WHICH RISK FACTORS DRIVE OIL FUTURES PRICE CURVES? SPECULATION AND HEDGING IN THE SHORT AND LONG-TERM

2018年6月15日 統計数理研究所 オープンハウス

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Introduction

Objective:

- Understand the dynamics of commodity spot and futures prices in terms of interpretable observable factors that influence speculators and hedgers heterogeneously.
  - This is **not attainable** with existing modelling approaches.

Problems:

- Existing approaches adopt a two stage estimation procedure to estimate latent stochastic factors followed by regression relationships in stage two for incorporation of exogenous factors:
  - inappropriate statistical assumptions and regression models.
  - claims and analysis coming from such models speculative at best, see detailed discussion in [1].

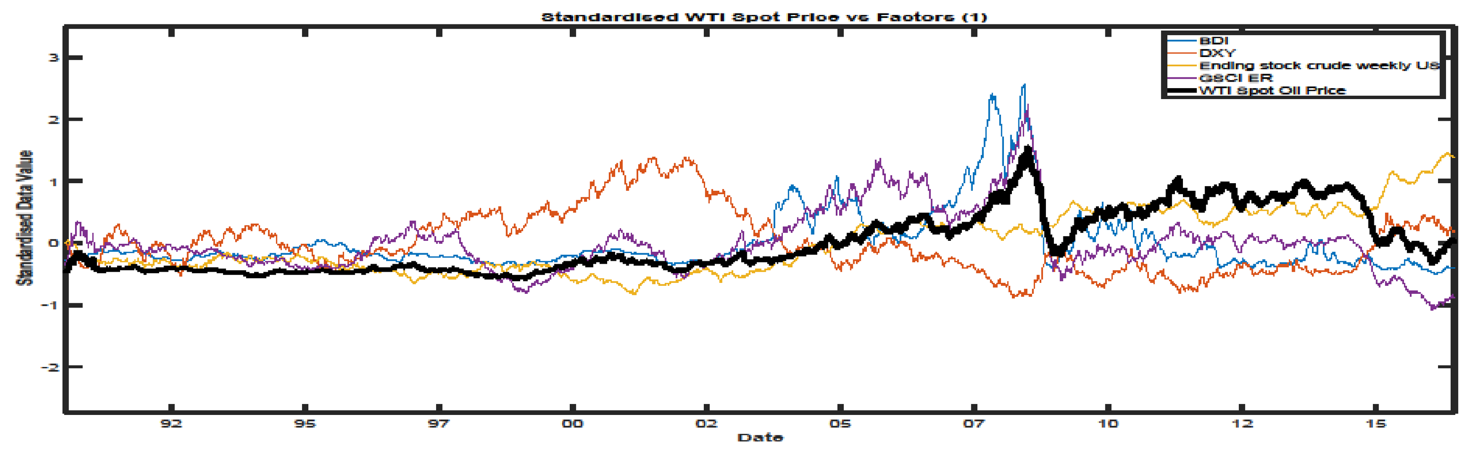
Approach:

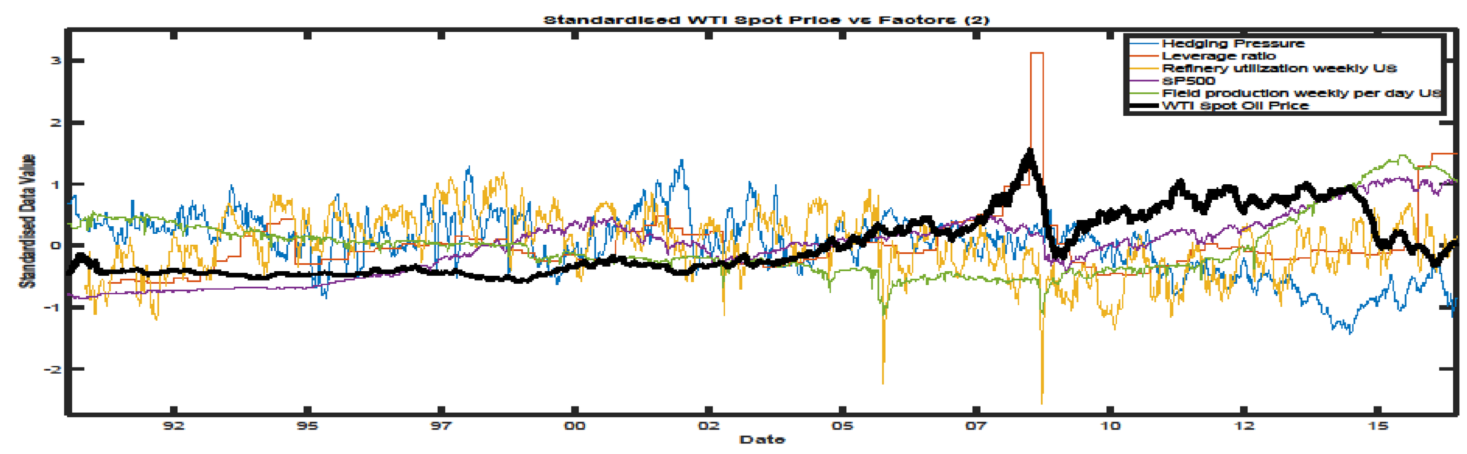
- We develop a novel, consistent estimation framework, named the Hybrid Multi-Factor (HMF) model, which builds on the familiar two-factor model of [2].
- We can obtain closed form futures prices under standard risk neutral pricing formulations, and we can incorporate state-space model estimation techniques to consistently estimate
  - the structural features related to the convenience yield and spot price dynamics (long and short term stochastic dynamics)
  - and also the structural parameters that relate to the influence on the spot price of the observed exogenous factors.
- We investigate the influence of observable factors, such as inventories, production or hedging pressure, on the term structure of crude oil futures prices.

Oil Price Data and Observable Factors

- West Texas Intermediate (WTI) crude oil futures prices traded on the New York Mercantile Exchange (NYMEX).
- Utilise the liquid 1, 5, 9, 13 and 17 month expiry contracts.
- Weekly Wednesday closing prices are retained to match with the weekly release of oil related data from the U.S. Energy Information Administration (EIA).
- The data sample covers the period from 11th July 1990 to 22nd June 2016, i.e. 26 years or 1355 weeks.
- Divide the sample into five equal length blocks of roughly five years in order to provide a more detailed granular analysis.
- Investigate the following 9 observable factors:

Factor	Description
Baltic Dry Index	Composite freighting cost
Dollar Index	Weighted mean of the dollar's relative value
Ending Stocks	Number of barrels of oil in US inventories
GSCI	Weighted average of 24 commodity prices
Leverage Ratio	Tightness of intermediaries' funding constraints
Refinery Utilization	% of operable crude oil distillation units utilized
S&P 500 Index	Weighted index of 500 largest US companies
SPEC Ratio	Net open speculative positions / open interest
US Field Production	Number of barrels of crude oil produced in US





Hybrid Multi-Factor (HMF) Model

Allows for several nested sub-classes of model to be developed, incorporating exogenous covariates through a link function to the stochastic latent spot price dynamic factors:

- in the long term equilibrium price and in the short and long term rates of mean reversion
- lagged, instantaneous and forward looking exogenous covariates.

$$X_t = ln(S_t) = \chi_t + \xi_t \quad (1)$$

$$d\chi_t = -\underbrace{\beta_t}_{\psi_{c1}+\sum_{j=1}^{J}\sum_{k=-K}^{K'}\psi_{1,j}m_{t+k,j}}\chi_t dt + \sigma_\chi dZ_t^\chi \quad (2)$$

$$d\xi_t = (\underbrace{\mu_{\xi,t}}_{\psi_{c2}+\sum_{j=1}^{J}\sum_{k=-K}^{K'}\psi_{2,j}m_{t+k,j}} - \underbrace{\gamma_t}_{\psi_{c3}+\sum_{j=1}^{J}\sum_{k=-K}^{K'}\psi_{3,j}m_{t+k,j}}\xi_t)dt + \sigma_\xi dZ_t^\xi \quad (3)$$

$$\mathbb{E}\left[dZ_t^\chi dZ_t^\xi\right] = \rho_{\chi\xi}dt \quad (4)$$

where $m_{t,j}$ is the value of the observable covariate j at time t, J is the number of covariates considered, and K and K' determine the time period over which the covariates are summed.

Theorem (Futures Price)

The futures price for the HMF model is given by the following expression (see [1]):

$$lnF_{t,T} = e^{-\int\beta_t d\tau}\chi_t + e^{-\int\gamma_t d\tau}\xi_t + B_{0,t}(\tau). \quad (5)$$

where

$$B_{0,t}(\tau) = -\frac{\sigma_\chi^2}{4\beta_t}(e^{-2\int\beta_t d\tau}-1) - \frac{\sigma_\xi^2}{4\gamma_t}(e^{-2\int\gamma_t d\tau}-1) + \frac{\lambda_\chi}{\beta_t}(e^{-\int\beta_t d\tau}-1) - \frac{1}{\gamma_t}(\mu_{\xi,t}-\lambda_\xi)(e^{-\int\gamma_t d\tau}-1) - \frac{\rho_{\chi\xi}\sigma_\chi\sigma_\xi}{(\beta_t+\gamma_t)}(e^{-\int(\beta_t+\gamma_t)d\tau}-1) \quad (6)$$

Filtering and Parameter Estimation via Kalman Filter

Measurement Equation:
Let $y_t(\tau) = lnF_t(\tau)$ and $\tau_i = T_i - t$, where $T_i, i = 1, \ldots, N$ are the maturities of the contract available at time t, and $\epsilon_t(\tau)$ is the observation error at time t.

$$\begin{bmatrix} y_t(\tau_1) \\ y_t(\tau_2) \\ \vdots \\ y_t(\tau_N) \end{bmatrix} = \begin{bmatrix} e^{-\int\beta_t d\tau_1} & e^{-\int\gamma_t d\tau_1} \\ e^{-\int\beta_t d\tau_2} & e^{-\int\gamma_t d\tau_2} \\ \vdots & \vdots \\ e^{-\int\beta_t d\tau_N} & e^{-\int\gamma_t d\tau_N} \end{bmatrix} \begin{bmatrix} \chi_t \\ \xi_t \end{bmatrix} + \begin{bmatrix} B_{0,t}(\tau_1) \\ B_{0,t}(\tau_2) \\ \vdots \\ B_{0,t}(\tau_N) \end{bmatrix} + \begin{bmatrix} \epsilon_t(\tau_1) \\ \epsilon_t(\tau_2) \\ \vdots \\ \epsilon_t(\tau_N) \end{bmatrix} \quad (7)$$

Transition Equation:

$$\begin{bmatrix} \chi_t \\ \xi_t \end{bmatrix} = \begin{bmatrix} 0 \\ \mu_{\xi,t}\Delta t \end{bmatrix} + \begin{bmatrix} e^{-\int\beta_t d\tau} & 0 \\ 0 & e^{-\int\gamma_t d\tau} \end{bmatrix} \begin{bmatrix} \chi_{t-1} \\ \xi_{t-1} \end{bmatrix} + \begin{bmatrix} \eta_t^\chi \\ \eta_t^\xi \end{bmatrix} \quad (8)$$

- Simultaneous optimisation of latent stochastic factors and all static model parameters via Kalman filtering followed by recursive least squares marginal likelihood estimation.

Empirical Results

The parameter link function coefficients for the three Highest AIC Criterion Contributors in each 5 year period are shown in the table below:

	1990-1995			1995-2000			2000-2006			2006-2011			2011-2016		
Covariate	ST Mean Reversion	LT Mean Reversion	LT Trend	ST Mean Reversion	LT Mean Reversion	LT Trend	ST Mean Reversion	LT Mean Reversion	LT Trend	ST Mean Reversion	LT Mean Reversion	LT Trend	ST Mean Reversion	LT Mean Reversion	LT Trend
BDI										-0.009	-0.029				
DXY				-0.193	0.010	-0.032	-0.422	0.021	-0.070	0.009	0.032	-0.028			
End Stocks								-0.037	0.117						
GSCI	-0.042		0.127	0.177	-0.011	0.034						0.191	-0.042	0.054	0.168
Lev Rat	-0.020	0.210	0.053				-0.344	0.017	-0.054				0.011		-0.036
Ref Util		0.172													
SP500	0.046	0.266	-0.129	-0.185	0.008	-0.025	-0.289				0.026	0.045	-0.017	-0.051	0.070
Hedging Pressure															
US Prod										0.002				-0.036	

References

[1] M. Ames, G. Bagnarosa, G. W. Peters, P. V. Shevchenko, and T. Matsui.
Which risk factors drive oil futures price curves? speculation and hedging in the short and long-term.
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[2] E. Schwartz and J. E. Smith.
Short-term variations and long-term dynamics in commodity prices.
Management Science, 46(7):893–911, 2000.