# Commodity Pricing: Evidence from Rational and Behavioral Models

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# Results

- For all 15 commodities we reject the VAR restrictions associated with the long-run model.
- Long-run fundamentals (RAPM) certainly play a role.
- Taking account of heterogenous expectations and investment horizons is important.
- Much greater role played by speculators and rational speculators in particular.

# Theory of Storage - Pindyck (2001)

- The value of all commodities (e.g. agricultural or energy), will be determined by the expectation of market scarcity, reflected in the interaction between current supply and demand.
- Commodities are likely to be sensitive to short-term supply bottlenecks or demand pressures.
- Cash market for immediate purchase and sale and a storage market for inventories of the commodity.
- The price of storage is unobserved, but can be determined from the futures-spot spread, marginal value of storage, i.e., the benefits of holding the physical stock.

- Return from holding a unit of commodity is;

$$\psi_{t,T} + P_{t+T} - P_t \tag{1}$$

- At the same time short a futures contract written on the same underlying asset. Return on the future;

$$F_{t,T} - P_{t+T} \tag{2}$$

- The total return is;

$$\psi_{t,T} + F_{t,T} - P_t \tag{3}$$

- The total return is risk-free and non-stochastic;

$$\begin{aligned} \psi_{t,T} + F_{t,T} - P_t &= r_{t,T} P_t \\ \psi_{t,T} &= P_t(1 + r_{t,T}) - F_{t,T} \\ &= P_t e^{r(t,T)(T-t)} - F_{t,T} \end{aligned} \tag{4}$$

# Rational Asset Pricing Model (RAPM)

- Commodity prices can be defined as the present value of expected future 'payoffs' associated with holding the commodity.
- Commodity prices will change when there is changes in expected futures 'payoffs' and/or changes to the discount factor.

$$P_t = \sum_{i=1}^{\infty} \delta_t^i E_t \psi_{t+i} \tag{5}$$

- with $\delta_t^i = \frac{1}{1+\mu_t}$
- The normal application in equity markets would adopt the cash flows (dividends) as the payoffs.
- Here the benefits that accrue to the holder of a storable commodity, the convenience yield, see Pindyck (1993).

- Drawing on Campbell and Shiller (1989), we take our version of the dividend-price ratio, the percentage net basis, and apply the test restrictions developed by Campbell and Shiller (1989). The percentage net basis is defined as;

$$y_t = \psi_{t-1} / P_t \tag{6}$$

- Long-solution

$$y_t'^L \approx \sum_{j=0}^{\infty} \beta^j E_t(\beta q_{t+j} - \Delta\psi'_{t+j}) \tag{7}$$

# Alternatives: Investment Horizon and Investors

- Speculator - Rational

$$y_t^{\prime SR} \approx \frac{1}{\bar{y}} E_t(q_t) - E_t(\Delta\psi_t') - \frac{1}{\bar{y}} E_t\left(\frac{\Delta P_{t+1}}{P_t}\right) = \frac{1}{\bar{y}}\left(E_t(q_t) - E_t\left(\frac{\Delta P_{t+1}}{P_t}\right)\right) - E_t(\Delta\psi_t') \tag{8}$$

- Speculator - Contrarian

$$y_t^{\prime SC} = \frac{1}{\bar{y}} E_t(q_t) - E_t(\Delta\psi_t') + \frac{1}{\bar{y}} E_t\left(\frac{\Delta P_{t+1}}{P_t}\right) = \frac{1}{\bar{y}}\left(E_t(q_t) + E_t\left(\frac{\Delta P_{t+1}}{P_t}\right)\right) - E_t(\Delta\psi_t') \tag{9}$$

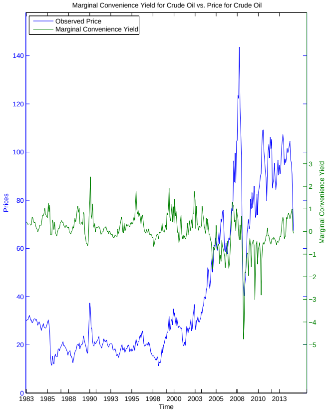
# Recent Empirical Evidence - Crude Oil

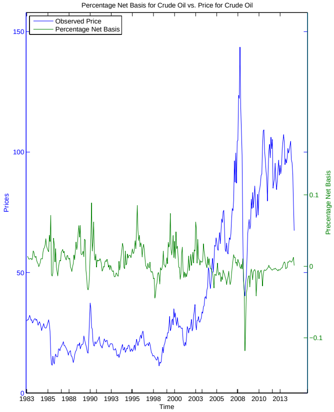
- Sanders and Irwin (2011), Miffre and Brooks (2013) and Brooks *et al.* (2015) all find evidence against speculative effects and consistent with fundamentals-based rational valuation.
- Both Smith (2009) and Kilian and Murphy (2014) find no empirical evidence to indicate that speculation increased oil prices.
- Juvenal and Petrella (2015) and Hamilton (2009a,b) find evidence in favour of speculation as well as economic fundamentals played a significant role in the oil price increase during the 2004-08 period.
- Knittel and Pindyck (2016) find that speculation certainly played a role in the 2004-08 oil price increase, but was not the only contributor of the price increases.

# Data

- 15 commodities covering agriculture, softs, energy and metals.
- Sample where possible covers the period from 1971 to 2014.
- Corn, Oats, Soybeans, Soybean Oil, Wheat, Coffee, Cotton, Lumber, Orange Juice, Natural Gas, Heating Oil, Crude Oil, Copper, Gold and Silver.
- Commodities Research Bureau (CRB)

# Crude Oil


Marginal Convenience Yield for Crude Oil vs. Price for Crude Oil
Observed Price
Marginal Convenience Yield
Prices
Marginal Convenience Yield
Time


Percentage Net Basis for Crude Oil vs. Price for Crude Oil
Observed Price
Percentage Net Basis
Prices
Precentage Net Basis
Time

# Results 1

| | Heating Oil | Crude Oil |
|---|---|---|
| | 1979-2014 | 1983-2014 |
| **Panel A: Unit Root Test** | | |
| $P_t$ | 0.617 | 0.226 |
| $\Delta P_t$ | $-18.856^{***}$ | $-16.419^{***}$ |
| $F_t$ | 0.683 | 0.278 |
| $\Delta F_t$ | $-17.374^{***}$ | $-16.277^{***}$ |
| $\psi_t$ | $-9.526^{***}$ | $-6.864^{***}$ |
| $\Delta\psi_t$ | $-25.843^{***}$ | $-22.392^{***}$ |
| $S(\hat{\rho})$ | $-9.594^{***}$ | $-7.089^{***}$ |
| $S(\bar{\rho})$ | $-9.303^{***}$ | $-7.089^{***}$ |
| $S'(\hat{\mu})$ | $-8.661^{***}$ | $-5.779^{***}$ |
| $S'(\bar{\mu})$ | $-9.527^{***}$ | $-6.815^{***}$ |

# VAR Model 1: Constant Expected Returns

$$y'_t \approx \sum_{j=0}^{\infty} \beta^j E_t(\beta\overline{r} - \Delta\psi'_{t+j}) \tag{10}$$

- The PNB predicts the variable $\phi_t = \beta\overline{r} - \Delta\psi'_t$. We therefore model both as the endogenous variables in VAR;

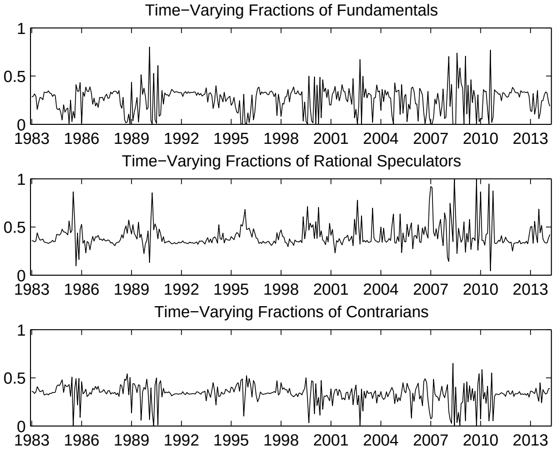
$$\begin{aligned} y'_t &= \gamma_{01} + \sum_{k=1}^{p} \gamma_{11k} y'_{t-k} + \sum_{k=1}^{p} \gamma_{12k}\phi_{t-k} + \varepsilon_{1,t} \\ \phi_{t-1} &= \gamma_{02} + \sum_{k=1}^{p} \gamma_{21k} y'_{t-k} + \sum_{k=1}^{p} \gamma_{22k}\phi_{t-k} + \varepsilon_{2,t} \end{aligned} \tag{11}$$

| | Heating Oil | Crude Oil |
|---|---|---|
| **Panel A: Summary Statistics** | | |
| $\bar{\psi}$ | 0.1086 | 0.0425 |
| $\bar{P}_t$ | 114.62 | 41.55 |
| $\bar{y} = \overline{\psi_{t+1}/P_t}$ | 0.0041 | 0.0051 |
| $\beta = 1/(1+\bar{y})$ | 0.9959 | 0.9949 |
| $\bar{\phi}$ | -0.0038 | 0.0288 |
| **Panel B: VAR Restrictions** | | |
| Wald Test - Model 1 | 112.51*** | 56.92*** |
| Wald Test - Model 2 | 247.48*** | 108.22*** |
| Wald Test - Model 3 | 142.66*** | 79.82*** |
| Wald Test - Model 4 | 140.85*** | 72.44*** |
| Wald Test - Model 5 | 157.17*** | 80.30*** |
| Wald Test - Model 6 | 158.98*** | 76.38*** |

# Results 3: Individual versus Heterogenous Agent Models (with constant discount rate)

| | Long-Run Rational | | | Short-run Rational | | | Short-run Contrarian | | | Heterogenous Agent | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VR | $\rho$ | $R^2$ | VR | $\rho$ | $R^2$ | VR | $\rho$ | $R^2$ | VR | $\rho$ | $R^2$ |
| Heating Oil | 2.430 | 0.495 | 0.572 | 1.793 | 0.745 | 0.197 | 2.312 | -0.136 | 0.209 | 1.217 | 0.890 | 0.793 |
| Crude Oil | 3.304 | 0.708 | 0.569 | 1.830 | 0.619 | 0.033 | 2.737 | -0.030 | 0.254 | 1.178 | 0.770 | 0.607 |

# Crude Oil - Heterogenous Agent Weights



# Results Summary

- Consistent rejection of the VAR restrictions associated with the long-run model.
- Taking account of heterogenous expectations and investment horizons is important.
- Long-run fundamentals (RAPM) certainly play a role.
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