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Economic determinants of oil futures volatility: A term structure perspective

ONLINE APPENDIX

Appendix A. Economic Variables

Oil sector variables

US inventory: The inventory measure used in the analysis is the logarithm of the U.S. ending stocks of crude oil[1] compiled from the U.S. Energy Information Administration (EIA) Total Energy Reviews (in thousand barrels). WTI prices are affected more by immediately available inventory (Geman and Ohana (2009); Kilian (2016)) and OECD inventory is less correlated with short-run U.S. crude oil prices. Nikitopoulos et al. (2017) have shown that U.S. inventory explains crude oil price volatility, while OECD inventory does not. Data series on the weekly stock of crude oil and petroleum products begins in 1990, thus we use the inventory data in crude oil only.

US consumption: The consumption is measured by the logarithm of U.S. product supplied of crude oil and petroleum products[2] compiled from the U.S. Energy Information Administration (EIA) Total Energy Reviews (in thousand barrels per day). This series is only available in monthly frequency.

Futures spreads: By using weekly observations of CME Light Sweet Crude Oil (WTI) futures prices for the nearest (first), fourth, and thirteenth monthly contract expiry dates, from CME Group, we compute weekly values of the crude oil futures spread with 3- and 12-month

[1] We use the EIA series for U.S. ending stocks of crude oil. The EIA definition is “Crude oil stocks include those domestic and Customs-cleared foreign crude oil stocks held at refineries, in pipelines, in lease tanks, and in transit to refineries. Crude oil that is in-transit by water from Alaska or that is stored on Federal leases or in the Strategic Petroleum Reserve is included. Primary stocks exclude stocks of foreign origin that are held in bonded warehouse storage.” See $https://www.eia.gov/dnav/pet/pet_stoc_wstk_dcu_nus_w.htm$.

[2] The definition provided in the EIA glossary for Monthly Product Supplied is “Approximately represents consumption of petroleum products because it measures the disappearance of these products from primary sources, i.e., refineries, natural gas processing plants, blending plants, pipelines, and bulk terminals. In general, product supplied of each product in any given period is computed as follows: field production, plus renewable fuels and oxygenate plant net production, plus refinery and blender net production, plus imports, plus net receipts, plus adjustments, minus stock change, minus refinery and blender net inputs, minus exports.” See $https://www.eia.gov/dnav/pet/pet_cons_psup_dc_nus_mbblpd_m.htm$.

maturities.[3] We treat the 1-month futures price as a proxy for the spot oil price, which it is customary in the literature. The futures spread (FS) at date t is computed as $(n-1)$-month $\text{FS}_t = [F(t,n) - F(t,1)]/F(t,1)$, where $F(t,n)$ is the n^{th}-month nearest futures price at date t, $F(t,1)$ is the 1^{st}-month nearest futures price at date t. It represents the slope of the futures curve and accordingly relates to backwardation/contango market conditions, see Symeonidis et al. (2012) and Nikitopoulos et al. (2017). Nikitopoulos et al. (2017) shown that crude oil implied volatility predicts spreads, a relation that becomes stronger with increasing spread maturity and historical and implied volatility predict positive spreads but not negative spreads consistent with Kogan et al. (2009).

Open interest: The daily open interest for all crude oil futures contracts is obtained from US Commodity Futures Trading Commission (CFTC).[4] This is considered as a trading variable that affect short- and medium- term crude oil prices, (Dempster et al. (2012)). Higher open interest growth rate leads to a futures curve that is deeper in backwardation. We study the logarithm of this series.

Hedging pressure: The Commitments of Traders (COT) reports a breakdown of each Tuesday's open interest for markets in which 20 or more traders hold positions equal or above the reporting levels established by the CFTC.[5] Using this data, we compute weekly (Tuesday) hedging pressure as the hedger's short position less their long position normalised by total open interest ((commercial total short-commercial total long)/(commercial total long+commercial total short)). Thus a positive hedging pressure implies an overall short position for hedgers. This is also considered as a trading variable with similar impact to spot oil prices as the open interest, (Dempster et al. (2012)).

Macroeconomic conditions/Business Cycle Variables

Treasury bond yield spreads: The weekly spreads between the 10-year and the 3-month Treasure bond yields are compiled from FRED (Federal Reserve Bank of St.Louis).[6] The spread

[3] A crude oil futures contract represents 1000bbl to be delivered at Cushing, Oklahoma. Each futures contract expires on the third business day prior to the 25^{th} calendar day of the month preceding the delivery month. If the 25^{th} day of the month is not a business day, trading ceases on the third business day prior to the business day preceding the 25^{th} calendar day.

[4] $http://www.cftc.gov/MarketReports/CommitmentsofTraders/index.htm$

[5] Futures Only Reports: The complete Commitments of Traders Futures Only reports file from 1986 is included by year. Beginning in 1998, Commitments of Traders grain data has been reported in contracts rather than bushels. Note that changes in commitments from the last reports in 1997 were not calculated for the 1998 grain reports. For dates before September 30, 1992, only mid-month and month-end data is available. Since the mid-month data was not published before that time, it may contain identifiable data errors and because a significant period elapsed between the report date for that data and its eventual compilation, it is not possible to correct the errors.

[6] See $https://fred.stlouisfed.org/series/T10Y3M$.

between long-term and short term yield rates is a key predictor of economic recessions, see Estrella and Mishkin (1998).

Consumer Price Index: The monthly data of the consumer price index where compiled is retrieved from FRED and represents the key measure of inflation.[7]

Chicago Fed National Activity Index: This monthly index compares the expanding rates of the economy to its historical trend rate of growth; negative values indicate below-average growth; and positive values indicate above-average growth. Data were compiled from FRED.[8]

Industrial Production: This monthly index reports changes to industrial production and serves as an indicator of growth in the industry, and thus reflects structural developments in the economy. Data were compiled from FRED.[9]

Financial Variables

FF size (Fama and French size), *FF value* (Fama and French value) and Mom[10]: These variables are considered as indicators of economic/financial stability, see Morana (2013). The data were compiled from Kenneth French data library.[11]

S&P 500 index returns: The weekly S&P 500 index has been compiled from Bloomberg. It has been shown that investors pursue trading strategies in oil futures conditional on equity markets, see Basak and Pavlova (2016).

VIX level: The weekly measure of the market's expectation of stock market volatility over the next 30 days is computed by the VIX index. The data are compiled from St.Louis. Fed[12] The dataset begins in 1990.

3-month Treasury rates: We use the weekly rates from St.Louis Fed[13]. We also have the 3-month LIBOR rates[14] but we avoid using them as LIBOR rates have been artificially low

[7]See $https://fred.stlouisfed.org/series/CPIAUCSL.$

[8]See $https://fred.stlouisfed.org/series/CFNAI.$

[9]See $https://fred.stlouisfed.org/series/INDPRO.$

[10]Mom is constructed by using six value-weighted portfolios formed on size and prior (2-12) returns. The portfolios, which are formed monthly, are the intersections of 2 portfolios formed on size (market equity, ME) and 3 portfolios formed on prior (2-12) returns. The monthly size breakpoint is the median NYSE market equity. The monthly prior (2-12) returns breakpoints are the 30th and 70th NYSE percentiles. Mom is the average return on the two high prior return portfolios minus the average return on the two low prior return portfolios.

[11]See $http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html$

[12]See $https://fred.stlouisfed.org/series/VIXCLS.$

[13]See $https://fred.stlouisfed.org/series/DGS3MO$

[14]$https://fred.stlouisfed.org/series/USD3MTD156N$

for an extended period of time. Interest rates impact inventories thus convenience yield and volatility (Casassus and Collin-Dufresne (2005)).

US dollar index: The weekly US dollar against a basket of currencies, namely trade weighted U.S. dollar index, is obtained from St.Louis Fed.[15]

Credit spreads: The monthly spread between Moody's BAA-rated and AAA-rated corporate yields are compiled from St.Louis Fed.[16] The credit spread is a proxy for the default premium.

Table A.1 reports results of the Augmented Dickey-Fuller unit root test (Dickey and Fuller (1979)) where the hypothesis is that the variables are stationary with a constant and a time trend.

Appendix B. State Variables and Derivative Prices

Appendix

We consider the process $X(t,T) = \ln F(t,T,\mathbf{V_t})$, where the futures price dynamics are given by (3.1) with the volatility specifications (3.3). Then an application of the Ito's formula derives

$$F(t,T,\mathbf{V_t}) = F(0,T)\exp\left[\sum_{i=1}^{3}\int_0^t \sigma_i(s,T,V_s)dW_i^1(s) - \frac{1}{2}\sum_{i=1}^{3}\int_0^t \sigma_i^2(s,T,V_s)ds\right], \qquad \text{(B.1)}$$

[15]https://fred.stlouisfed.org/series/DTWEXM

[16]See https://fred.stlouisfed.org/series/AAA and https://fred.stlouisfed.org/series/BAA

Then, by applying the volatility specifications (3.3)

$$
\begin{aligned}
\ln F(t,T,\mathbf{V_t}) = \ln F(0,T) &+ \int_0^t \kappa_1 e^{-\eta_1(T-s)}\sqrt{V_s^1}dW_1^1(s) \\
&+ \int_0^t \kappa_2(T-s)e^{-\eta_2(T-s)}\sqrt{V_s^2}dW_2^1(s) \\
&+ \int_0^t \kappa_3(1-e^{-\eta_3(T-s)})\sqrt{V_s^3}dW_3^1(s) \\
&- \frac{1}{2}\int_0^t \kappa_1^2 e^{-2\eta_1(T-s)}V_s^1 ds \\
&- \frac{1}{2}\int_0^t \kappa_2^2(T-s)^2 e^{-2\eta_2(T-s)}V_s^2 ds \\
&- \frac{1}{2}\int_0^t \kappa_3^2(1-e^{-\eta_3(T-s)})^2 V_s^3 ds.
\end{aligned}
\tag{B.2}
$$

Further,

$$
\begin{aligned}
&\ln F(t,T,V_t) = \\
&\ln F(0,T) + \kappa_1 e^{-\eta_1(T-t)}\int_0^t e^{-\eta_1(t-s)}\sqrt{V_s^1}dW_1^1(s) \\
&+ \kappa_2(T-t)e^{-\eta_2(T-t)}\int_0^t e^{-\eta_2(t-s)}\sqrt{V_s^2}dW_2^1(s) + \kappa_2 e^{-\eta_2(T-t)}\int_0^t (t-s)e^{-\eta_2(t-s)}\sqrt{V_s^2}dW_2^1(s) \\
&+ \kappa_3\int_0^t \sqrt{V_s^3}dW_3^1(s) - \kappa_3 e^{-\eta_3(T-t)}\int_0^t e^{-\eta_3(t-s)}\sqrt{V_s^3}dW_3^1(s) \\
&- \frac{1}{2}\kappa_1^2 e^{-2\eta_1(T-t)}\int_0^t e^{-2\eta_1(t-s)}V_s^1 ds - \frac{1}{2}\kappa_2^2(T-t)^2 e^{-2\eta_2(T-t)}\int_0^t e^{-2\eta_2(t-s)}V_s^2 ds \\
&- \frac{1}{2}2\kappa_2^2(T-t)e^{-2\eta_2(T-t)}\int_0^t (t-s)e^{-2\eta_2(t-s)}V_s^2 ds - \frac{1}{2}\kappa_2^2 e^{-2\eta_2(T-t)}\int_0^t (t-s)^2 e^{-2\eta_2(t-s)}V_s^2 ds \\
&- \frac{1}{2}\kappa_3^2\int_0^t V_s^3 ds + \frac{1}{2}2\kappa_3^2 e^{-\eta_3(T-t)}\int_0^t e^{-\eta_3(t-s)}V_s^3 ds \\
&- \frac{1}{2}\kappa_3^2 e^{-2\eta_3(T-t)}\int_0^t e^{-2\eta_3(t-s)}V_s^3 ds.
\end{aligned}
\tag{B.3}
$$

We introduce the state variables

$$\begin{aligned}
\xi_1(t) &= \int_0^t e^{-\eta_1(t-s)}\sqrt{V_s^1}dW_1^1(s), \quad \xi_2(t) = \int_0^t e^{-\eta_2(t-s)}\sqrt{V_s^2}dW_2^1(s) \\
\xi_3(t) &= \int_0^t (t-s)e^{-\eta_2(t-s)}\sqrt{V_s^2}dW_2^1(s) \\
\xi_4(t) &= \int_0^t \sqrt{V_s^3}dW_3^1(s), \quad \xi_5(t)(t) = \int_0^t e^{-\eta_3(t-s)}\sqrt{V_s^3}dW_3^1(s),
\end{aligned} \tag{B.4}$$

and

$$\begin{aligned}
\psi_1(t) &= \int_0^t e^{-2\eta_1(t-s)}V_s^1 ds, \quad \psi_2(t) = \int_0^t e^{-2\eta_2(t-s)}V_s^2 ds, \\
\psi_3(t) &= \int_0^t (t-s)e^{-2\eta_2(t-s)}V_s^2 ds, \quad \psi_4(t) = \int_0^t (t-s)^2 e^{-2\eta_2(t-s)}V_s^2 ds, \\
\psi_5(t) &= \int_0^t V_s^3 ds, \quad \psi_6(t) = \int_0^t e^{-\eta_3(t-s)}V_s^3 ds, \quad \psi_7(t) = \int_0^t e^{-2\eta_3(t-s)}V_s^3 ds.
\end{aligned} \tag{B.5}$$

Then the equation B.3 becomes

$$\ln F(t,T,\mathbf{V_t}) = \ln F(0,T,V_0) + \sum_{n=1}^{5}\alpha_n(T-t)\xi_n(t) - \frac{1}{2}\sum_{m=1}^{7}\beta_m(T-t)\psi_m(t), \tag{B.6}$$

where for $\tau = T - t$,

$$\begin{aligned}
&\alpha_1(\tau) = \kappa_1 e^{-\eta_1\tau}, \quad \alpha_2(\tau) = \kappa_2\tau e^{-\eta_2\tau}, \quad \alpha_3(\tau) = \kappa_2 e^{-\eta_2\tau}, \\
&\alpha_4(\tau) = \kappa_3, \quad \alpha_5(\tau) = -\kappa_3 e^{-\eta_3\tau}, \quad \beta_1(\tau) = \alpha_1(\tau)^2, \\
&\beta_2(\tau) = \alpha_2(\tau)^2, \quad \beta_3(\tau) = 2\alpha_2(\tau)\alpha_3(\tau), \quad \beta_4(\tau) = \alpha_3(\tau)^2, \\
&\beta_5(\tau) = \alpha_4(\tau)^2, \quad \beta_6(\tau) = 2\alpha_4(\tau)\alpha_5(\tau), \quad \beta_7(\tau) = \alpha_5(\tau)^2.
\end{aligned} \tag{B.7}$$

The state space variables $\xi_n(t)$, $n = 1, \ldots, 5$ and $\psi_m(t)$, $m = 1, \ldots, 7$ satisfy the stochastic differential equations

$$\begin{aligned}
d\xi_1(t) &= -\eta_1\xi_1(t)dt + \sqrt{V_t^1}dW_1^1(t), \\
d\xi_2(t) &= -\eta_2\xi_2(t)dt + \sqrt{V_t^2}dW_2^1(t), \\
d\xi_3(t) &= (-\eta_2\xi_3(t) + \xi_2(t))dt, \\
d\xi_4(t) &= \sqrt{V_t^3}dW_3^1(t), \\
d\xi_5(t) &= -\eta_3\xi_5(t)dt + \sqrt{V_t^3}dW_3^1(t), \\
d\psi_1(t) &= \left(-2\eta_1\psi_1(t) + V_t^1\right) dt, \\
d\psi_2(t) &= \left(-2\eta_2\psi_2(t) + V_t^2\right) dt, \\
d\psi_3(t) &= \left(-2\eta_2\psi_3(t) + \psi_2(t)\right) dt, \\
d\psi_4(t) &= \left(-2\eta_2\psi_4(t) + 2\psi_3(t)\right) dt, \\
d\psi_5(t) &= V_t^3 dt \\
d\psi_6(t) &= \left(-\eta_3\psi_6(t) + V_t^3\right) dt, \\
d\psi_7(t) &= \left(-2\eta_3\psi_7(t) + V_t^3\right) dt.
\end{aligned} \tag{B.8}$$

subject to $\xi_n(0) = \psi_m(0) = 0$, for all n and m. The associated variance process $\mathbf{V_t} = \{V_t^1, V_t^2, V_t^3, \}$ follows the dynamics (3.2).

Further by employing Fourier transforms, both call and put options on futures contracts can be priced. Under the stochastic volatility specifications (3.3), and given the results presented in Duffie et al. (2000), for $t \leq T_o \leq T$, the transform $\varphi(t; v, T_o, T) =: \mathbf{E}_t^Q[\exp\{v \ln F(T_o, T, V_{T_o})\}]$ can be expressed as

$$\varphi(t; v, T_o, T) = \exp\{M(t; v, T_o) + \sum_{i=1}^{3} N_i(t; v, T_o)\mathbf{V_t}^i + v \ln F(t, T, \mathbf{V_t})\}, \tag{B.9}$$

where $M(t) = M(t; v, T_o)$ and $N_i(t) = N_i(t; v, T_o)$ satisfy the ordinary Ricatti equations

$$\frac{dM(t)}{dt} = -\sum_{i=1}^{n} \mu_i\nu_i N_i(t), \tag{B.10}$$

$$\frac{dN_i(t)}{dt} = -\frac{v^2 - v}{2}(\varphi_i)^2 - (\varepsilon_i v\rho_i\varphi_i - \mu_i) N_i(t) - \frac{1}{2}{\varepsilon_i}^2 N_i^2(t), \tag{B.11}$$

subject to the terminal conditions $M(T_o) = N_i(T_o) = 0$, for $i = 1, 2, 3$, where $\phi_1 = \kappa_1 e^{-\eta_1(T-t)}$, $\phi_2 = \kappa_2(T-t)e^{-\eta_2(T-t)}$ and $\phi_3 = \kappa_3(1 - e^{-\eta_3(T-t)})$.

The price at time t of a European put option maturing at T_o with strike K on a futures contract maturing at time T, is then given by

$$\mathcal{P}(t, T_o, T, K) = B(t, T_o)[KG_{0,1}(\log(K)) - G_{1,1}(\log(K))] \tag{B.12}$$

where $B(t, T_o)$ is the price at time t of a zero-coupon bond maturing at T_o and $G_{m,n}(y)$ is given by

$$G_{m,n}(y) = \frac{\varphi(t; m, T_o, T)}{2} - \frac{1}{\pi} \int_0^\infty \frac{Im[\varphi(t; m + \mathbf{i}nu, T_o, T)e^{-\mathbf{i}uy}]}{u} du, \tag{B.13}$$

with $\mathbf{i}^2 = -1$.

Appendix C. Full Sample

Appendix

Table C.2, Table C.3 and Table C.4 show the regression results over the whole sample period of 30 years, from 1987 to 2017.

Table A.1: **Augmented Dickey-Fuller Unit-Root Tests**

The table reports the Augmented Dickey-Fuller t-statistic of the model $\Delta x_t = \mu + \alpha x_{t-1} + \sum_{i=1}^{p} \beta_i \Delta x_{t-i} + \gamma t + \epsilon_t$. The number of lagged changes p is selected based on the Akaike Information Criterion, testing up to a maximum of $p = 15$ lags. The symbols ***, **, and * indicate rejection of the unit-root null hypothesis at the 99%, 95%, and 90% confidence levels, respectively. The weekly series are presented at the top panel and the monthly series in the bottom panel.

	January 1987 - October 2017			January 1987 - December 2004			January 2005 - October 2017		
Series	Optim. Lags	T-Stat.	p-value	Optim. Lags	T-Stat.	p-value	Optim. Lags	T-Stat.	p-value
Oil sector Variables									
US Inventory (log)	9	-12.20***	0.00	9	-9.79***	0.00	4	-7.79***	0.00
Consumption (log)	13	-2.31	0.43	8	-4.44	0.00	9	-1.99	0.61
12-month futures spreads	3	-5.02***	0.00	3	-4.18***	0.01	3	-3.63**	0.03
Open interest (log)	15	-12.82***	0.00	15	-9.97***	0.00	15	-7.43***	0.00
Hedging pressure	10	–4.99***	0.00	1	-7.68***	0.00	11	-3.52**	0.04
Macro-economic conditions									
Treasury bond yield spread	13	-2.81	0.19	4	-2.00	0.60	13	-1.56	0.81
Financial variables									
FF size	4	-17.64***	0.00	4	-13.08***	0.00	0	-28.18***	0.00
FF value	14	-8.88***	0.00	1	-17.81***	0.00	14	-6.54***	0.00
Mom	12	-10.54***	0.00	1	-24.41***	0.00	11	-7.60***	0.00
S&P 500 returns	5	-16.15***	0.00	7	-11.59***	0.00	0	-26.89***	0.00
VIX level	11	-4.23***	0.00	2	-4.06***	0.01	11	-2.79	0.20
3-month Treasury rates	15	-2.71	0.23	15	-2.40	0.38	13	-1.16	0.92
US dollar index	0	-1.91	0.65	3	-1.62	0.78	0	-1.64	0.78
Oil sector Variables									
US Inventory (log)	12	-2.474	0.34	3	-1.073	0.93	12	-3.334*	0.07
Consumption (log)	14	-1.582	0.80	14	-2.447	0.35	12	-1.297	0.88
12-month futures spreads	11	-4.808***	0.00	11	-4.056**	0.01	3	-2.982	0.14
Open interest (log)	1	-3.651**	0.03	1	-3.770**	0.02	0	-3.381*	0.06
Hedging pressure	8	-3.265*	0.07	0	-7.103***	0.00	0	-4.722***	0.00
Macro-economic conditions									
Treasury bond yield spread	8	-3.900**	0.01	4	-2.454	0.35	0	-1.447	0.84
Consumer Price Index	2	-2.621	0.27	2	0.457	1.00	1	-3.494**	0.04
CFNAI	11	-4.422***	0.00	2	-3.430*	0.05	11	-3.363*	0.06
Industrial Production	7	-2.203	0.49	3	-1.746	0.73	4	-2.794	0.20
Financial variables									
FF size	7	-6.565***	0.00	0	-15.101***	0.00	0	-12.450***	0.00
FF value	0	-17.121***	0.00	0	-12.160***	0.00	0	-11.813***	0.00
Mom	8	-6.562***	0.00	0	-16.311***	0.00	9	-4.862***	0.00
S&P 500 returns	0	-21.309***	0.00	0	-17.711***	0.00	0	-12.214***	0.00
VIX level	2	-4.121***	0.01	0	-3.852**	0.02	2	-3.045	0.12
3-month Treasury rates	16	-4.080***	0.01	10	-3.127	0.10	12	-2.650	0.26
US dollar index	11	-2.017	0.59	2	-1.482	0.83	9	-1.526	0.82
Credit spreads	1	-4.316***	0.00	1	-2.745	0.22	1	-3.384*	0.06

Table C.2: $\sqrt{V_1}$ **1987-2017**

The table reports the regressions of the square root of the variance term $V_1(t)$ on a constant, its lagged value, $V_1(t-1)$, and the economic variables. The selected frequency is monthly (end of the month) between 1987 and 2017 accumulating 370 observations. We report t-statistics in parentheses and *, **, *** indicate significance at the 10%, 5% and 1% significance levels, respectively. Newely and West (1987) corrected standard errors with 12 lags have been used in the estimations.

	$\sqrt{V_1(t)}$																						
c	0.061***	0.063***	0.062***	0.066***	-0.099	0.068***	0.061***	0.057***	0.064***	0.060***	0.062***	0.062***	0.061***	0.061***	-0.030	0.079***	0.061***	-0.003	-0.764***	0.063***	-0.031	-1.288**	-2.625***
	(4.25)	(4.32)	(4.23)	(4.25)	(-0.57)	(4.55)	(4.22)	(4.04)	(4.32)	(4.16)	(4.18)	(4.31)	(4.22)	(4.25)	(-1.29)	(2.99)	(4.31)	(-0.13)	(-3.60)	(4.17)	(-0.74)	(-2.57)	(-3.03)
$\sqrt{V_1(t-1)}$	0.881***	0.878***	0.881***	0.874***	0.872***	0.883***	0.882***	0.891***	0.875***	0.881***	0.880***	0.878***	0.881***	0.882***	0.785***	0.871***	0.881***	0.799***	0.832***	0.874***	0.759***	0.689***	
	(29.33)	(28.32)	(28.90)	(27.22)	(25.38)	(29.54)	(29.57)	(30.12)	(27.94)	(29.90)	(27.93)	(29.76)	(28.51)	(29.24)	(25.09)	(24.89)	(29.78)	(22.80)	(19.19)	(26.92)	(20.54)	(14.14)	
$Inv(t)$		-0.341																	-0.371			1.227	2.531
		(-0.88)																	(-0.46)			(1.19)	(1.34)
$D(Cons(t))$			-0.497																-0.428			-0.280	-0.640
			(-0.69)																(-0.61)			(-0.49)	(-1.13)
$FutSpread_{12m}(t)$				0.094															0.027			-0.215	-0.375
				(0.81)															(0.13)			(-0.91)	(-0.83)
$OI(t)$					0.029														0.151***			0.217***	0.441***
					(0.91)														(3.98)			(2.66)	(3.16)
$HP(t)$						-0.161*													-0.500***			-0.544***	-0.876***
						(-1.87)													(-3.24)			(-3.07)	(-2.99)
$D(TS)(t)$							-0.025													-0.028		-0.019	-0.005
							(-0.64)													(-0.71)		(-0.50)	(-0.12)
$CPI(t)$								-0.003												-0.004		-0.016***	-0.041***
								(-0.88)												(-1.26)		(-4.14)	(-5.18)
$CFNAI(t)$									-0.011*											-0.016**		-0.005	-0.008
									(-1.67)											(-2.18)		(-0.42)	(-0.33)
$IP(t)$										0.000										0.000		0.003	0.012***
										(0.23)										(0.26)		(1.21)	(2.89)
$FFsize(t)$											-0.017**										-0.015**	-0.015**	0.000
											(-2.31)										(-2.11)	(-2.02)	(0.07)
$FFvalue(t)$												-0.008									-0.005	-0.004	-0.009
												(-1.18)									(-0.57)	(-0.60)	(-0.98)
$Mom(t)$													0.011								0.006	0.002	-0.009
													(1.18)								(0.78)	(0.22)	(-0.87)
$S\&P500(t)$														0.079							0.549	0.493	0.492
														(0.22)							(1.55)	(1.43)	(0.97)
$VIX(t)$															0.008***						0.006***	0.006***	0.007**
															(5.31)						(4.07)	(3.47)	(2.50)
$TR_{3m}(t)$																-0.004					-0.002	0.001	0.007
																(-0.90)					(-0.44)	(0.17)	(0.43)
$D(USdollar)(t)$																	0.004				0.003	0.003	0.001
																	(0.70)				(0.66)	(0.56)	(0.18)
$CS(t)$																		0.111***			0.054	0.098**	0.482***
																		(3.54)			(1.48)	(2.49)	(4.99)
$Adj.R^2$	0.775	0.775	0.774	0.775	0.775	0.777	0.775	0.779	0.775	0.775	0.775	0.775	0.774	0.774	0.797	0.775	0.775	0.786	0.786	0.775	0.801	0.812	0.600

Table C.3: $\sqrt{V_2}$ **1987-2017**

The table reports the regressions of the square root of the variance term $V_2(t)$ on a constant, its lagged value, $V_2(t-1)$, and the economic variables. The selected frequency is monthly (end of the month) between 1987 and 2017 accumulating 370 observations. We report t-statistics in parentheses and *, **, *** indicate significance at the 10%, 5% and 1% significance levels, respectively. Newely and West (1987) corrected standard errors with 12 lags have been used in the estimations.

	$\sqrt{V_2(t)}$																						
c	0.095***	0.097***	0.096***	0.098***	-0.225***	0.094***	0.096***	0.095***	0.095***	0.095***	0.096***	0.094***	0.098***	0.096***	0.087***	0.123***	0.095***	0.074***	-0.441***	0.097***	0.100***	-0.377	-0.604
	(8.20)	(8.56)	(8.12)	(8.66)	(-2.68)	(8.06)	(8.17)	(8.25)	(8.10)	(8.19)	(8.13)	(8.04)	(8.70)	(8.18)	(5.72)	(9.61)	(8.15)	(4.78)	(-3.14)	(8.60)	(5.70)	(-1.23)	(-1.34)
$\sqrt{V_2(t-1)}$	0.461***	0.455***	0.452***	0.453***	0.417***	0.451***	0.458***	0.462***	0.465***	0.461***	0.461***	0.457***	0.450***	0.461***	0.459***	0.422***	0.462***	0.443***	0.402***	0.441***	0.425***	0.384***	
	(5.65)	(5.89)	(5.41)	(5.79)	(5.45)	(5.63)	(5.57)	(5.68)	(5.63)	(5.65)	(5.61)	(5.54)	(5.94)	(5.64)	(5.39)	(5.58)	(5.63)	(5.26)	(5.32)	(5.77)	(5.33)	(5.22)	
$Inv(t)$		0.301																	0.389*			0.683	0.964
		(1.43)																	(1.76)			(1.34)	(1.34)
$D(Cons(t))$			-0.010																0.049			-0.102	-0.122
			(-0.02)																(0.13)			(-0.23)	(-0.32)
$FutSpread_{12m}(t)$				0.065															-0.066			-0.092	-0.140*
				(1.63)															(-1.51)			(-1.59)	(-1.78)
$OI(t)$					0.057***														0.095***			0.085	0.132*
					(3.88)														(3.83)			(1.63)	(1.71)
$HP(t)$						0.069													-0.16*			-0.202**	-0.243
						(1.30)													(-1.96)			(-1.97)	(-1.61)
$D(TS)(t)$							-0.028													-0.034**		-0.044**	-0.055***
							(-1.59)													(-1.96)		(-2.39)	(-2.70)
$CPI(t)$								0.001												-0.001		-0.004	-0.006
								(0.27)												(-0.50)		(-1.27)	(-1.08)
$CFNAI(t)$									-0.016***											-0.017***		-0.016*	-0.015
									(-2.69)											(-3.08)		(-1.68)	(-1.39)
$IP(t)$										-0.002*										-0.001*		-0.001	-0.001
										(-1.86)										(-1.76)		(-0.31)	(-0.42)
$FFsize(t)$											0.005										0.005	0.005	0.005
											(1.00)										(1.02)	(1.02)	(0.97)
$FFvalue(t)$												0.003									0.006*	0.007**	0.007
												(1.16)									(2.23)	(2.13)	(1.49)
$Mom(t)$													0.002								0.003	0.001	0.001
													(0.32)								(0.58)	(0.16)	(0.09)
$S\&P500(t)$														-0.011							0.075	0.033	0.096
														(-0.05)							(0.31)	(0.14)	(0.35)
$VIX(t)$															0.001						0.000	0.001	0.002
															(0.68)						(0.18)	(0.71)	(1.24)
$TR_{3m}(t)$																-0.006***					-0.006**	-0.005	-0.007
																(-3.63)					(-2.39)	(-0.99)	(-0.87)
$D(USdollar)(t)$																	-0.001				-0.000	0.001	0.003
																	(-0.33)				(-0.04)	(0.37)	(0.94)
$CS(t)$																		0.026*			0.018	-0.004	-0.004
																		(1.73)			(0.86)	(-0.18)	(-0.12)
$Adj.R^2$	0.211	0.213	0.201	0.212	0.234	0.212	0.214	0.212	0.210	0.209	0.209	0.222	0.215	0.209	0.214	0.230	0.209	0.216	0.229	0.229	0.225	0.238	0.106

Table C.4: $\sqrt{V_3}$ **1987-2017**

The table reports the regressions of the square root of the variance term $V_3(t)$ on a constant, its lagged value, $V_3(t-1)$, and the economic variables. The selected frequency is monthly (end of the month) between 1987 and 2017 accumulating 370 observations. We report t-statistics in parentheses and *, **, *** indicate significance at the 10%, 5% and 1% significance levels, respectively. Newely and West (1987) corrected standard errors with 12 lags have been used in the estimations.

	$\sqrt{V_3(t)}$																						
c	0.119***	0.121***	0.119***	0.120***	-0.036	0.118***	0.119***	0.119***	0.119***	0.120***	0.120***	0.120***	0.119***	0.119***	0.121***	0.124***	0.119***	0.115***	-0.140	0.121***	0.120***	-0.279	-0.318
	(6.60)	(7.04)	(6.62)	(6.60)	(-0.47)	(6.32)	(6.55)	(6.63)	(6.56)	(6.67)	(6.19)	(6.31)	(0.73)	(6.59)	(8.22)	(7.74)	(6.61)	(7.59)	(-1.44)	(6.12)	(8.47)	(-1.35)	(-1.27)
$\sqrt{V_3(t-1)}$	0.213	0.201	0.214	0.209	0.191	0.207*	0.213	0.213	0.212	0.212	0.206	0.200	0.210	0.214	0.218	0.209	0.210	0.212	0.175	0.195	0.205	0.164	
	(1.59)	(1.59)	(1.59)	(1.54)	(1.49)	(1.66)	(1.58)	(1.59)	(1.57)	(1.57)	(1.43)	(1.38)	(1.59)	(1.59)	(1.59)	(1.59)	(1.56)	(0.50)	(1.39)	(1.30)	(1.44)	(1.20)	
$Inv(t)$		0.271*																	0.361**			0.515**	0.610*
		(1.79)																	(2.07)			(1.97)	(1.78)
$D(Cons(t))$			-0.145																-0.116			-0.076	-0.058
			(-0.56)																(-0.44)			(-0.23)	(-0.19)
$FutSpread_{12m}(t)$				0.027															-0.054			-0.066	-0.077
				(0.96)															(-1.15)			(-1.35)	(-1.28)
$OI(t)$					0.027**														0.046**			0.068**	0.079*
					(2.32)														(2.53)			(2.07)	(1.89)
$HP(t)$						0.049													-0.068			-0.102	-0.113
						(0.86)													(-0.83)			(-1.50)	(-1.64)
$D(TS)(t)$							0.010													0.007		0.006	0.007
							(0.92)													(0.67)		(0.47)	(0.55)
$CPI(t)$								0.002												0.001		-0.002	-0.02
								(1.06)												(0.72)		(-0.91)	(-0.83)
$CFNAI(t)$									-0.009											-0.008		-0.005	-0.006
									(-1.65)											(-1.48)		(-0.74)	(-0.97)
$IP(t)$										-0.001										-0.000		0.000	0.000
										(-0.94)										(-0.60)		(0.02)	(0.04)
$FFsize(t)$											-0.001										-0.002	-0.002	-0.003
											(-0.41)										(-0.81)	(-0.91)	(-1.00)
$FFvalue(t)$												-0.001									-0.001	-0.001	-0.002
												(-0.34)									(-0.56)	(-0.47)	(-0.69)
$Mom(t)$													-0.008**								-0.010**	-0.010**	-0.010**
													(-2.02)								(-2.44)	(-2.43)	(-2.49)
$S\&P500(t)$														-0.119							-0.181	-0.248	-0.259
														(-0.71)							(-1.10)	(-1.41)	(-1.47)
$VIX(t)$															-0.000						-0.001	0.000	0.000
															(-0.12)						(-0.96)	(0.34)	(0.36)
$TR_{3m}(t)$																-0.001					0.000	0.003	0.003
																(-1.12)					(0.14)	(0.87)	(0.91)
$D(USdollar)(t)$																	-0.002				-0.002	-0.002	-0.002
																	(-1.20)				(-0.88)	(-0.93)	(-1.35)
$CS(t)$																		0.005			0.014	0.000	0.001
																		(0.50)			(1.10)	(0.04)	(0.10)
$Adj.R^2$	0.043	0.049	0.041	0.041	0.056	0.045	0.042	0.041	0.041	0.052	0.046	0.052	0.042	0.042	0.042	0.043	0.042	0.041	0.060	0.048	0.044	0.055	0.031

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