Exploration Activity, Long Run Decisions, and the Risk Premium in Energy Futures

Alexander David

Haskayne School of Business
University of Calgary

June 25, 2014

Exploration Activity, Long Run Decisions, and the Risk Premium in Energy Futures

Alexander David

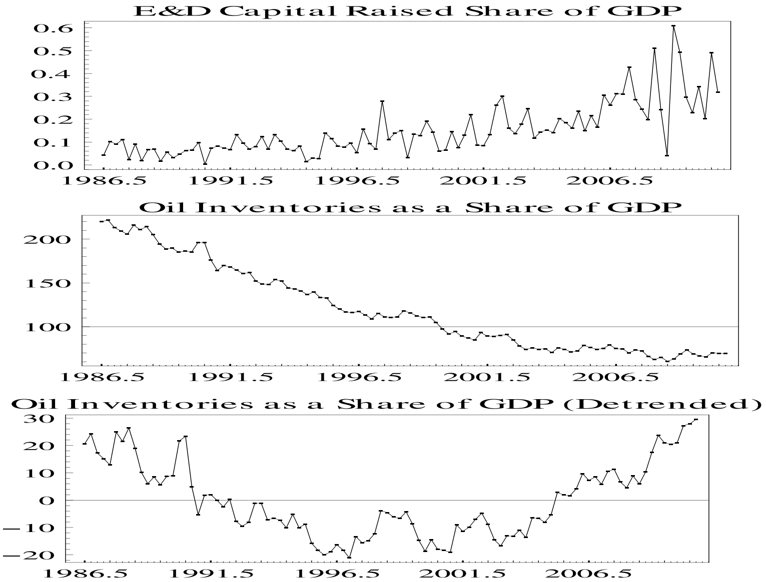
Haskayne School of Business
University of Calgary

June 25, 2014

Exploration Activity

- Recent years have seen the development of increasingly sophisticated technologies for the extraction of natural resources such as hydraulic fracturing through large scale investment
- At the same time, futures curve has turned from being predominantly being downward sloping (backwardation) to predominantly positive sloping (contango)
- **Question of Paper:** Is investment activity related to futures slope? Does it affect risk premiums

Two Economic Variables That Might Explain Oil Futures



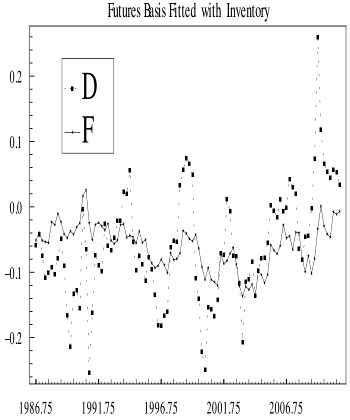
What Explains the Futures Relative Basis?

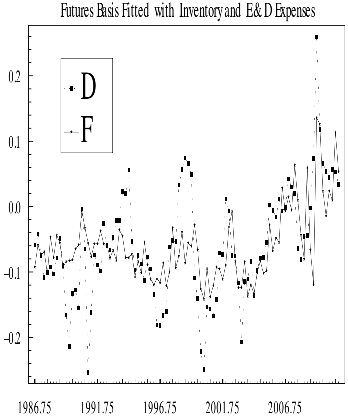
No.	α	β_1	β_2	R^2
1.	-6.36	0.209		0.103
	[-4.382]*	[1.986]*		
2.	-11.203		0.106	0.179
	[-6.095]*		[4.673]*	
3.	-10.483	0.147	0.912	0.228
	[7.885]*	[2.405]*	[3.859]*	

$$\text{Rel.Basis}(t) = \alpha + \beta_1(t)\,\text{Inv./GDP}(t-1) + \beta_2\,\text{New Capital/GDP}(t-1) + \epsilon(t)$$

- Both short-run (inventory) and long-run (E&D) affect the basis
- **Surprisingly** Latter is more important.
- Storage models: Kaldor (1939), Working (1948), Deaton and Laroque (1982), Routledge, Seppi and Spatt(2000) focus on former
- Also obtain similar results for natural gas futures

Futures Relative Basis, Inventory and New Capital for E&D





- E&D helps to explain the upward spikes more than the downward spikes

Predicting Oil Roll Excess Returns with Economic Variables

No.	α	β_1	β_2	R^2
1.	1.372	-0.635		0.056
	[0.298]	[-1.951]*		
2.	12.875		-0.251	0.058
	[2.055]*		[-2.588]*	
3.	10.645	-0.535	-0.213	0.096
	[1.826]*	[-1.619]*	[-2.285]*	

$$\text{Roll Return}(t) = \alpha + \beta_1(t)\,\text{Inventory}(t-1) + \beta_2\,\text{New Capital Share}(t-1) + \epsilon(t)$$

The roll return is defined as:

$$\begin{aligned} \text{Roll Return}(t) &= -\left(\frac{S(t+4) - F(t)}{F(t)}\right) && \text{If } F(t) > S(t) \\ &= \left(\frac{S(t+4) - F(t)}{F(t)}\right) && \text{If } F(t) < S(t), \end{aligned}$$

where $F(t)$ is the 1-year futures prices and $S(t)$ is the spot price of WTI oil in Cushing, Oklahoma.

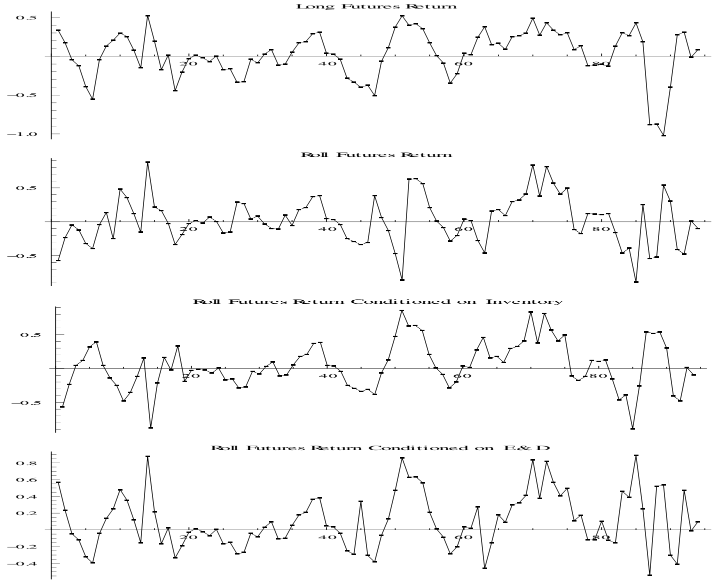
Statistics of Excess Returns on Alternative Rolling Strategies on Oil Futures

Strategy	Mean	Sharpe Ratio	Skewness
Long Futures	0.022	0.362	-0.982
Unconditional Roll	0.021	0.061	0.067
Roll Conditioned on Inventory	0.042	0.318	0.059
Roll Conditioned on E&D Capital	0.109	0.333	0.460

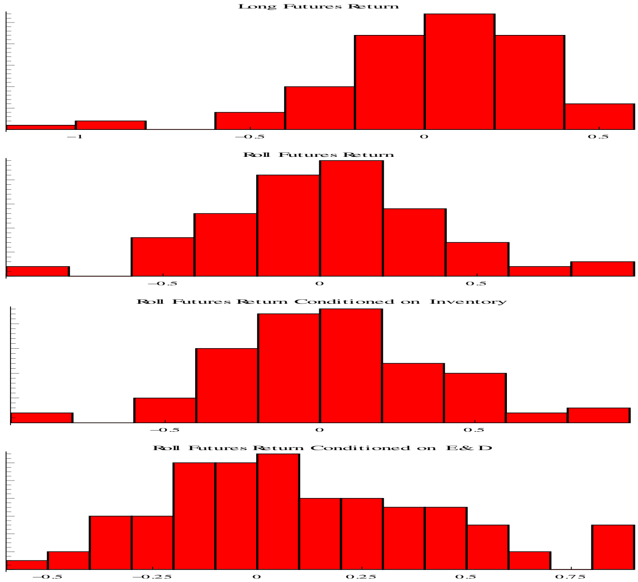
The roll return conditioned on a variable x is defined as:

$$
\begin{aligned}
\text{Roll Return}(t) &= -\left(\frac{S(t+4)-F(t)}{F(t)}\right) && \text{If} \quad x > \bar{x} \\
&= \left(\frac{S(t+4)-F(t)}{F(t)}\right) && \text{If} \quad x < \bar{x},
\end{aligned}
$$

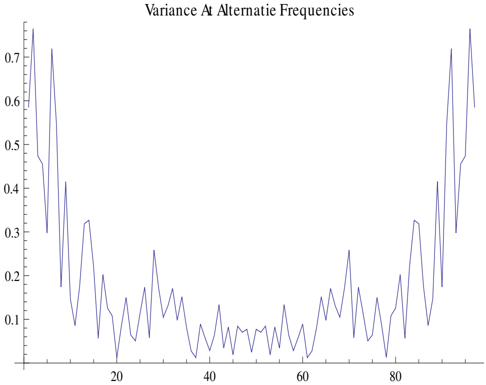
Returns of Roll Strategies



Distribution of Returns on Roll Strategies



Short-Run and Long-Run Risk In Futures Basis



What's surprising?

- Low frequency component (long-run risk) and high frequency component are both important.
- Business cycle frequency (2-4 years is not). Suggests that commodities pricing cycle is different from business cycle.

Optimal Extraction Models and Storage Models

- Existing models of resource extraction have no storage [e.g. Pindyck (1980), Litzenberger and Rabinowitz (1995), Carlson, Khokker and Titman (2007), Cassasus, Collin-Dufresne, and Routledge (2008), Kogan, Livdan and Yaron (2008)]
- Models with inventory do not have optimal resource extraction [e.g. Deaton and Laroque (1992) and Routledge, Seppi and Spatt (2000)]. storage model: owner of resource can sell it at strategic points of time, in particular in periods of shortages
- None of these models have exploration activity.
- Here we provide the analysis of a model with production, storage and exploration.

Elements of the Model

- The demand function for the resource at time t is $q_t = f(S_t, \epsilon_t)$. We set $\epsilon_0 = 0$, and $\epsilon_1 = \epsilon$. The inverse demand function is $s = f^{-1}(q_t; \epsilon_t)$.
- Pricing kernel of economy is related to energy shocks

$$M_1 \; = \; M_0 \cdot \exp(-r - \sigma_M \, \epsilon).$$

- Resource is of varying quality. Extraction costs across grades of resources are uniformly distributed $x \in [0, \bar{x}]$.
- Resource that is not extracted in period 0 is available for extraction in period 1.
- Extraction costs are related to amount of capital in industry by function $g(K) = \gamma_0/(\gamma_1 \, K)$. In periods where there is low capital production becomes uneconomical.
- New Capital: $K_1 = (1 - \delta) \, K_0 + I_0$
- Timing: The investment choice is made *before* any extraction decisions are made.

The Plant's Optimal Extraction Decision

- Firm's objective

$$\begin{aligned}\pi_0 &= \max_{I_0>0} \max_{x_0^e \in [0,\bar{x}]} \max_{Z_1 \in [0, \frac{x_0^e}{\bar{x}} R_0 + Z_0]} S_0 \left[\frac{x_0^e}{\bar{x}} R_0 + Z_0 - Z_1 \right] \\ &- 0.5 \frac{(x_0^e)^2}{\bar{x}} g(K_0) R_0 - P_0 I_0 \\ &+ E^Q \left[e^{-(r+u)} \tilde{S}_1 Z_1 \right] + \left(\int_{x_0^e}^{\bar{x}} C(x\, g(K_1) | Y_0)\, dx \right) \frac{R_0}{\bar{x}},\end{aligned}$$

- Optimal extraction choice of firm x satisfies:

$$\begin{aligned}S_0 - x_0^e\, g(K_0) &= C(x_0^e\, e^{g(K_1)} | Y_0), \text{ if } 0 < x_0^e < \bar{x}, \\ x_0^e &= 0 \text{ if } s(0)\, g(K_0) < C(0|Y_0), \\ x_0^e &= \bar{x} \text{ if } s(\bar{x})\, g(K_0) - \bar{x} > C(\bar{x}|Y_0),\end{aligned}$$

- The call option is American with an endogenous stock price, which depends on firm level decision on investment and the optimal choices of all plants on extraction

The Firm's Optimal Inventory Decision

- Inventory can be used to take advantage of price spikes
- Optimal inventory satisfies:

$$
\begin{aligned}
-S_0 + e^{-(r+u)} E^Q[S_1] \quad &= \quad 0 \text{ if } 0 < Z_1 < \frac{x^e}{\bar{x}} R_0 + Z_0, \\
&< \quad 0 \text{ if } Z_1 = 0, \\
&> 0 \quad \text{ if } Z_1 = \frac{x^e}{\bar{x}} R_0 + Z_0.
\end{aligned}
$$

Linear Demand and Lognormal Shocks

- Specializing to the linear demand case: $q_0 = a - b\,S_0$, and $q_1 = a \cdot e^{m+\sigma\,\epsilon} - b\,S_1$,
- Equilibrium at date 1 now requires:

$$\frac{1}{\bar{x}}\left(S_1/g(K_1) - x_0^e\right) R_0 + Z_1\,e^{-u} = a\,e^{\mu+\sigma\,\epsilon} - b\,S_1.$$

- Solving for prices

$$\begin{aligned} S_0 &= 1/b\left(a + Z_1 - Z_0 - \frac{x_0^e}{\bar{x}} R_0\right), \\ S_1 &= \frac{a\,e^{\mu+\sigma\,\epsilon} + \frac{x_0^e}{\bar{x}}\,R_0 - Z_1\,e^{-u}}{b + \frac{R_0}{\bar{x}\,g(K_1)}}. \end{aligned}$$

Model Basis, Firm's Decision, and Expected Returns

- Futures Price:

$$F_0 = E^Q[s(Q_1;\epsilon)] = \frac{a\, e^{\mu - \sigma_M \sigma + 0.5\sigma^2} + \frac{x_0^e}{\bar{x}} R_0 - Z_1\, e^{-u}}{b + \frac{R_0}{\bar{x}\, g(K_1)}}.$$

- Comparative statics make sense: lower capital, higher extraction costs, less future supply, imply higher future price.
- Risk Premium:

$$\frac{E[S_T] - F_0}{F_0} = \frac{a\, e^{\mu + 0.5\,\sigma^2} - e^{\mu - \sigma_m \sigma + 0.5\,\sigma^2}}{a\, e^{\mu - \sigma_m \sigma + 0.5\,\sigma^2} + \frac{x_0^e}{\bar{x}} R_0 - Z_1\, e^{-u}}$$

- In addition to $-\sigma_M\,\sigma$, risk premium depends on firm's investment policy through its effect on the firm's production and inventories
- These variables are endogenous and in equilibrium are related to the firm's investment policy

Extraction Option Value and Optimal Inventory

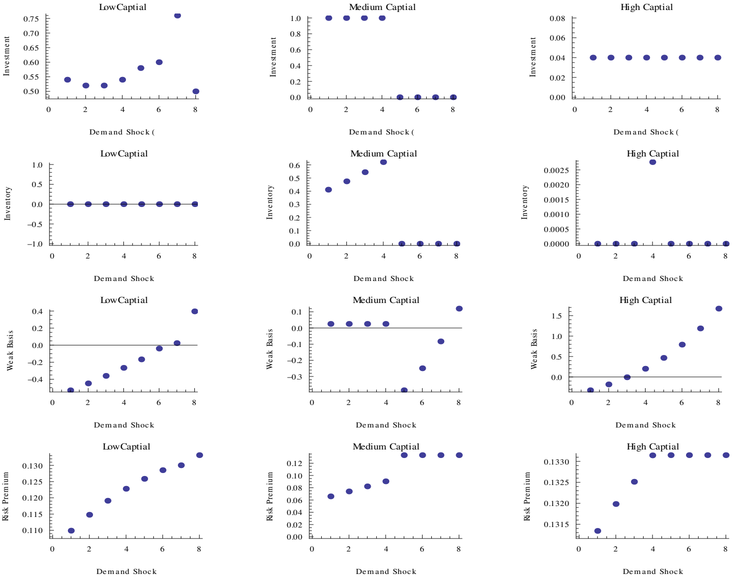
- Call option value:

$$
\begin{aligned}
C(x\,g(K_1)|Y_0) &= \frac{a\,e^{-r}}{D}\left[e^{(\mu-\sigma_M\,\sigma+0.5\,\sigma^2)}N(-d_1^s) - kN(-d_2^s)\right], \\
d_1^s &= \frac{\log(k^s) - m - \sigma_M\,\sigma - \sigma^2}{\sigma};\ d_2^s = \frac{\log(k^s) - m -}{\sigma} \\
k^s &= \frac{1}{a}\left(D\,x\,g(K_1) - \frac{x_0^e}{\bar{x}}\,R_0 + Z_1\,e^{-u}\right); \\
D^s &= b + \frac{R_0}{\bar{x}\,g(K_1)}.
\end{aligned}
$$

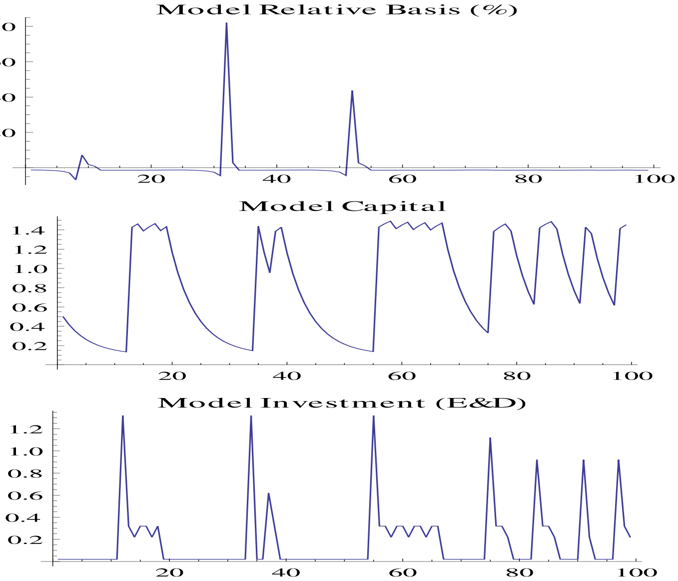
- Inventory:

$$
\begin{aligned}
Z_1(x_0^e) &= \frac{e^{r+u}(-a + \frac{x^e}{\bar{x}}R_0 + Z_0)(b\,g(K_1)\bar{x} + R_0) + b\,g(K_1)\bar{x}(a\,e^{\mu-\sigma_M\,\sigma+0.5\sigma^2}}{e^{r+u}(b\,g(K_1)\bar{x} + R_0)\ +\ e^{-u}\,b\,g(K_1)\bar{x}} \\
&= 0\ \text{ if }\ s(x_0^e|Z_1 = 0) > e^{-(r+u)}F(x_0^e|Z_1 = 0) \\
&= \frac{x}{\bar{x}}\,R_0\ \text{ if }\ s(x_0^e|Z_1 = \frac{x_0^e}{\bar{x}}\,R_0 + Z_0) < e^{-(r+u)}F(x_0^e|Z_1 = \frac{x_0^e}{\bar{x}}\,R_0 + Z_0),
\end{aligned}
$$

Optimal Decisions, Basis, and Risk Premium



Model Relative Basis, Capital and Investment (2 Regime Model for Demand Shocks)



Roll Returns in Model (2 Regimes)

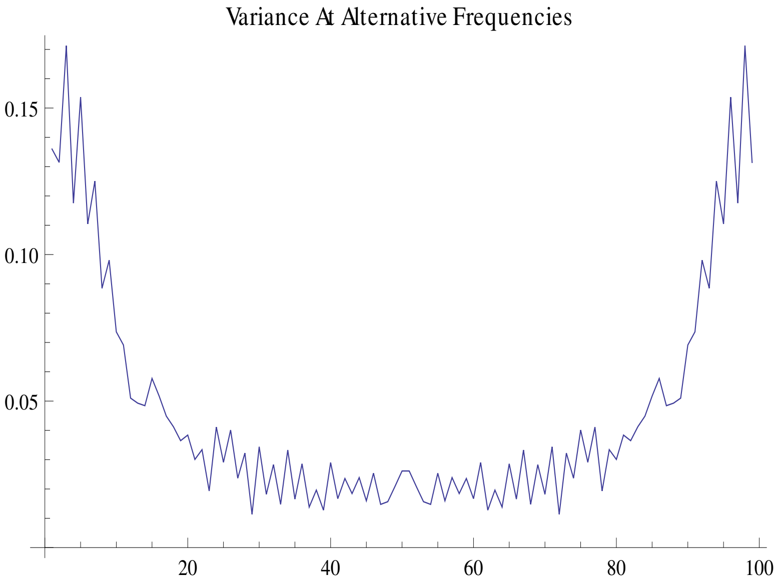
Strategy	Mean	Sharpe Ratio	Skewness
Long Futures	0.001	0.000	-0.55
Unconditional Roll	0.000	0.000	-0.67
Roll Conditioned on Investment	0.065	0.213	0.051

$$
\begin{aligned}
\text{Roll Return}(t) &= -\left(\frac{S(t+4)-F(t)}{F(t)}\right) && \text{If} \quad x > \bar{x} \\
&= \left(\frac{S(t+4)-F(t)}{F(t)}\right) && \text{If} \quad x < \bar{x},
\end{aligned}
$$

where x is the level of investment in the model.

- Long futures return is close to 0. Not surprising, since we have assumed risk neutrality
- We get a 6.5 percent return when the roll is conditioned on investment. Why? The model investment predicts the futures basis

Model Short and Long Run Risk Decomposition



Conclusion

- We build a model of optimal choice of inventory, extraction, and exploration of resources by energy firms
- Decisions are driven by demand shocks
- Since thee are unobservable by the econometrician, she can use optimal decisions to back out firm's risk premiums
- Model helps to understand relation in data between investment, futures basis, and risk premium