Time-Varying Jump Intensities and the Interconnectedness of the North American Crude Oil Complex

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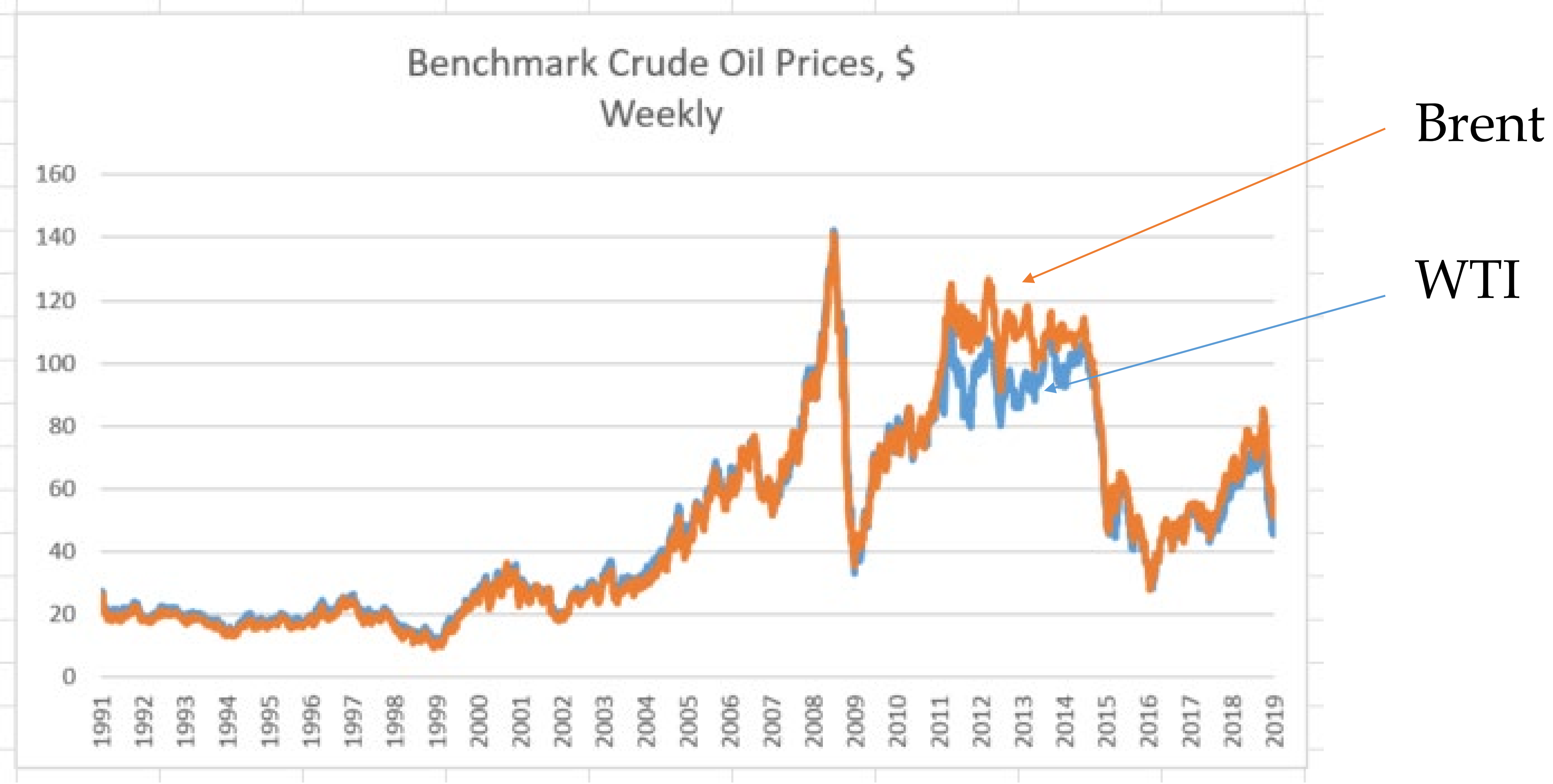
Global Pool Hypothesis

- Adleman (1984)
  "The world oil market, like the world ocean, is one great pool."

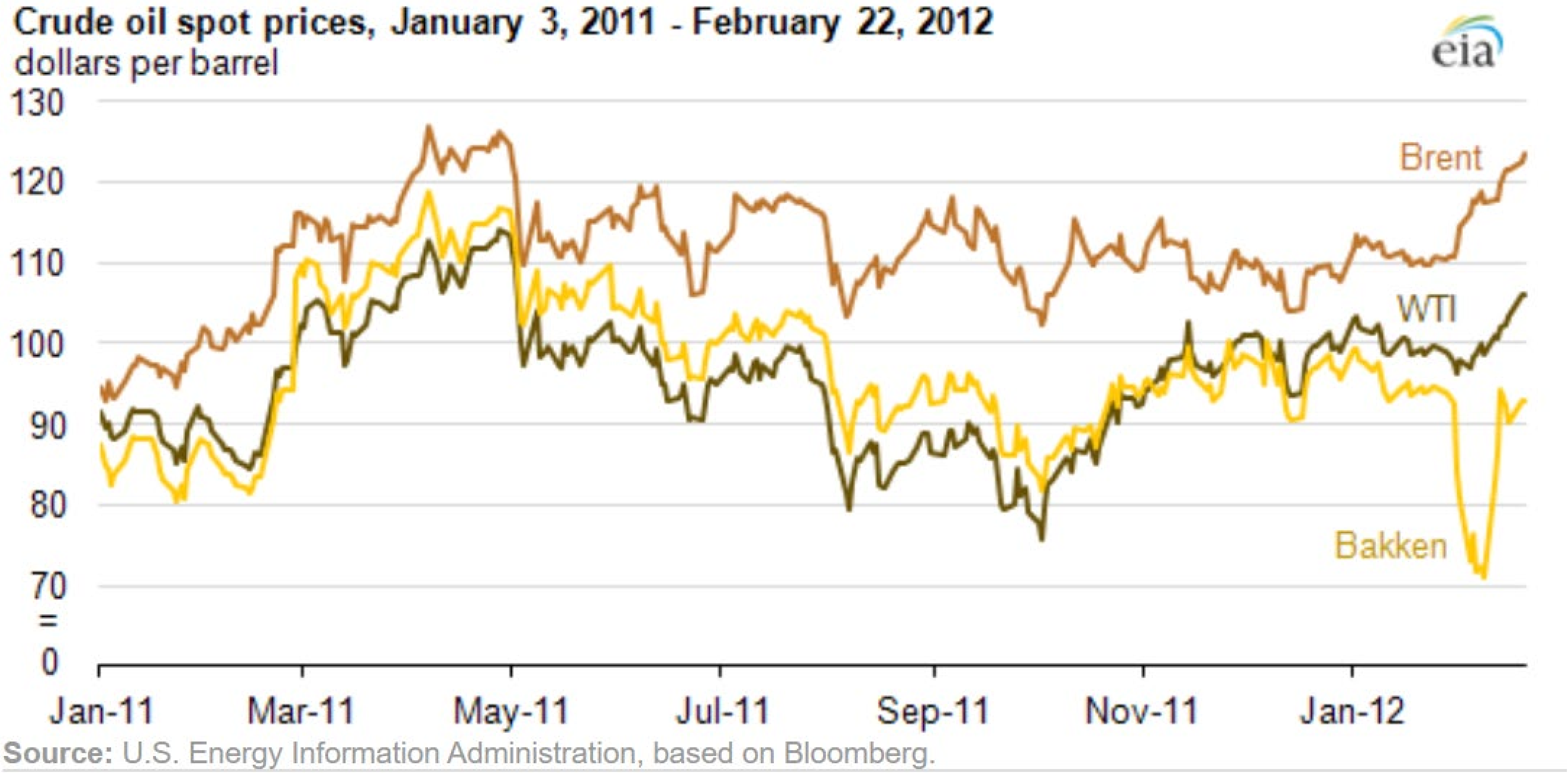
- Large price differentials between crude streams have been observed recently.

- Dar (2019)
  - post-2010, the two markets [*WTI, Brent*] have been witnessing growing divergence, providing evidence that the two markets have moved toward 'regionalization'.

West Texas Intermediate, Brent crude oil



WTI, Brent and Bakken



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Can we quantify the relationship between the crude oil streams, specifically within the North American complex?

Literature Review

- Global Pool Hypothesis
  - Adleman (1984), Ewing and Harter (2000), Hammoudeh *et al* (2008), Fattouh (2010), Wilmot (2013), Dar (2019)

- Discontinous stochastic processes
  - Askari and Krichene (2008), Lee *et al* (2010), Wilmot and Mason (2013); Postali and Pichetti (2006)

- Volatility
  - Bollerslev (1986), Pindyck, R. (2004), Efimova and Serletis (2014)

Methodology

- Utilizing the autoregressive Jump Intensity (*ARJI*) model of Chan and Maheu (2002)

$$R_t = \mu + \sum_{i=1}^{l} \phi R_{t-i} + \sqrt{h_t} z_t + \sum_{k=1}^{n_t} Y_{t.k} \qquad z_t \sim NID(0,1)$$

- The conditional jump size is given as $Y_{t,k} \sim N(\theta, \delta^2)$
- And the number of jumps arriving between *t – 1* and *t*, is described by the discrete counting process, n_t
- And this process is distributed as a Poisson random variable, described by the jump intensity $\lambda_t > 0$

Methodology cont'd

- The process that describes the evolution of the conditional jump intensity must be specified.
- As in Chan and Maheu (2002), an AR(1) process describes the evolution of λ_t such as:

$$\lambda_t = \lambda_0 + \sum_{i=1}^{r} \rho_i \lambda_{i-1} + \sum_{i=1}^{s} \gamma_i \xi_{t-i}$$

Methodology cont'd

- The time series values of $\hat{\lambda}_t$ are obtained, and a GARCH model is constructed.
- Univariate Model

$$\hat{\lambda}_t = c_0 + \varepsilon_t, \quad \text{and} \quad \varepsilon_t \sim N\left(0, h_t\right)$$

- where

$$h_t = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \ldots + \alpha_q \varepsilon_{t-q}^2 + \beta_1 h_{t-1} + \ldots + \beta_p h_{t-p}$$

Methodology cont'd

- Bollerslev (1990) specifies a multivariate GARCH model that has a constant conditional correlations (CCC), with conditional covariance matrix

$$H_t = D_t \Gamma D_t$$

- For example, in the bivariate case

$$D_t = \begin{bmatrix} \sqrt{h_{11t}} & 0 \\ 0 & \sqrt{h_{22t}} \end{bmatrix} \text{ and } \Gamma = \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix}.$$

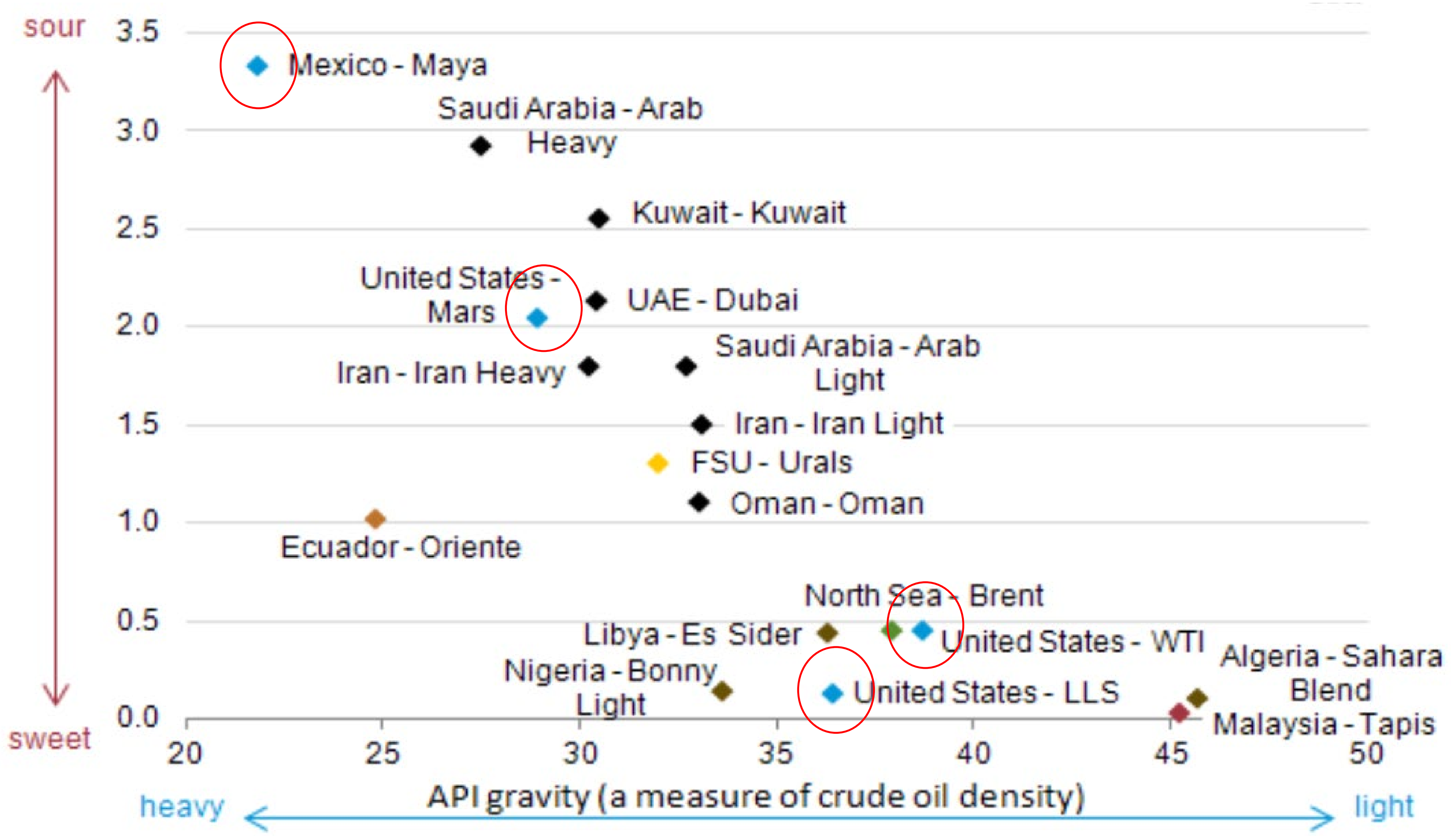
Data

The benchmark *WTI* series along with a mix of secondary blends, across *density* and *Sulphur* content

Table 2: Summary Statistics for Log Crude Oil Price Returns

Blend	ln *WTI*	ln *LLS*	ln *Mars*	ln *Lou. Heavy*	ln *Mex. Maya*
Start	01/05/2000	01/05/2000	01/05/2000	01/05/2000	01/05/2000
End	12/31/2018	12/31/2018	12/31/2018	12/31/2018	12/31/2018
Mean	0.010	0.014	0.016	0.014	0.020
Median	0.090	0.071	0.072	0.102	0.095
Maximum	21.28	15.437	15.431	15.028	13.274
Minimum	-16.550	-18.349	-18.619	-19.060	-18.437
Std. Dev.	2.420	2.356	2.646	2.437	2.285
Coefficient of Variation	220.80%	164.5%	161.9%	169.8%	116.5%
Skewness	-0.04	-0.085	-0.165	-0.168	-0.283
Kurtosis	4.51	3.78	3.65	3.71	4.71
JB Test	4030.7	2836.7	2688.2	2760.6	4469.9
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Count	4763	4763	4763	4763	4763
Crude Characteristics					
API Density	40 *Light*	35.6 *Light*	30.3 *Light*	32.9 *Heavy*	22 *Heavy*
Sulphur content %	0.3 *Sweet*	0.37 *Sweet*	1.91 *Sour*	0.35 *Sweet*	3.3 *Sour*

Crude Oil Blends (*EIA*)



Results: *Stationarity*

Table: Stationarity Tests

Series	Modified ADF test	Lags	KPSS	Lags
Prices				
WTI	-1.529	5	2.29	31
LLS	-1.396	1	2.33	31
Mars	-1.495	1	2.30	31
Lou. Hvy	-1.428	1	2.29	31
Mex. Maya	-1.547	4	2.22	31
Ln Returns				
WTI	-3.732	31	0.0323	31
LLS	-3.473	30	0.0367	31
Mars	-3.529	30	0.036	31
Lou. Hvy	-3.308	30	0.0361	31
Mex. Maya	-7.23	30	0.0336	31

Note: Modified ADF test with ERS critical values-3.48 (1%), -2.89 (5%), -2.57 (10%). Trend.

Results: Jump Diffusion Process (*ARJI*)

Table: ARJI Results

	LLS		West Texas intermediate		Mars		Mex. Maya		Lou. Heavy	
	Constant	ARJI	Constant	ARJI	Constant	ARJI	Constant	ARJI	Constant	ARJI
μ	0.1074 ***	0.0889 ***	0.1149 ***	0.0906 ***	0.1787 ***	0.1408 ***	0.1238 ***	0.1352 ***	0.1134 ***	0.0935 ***
	0.033	0.030	0.032	0.030	0.046	0.043	0.029	0.031	0.035	0.032
ω	0.0221 ***	0.0190 ***	0.0191 **	0.0185 ***	0.0063	0.0129	0.0172 **	0.0164 ***	0.0235 **	0.0019 ***
	0.010	0.007	0.008	0.006	0.011	0.008	0.007	0.006	0.010	0.007
α	0.0499 ***	0.0295 ***	0.0452 ***	0.0280 ***	0.0557 ***	0.0291 ***	0.0455 ***	0.0367 ***	0.0442 ***	0.0288 ***
	0.007	0.005	0.006	0.005	0.007	0.008	0.006	0.005	0.007	0.005
β	0.9344 ***	0.9571 ***	0.9409 ***	0.9590 ***	0.9309 ***	0.9575 ***	0.9384 ***	0.9478 ***	0.9418 ***	0.9591 ***
	0.009	0.007	0.008	0.007	0.009	0.009	0.008	0.007	0.009	0.006
ζ	2.8578 ***	2.9105 ***	3.0600 ***	3.1476 ***	2.2538 ***	2.4169 ***	3.1266 ***	2.9550 ***	3.1263 ***	3.1365 ***
	0.373	0.319	0.401	0.357	0.330	0.298	0.358	0.331	0.418	0.363
η	-0.8883 ***	-0.6302 ***	-1.2451 ***	-0.7761 ***	-0.9096 ***	-0.5988 ***	-1.2078 ***	-1.1648 ***	-1.1474 ***	-0.7660 ***
	0.266	0.208	0.336	0.245	0.256	0.175	0.331	0.263	0.271	0.249
λ	0.0980 ***	0.0417 ***	0.0847 ***	0.0303 **	0.1887 ***	0.0303 *	0.0855 ***	0.0606 **	0.0823 ***	0.0469 ***
	0.033	0.015	0.027	0.015	0.071	0.018	0.023	0.025	0.029	0.017
ρ	.	0.6795 ***	.	0.7524 ***	.	0.8908 ***	.	0.4408 **	.	0.5756 ***
		0.115		0.143		0.065		0.190		0.102
γ	.	0.7373 ***	.	0.6004 ***	.	0.4932 ***	.	0.4496 ***	.	0.8221 ***
		0.196		0.174		0.178		0.149		0.188

Results: GARCH(1,1) Process for $\hat{\lambda}_t$

Table: Univarite GARCH Model on Conditional Jump Intensities

	WTI	LLS	Mars	Mex. Maya	Lou. Heavy
c_0	0.0889 ***	0.1001 ***	0.2065 ***	0.1006 ***	0.0886 ***
	0.0007	0.0007	0.0009	0.0007	0.0006
α_0	0.0038 ***	0.0057 ***	0.0040 ***	0.0031 ***	0.0064 ***
	0.0001	0.0001	0.0001	0.0000	0.0000
α_1	0.8294 ***	0.9402 ***	0.7780 ***	0.6838 ***	1.1734 ***
	0.0260	0.0271	0.0267	0.0188	0.0293
β_1	0.1022 ***	0.0652 ***	0.1474 ***	0.0320 ***	.
	0.0114	0.0084	0.0181	0.0044	
L	5070.6	4354.8	3345.4	6295.4	4418.7
AIC	-10133.2	-8701.7	-6682.8	-12582.8	-8831.5

Note: The standard errors are presented below the coefficients. L is the log-likelihood function. *, **, and * representn the 10%, 5% and 1% level of significance, respectively. n = 4760

Results: Multivariate GARCH model; CCC

		CCC Model							
	i =	WTI		WTI		WTI		WTI	
Coefficient	j =	LLS		Mars		Maya		Lou Heavy	
GARCH Model Parameter Estimates									
ρ		0.8492	***	0.8088	***	0.7493	***	0.8093	***
		0.004		0.005		0.006		0.005	
C_{11}		0.0041	***	0.0031	***	0.0027	***	0.0037	***
		0.000		0.000		0.000		0.000	
C_{22}		0.0059	***	0.0020	***	0.0031	***	0.0063	***
		0.000		0.000		0.000		0.000	
α_{11}		0.6292	***	0.4589	***	0.2942	***	0.5264	***
		0.059		0.043		0.030		0.052	
α_{22}		0.6766	***	0.1574	***	0.3050	***	0.9369	***
		0.062		0.018		0.051		0.075	
β_{11}		0.0792	***	0.2673	***	0.3775	***	0.1468	***
		0.018		0.030		0.030		0.029	
β_{22}		0.0752	***	0.5983	***	0.1082	***	0.0226	***
		0.020		0.044		0.035		0.008	

Implications of Multivariate GARCH model

- The ARJI models fits the data well.
    - Jumps are statistically important in the crude oil markets

- Time varying volatility found in the $\hat{\lambda}_t$ series.

- Based on the results of the CCC estimates, there appears to be a significant degree of correlation among the contemporaneous shocks to the jump intensities, in the series under study.

Future Work

- The CCC garch assumption of time invariant conditional correlation matrix is restrictive.
  - Dynamic conditional correlation (DCC) model, BEKK specification
- Structural breaks
  - The shale oil revolution, experienced in the US, could plausibility be responsible for a break in the models or relationships.
- Breadth of coverage
  - Bakken prices, Canadian prices, other regional prices