.0040*** | -5062.43 | 10187.51 | 0.2908 |
| <i>EERUS</i>           | 0.0316 | 0.0490*** | 0.9506*** | 3.0846*** | 0.8373*    | 3.2174***   | 1.6692***   | 9.5562***  | -5061.31 | 10185.25 | 0.7858 |
| <i>MOVE</i>            | 0.0289 | 0.0537*** | 0.9417*** | 1.4559*** | 0.0775     | 1.1604**    | 1.9372**    | 9.7172***  | -5063.93 | 10190.49 | 0.2319 |
| <i>VIX</i>             | 0.0333 | 0.0537*** | 0.9403*** | 1.3486*** | -0.0064**  | 406.7213*** | 163.0740*** | 10.1173*** | -5063.52 | 10189.68 | 0.0457 |
| <i>TB3M</i>            | 0.0294 | 0.0572*** | 0.9374*** | 1.5504*** | -0.0247*   | 2.6795*     | 3.3784***   | 9.9203***  | -5065.39 | 10193.42 | 0.1533 |
| <i>TED</i>             | 0.0287 | 0.0549*** | 0.9381*** | 1.1643*** | 0.0204     | 2.0699**    | 5.9154**    | 10.1046*** | -5065.11 | 10192.86 | 0.1243 |
| <i>GREA</i>            | 0.0297 | 0.0558*** | 0.9307*** | 0.8570*** | 0.0211***  | 8.9299**    | 15.3925**   | 9.9207***  | -5061.06 | 10184.76 | 0.4400 |
| quarterly variances    |        |           |           |           |            |             |             |            |          |          |        |
| <i>PPI</i>             | 0.0289 | 0.0550*** | 0.9387*** | 0.8066*   | 0.4461***  | 1.0000      | 1.4579      | 9.8409***  | -5063.89 | 10190.42 | 0.2504 |
| <i>IP</i>              | 0.0289 | 0.0553*** | 0.9393*** | 1.0785*** | 0.3594*    | 1.0000      | 1.4348      | 9.9637***  | -5065.05 | 10192.73 | 0.1742 |
| <i>SENTI</i>           | 0.0298 | 0.0510*** | 0.9437*** | 0.8463*   | 0.5304*    | 8.6925      | 2.1792      | 10.3900*** | -5062.38 | 10187.39 | 0.2961 |
| <i>EPUI</i>            | 0.0302 | 0.0555*** | 0.9400*** | 1.0562*** | 0.3597     | 2.9625      | 1.0426***   | 10.1742*** | -5064.87 | 10192.38 | 0.1219 |
| <i>EERUS</i>           | 0.0290 | 0.0582*** | 0.9338*** | 0.9664*** | 0.3078**   | 1.8273      | 9.1927      | 10.0634*** | -5064.50 | 10191.63 | 0.1569 |
| <i>MOVE</i>            | 0.0296 | 0.0565*** | 0.9401*** | 1.1125**  | 0.3966     | 3.2913      | 1.4248      | 10.1875*** | -5065.27 | 10193.18 | 0.1710 |
| <i>VIX</i>             | 0.0317 | 0.0532*** | 0.9293*** | 1.8201*** | -0.4233*** | 14.3902**   | 7.4703***   | 9.9043***  | -5057.03 | 10176.69 | 0.4439 |
| <i>TB3M</i>            | 0.0303 | 0.0526*** | 0.9347*** | 1.8269*** | -1.5398*** | 17.9972***  | 15.1325***  | 9.9078***  | -5059.93 | 10182.49 | 0.3916 |
| <i>TED</i>             | 0.0294 | 0.0537*** | 0.9423*** | 1.3991*** | 0.0116     | 235.1124    | 2.1210**    | 10.2009*** | -5065.93 | 10194.50 | 0.0072 |
| <i>GREA</i>            | 0.0309 | 0.0539*** | 0.9417*** | 1.4647    | -0.0422    | 143.9873    | 193.0913    | 10.2171*** | -5065.09 | 10192.81 | 0.0539 |

Table 9: GARCH-MIDAS estimation results for WTI log returns 03 Jan 2006-30 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$     | $\alpha$  | $\beta$   | $m$       | $\theta$  | $\omega_1$  | $\omega_2$  | $\nu$     | LogL     | BIC      | VR     |
|------------------------|-----------|-----------|-----------|-----------|-----------|-------------|-------------|-----------|----------|----------|--------|
| GARCH                  | 0.0794*   | 0.0290*** | 0.9547*** | 1.6412*** |           |             |             | 5.8893*** | -5704.53 | 11448.40 | -      |
| GARCH-RV               | 0.0764*   | 0.0257**  | 0.8389*** | 0.7362*** | 0.0024*** | 1.0081**    | 84.8301***  | 6.7592*** | -5678.03 | 11418.99 | 1.6833 |
| quarterly growth rates |           |           |           |           |           |             |             |           |          |          |        |
| PPI                    | 0.0823**  | 0.0291*** | 0.9544*** | 1.5410*** | 0.1488    | 1.0865      | 111.0648    | 5.8706*** | -5703.08 | 11469.10 | 0.0821 |
| IP                     | 0.0789*   | 0.0287*** | 0.9538*** | 1.5615*** | 0.0899    | 431.7507**  | 290.0333**  | 5.9048*** | -5703.75 | 11470.44 | 0.0950 |
| SENTI                  | 0.0776*   | 0.0264*** | 0.9567*** | 1.6328*** | -0.0472*  | 5.7097      | 33.4820     | 5.8805*** | -5702.44 | 11467.83 | 0.2150 |
| EPUI                   | 0.0793*   | 0.0250*** | 0.9577*** | 1.5930*** | 0.0169**  | 4.1082***   | 26.8004**   | 5.8842*** | -5702.42 | 11467.77 | 0.2226 |
| EERUS                  | 0.0769*   | 0.0275*** | 0.9495*** | 1.5939*** | 0.1017*   | 30.8319     | 13.5147     | 5.9490*** | -5702.11 | 11467.15 | 0.3033 |
| MOVE                   | 0.0787*   | 0.0277*** | 0.9544*** | 1.6232*** | 0.0180**  | 1.0000      | 6.2839      | 5.9642*** | -5702.91 | 11468.76 | 0.1469 |
| VIX                    | 0.0816**  | 0.0295*** | 0.9550*** | 1.6334*** | 0.0034    | 172.9569**  | 1.3710***   | 5.9087*** | -5703.49 | 11469.91 | 0.0642 |
| TB3M                   | 0.0830*** | 0.0290*** | 0.9556*** | 1.6500*** | 0.0082*** | 326.7210    | 1001.1585   | 5.8352*** | -5702.49 | 11467.92 | 0.1980 |
| TED                    | 0.0823**  | 0.0250*** | 0.9632*** | 1.5989*** | 0.0056**  | 232.8204*** | 23.4961***  | 5.8945*** | -5701.97 | 11466.87 | 0.2099 |
| GREA                   | 0.0805**  | 0.0291*** | 0.9526*** | 1.7050*** | 0.0076    | 820.4496    | 125.4143    | 5.9403*** | -5703.69 | 11470.33 | 0.1165 |
| quarterly variances    |           |           |           |           |           |             |             |           |          |          |        |
| PPI                    | 0.0788**  | 0.0272*** | 0.9573*** | 1.4739*** | 0.8336**  | 365.3434*** | 137.8913*** | 5.9284*** | -5701.29 | 11465.53 | 0.3273 |
| IP                     | 0.0798**  | 0.0283*** | 0.9519*** | 1.2452*** | 0.7040*   | 13.6770     | 13.4601     | 5.8683*** | -5701.06 | 11465.05 | 0.4925 |
| SENTI                  | 0.0793**  | 0.0281*** | 0.9568*** | 1.6112*** | 0.0658    | 566.1770    | 70.7841     | 5.9051*** | -5704.07 | 11471.08 | 0.0335 |
| EPUI                   | 0.0765*   | 0.0262*** | 0.9624*** | 1.5014*** | 0.1761**  | 92.4390     | 170.0783    | 5.9102*** | -5700.65 | 11464.23 | 0.3451 |
| EERUS                  | 0.0810**  | 0.0285*** | 0.9519*** | 1.4590*** | 0.2068    | 20.9637     | 4.3382      | 5.9553*** | -5703.78 | 11470.50 | 0.1097 |
| MOVE                   | 0.0793    | 0.0286**  | 0.9541*** | 1.5589*** | 0.1054    | 5.4162      | 45.0300     | 5.9520*** | -5702.67 | 11470.28 | 0.1062 |
| VIX                    | 0.0782**  | 0.0269*** | 0.9579*** | 1.4869*** | 0.1929**  | 4.3678**    | 31.0806***  | 5.8870*** | -5702.22 | 11467.38 | 0.2513 |
| TB3M                   | 0.0782**  | 0.0258*** | 0.9581*** | 1.4978*** | 1.9915*** | 35.2943     | 349.7361    | 5.9021*** | -5701.68 | 11466.30 | 0.2321 |
| TED                    | 0.0786*   | 0.0264*** | 0.9576*** | 1.5356*** | 0.1668    | 7.5629      | 42.6644     | 5.8816*** | -5703.43 | 11469.80 | 0.1495 |
| GREA                   | 0.0788**  | 0.0268*** | 0.9583*** | 1.5421*** | 0.3049*   | 358.6663    | 95.7315     | 5.8934*** | -5702.12 | 11467.18 | 0.1758 |

Table 10: GARCH-MIDAS estimation results for Brent log returns 01 Jan 1996-30 Dec 2005 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$    | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$ | $\omega_2$ | $\nu$     | LogL      | BIC      | VR     |
|------------------------|----------|-----------|-----------|-----------|------------|------------|------------|-----------|-----------|----------|--------|
| GARCH                  | 0.0391** | 0.0413*** | 0.9560*** | 1.7228*** |            |            |            | 7.0635*** | -10892.81 | 21828.42 | -      |
| GARCH-RV               | 0.0398*  | 0.0422*** | 0.9442*** | 0.9011*** | 0.0019***  | 1.0092***  | 83.7747**  | 7.3900*** | -10868.94 | 21806.36 | 0.6140 |
| quarterly growth rates |          |           |           |           |            |            |            |           |           |          |        |
| PPI                    | 0.0395*  | 0.0404*** | 0.9573*** | 1.9064*** | -0.2977**  | 52.6614*** | 37.3540*** | 7.0876*** | -10890.58 | 21849.64 | 0.0330 |
| IP                     | 0.0387   | 0.0400*** | 0.9573*** | 1.7284*** | -0.0501    | 1.0091     | 83.7762    | 7.0442*** | -10892.28 | 21853.04 | 0.0128 |
| SENTI                  | 0.0397   | 0.0417*** | 0.9533*** | 1.7244*** | -0.2193*** | 1.9143***  | 3.1494**   | 6.8354*** | -10890.06 | 21848.60 | 0.2764 |
| EPUI                   | 0.0386   | 0.0397*** | 0.9581*** | 1.7547*** | 0.0037***  | 429.8582   | 87.3651    | 7.0649*** | -10889.90 | 21848.28 | 0.0173 |
| EERUS                  | 0.0389   | 0.0397*** | 0.9574*** | 1.6975*** | 0.3520     | 4.3312     | 1.7986     | 7.2184*** | -10888.67 | 21845.82 | 0.3629 |
| MOVE                   | 0.0387*  | 0.0391*** | 0.9577*** | 1.5995*** | 0.0728*    | 1.2266***  | 2.4010***  | 7.0733*** | -10887.77 | 21844.02 | 0.2203 |
| VIX                    | 0.0393   | 0.0415*** | 0.9552*** | 1.8809*** | -0.0479    | 4.1850     | 2.9425     | 6.9516*** | -10890.68 | 21849.83 | 0.1487 |
| TB3M                   | 0.0403   | 0.0431*** | 0.9531*** | 1.7405*** | -0.0222*** | 4.6519***  | 5.1642***  | 6.9698*** | -10890.11 | 21848.70 | 0.1616 |
| TED                    | 0.0412*  | 0.0416*** | 0.9551*** | 1.9759*** | -0.0322**  | 4.9531***  | 3.4181***  | 7.0685*** | -10889.68 | 21847.85 | 0.2324 |
| GREA                   | 0.0411   | 0.0392*** | 0.9569*** | 1.4976*** | 0.0137***  | 157.1200   | 423.7567*  | 7.0023*** | -10885.44 | 21839.36 | 0.3445 |
| quarterly variances    |          |           |           |           |            |            |            |           |           |          |        |
| PPI                    | 0.0395*  | 0.0412*** | 0.9561*** | 1.7307*** | -0.0228    | 363.0267** | 69.0795**  | 7.0754*** | -10892.54 | 21853.56 | 0.0048 |
| IP                     | 0.0394   | 0.0406*** | 0.9567*** | 1.7362*** | -0.0389    | 812.3569** | 100.9616   | 7.0706*** | -10891.40 | 21851.28 | 0.0165 |
| SENTI                  | 0.0399   | 0.0414*** | 0.9543*** | 2.0201*** | -0.4870    | 5.2990     | 7.2992     | 7.1336*** | -10890.13 | 21848.73 | 0.2428 |
| EPUI                   | 0.0396   | 0.0399*** | 0.9567*** | 1.7612*** | -0.1075*** | 20.7665*   | 101.2644   | 7.0357*** | -10889.05 | 21846.59 | 0.0603 |
| EERUS                  | 0.0406*  | 0.0407*** | 0.9551*** | 1.9450*** | -0.2535*   | 18.4517    | 2.4228     | 6.9597*** | -10887.78 | 21844.03 | 0.1249 |
| MOVE                   | 0.0391*  | 0.0410*** | 0.9552*** | 1.9455*** | -0.2472    | 6.9609     | 22.4703    | 6.9623*** | -10888.27 | 21845.01 | 0.1640 |
| VIX                    | 0.0404   | 0.0430*** | 0.9440*** | 2.1546*** | -0.6247**  | 4.2526     | 2.6998     | 6.9803*** | -10878.25 | 21824.98 | 0.5306 |
| TB3M                   | 0.0411   | 0.0415*** | 0.9456*** | 1.8457*** | -1.7622*** | 14.5751**  | 14.3853*   | 7.0559*** | -10878.23 | 21824.94 | 0.5652 |
| TED                    | 0.0401*  | 0.0408*** | 0.9564*** | 1.7235*** | -0.0136*   | 465.3439   | 64.3570    | 7.0830*** | -10891.79 | 21852.05 | 0.0075 |
| GREA                   | 0.0386   | 0.0401*** | 0.9566*** | 1.8793*** | -0.2427    | 1.6053     | 4.0392     | 7.1536*** | -10890.22 | 21848.93 | 0.3248 |

Table 11: GARCH-MIDAS estimation results for Brent log returns 01 Jan 1996-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$  | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$ | $\omega_2$ | $\nu$     | LogL     | BIC      | VR     |
|------------------------|--------|-----------|-----------|-----------|------------|------------|------------|-----------|----------|----------|--------|
| GARCH                  | 0.0198 | 0.0546*** | 0.9423*** | 1.5212*** |            |            |            | 9.1887*** | -5174.70 | 10388.74 | -      |
| GARCH-RV               | 0.0201 | 0.0623*** | 0.9248*** | 0.8574*** | 0.0017***  | 1.0093     | 83.6529    | 9.4896*** | -5166.06 | 10395.05 | 0.5619 |
| quarterly growth rates |        |           |           |           |            |            |            |           |          |          |        |
| <i>PPI</i>             | 0.0192 | 0.0512*** | 0.9450*** | 0.9825    | 0.7115     | 3.5710     | 9.0788     | 9.2305*** | -5174.03 | 10411.00 | 0.0629 |
| <i>IP</i>              | 0.0190 | 0.0505*** | 0.9468*** | 1.6518*** | -0.1430**  | 1.1327     | 198.1292   | 9.0883*** | -5172.36 | 10407.65 | 0.0941 |
| <i>SENTI</i>           | 0.0210 | 0.0573*** | 0.9335*** | 1.4652*** | -0.2954*** | 1.9374***  | 3.1332*    | 8.7528*** | -5172.81 | 10408.55 | 0.4663 |
| <i>EPUI</i>            | 0.0203 | 0.0549*** | 0.9409*** | 1.3770*** | 0.0793     | 2.0858     | 5.1262     | 8.9194*** | -5172.10 | 10407.14 | 0.3045 |
| <i>EERUS</i>           | 0.0191 | 0.0515*** | 0.9446*** | 1.3705*** | -0.2905    | 3.3980     | 6.9437     | 9.2703*** | -5173.41 | 10409.75 | 0.1316 |
| <i>MOVE</i>            | 0.0189 | 0.0521**  | 0.9451*** | 1.6082**  | 0.0644     | 1.0493     | 2.0981     | 9.0048*** | -5171.81 | 10406.56 | 0.1738 |
| <i>VIX</i>             | 0.0203 | 0.0553*** | 0.9415*** | 1.5149*** | 0.0085     | 15.7627    | 48.6047    | 9.2185*** | -5173.43 | 10409.80 | 0.0290 |
| <i>TB3M</i>            | 0.0211 | 0.0568*** | 0.9396*** | 1.7014*** | -0.0229    | 4.6825     | 5.2851     | 8.9775*** | -5172.97 | 10408.88 | 0.1771 |
| <i>TED</i>             | 0.0194 | 0.0529*** | 0.9438*** | 1.0947*** | 0.0404*    | 1.0000***  | 1.1141***  | 9.0427*** | -5171.64 | 10406.22 | 0.1233 |
| <i>GREA</i>            | 0.0202 | 0.0542*** | 0.9340*** | 0.7799*** | 0.0256**   | 5.1782     | 11.0962    | 8.8998*** | -5168.27 | 10399.47 | 0.5997 |
| quarterly variances    |        |           |           |           |            |            |            |           |          |          |        |
| <i>PPI</i>             | 0.0200 | 0.0549*** | 0.9406*** | 0.9413*   | 0.4341**   | 1.0000     | 1.7103     | 8.9181*** | -5172.44 | 10407.81 | 0.2427 |
| <i>IP</i>              | 0.0202 | 0.0550*** | 0.9412*** | 1.2135**  | 0.3413     | 1.0000     | 1.7941     | 9.0087*** | -5173.49 | 10409.91 | 0.1689 |
| <i>SENTI</i>           | 0.0221 | 0.0497*** | 0.9478*** | 0.8688    | 0.7251     | 7.0203     | 2.3635     | 8.9869*** | -5169.90 | 10402.73 | 0.3667 |
| <i>EPUI</i>            | 0.0208 | 0.0534*** | 0.9444*** | 1.0401*   | 0.5672     | 1.0000     | 1.0475***  | 9.1331*** | -5173.50 | 10409.93 | 0.1255 |
| <i>EERUS</i>           | 0.0203 | 0.0559*** | 0.9395*** | 1.2204*** | 0.2169     | 1.0000     | 8.5541     | 9.1091*** | -5172.53 | 10407.99 | 0.0938 |
| <i>MOVE</i>            | 0.0209 | 0.0562*** | 0.9417*** | 1.2691*** | 0.4303     | 3.3155**   | 1.3649     | 9.1800*** | -5172.51 | 10409.95 | 0.1914 |
| <i>VIX</i>             | 0.0210 | 0.0534*** | 0.9289*** | 1.9656*** | -0.5538*** | 9.0335*    | 5.6418**   | 8.9773*** | -5163.95 | 10390.83 | 0.5804 |
| <i>TB3M</i>            | 0.0225 | 0.0540*** | 0.9341*** | 1.9235*** | -1.7958*** | 13.9763*** | 14.1407**  | 8.9573*** | -5167.32 | 10397.57 | 0.4755 |
| <i>TED</i>             | 0.0189 | 0.0492*** | 0.9479*** | 1.3852*** | 0.1183     | 1.6790     | 9.9834     | 9.0410*** | -5171.31 | 10405.56 | 0.1476 |
| <i>GREA</i>            | 0.0189 | 0.0509*** | 0.9462*** | 1.6695*** | -0.1678    | 1.7362     | 5.1397     | 9.3411*** | -5173.42 | 10409.78 | 0.1679 |

Table 12: GARCH-MIDAS estimation results for Brent log returns 02 Jan 2006-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$   | $\alpha$  | $\beta$   | $m$        | $\theta$   | $\omega_1$ | $\omega_2$ | $\nu$     | LogL     | BIC     | VR     |
|------------------------|---------|-----------|-----------|------------|------------|------------|------------|-----------|----------|---------|--------|
| GARCH                  | -0.0063 | 0.0480*** | 0.9486*** | -0.0736    |            |            |            | 4.1517*** | -2986.31 | 6011.96 | -      |
| GARCH-RV               | -0.0053 | 0.0642*** | 0.9257*** | -0.7402    | 0.0212***  | 1.0000     | 8.4528     | 3.7816*** | -2974.39 | 6011.72 | 0.6597 |
| quarterly growth rates |         |           |           |            |            |            |            |           |          |         |        |
| <i>PPI</i>             | -0.0068 | 0.0565*** | 0.9392*** | 4.4361**   | -6.5927**  | 1.3087***  | 1.0258***  | 3.9631*** | -2982.97 | 6028.88 | 0.2795 |
| <i>IP</i>              | -0.0067 | 0.0546*** | 0.9370*** | 0.6681     | -0.6291*** | 50.8573    | 52.7204    | 3.7538*** | -2978.69 | 6020.31 | 0.6819 |
| <i>SENTI</i>           | -0.0068 | 0.0555*** | 0.9277*** | 0.1701     | -0.4198*** | 4.1774***  | 2.0004***  | 3.6899*** | -2975.79 | 6014.51 | 0.7431 |
| <i>EPUI</i>            | -0.0061 | 0.0544*** | 0.9265*** | -0.4683    | 0.1487***  | 7.4260     | 2.7882     | 3.7882*** | -2975.39 | 6013.72 | 0.7058 |
| <i>EERUS</i>           | -0.0077 | 0.0512**  | 0.9421*** | -0.0965    | -0.2263    | 7.6506     | 28.8344    | 4.0438*** | -2984.45 | 6031.83 | 0.3597 |
| <i>MOVE</i>            | -0.0066 | 0.0467*** | 0.9488*** | 0.3805     | -0.2624**  | 1.8033***  | 2.1635*    | 3.9729*** | -2979.51 | 6021.95 | 0.5505 |
| <i>VIX</i>             | -0.0072 | 0.0495    | 0.9466*** | 0.1976     | -0.0295    | 16.5236    | 11.2721    | 4.0616*   | -2985.31 | 6033.56 | 0.0778 |
| <i>TB3M</i>            | -0.0076 | 0.0553*** | 0.9279*** | -0.1367    | -0.0786*** | 7.4019**   | 6.4276*    | 3.7012*** | -2972.67 | 6008.27 | 0.7652 |
| <i>TED</i>             | -0.0066 | 0.0507*** | 0.9279*** | 0.2775     | -0.0911*** | 5.0520***  | 3.6726***  | 3.7270*** | -2970.56 | 6004.06 | 0.8130 |
| <i>GREA</i>            | -0.0063 | 0.0489*** | 0.9459*** | -0.0779    | 0.0212***  | 1.2564     | 226.1724   | 4.0405*** | -2982.11 | 6027.15 | 0.5670 |
| quarterly variances    |         |           |           |            |            |            |            |           |          |         |        |
| <i>PPI</i>             | -0.0076 | 0.0520*** | 0.9359*** | -1.3397*** | 7.0229***  | 2.4532***  | 3.1795***  | 3.6833*** | -2973.82 | 6010.57 | 0.9732 |
| <i>IP</i>              | -0.0071 | 0.0496*** | 0.9442*** | 0.3769     | -0.8283    | 2.5334     | 14.4310    | 4.0336*** | -2983.98 | 6030.90 | 0.2037 |
| <i>SENTI</i>           | -0.0063 | 0.0536*** | 0.9390*** | -0.7613*   | 1.9547***  | 2.4203***  | 5.0475***  | 3.8622*** | -2981.53 | 6025.99 | 0.5366 |
| <i>EPUI</i>            | -0.0061 | 0.0471*** | 0.9497*** | 0.0317     | -0.1113    | 157.9278   | 1.3253     | 4.1866*** | -2985.62 | 6034.18 | 0.0269 |
| <i>EERUS</i>           | -0.0073 | 0.0505*** | 0.9448*** | 0.2044     | -0.2320    | 348.2565   | 35.3930    | 4.0838*** | -2985.14 | 6033.23 | 0.0482 |
| <i>MOVE</i>            | -0.0053 | 0.0558*** | 0.9280*** | 1.0713**   | -1.4279*** | 2.1832*    | 4.7614     | 3.7343*** | -2975.47 | 6013.87 | 0.8051 |
| <i>VIX</i>             | -0.0079 | 0.0562**  | 0.9371*** | 0.6181     | -0.5239    | 17.7737    | 12.3365    | 3.9006*** | -2983.67 | 6030.27 | 0.1892 |
| <i>TB3M</i>            | -0.0055 | 0.0406*** | 0.9561*** | -0.1366    | -3.7329**  | 144.1225   | 509.3292   | 4.3050*** | -2982.12 | 6027.18 | 0.1558 |
| <i>TED</i>             | -0.0080 | 0.0380*** | 0.9607*** | 0.5356     | -2.6951**  | 1.2195**   | 2.0021**   | 4.3669*** | -2981.92 | 6026.78 | 2.3908 |
| <i>GREA</i>            | -0.0071 | 0.0460*** | 0.9501*** | -1.2550    | 3.9935     | 2.2698*    | 2.7228***  | 3.9230*** | -2977.82 | 6018.58 | 0.7409 |

Table 13: GARCH-MIDAS estimation results for Gold log returns 01 Jan 1996-30 Dec 2005 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$  | $\alpha$  | $\beta$   | $m$        | $\theta$   | $\omega_1$ | $\omega_2$ | $\nu$     | LogL     | BIC      | VR     |
|------------------------|--------|-----------|-----------|------------|------------|------------|------------|-----------|----------|----------|--------|
| GARCH                  | 0.0111 | 0.0399*** | 0.9578*** | -0.0064**  |            |            |            | 4.5391*** | -6999.85 | 14042.51 | -      |
| GARCH-RV               | 0.0126 | 0.0467*** | 0.9443*** | -0.4543**  | 0.0107***  | 1.0000     | 15.4420    | 4.2019*** | -6973.45 | 14015.37 | 0.7652 |
| quarterly growth rates |        |           |           |            |            |            |            |           |          |          |        |
| PPI                    | 0.0101 | 0.0415*** | 0.9563*** | 2.6572***  | -4.1571*** | 3.1520***  | 2.4573***  | 4.4335*** | -6994.06 | 14056.59 | 0.6663 |
| IP                     | 0.0106 | 0.0437*** | 0.9518*** | 0.7593***  | -0.8213*** | 1.1768     | 1.1548***  | 4.2259*** | -6992.84 | 14054.17 | 0.5417 |
| SENTI                  | 0.0107 | 0.0427*** | 0.9537*** | 0.4770*    | -0.2690    | 2.4985     | 1.5160***  | 4.2807*** | -6994.70 | 14057.88 | 0.2907 |
| EPUI                   | 0.0109 | 0.0405*** | 0.9559*** | -0.1940    | 0.1306***  | 1.3286***  | 1.0161***  | 4.4043*** | -6992.65 | 14053.79 | 0.3743 |
| EERUS                  | 0.0112 | 0.0398*** | 0.9577*** | -0.0078    | -0.0146    | 298.5877   | 30.6834    | 4.5356*** | -6999.66 | 14067.81 | 0.0025 |
| MOVE                   | 0.0111 | 0.0397*** | 0.9582*** | -0.0023    | 0.0039     | 11.8956    | 81.3825    | 4.5484*** | -6998.95 | 14066.38 | 0.0064 |
| VIX                    | 0.0112 | 0.0395*** | 0.9578*** | -0.0079    | 0.0203     | 13.3564    | 18.9974    | 4.4888*** | -6997.82 | 14064.12 | 0.0601 |
| TB3M                   | 0.0111 | 0.0399*   | 0.9578*** | -0.0048    | 0.0002     | 81.8171    | 10.6749    | 4.5381*** | -6999.85 | 14068.18 | 0.0000 |
| TED                    | 0.0108 | 0.0397*** | 0.9572*** | 0.4695     | -0.0318    | 13.4047    | 10.1279    | 4.3877*** | -6991.57 | 14051.62 | 0.3690 |
| GREA                   | 0.0092 | 0.0404*** | 0.9571*** | 0.0906     | 0.0390**   | 2.3630     | 1.0000***  | 4.3121*** | -6987.87 | 14044.23 | 1.2407 |
| quarterly variances    |        |           |           |            |            |            |            |           |          |          |        |
| PPI                    | 0.0102 | 0.0420*** | 0.9545*** | -0.1863    | 0.6714***  | 1.0295***  | 1.1398***  | 4.2715*** | -6989.63 | 14047.73 | 0.6539 |
| IP                     | 0.0099 | 0.0403*** | 0.9574*** | -0.2014    | 0.5305***  | 4.6840     | 2.3209     | 4.4440*** | -6993.48 | 14055.45 | 0.4093 |
| SENTI                  | 0.0117 | 0.0415*** | 0.9530*** | -0.9896*** | 1.5606***  | 1.1595***  | 1.3229***  | 4.2007*** | -6987.97 | 14044.43 | 1.0896 |
| EPUI                   | 0.0110 | 0.0398*** | 0.9578*** | -0.0140    | 0.0485     | 37.6192    | 346.9290   | 4.5362*** | -6998.29 | 14045.06 | 0.0132 |
| EERUS                  | 0.0097 | 0.0397*** | 0.9574*** | -0.5081**  | 0.6944***  | 16.8067**  | 7.9749***  | 4.4111*** | -6989.58 | 14047.64 | 0.5018 |
| MOVE                   | 0.0116 | 0.0406*** | 0.9566*** | 0.2243     | -0.1517    | 9.3847     | 25.8016    | 4.5069*** | -6998.76 | 14066.00 | 0.0488 |
| VIX                    | 0.0108 | 0.0403*** | 0.9572*** | -0.0269    | 0.0663     | 76.8542*   | 102.4869*  | 4.5406*** | -6997.60 | 14063.69 | 0.0261 |
| TB3M                   | 0.0104 | 0.0417*** | 0.9555*** | -0.1229    | 1.8944***  | 9.5790***  | 16.9602*** | 4.3972*** | -6994.09 | 14056.65 | 0.4953 |
| TED                    | 0.0114 | 0.0391*** | 0.9585*** | -0.0285    | 0.0331*    | 31.1878    | 290.8318   | 4.5425*** | -6997.10 | 14062.69 | 0.0197 |
| GREA                   | 0.0100 | 0.0401*** | 0.9574*** | -0.1692    | 0.2863     | 6.6844     | 3.6795     | 4.4617*** | -6993.68 | 14055.84 | 0.4009 |

Table 14: GARCH-MIDAS estimation results for Gold log returns 01 Jan 1996-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$     | $\alpha$  | $\beta$   | $m$        | $\theta$   | $\omega_1$  | $\omega_2$  | $\nu$     | LogL     | BIC     | VR     |
|------------------------|-----------|-----------|-----------|------------|------------|-------------|-------------|-----------|----------|---------|--------|
| GARCH                  | 0.0533*** | 0.0378*** | 0.9586*** | 0.9930**   |            |             |             | 4.3351*** | -3998.31 | 8035.95 | -      |
| GARCH-RV               | 0.0561*** | 0.0307*** | 0.9215*** | -0.3495*** | 0.0066***  | 1.0092*     | 83.7635*    | 4.8198*** | -3978.81 | 8020.56 | 1.0031 |
| quarterly growth rates |           |           |           |            |            |             |             |           |          |         |        |
| PPI                    | 0.0527*** | 0.0321*** | 0.9650*** | 0.8799*    | 0.1722**   | 89.4027***  | 436.1480**  | 4.4236*** | -3993.15 | 8049.24 | 0.1009 |
| IP                     | 0.0537*** | 0.0357*** | 0.9604*** | 1.0935     | -0.1511*** | 1.3349      | 179.6378    | 4.1842*** | -3994.74 | 8052.42 | 0.2178 |
| SENTI                  | 0.0522*** | 0.0292*** | 0.9564*** | 0.5629***  | -0.1873*** | 2.2877***   | 7.0555**    | 4.4506*** | -3989.78 | 8042.49 | 0.8206 |
| EPUI                   | 0.0536*** | 0.0370*** | 0.9588*** | 0.8557     | 0.0597**   | 2.1970***   | 6.4966***   | 4.1478*** | -3994.89 | 8052.71 | 0.4198 |
| EERUS                  | 0.0507*** | 0.0337*** | 0.9592*** | 0.5893     | -0.3873    | 2.4038      | 3.8472***   | 4.4914*** | -3996.03 | 8054.99 | 0.3168 |
| MOVE                   | 0.0534*** | 0.0374*** | 0.9578*** | 0.8820     | 0.0190     | 4.0866      | 25.3003     | 4.2914*** | -3995.45 | 8053.83 | 0.1418 |
| VIX                    | 0.0528*** | 0.0381*** | 0.9581*** | 0.9821**   | 0.0030     | 14.2641*    | 78.7089     | 4.3137*** | -3997.75 | 8058.43 | 0.0136 |
| TB3M                   | 0.0531*** | 0.0374*** | 0.9594*** | 1.0675**   | 0.0039**   | 465.8977*** | 89.4272***  | 4.3558*** | -3995.46 | 8053.85 | 0.0870 |
| TED                    | 0.0518*** | 0.0373*** | 0.9587*** | 0.7173     | 0.0257     | 1.3768***   | 1.2248**    | 4.2911*** | -3997.00 | 8056.93 | 0.0863 |
| GREA                   | 0.0513*** | 0.0342*** | 0.9583*** | 0.3619     | 0.0146***  | 347.4642**  | 501.3855**  | 4.3382*** | -3991.69 | 8046.31 | 0.5259 |
| quarterly variances    |           |           |           |            |            |             |             |           |          |         |        |
| PPI                    | 0.0539*** | 0.0361*** | 0.9589*** | 0.7325     | 0.0679**   | 33.8917***  | 332.4765*** | 4.3598*** | -3996.31 | 8055.55 | 0.0970 |
| IP                     | 0.0546**  | 0.0348*** | 0.9600*** | 0.7194     | 0.0910**   | 33.6692     | 332.2703    | 4.3355*** | -3994.91 | 8052.75 | 0.1492 |
| SENTI                  | 0.0537*** | 0.0351*** | 0.9542*** | -1.0135    | 1.2936***  | 1.0558***   | 1.0443***   | 4.3795*** | -3994.91 | 8052.75 | 0.4641 |
| EPUI                   | 0.0534*** | 0.0371*** | 0.9592*** | 0.9208     | 0.0735*    | 36.8038*    | 354.9241*   | 4.3153*** | -3996.44 | 8055.81 | 0.0621 |
| EERUS                  | 0.0501*** | 0.0332*** | 0.9642*** | 0.6495     | 0.2513**   | 74.4816**   | 27.6554**   | 4.3852*** | -3993.72 | 8050.38 | 0.2685 |
| MOVE                   | 0.0540*** | 0.0372*** | 0.9585*** | 0.9247     | 0.0567     | 7.6241      | 53.8093     | 4.3105*** | -3997.41 | 8057.75 | 0.0301 |
| VIX                    | 0.0519*** | 0.0372*** | 0.9594*** | 0.9492**   | 0.0627***  | 308.5964    | 357.9909    | 4.3818*** | -3995.93 | 8054.79 | 0.0862 |
| TB3M                   | 0.0518*** | 0.0344*** | 0.9576*** | 1.0640**   | -1.2912*** | 13.9594**   | 9.5808*     | 4.4049*** | -3994.24 | 8051.41 | 0.5110 |
| TED                    | 0.0537*** | 0.0348**  | 0.9617*** | 0.9349*    | 0.0442***  | 15.9730***  | 142.1546*** | 4.3178*** | -3994.20 | 8051.33 | 0.1027 |
| GREA                   | 0.0536*** | 0.0378*** | 0.9585*** | 0.9805**   | 0.0095     | 1.2144      | 195.9439    | 4.3257*** | -3998.13 | 8059.19 | 0.0063 |

Table 15: GARCH-MIDAS estimation results for Gold log returns 02 Jan 2006-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$  | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$ | $\omega_2$ | $\nu$     | LogL     | BIC     | VR     |
|------------------------|--------|-----------|-----------|-----------|------------|------------|------------|-----------|----------|---------|--------|
| GARCH                  | 0.0256 | 0.0267*** | 0.9693*** | 0.8990*** |            |            |            | 4.0100*** | -4328.07 | 8695.48 | -      |
| GARCH-RV               | 0.0293 | 0.0260*** | 0.9350*** | -0.0256   | 0.0052***  | 1.0096     | 83.3781**  | 4.0128*** | -4311.63 | 8686.19 | 1.0460 |
| quarterly growth rates |        |           |           |           |            |            |            |           |          |         |        |
| PPI                    | 0.0265 | 0.0236*** | 0.9718*** | 1.9031*** | -1.5942*   | 2.5646*    | 8.8017     | 3.9515*** | -4325.63 | 8714.19 | 0.1959 |
| IP                     | 0.0235 | 0.0217*** | 0.9726*** | 1.2240*** | -0.4997*   | 26.3244    | 8.3590     | 4.0081*** | -4323.26 | 8709.46 | 0.5734 |
| SENTI                  | 0.0248 | 0.0250*** | 0.9709*** | 1.0632*** | -0.1306    | 8.0119     | 2.3737*    | 3.8982*** | -4326.37 | 8715.68 | 0.1898 |
| EPUI                   | 0.0258 | 0.0255*** | 0.9711*** | 0.8139**  | 0.0440     | 1.8150     | 1.5926     | 4.0071*** | -4327.73 | 8718.40 | 0.0458 |
| EERUS                  | 0.0243 | 0.0251*** | 0.9703*** | 0.8453*** | -0.1283*   | 71.0667    | 31.5628    | 4.0634*** | -4323.69 | 8710.31 | 0.1850 |
| MOVE                   | 0.0248 | 0.0277*** | 0.9665*** | 1.1603*** | -0.1078*** | 5.2926**   | 6.0696***  | 3.8375*** | -4323.78 | 8710.50 | 0.3425 |
| VIX                    | 0.0251 | 0.0260*** | 0.9701*** | 0.9104*** | -0.0027    | 1.1029     | 103.0630   | 4.0076*** | -4326.71 | 8716.35 | 0.0243 |
| TB3M                   | 0.0255 | 0.0271*** | 0.9688*** | 0.9103*** | 0.0023     | 1.0091     | 83.7994    | 4.0003*** | -4327.98 | 8718.90 | 0.0047 |
| TED                    | 0.0260 | 0.0210*** | 0.9750*** | 1.1719*** | -0.0577**  | 7.3549     | 3.2300**   | 3.9547*** | -4323.09 | 8709.13 | 0.7070 |
| GREA                   | 0.0258 | 0.0265*** | 0.9659*** | 1.3515*** | 0.0653***  | 2.5013***  | 1.0000***  | 3.9074*** | -4323.11 | 8709.15 | 0.5908 |
| quarterly variances    |        |           |           |           |            |            |            |           |          |         |        |
| PPI                    | 0.0255 | 0.0250*** | 0.9709*** | 0.5932*   | 2.0331**   | 23.6553    | 22.3869    | 3.9071*** | -4324.55 | 8712.04 | 0.3095 |
| IP                     | 0.0243 | 0.0248*** | 0.9698*** | 1.1851*** | -0.7281    | 9.5033     | 9.2858     | 4.0277*** | -4326.21 | 8715.36 | 0.1139 |
| SENTI                  | 0.0232 | 0.0252*** | 0.9707*** | 0.4672    | 0.9662     | 1.8210     | 3.6961     | 3.9573*** | -4325.41 | 8713.75 | 0.2096 |
| EPUI                   | 0.0243 | 0.0237*** | 0.9711*** | 0.3670    | 0.5371*    | 11.3211    | 4.7761     | 4.0525*** | -4325.75 | 8714.43 | 0.3068 |
| EERUS                  | 0.0249 | 0.0251*** | 0.9672*** | 0.1209    | 0.6854     | 1.9638     | 7.5044     | 4.0094*** | -4324.44 | 8711.81 | 0.2996 |
| MOVE                   | 0.0236 | 0.0248*** | 0.9699*** | 1.5228*** | -0.7865*** | 6.0742**   | 7.3216**   | 3.8945*** | -4323.23 | 8709.39 | 0.4685 |
| VIX                    | 0.0256 | 0.0276*** | 0.9680*** | 0.6562**  | 0.4084**   | 4.0166**   | 16.2990*   | 3.9070*** | -4324.78 | 8712.50 | 0.1503 |
| TB3M                   | 0.0257 | 0.0266*** | 0.9695*** | 0.8351*** | 1.0013     | 10.3411    | 76.6569    | 4.0069*** | -4327.47 | 8717.88 | 0.0169 |
| TED                    | 0.0259 | 0.0252*** | 0.9690*** | 1.0498*** | -0.4232**  | 2.3613     | 18.6653    | 4.0432*** | -4323.46 | 8709.85 | 0.2514 |
| GREA                   | 0.0250 | 0.0261*** | 0.9680*** | 0.2193    | 2.0565***  | 1.4045***  | 2.4596***  | 3.8446*** | -4323.41 | 8709.76 | 0.4006 |

Table 16: GARCH-MIDAS estimation results for Silver log returns 01 Jan 1996-30 Dec 2005 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$     | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$ | $\omega_2$ | $\nu$     | LogL     | BIC      | VR     |
|------------------------|-----------|-----------|-----------|-----------|------------|------------|------------|-----------|----------|----------|--------|
| GARCH                  | 0.0437**  | 0.0320*** | 0.9651*** | 1.3212*** |            |            |            | 4.0933*** | -9821.85 | 19686.50 | -      |
| GARCH-RV               | 0.0465*** | 0.0443**  | 0.9381*** | 0.7810**  | 0.0024***  | 1.0099     | 83.0789*   | 3.9107*** | -9807.06 | 19682.60 | 0.6349 |
| quarterly growth rates |           |           |           |           |            |            |            |           |          |          |        |
| PPI                    | 0.0438**  | 0.0313*** | 0.9661*** | 1.8006**  | -0.8058    | 3.8597     | 3.5828     | 4.1071*** | -9821.54 | 19711.56 | 0.0328 |
| IP                     | 0.0413**  | 0.0313*** | 0.9638*** | 1.6979*** | -0.5755*** | 7.9290**   | 3.2556**   | 3.9458*** | -9810.22 | 19688.91 | 0.5929 |
| SENTI                  | 0.0432**  | 0.0310*** | 0.9660*** | 1.4688*** | -0.1096    | 6.3735     | 1.9238     | 4.0162*** | -9818.16 | 19704.79 | 0.1200 |
| EPUI                   | 0.0432*** | 0.0304*** | 0.9670*** | 1.0527*** | 0.1041***  | 1.3912***  | 1.0160***  | 4.0715*** | -9817.14 | 19702.77 | 0.2633 |
| EERUS                  | 0.0433*** | 0.0332*** | 0.9633*** | 1.3684*** | -0.1165    | 10.6712    | 6.3816     | 4.0422*** | -9820.93 | 19710.34 | 0.0468 |
| MOVE                   | 0.0424**  | 0.0330*** | 0.9640*** | 1.5793*** | -0.0989*** | 4.8681***  | 6.2699***  | 4.0090*** | -9815.79 | 19700.06 | 0.5141 |
| VIX                    | 0.0432**  | 0.0323*** | 0.9648*** | 1.3804*** | -0.0177    | 1.0000     | 1.5541     | 4.1158*** | -9821.13 | 19710.75 | 0.0127 |
| TB3M                   | 0.0437**  | 0.0319*** | 0.9652*** | 1.3197*** | -0.0002*** | 1.0091*    | 83.8038*** | 4.0940*** | -9821.83 | 19712.15 | 0.0001 |
| TED                    | 0.0436*** | 0.0324*** | 0.9645*** | 1.1627*** | 0.0187     | 2.8007     | 1.0278***  | 4.0941*** | -9820.27 | 19709.03 | 0.0555 |
| GREA                   | 0.0409**  | 0.0343*** | 0.9585*** | 1.2123*** | 0.0303***  | 1.7438***  | 1.0000***  | 3.8106*** | -9805.35 | 19679.18 | 0.7758 |
| quarterly variances    |           |           |           |           |            |            |            |           |          |          |        |
| PPI                    | 0.0423*** | 0.0328*** | 0.9624*** | 1.0157*** | 0.5806***  | 3.8481     | 2.0668**   | 3.8862*** | -9809.51 | 19687.49 | 0.6934 |
| IP                     | 0.0431    | 0.0310*** | 0.9663*** | 1.1171*   | 0.4158     | 11.7699    | 5.1126     | 4.0287*** | -9814.09 | 19696.67 | 0.4184 |
| SENTI                  | 0.0429*** | 0.0324*** | 0.9621*** | 0.5284*   | 1.0944***  | 1.1030***  | 1.1206***  | 3.9014*** | -9812.88 | 19694.23 | 0.5758 |
| EPUI                   | 0.0425*** | 0.0331*** | 0.9624*** | 0.8464*** | 0.5059***  | 7.7741***  | 2.3468***  | 4.0287*** | -9815.66 | 19699.80 | 0.3144 |
| EERUS                  | 0.0430**  | 0.0348*** | 0.9588*** | 0.0987    | 1.1393***  | 1.0000***  | 1.0035***  | 3.9217*** | -9812.08 | 19692.65 | 0.5212 |
| MOVE                   | 0.0440**  | 0.0315*** | 0.9654*** | 1.2063*** | 0.0900     | 2.8670**   | 17.8667*** | 4.0923*** | -9820.99 | 19710.47 | 0.0207 |
| VIX                    | 0.0438**  | 0.0330*** | 0.9637*** | 1.1519*** | 0.2404     | 3.3450***  | 7.9462*    | 4.0268*** | -9820.63 | 19709.73 | 0.0866 |
| TB3M                   | 0.0438    | 0.0335*** | 0.9629*** | 1.1401*** | 1.5771     | 1.9279     | 4.7203     | 3.9665*** | -9817.53 | 19703.54 | 0.3332 |
| TED                    | 0.0426**  | 0.0318*** | 0.9648*** | 1.0386**  | 0.3296     | 9.2090     | 3.9062     | 3.9782*** | -9812.80 | 19694.08 | 0.5940 |
| GREA                   | 0.0429*   | 0.0328*** | 0.9634*** | 1.1146*   | 0.3024     | 6.6235     | 3.9496     | 3.9844*** | -9814.33 | 19697.14 | 0.4840 |

Table 17: GARCH-MIDAS estimation results for Silver log returns 01 Jan 1996-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$     | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$  | $\omega_2$  | $\nu$     | LogL     | BIC      | VR     |
|------------------------|-----------|-----------|-----------|-----------|------------|-------------|-------------|-----------|----------|----------|--------|
| GARCH                  | 0.0907*** | 0.0375*** | 0.9587*** | 2.1132*** |            |             |             | 3.8691*** | -5483.77 | 11006.88 | -      |
| GARCH-RV               | 0.0993*** | 0.0548*** | 0.8743*** | 0.9295*** | 0.0019***  | 1.0095**    | 83.4410***  | 4.1106*** | -5468.47 | 10999.88 | 0.9018 |
| quarterly growth rates |           |           |           |           |            |             |             |           |          |          |        |
| PPI                    | 0.0913*** | 0.0348*** | 0.9621*** | 2.4923*** | -0.6830    | 9.8578      | 5.0049      | 3.9153*** | -5483.29 | 11029.52 | 0.0970 |
| IP                     | 0.0878*** | 0.0364*** | 0.9587*** | 2.1420*** | -0.2459*** | 179.9227    | 82.6539     | 3.8218*** | -5476.51 | 11015.96 | 0.4993 |
| SENTI                  | 0.0897**  | 0.0417*** | 0.9431*** | 1.9118*** | -0.2218*   | 1.9385      | 3.9716      | 3.7376*** | -5477.23 | 11017.40 | 0.6529 |
| EPUI                   | 0.0902*** | 0.0374*** | 0.9587*** | 2.0856*** | 0.0012     | 81.9244     | 1.6282      | 3.8775*** | -5483.64 | 11030.21 | 0.0026 |
| EERUS                  | 0.0874*** | 0.0348*** | 0.9585*** | 1.8484*** | -0.4669**  | 1.8373*     | 3.5444***   | 3.8450*** | -5478.97 | 11020.87 | 0.5169 |
| MOVE                   | 0.0888*** | 0.0369*** | 0.9600*** | 2.2329*** | 0.0205     | 48.2304     | 17.1513     | 3.8579*** | -5481.21 | 11025.35 | 0.1320 |
| VIX                    | 0.0909*** | 0.0373*** | 0.9588*** | 2.0690*** | 0.0020     | 145.5044    | 1.3124***   | 3.8846*** | -5483.30 | 11029.53 | 0.0094 |
| TB3M                   | 0.0876**  | 0.0306*** | 0.9659*** | 1.8408*** | 0.0100*    | 22.8378     | 38.3590     | 4.0344*** | -5479.86 | 11022.65 | 0.2495 |
| TED                    | 0.0859*** | 0.0447*** | 0.9420*** | 1.1699*** | 0.0665***  | 1.4902***   | 1.6795***   | 3.6900*** | -5477.28 | 11017.50 | 0.5806 |
| GREA                   | 0.0856*** | 0.0394*** | 0.9461*** | 1.4230*** | 0.0179***  | 287.3127*** | 416.9896*** | 3.7682*** | -5472.45 | 11007.82 | 0.7409 |
| quarterly variances    |           |           |           |           |            |             |             |           |          |          |        |
| PPI                    | 0.0849*** | 0.0359*** | 0.9614*** | 1.9179*** | 0.4612*    | 5.4713      | 2.5666      | 3.6182*** | -5475.67 | 11014.28 | 0.9643 |
| IP                     | 0.0871*** | 0.0345*** | 0.9613*** | 1.8278*** | 0.3100**   | 13.8031     | 5.9790      | 3.7692*** | -5476.30 | 11015.54 | 0.6944 |
| SENTI                  | 0.0921**  | 0.0377*** | 0.9583*** | 1.8458*** | 0.3124*    | 14.0765     | 3.1050*     | 3.8052*** | -5481.10 | 11025.14 | 0.2584 |
| EPUI                   | 0.0907*** | 0.0337*** | 0.9630*** | 2.1305*** | -0.0776*   | 362.5067*** | 406.4929*** | 3.9312*** | -5482.07 | 11027.06 | 0.0681 |
| EERUS                  | 0.0845*** | 0.0380*** | 0.9561*** | 0.9829*** | 0.7489***  | 1.8372      | 1.9628**    | 3.7743*** | -5478.60 | 11020.14 | 0.6017 |
| MOVE                   | 0.0904*** | 0.0346*** | 0.9620*** | 2.1397*** | -0.0851*   | 326.3961**  | 367.8816**  | 3.9291*** | -5481.69 | 11026.31 | 0.0811 |
| VIX                    | 0.0881*** | 0.0368*** | 0.9550*** | 2.1525*** | -0.1949*   | 20.5215     | 9.7711      | 3.8327*** | -5480.11 | 11023.15 | 0.2124 |
| TB3M                   | 0.0856**  | 0.0403*** | 0.9513*** | 2.2544*** | -1.0564**  | 13.2454     | 5.1491      | 3.8439*** | -5480.91 | 11024.75 | 0.3405 |
| TED                    | 0.0903*** | 0.0375*** | 0.9586*** | 2.0368*** | 0.0866**   | 17.1358     | 30.7011     | 3.7756*** | -5481.07 | 11025.08 | 0.1611 |
| GREA                   | 0.0887*** | 0.0353*** | 0.9615*** | 1.9409*** | 0.1567     | 16.5214     | 9.0003      | 3.8249*** | -5479.60 | 11022.12 | 0.4984 |

Table 18: GARCH-MIDAS estimation results for Silver log returns 02 Jan 2006-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$    | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$ | $\omega_2$ | $\nu$     | LogL     | BIC     | VR     |
|------------------------|----------|-----------|-----------|-----------|------------|------------|------------|-----------|----------|---------|--------|
| GARCH                  | 0.0339*  | 0.1586    | 0.8150*** | 1.2934**  |            |            |            | 3.4664*** | -4013.71 | 8066.76 | -      |
| GARCH-RV               | 0.0323*  | 0.0791    | 0.8947*** | 0.3364    | 0.0035***  | 1.0090     | 83.9702    | 3.8138*** | -4002.70 | 8068.34 | 0.4224 |
| quarterly growth rates |          |           |           |           |            |            |            |           |          |         |        |
| PPI                    | 0.0333*  | 0.2578**  | 0.6848*** | 3.2823*** | -3.1115*** | 2.5128***  | 12.1340*** | 3.2540*** | -3992.55 | 8048.03 | 0.7136 |
| IP                     | 0.0342*  | 0.1589    | 0.8132*** | 1.2390    | 0.0286     | 81.9483    | 1.6262     | 3.4693*** | -4013.66 | 8090.25 | 0.0021 |
| SENTI                  | 0.0304*  | 0.2158    | 0.7206**  | 1.2214**  | -0.2600*** | 3.7847     | 1.5212**   | 3.3790*** | -4000.42 | 8063.77 | 0.3361 |
| EPUI                   | 0.0341*  | 0.2128    | 0.6749    | 0.6886**  | 0.0631***  | 15.6968**  | 4.1246***  | 3.4973*** | -4004.72 | 8072.38 | 0.2287 |
| EERUS                  | 0.0341*  | 0.2151    | 0.7316*** | 1.2224    | 0.2138***  | 35.3422    | 55.6114    | 3.3163*** | -4000.45 | 8063.83 | 0.3790 |
| MOVE                   | 0.0277   | 0.2776*** | 0.6991*** | 1.6964**  | 0.1594***  | 11.8624*** | 3.0591***  | 3.1712*** | -3994.52 | 8051.98 | 1.0162 |
| VIX                    | 0.0381** | 0.2031**  | 0.6526*** | 0.5193**  | 0.0535***  | 12.4498**  | 17.1932*** | 3.5645*** | -3999.16 | 8061.26 | 0.3510 |
| TB3M                   | 0.0343** | 0.2459*   | 0.6558*** | 0.9231**  | -0.0630*** | 1.2903***  | 1.8357     | 3.4004*** | -3999.79 | 8062.52 | 0.3113 |
| TED                    | 0.0311*  | 0.2491    | 0.6734**  | 1.4745**  | -0.0810*** | 2.4157***  | 2.1967***  | 3.3456*** | -3996.69 | 8056.32 | 0.3832 |
| GREA                   | 0.0353** | 0.1719*   | 0.7982*** | 1.4817**  | 0.0183**   | 82.0635*** | 1.6174     | 3.4072*** | -4010.61 | 8084.17 | 0.1210 |
| quarterly variances    |          |           |           |           |            |            |            |           |          |         |        |
| PPI                    | 0.0380*  | 0.2257    | 0.7067**  | 1.5199*** | -2.1606**  | 55.1574    | 13.8272    | 3.3845*** | -4005.06 | 8073.06 | 0.3001 |
| IP                     | 0.0356   | 0.1887    | 0.7544    | 0.7661    | 0.6056     | 85.9877    | 26.9975    | 3.4357*** | -4006.44 | 8075.82 | 0.2591 |
| SENTI                  | 0.0312*  | 0.2359*   | 0.7218*** | 0.8482    | 1.3691***  | 7.9020***  | 28.7594**  | 3.3212*** | -3997.67 | 8058.28 | 0.5587 |
| EPUI                   | 0.0331*  | 0.1728    | 0.7969*** | 1.1877**  | 0.1453*    | 149.8911** | 523.9091** | 3.4414*** | -4011.60 | 8086.13 | 0.0530 |
| EERUS                  | 0.0404** | 0.2106*** | 0.5791*** | 1.3501*** | -0.7587*** | 20.7528*** | 31.0566*** | 3.6414*** | -3996.97 | 8056.88 | 0.3435 |
| MOVE                   | 0.0021   | 0.3876*** | 0.6095*** | 5.9311*** | -3.0950*** | 21.0106*** | 21.3607*** | 3.3348*** | -3996.76 | 8036.47 | 9.9683 |
| VIX                    | 0.0233   | 0.2835*** | 0.7061*** | 4.9491**  | -2.7049    | 5.1241     | 4.8063     | 3.1888*** | -3989.07 | 8041.07 | 1.1482 |
| TB3M                   | 0.0302*  | 0.1901*   | 0.7805*** | 0.9941    | 7.1550***  | 20.5930    | 28.3359    | 3.4395*** | -4006.26 | 8075.47 | 0.2142 |
| TED                    | 0.0386** | 0.2278    | 0.6869    | 0.8365    | 0.3116**   | 1.0746     | 47.3333    | 3.4125*** | -4009.09 | 8081.11 | 0.1941 |
| GREA                   | 0.0293   | 0.3390*   | 0.6287*** | 2.5732    | -1.9193    | 110.8338   | 13.6325    | 3.2338*** | -4002.47 | 8067.88 | 1.1297 |

Table 19: GARCH-MIDAS estimation results for Platinum log returns 01 Jan 1996-30 Dec 2005 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$    | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$  | $\omega_2$  | $\nu$     | LogL     | BIC      | VR     |
|------------------------|----------|-----------|-----------|-----------|------------|-------------|-------------|-----------|----------|----------|--------|
| GARCH                  | 0.0330** | 0.0518*** | 0.9388*** | 0.7359*** |            |             |             | 4.7068*** | -8459.52 | 16961.84 | -      |
| GARCH-RV               | 0.0335** | 0.0700*** | 0.8912*** | 0.1348    | 0.0036***  | 1.0094***   | 83.5819***  | 4.9570*** | -8432.08 | 16932.63 | 0.6199 |
| quarterly growth rates |          |           |           |           |            |             |             |           |          |          |        |
| PPI                    | 0.0335** | 0.0553*** | 0.9326*** | 1.4729*** | -1.3339*** | 2.5123***   | 7.4165**    | 4.5780*** | -8453.98 | 16976.44 | 0.2098 |
| IP                     | 0.0316** | 0.0581*** | 0.9267*** | 0.9541*** | -0.4889*** | 1.0000      | 2.0819      | 4.5984*** | -8452.55 | 16973.58 | 0.3059 |
| SENTI                  | 0.0331** | 0.0507*** | 0.9386*** | 0.7362*** | -0.0631    | 21.1998     | 21.8385     | 4.6768*** | -8456.72 | 16981.91 | 0.0820 |
| EPUI                   | 0.0340** | 0.0651*   | 0.9111*** | 0.4465*** | 0.0820***  | 1.8464**    | 4.2458      | 4.6069*** | -8452.31 | 16973.11 | 0.3451 |
| EERUS                  | 0.0335** | 0.0503*** | 0.9407*** | 0.7561*** | 0.2414***  | 5.9780**    | 9.7761**    | 4.6249*** | -8453.59 | 16975.67 | 0.2373 |
| MOVE                   | 0.0317** | 0.0522*** | 0.9396*** | 0.8088*** | -0.0473    | 2.8624      | 4.6507      | 4.6995*** | -8458.52 | 16985.52 | 0.1128 |
| VIX                    | 0.0345** | 0.0492*** | 0.9348*** | 0.4568**  | 0.0461*    | 8.3231      | 11.4871     | 4.6300*** | -8450.06 | 16968.60 | 0.2675 |
| TB3M                   | 0.0334** | 0.0524*** | 0.9376*** | 0.7355*** | 0.0026     | 78.4182*    | 8.0393      | 4.6778*** | -8458.93 | 16986.35 | 0.0128 |
| TED                    | 0.0335** | 0.0491*** | 0.9428*** | 0.8346*** | -0.0160    | 1.0000      | 1.7985**    | 4.7439*** | -8458.59 | 16985.67 | 0.0399 |
| GREA                   | 0.0315** | 0.0535*** | 0.9358*** | 0.6453*** | 0.0128**   | 6.1040      | 3.0419      | 4.6273*** | -8454.99 | 16978.47 | 0.1994 |
| quarterly variances    |          |           |           |           |            |             |             |           |          |          |        |
| PPI                    | 0.0322** | 0.0567*** | 0.9279*** | 0.4254**  | 0.3385     | 1.0000      | 2.7265      | 4.5680*** | -8451.67 | 16971.83 | 0.2871 |
| IP                     | 0.0326*  | 0.0543*** | 0.9335*** | 0.4305    | 0.3813     | 1.0000      | 1.0077***   | 4.6311*** | -8455.44 | 16979.35 | 0.1471 |
| SENTI                  | 0.0333   | 0.0484*** | 0.9379*** | 0.3791    | 0.3483     | 8.8676      | 42.0634     | 4.6234*** | -8445.72 | 16959.92 | 0.3033 |
| EPUI                   | 0.0334*  | 0.0545*** | 0.9343*** | 0.2920    | 0.4199**   | 1.9911      | 2.7254      | 4.6435*** | -8456.91 | 16982.31 | 0.1540 |
| EERUS                  | 0.0342** | 0.0472*** | 0.9425*** | 0.4624**  | 0.1590***  | 134.5047*** | 476.9330*** | 4.7343*** | -8455.09 | 16978.65 | 0.0767 |
| MOVE                   | 0.0328** | 0.0530*** | 0.9364*** | 0.5011**  | 0.2338**   | 24.9823     | 7.5259      | 4.6662*** | -8456.59 | 16981.67 | 0.1004 |
| VIX                    | 0.0321** | 0.0502*** | 0.9398*** | 0.9216*** | -0.1957*   | 23.5924***  | 13.9511***  | 4.7352*** | -8456.27 | 16981.02 | 0.1133 |
| TB3M                   | 0.0329** | 0.0514*** | 0.9383*** | 0.4731**  | 1.1478***  | 8.7651***   | 17.6852***  | 4.6256*** | -8452.49 | 16973.46 | 0.2356 |
| TED                    | 0.0329** | 0.0534*** | 0.9344*** | 0.5419*** | 0.1390***  | 7.9833      | 15.0613*    | 4.6330*** | -8454.88 | 16978.23 | 0.1449 |
| GREA                   | 0.0331** | 0.0538*** | 0.9342*** | 0.5439**  | 0.1548**   | 2.4824      | 6.7928      | 4.6040*** | -8454.58 | 16977.64 | 0.1589 |

Table 20: GARCH-MIDAS estimation results for Platinum log returns 01 Jan 1996-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$  | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$  | $\omega_2$  | $\nu$     | LogL     | BIC     | VR     |
|------------------------|--------|-----------|-----------|-----------|------------|-------------|-------------|-----------|----------|---------|--------|
| GARCH                  | 0.0300 | 0.0456*** | 0.9447*** | 0.7478*** |            |             |             | 6.2938*** | -4425.83 | 8890.99 | -      |
| GARCH-RV               | 0.0311 | 0.0604*** | 0.8774*** | 0.0758    | 0.0037***  | 24.3272     | 255.1780    | 6.9227*** | -4409.27 | 8881.47 | 0.8150 |
| quarterly growth rates |        |           |           |           |            |             |             |           |          |         |        |
| PPI                    | 0.0306 | 0.0440*** | 0.9437*** | 1.0334    | -0.5756    | 12.6634     | 3.4820      | 6.2714*** | -4424.10 | 8911.13 | 0.0877 |
| IP                     | 0.0315 | 0.0529*** | 0.9253*** | 0.7417*** | -0.2508**  | 1.0000      | 5.7033      | 6.3182*** | -4424.12 | 8911.18 | 0.2267 |
| SENTI                  | 0.0287 | 0.0545*** | 0.9139*** | 0.7380*** | -0.1761*** | 2.6163***   | 5.7937***   | 6.4853*** | -4422.37 | 8907.67 | 0.4884 |
| EPUI                   | 0.0340 | 0.0524*** | 0.9225*** | 0.5001*** | 0.0528***  | 6.4260*     | 14.3876**   | 6.2923*** | -4421.54 | 8906.01 | 0.3897 |
| EERUS                  | 0.0304 | 0.0424**  | 0.9472*** | 0.8112*** | 0.1081     | 19.5980     | 4.4161      | 6.2459*** | -4423.75 | 8910.43 | 0.1019 |
| MOVE                   | 0.0311 | 0.0462*** | 0.9418*** | 0.7085*** | 0.0293     | 6.5894      | 6.5141**    | 6.2270*** | -4424.36 | 8911.65 | 0.1159 |
| VIX                    | 0.0317 | 0.0493**  | 0.9348*** | 0.5724**  | 0.0362     | 3.9869      | 6.6769**    | 6.2280*** | -4423.99 | 8910.92 | 0.1590 |
| TB3M                   | 0.0296 | 0.0448*** | 0.9454*** | 0.7415*** | 0.0027     | 75.4897     | 16.0426     | 6.3418*** | -4425.07 | 8913.08 | 0.0260 |
| TED                    | 0.0303 | 0.0516*** | 0.9211*** | 0.4067**  | 0.0243**   | 3.8885      | 7.4124*     | 6.4031*** | -4422.02 | 8906.97 | 0.2929 |
| GREA                   | 0.0294 | 0.0430*** | 0.9419*** | 0.5022*** | 0.0083***  | 157.0659**  | 194.9784**  | 6.4949*** | -4422.73 | 8908.39 | 0.1519 |
| quarterly variances    |        |           |           |           |            |             |             |           |          |         |        |
| PPI                    | 0.0301 | 0.0452*** | 0.9437*** | 0.6786*** | 0.0372     | 1.2090      | 186.0719    | 6.3186*** | -4424.98 | 8912.88 | 0.0355 |
| IP                     | 0.0304 | 0.0429*** | 0.9481*** | 0.6976*** | 0.0433     | 274.0033*** | 507.6348*** | 6.2969*** | -4424.74 | 8912.42 | 0.0342 |
| SENTI                  | 0.0301 | 0.0359**  | 0.9527*** | 0.3958**  | 0.1810***  | 65.6088***  | 354.0111*** | 6.4251*** | -4420.05 | 8903.03 | 0.2115 |
| EPUI                   | 0.0300 | 0.0454*** | 0.9451*** | 0.7255*** | 0.0245     | 64.3915     | 14.7670     | 6.2937*** | -4425.72 | 8914.37 | 0.0036 |
| EERUS                  | 0.0312 | 0.0360*** | 0.9562*** | 0.8525*** | -0.1308*   | 365.2327**  | 418.5269**  | 6.3115*** | -4423.51 | 8909.96 | 0.0866 |
| MOVE                   | 0.0304 | 0.0406*** | 0.9511*** | 0.7785*** | -0.0420    | 437.5169    | 471.1373    | 6.3628*** | -4424.19 | 8911.31 | 0.0353 |
| VIX                    | 0.0288 | 0.0458*** | 0.9406*** | 0.8521*** | -0.1153*   | 28.6868     | 13.5037     | 6.4315*** | -4423.86 | 8910.66 | 0.0840 |
| TB3M                   | 0.0289 | 0.0455*** | 0.9434*** | 0.8256*** | -0.2740    | 14.2147     | 9.1240      | 6.3559*** | -4425.59 | 8914.12 | 0.0202 |
| TED                    | 0.0302 | 0.0431*** | 0.9468*** | 0.6224*** | 0.0613     | 18.2489     | 31.1852     | 6.2360*** | -4424.42 | 8911.76 | 0.0746 |
| GREA                   | 0.0309 | 0.0428*** | 0.9477*** | 0.7735*** | -0.0245    | 292.0120    | 416.8249    | 6.3483*** | -4424.89 | 8912.72 | 0.0285 |

Table 21: GARCH-MIDAS estimation results for Platinum log returns 02 Jan 2006-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$   | $\alpha$  | $\beta$   | $m$        | $\theta$   | $\omega_1$ | $\omega_2$ | $\nu$     | LogL     | BIC     | VR     |
|------------------------|---------|-----------|-----------|------------|------------|------------|------------|-----------|----------|---------|--------|
| GARCH                  | 0.0337  | 0.0296*** | 0.9623*** | 0.5866***  |            |            |            | 7.7919*** | -4296.02 | 8631.38 | -      |
| GARCH-RV               | 0.0413* | 0.0273**  | 0.8740*** | -0.3922*** | 0.0076***  | 1.0092*    | 83.7609    | 9.3249*** | -4274.46 | 8611.86 | 1.2897 |
| quarterly growth rates |         |           |           |            |            |            |            |           |          |         |        |
| PPI                    | 0.0351  | 0.0298*** | 0.9593*** | 0.0490     | 0.8052***  | 2.3534*    | 14.5811*   | 7.6468*** | -4293.61 | 8650.16 | 0.2351 |
| IP                     | 0.0328  | 0.0265*** | 0.9642*** | 0.7595***  | -0.2368**  | 69.8688    | 93.1873    | 7.7217*** | -4292.31 | 8647.56 | 0.3913 |
| SENTI                  | 0.0373  | 0.0297*** | 0.9534*** | 0.6121***  | -0.2158*** | 1.4336     | 1.0305***  | 8.1249*** | -4292.43 | 8647.80 | 0.4481 |
| EPUI                   | 0.0350  | 0.0281*** | 0.9635*** | 0.5517***  | 0.0129     | 57.5813    | 15.4331    | 7.9140*** | -4293.48 | 8649.90 | 0.1192 |
| EERUS                  | 0.0328  | 0.0294*** | 0.9547*** | 0.5349***  | -0.1210**  | 8.8021     | 34.7204    | 7.8958*** | -4293.11 | 8649.15 | 0.4082 |
| MOVE                   | 0.0335  | 0.0295*** | 0.9635*** | 0.5756***  | 0.0109**   | 165.2972   | 1.3426***  | 7.8307*** | -4291.79 | 8646.52 | 0.1743 |
| VIX                    | 0.0341  | 0.0284*** | 0.9540*** | 0.6867***  | -0.0442*   | 2.7346     | 6.3189     | 7.9551*** | -4292.48 | 8647.91 | 0.5282 |
| TB3M                   | 0.0348  | 0.0302*** | 0.9467*** | 0.4599***  | -0.0384*** | 3.7532     | 1.4671     | 8.1731*** | -4292.12 | 8647.19 | 0.5351 |
| TED                    | 0.0326  | 0.0263*** | 0.9673*** | 0.5283***  | 0.0090     | 7.1072     | 45.6490    | 7.9765*** | -4292.44 | 8647.83 | 0.1953 |
| GREA                   | 0.0351  | 0.0302*** | 0.9535*** | 0.5230***  | 0.0107***  | 1.0942***  | 215.7361   | 7.9720*** | -4292.45 | 8647.83 | 0.5465 |
| quarterly variances    |         |           |           |            |            |            |            |           |          |         |        |
| PPI                    | 0.0307  | 0.0140    | 0.9814*** | 0.2032     | 1.7909**   | 16.4393    | 1.2627**   | 7.7372*** | -4287.23 | 8637.40 | 0.7699 |
| IP                     | 0.0347  | 0.0298*** | 0.9589*** | 0.9351***  | -0.7060*   | 8.2033*    | 19.8492**  | 7.8330*** | -4293.06 | 8649.06 | 0.4240 |
| SENTI                  | 0.0346  | 0.0314*** | 0.9587*** | 0.5201***  | 0.1329     | 12.1836    | 73.1224    | 7.8001*** | -4295.40 | 8653.74 | 0.0397 |
| EPUI                   | 0.0331  | 0.0267*** | 0.9650*** | 0.3415**   | 0.2801***  | 44.8413*** | 76.6800**  | 7.8621*** | -4290.06 | 8643.06 | 0.4668 |
| EERUS                  | 0.0334  | 0.0295*** | 0.9631*** | 0.5552***  | 0.0500     | 539.9855   | 362.1371   | 7.7629*** | -4295.79 | 8654.51 | 0.0112 |
| MOVE                   | 0.0356  | 0.0297*** | 0.9600*** | 0.6920***  | -0.1632    | 30.3358    | 90.4268    | 7.8497*** | -4292.46 | 8649.86 | 0.2200 |
| VIX                    | 0.0361  | 0.0308*** | 0.9607*** | 0.7287**   | -0.1846    | 58.1115    | 10.6744    | 8.1741*** | -4291.18 | 8645.29 | 0.2935 |
| TB3M                   | 0.0351  | 0.0247*** | 0.9644*** | 0.2718*    | 4.4812***  | 22.4442*** | 48.3471*** | 7.7858*** | -4290.20 | 8643.34 | 0.4628 |
| TED                    | 0.0337  | 0.0290*** | 0.9585*** | 0.2638     | 0.4441**   | 10.6457    | 2.9070**   | 7.8732*** | -4293.75 | 8650.43 | 0.4117 |
| GREA                   | 0.0337  | 0.0289*** | 0.9631*** | 0.5704***  | 0.0311     | 1.1348     | 163.7488   | 7.8064*** | -4295.95 | 8654.83 | 0.0034 |

Table 22: GARCH-MIDAS estimation results for GSCI log returns 01 Jan 1996-30 Dec 2005 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$  | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$  | $\omega_2$  | $\nu$     | LogL     | BIC      | VR     |
|------------------------|--------|-----------|-----------|-----------|------------|-------------|-------------|-----------|----------|----------|--------|
| GARCH                  | 0.0138 | 0.0355*** | 0.9621*** | 0.7735*** |            |             |             | 7.9946*** | -8633.33 | 17309.47 | -      |
| GARCH-RV               | 0.0138 | 0.0321**  | 0.9612*** | 0.1774    | 0.0036***  | 1.0093      | 83.6688     | 8.3741*** | -8616.70 | 17301.88 | 0.4904 |
| quarterly growth rates |        |           |           |           |            |             |             |           |          |          |        |
| PPI                    | 0.0140 | 0.0337*** | 0.9634*** | 0.1585    | 0.9523***  | 2.7977*     | 7.9148      | 7.9797*** | -8631.41 | 17331.30 | 0.1195 |
| IP                     | 0.0138 | 0.0355*** | 0.9619*** | 0.8864*   | -0.1665    | 1.0002      | 1.3451      | 7.9548*** | -8633.16 | 17334.81 | 0.0329 |
| SENTI                  | 0.0145 | 0.0366*** | 0.9581*** | 0.8109*** | -0.2637*** | 1.9431***   | 2.4398**    | 7.8219*** | -8630.43 | 17329.34 | 0.3646 |
| EPUI                   | 0.0140 | 0.0339*** | 0.9635*** | 0.6465**  | 0.0433     | 1.3927**    | 2.4952**    | 7.9557*** | -8631.76 | 17332.00 | 0.0846 |
| EERUS                  | 0.0133 | 0.0343*** | 0.9625*** | 0.6732    | -0.1964    | 3.6775      | 6.7039      | 8.0688*** | -8631.81 | 17332.11 | 0.1524 |
| MOVE                   | 0.0139 | 0.0350*** | 0.9617*** | 0.6130**  | 0.0801*    | 1.6295***   | 2.3221**    | 7.9797*** | -8631.09 | 17330.67 | 0.2385 |
| VIX                    | 0.0140 | 0.0355*** | 0.9612*** | 0.9785*** | -0.0643    | 2.7828      | 2.3999**    | 7.8885*** | -8631.26 | 17330.99 | 0.2274 |
| TB3M                   | 0.0147 | 0.0373*** | 0.9589*** | 0.7852*** | -0.0260**  | 3.9756*     | 4.3302***   | 7.9396*** | -8630.82 | 17330.12 | 0.2172 |
| TED                    | 0.0139 | 0.0349*** | 0.9621*** | 0.6522**  | 0.0160     | 2.7806***   | 10.7078     | 8.0273*** | -8629.56 | 17327.61 | 0.1362 |
| GREA                   | 0.0156 | 0.0338*** | 0.9616*** | 0.5567*** | 0.0133***  | 139.2172*** | 379.6359*** | 8.1156*** | -8626.68 | 17321.84 | 0.3587 |
| quarterly variances    |        |           |           |           |            |             |             |           |          |          |        |
| PPI                    | 0.0137 | 0.0328*** | 0.9650*** | 0.7209*** | 0.0629     | 5.1439      | 57.4938     | 7.9586*** | -8631.28 | 17331.04 | 0.0409 |
| IP                     | 0.0141 | 0.0357*** | 0.9616*** | 0.5661*   | 0.3206     | 1.0000      | 1.6954      | 7.9292*** | -8631.93 | 17332.33 | 0.1472 |
| SENTI                  | 0.0142 | 0.0307*** | 0.9672*** | 0.5416    | 0.1484***  | 355.1335    | 98.6121     | 8.1465*** | -8628.22 | 17324.93 | 0.0861 |
| EPUI                   | 0.0136 | 0.0350**  | 0.9625*** | 0.4693    | 0.2860     | 1.9733      | 1.0097***   | 8.0058*** | -8632.48 | 17333.45 | 0.0634 |
| EERUS                  | 0.0145 | 0.0357*** | 0.9612*** | 0.5736*** | 0.1239**   | 117.4395    | 421.5937    | 8.0356*** | -8630.49 | 17329.45 | 0.0517 |
| MOVE                   | 0.0146 | 0.0361*** | 0.9603*** | 0.9706*** | -0.2153    | 5.4298      | 16.9621     | 7.9138*** | -8630.69 | 17329.86 | 0.1218 |
| VIX                    | 0.0155 | 0.0367*** | 0.9545*** | 1.1878*** | -0.5452**  | 4.1654      | 2.4004*     | 8.0417*** | -8624.41 | 17317.29 | 0.4437 |
| TB3M                   | 0.0157 | 0.0343*** | 0.9602*** | 0.9128*** | -1.3805*** | 15.0349**   | 14.8720*    | 8.0454*** | -8626.68 | 17321.85 | 0.3833 |
| TED                    | 0.0145 | 0.0345*** | 0.9630*** | 0.7758*** | -0.0229    | 156.1020*   | 26.7437*    | 8.0657*** | -8631.77 | 17332.02 | 0.0142 |
| GREA                   | 0.0138 | 0.0355*** | 0.9621*** | 0.7736*** | -0.0004    | 81.9808     | 3.7147      | 7.9945*** | -8633.33 | 17335.15 | 0.0000 |

Table 23: GARCH-MIDAS estimation results for GSCI log returns 01 Jan 1996-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|                        | $\mu$     | $\alpha$  | $\beta$   | $m$       | $\theta$   | $\omega_1$ | $\omega_2$ | $\nu$     | LogL     | BIC     | VR     |
|------------------------|-----------|-----------|-----------|-----------|------------|------------|------------|-----------|----------|---------|--------|
| GARCH                  | -0.0013   | 0.0410*** | 0.9577*** | 0.9868*** |            |            |            | 8.2257*** | -4332.77 | 8704.88 | -      |
| GARCH-RV               | -0.0030   | 0.0366**  | 0.9611*** | 0.5325    | 0.0027***  | 1.0094     | 83.5544    | 8.4427*** | -4325.33 | 8713.59 | 0.2929 |
| quarterly growth rates |           |           |           |           |            |            |            |           |          |         |        |
| <i>PPI</i>             | -0.0012   | 0.0393*** | 0.9594*** | 0.9292*** | 0.0861     | 86.9516**  | 335.2204*  | 8.2212*** | -4331.70 | 8726.34 | 0.0103 |
| <i>IP</i>              | -0.0013*  | 0.0421*** | 0.9561*** | 1.2429*** | -0.5693    | 1.0000     | 1.2227     | 8.0693*** | -4331.83 | 8726.60 | 0.1853 |
| <i>SENTI</i>           | -0.0010   | 0.0427*** | 0.9523*** | 0.9142**  | -0.3322*** | 1.9839***  | 2.6837**   | 7.9402*** | -4331.53 | 8726.00 | 0.5223 |
| <i>EPUI</i>            | -0.0012   | 0.0399*** | 0.9588*** | 1.0297**  | 0.0684     | 1.8943     | 3.9855     | 8.0367*** | -4331.05 | 8725.03 | 0.2017 |
| <i>EERUS</i>           | -0.0014   | 0.0386*** | 0.9597*** | 0.8613**  | -0.2350    | 3.0571**   | 6.6568**   | 8.2653*** | -4331.82 | 8726.57 | 0.0911 |
| <i>MOVE</i>            | -0.0020   | 0.0388*** | 0.9601*** | 1.1720*** | 0.0586     | 1.1462***  | 1.9691***  | 8.0081*** | -4330.91 | 8724.75 | 0.1293 |
| <i>VIX</i>             | -0.0011   | 0.0399*** | 0.9570*** | 0.7976*** | -0.0417    | 5.2271     | 3.5473**   | 8.2804*** | -4332.06 | 8727.04 | 0.1370 |
| <i>TB3M</i>            | -0.0003   | 0.0428*** | 0.9556*** | 1.2595**  | -0.0267    | 3.6507     | 4.1815***  | 8.0109*** | -4331.62 | 8726.17 | 0.2036 |
| <i>TED</i>             | -0.0010   | 0.0390*** | 0.9599*** | 1.2940*** | -0.0295    | 4.3113***  | 3.6607**   | 8.2753*** | -4331.58 | 8726.10 | 0.1438 |
| <i>GREA</i>            | -0.0011   | 0.0388*** | 0.9513*** | 0.0211**  | 0.0300***  | 4.1313     | 8.3313     | 8.2099*** | -4326.54 | 8716.02 | 0.7998 |
| quarterly variances    |           |           |           |           |            |            |            |           |          |         |        |
| <i>PPI</i>             | -0.0014   | 0.0417*** | 0.9564*** | 0.4472    | 0.5034**   | 1.0000     | 1.3721     | 7.9760*** | -4330.54 | 8724.01 | 0.2963 |
| <i>IP</i>              | -0.0011   | 0.0416    | 0.9566*** | 0.6878    | 0.3966     | 1.0000     | 1.4148     | 8.0926*** | -4331.60 | 8726.13 | 0.2007 |
| <i>SENTI</i>           | -0.0002   | 0.0360*** | 0.9632*** | 0.5362    | 0.6649     | 6.3414     | 2.2041**   | 8.1227*** | -4328.28 | 8719.49 | 0.2877 |
| <i>EPUI</i>            | -0.0006   | 0.0381*** | 0.9613*** | 0.4079    | 0.8519**   | 1.0423***  | 1.0280***  | 8.1019*** | -4330.06 | 8723.05 | 0.2776 |
| <i>EERUS</i>           | -0.0015   | 0.0412*** | 0.9571*** | 0.8314    | 0.1266     | 1.0000     | 8.5213     | 8.1972*** | -4331.88 | 8726.70 | 0.0324 |
| <i>MOVE</i>            | -0.0004   | 0.0407*** | 0.9580*** | 0.9732*** | 0.0363     | 299.1063   | 14.4674    | 8.2752*** | -4332.16 | 8727.26 | 0.0073 |
| <i>VIX</i>             | 0.0005    | 0.0401*** | 0.9437*** | 1.3351*** | -0.5838*** | 8.4087*    | 4.9784**   | 8.2239*** | -4323.59 | 8710.11 | 0.6389 |
| <i>TB3M</i>            | 0.0009    | 0.0382*** | 0.9534*** | 1.3114*** | -1.9862*** | 12.2317**  | 11.1743*   | 8.1446*** | -4326.98 | 8716.90 | 0.5752 |
| <i>TED</i>             | -0.0004** | 0.0383*** | 0.9604*** | 0.9876*** | -0.0235*   | 264.0076** | 45.8487*   | 8.3710*** | -4331.07 | 8725.08 | 0.0181 |
| <i>GREA</i>            | -0.0011   | 0.0399*** | 0.9588*** | 0.9779**  | 0.0176     | 420.2258   | 44.6902    | 8.2203*** | -4332.32 | 8727.58 | 0.0086 |

Table 24: GARCH-MIDAS estimation results for GSCI log returns 02 Jan 2006-31 Dec 2015 with  $K = 16$  and Beta-weighting scheme. The asterisks \*\*\*, \*\*, and \* indicate significance at 1%, 5%, and 10%, respectively.

|          | PPI    | IP         | SENTI      | EPUI       | EERUS      | MOVE       | VIX        | TBM        | TED        | GREA       | GARCH      | RV         | Spline     |
|----------|--------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| WTI      |        |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day  | 0.0859     | 0.1252     | -0.0288    | 0.0027     | 0.0831     | 0.1562     | 0.0436     | 0.1305     | -0.0141    | 0.0872     | 0.2118     | -0.0200    |
|          | 5-day  | -0.1012    | 0.0129     | -0.3228**  | -0.1772    | -0.1664    | -0.0930    | -0.1592    | -0.0165    | -0.2359*   | -0.1640    | 0.1840     | -0.4295*** |
|          | 20-day | -0.0509    | 0.0829     | -0.2178**  | -0.1651    | -0.1054    | -0.0903    | -0.2322*   | 0.0563     | -0.1937*   | -0.0478    | 0.3919     | -0.4810*** |
| short    | 1-day  | 0.7265     | 0.6922     | 0.6540     | 0.6570     | 0.6556     | 0.6579     | 0.7235     | 0.6962     | 0.6580     | 0.6944     | 0.7655     | 0.5562     |
|          | 5-day  | 0.4534     | 0.3581     | 0.3353     | 0.4432     | 0.4456     | 0.3812     | 0.4735     | 0.4900     | 0.4498     | 0.4498     | 0.5660     | 0.2919     |
|          | 20-day | 0.4875     | 0.4907     | 0.4352     | 0.4431     | 0.4538     | 0.4560     | 0.4750     | 0.4714     | 0.4488     | 0.4840     | 0.5864     | 0.2625     |
| Brent    |        |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day  | 0.0654     | 0.1660     | 0.0943     | 0.0698     | 0.0295     | 0.1743     | 0.1752     | 0.2402     | 0.0654     | 0.1951     | 0.2347     | -0.2265*   |
|          | 5-day  | -0.1097    | -0.0580    | -0.1420    | -0.1628    | -0.1055    | -0.0616    | -0.1346    | 0.0177     | -0.1968*   | -0.0643    | 0.1129     | -0.5346*** |
|          | 20-day | 0.0398     | 0.1704     | -0.0115    | -0.0206    | 0.1418     | 0.0376     | 0.1182     | 0.1383     | 0.0211     | 0.1406     | 0.3841     | -0.4741*** |
| short    | 1-day  | 0.6285     | 0.6025     | 0.6611     | 0.6569     | 0.6632     | 0.6920     | 0.5703     | 0.6673     | 0.5925     | 0.6619     | 0.6766     | 0.3696     |
|          | 5-day  | 0.3581     | 0.3722     | 0.3930     | 0.3696     | 0.4032     | 0.3724     | 0.3319     | 0.4788     | 0.3319     | 0.3717     | 0.4585     | 0.0876     |
|          | 20-day | 0.3242     | 0.3535     | 0.3676     | 0.3531     | 0.3885     | 0.3610     | 0.3902     | 0.3826     | 0.3405     | 0.3511     | 0.5002     | 0.1905     |
| Gold     |        |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day  | -0.1284    | -0.1815    | -0.1602    | -0.2137    | -0.2586*   | -0.1984    | -0.1395    | -0.2618*   | -0.2284    | -0.2269    | 0.0381     | 0.0430     |
|          | 5-day  | -0.6236*** | -0.5865*** | -0.7474*** | -0.6876*** | -0.7362*** | -0.6510*** | -0.6504*** | -0.8511*** | -0.6831*** | -0.6795*** | -0.7038*** | -0.3897**  |
|          | 20-day | -0.4255**  | -0.5302*** | -0.5573*** | -0.5335*** | -0.5942*** | -0.5651*** | -0.4464**  | -0.6777*** | -0.5985*** | -0.6004*** | -0.5961*** | -0.0772    |
| short    | 1-day  | 0.3159     | 0.2041     | 0.1554     | 0.1397     | 0.0997     | 0.1320     | 0.0944     | 0.1330     | 0.1322     | 0.1058     | 0.3179     | 0.4005     |
|          | 5-day  | 0.0178     | -0.0446    | -0.0923    | -0.0250    | -0.0997    | -0.0401    | -0.0903    | -0.1386    | -0.0669    | -0.0653    | 0.0539     | 0.0596     |
|          | 20-day | 0.0265     | -0.0268    | -0.0736    | -0.0329    | -0.1319    | -0.1670    | -0.1157    | -0.1864    | -0.1184    | -0.1638    | 0.3050     | 0.3017     |
| Silver   |        |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day  | -0.3196**  | -0.3449**  | -0.2468*   | -0.3913**  | -0.3390**  | -0.2993*   | -0.2965*   | -0.2384*   | -0.2949*   | -0.2979**  | -0.2468*   | -0.1982    |
|          | 5-day  | -0.5890*** | -0.5829*** | -0.5185*** | -0.6511*** | -0.5774*** | -0.5696*** | -0.6128*** | -0.5591*** | -0.6490*** | -0.5574*** | -0.5547*** | -0.4472**  |
|          | 20-day | -0.5100*** | -0.3552**  | -0.4743**  | -0.4737*** | -0.4504**  | -0.4839*** | -0.4864*** | -0.4800*** | -0.4486**  | -0.2744*   | -0.4748**  | -0.4654**  |
| short    | 1-day  | 0.2521     | 0.3223     | 0.2516     | 0.2447     | 0.2539     | 0.2773     | 0.2808     | 0.3648     | 0.2045     | 0.2815     | 0.1565     | 0.3655     |
|          | 5-day  | 0.1398     | 0.1322     | 0.1400     | 0.0746     | 0.1363     | 0.1120     | 0.1643     | 0.1157     | 0.1749     | 0.1678     | 0.0915     | 0.2552     |
|          | 20-day | 0.2852     | 0.3036     | 0.2825     | 0.1882     | 0.2428     | 0.2492     | 0.2517     | 0.2542     | 0.3489     | 0.2549     | 0.3716     | 0.3701     |
| Platinum |        |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day  | 0.5275     | 0.3959     | 0.3755     | 0.4946     | 0.3854     | 0.3863     | 0.3496     | 0.3493     | 0.3238     | 0.3750     | 0.4654     | 0.5890     |
|          | 5-day  | 0.3424     | 0.2143     | 0.1088     | 0.1946     | 0.1762     | 0.1381     | 0.1074     | 0.1600     | 0.1123     | 0.1356     | 0.2942     | 0.4215     |
|          | 20-day | 0.6303     | 0.4262     | 0.3569     | 0.5533     | 0.3946     | 0.4017     | 0.5559     | 0.3885     | 0.3724     | 0.4003     | 0.6276     | 0.6961     |
| short    | 1-day  | 0.7805     | 0.6911     | 0.6263     | 0.6671     | 0.6558     | 0.6815     | 0.5459     | 0.6820     | 0.6552     | 0.6548     | 0.7223     | 0.7601     |
|          | 5-day  | 0.6449     | 0.5750     | 0.4126     | 0.5417     | 0.5893     | 0.5027     | 0.5158     | 0.5357     | 0.4698     | 0.5076     | 0.6313     | 0.7133     |
|          | 20-day | 0.8711     | 0.7506     | 0.6516     | 0.7504     | 0.6583     | 0.6789     | 0.8057     | 0.6524     | 0.6775     | 0.6806     | 0.8739     | 0.8763     |
| GSCI     |        |            |            |            |            |            |            |            |            |            |            |            |            |
| long     | 1-day  | 0.0418     | 0.1139     | 0.0445     | -0.0353    | 0.1125     | 0.0921     | 0.1288     | 0.0428     | 0.0521     | 0.0469     | 0.1406     | -0.2155*   |
|          | 5-day  | -0.2504*   | -0.1028    | -0.2147*   | -0.1969*   | -0.0830    | -0.2230*   | -0.1662    | -0.1816    | -0.1724    | -0.2110*   | -0.0288    | -0.5244*** |
|          | 20-day | -0.0735    | 0.0112     | -0.1044    | -0.1204    | -0.0260    | -0.1315    | 0.0239     | -0.1159    | -0.0951    | 0.0242     | 0.1866     | -0.4334*** |
| short    | 1-day  | 0.5911     | 0.6308     | 0.5595     | 0.5965     | 0.6295     | 0.6049     | 0.6345     | 0.5709     | 0.5318     | 0.6305     | 0.7020     | 0.5131     |
|          | 5-day  | 0.4320     | 0.4476     | 0.4306     | 0.3997     | 0.4742     | 0.4814     | 0.4733     | 0.4093     | 0.4075     | 0.4088     | 0.5421     | 0.2356     |
|          | 20-day | 0.5258     | 0.5530     | 0.5354     | 0.4405     | 0.5473     | 0.4856     | 0.5882     | 0.4873     | 0.5458     | 0.5412     | 0.5976     | 0.2830     |

Table 25: Results for the Expected Shortfall “direct” backtest  $Z_2$  of Acerbi & Szekely (2014) 0.975% confidence.