Demand Effects and Speculation in Oil Markets: Theory and Evidence

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Introduction

- Is there a long-run stable relationship between the price of crude oil and inventories? Should there be?
- Currently there is no agreement on either question (Fattouh et al. 2012, Hamilton 2009, Murphy and Kilian 2012, Singleton 2012)
- Our extension of the canonical commodity storage model predicts a stable relationship between price, inventories, supply and demand
- Our results in this paper show that U.S. oil market monthly data are consistent with the model's predictions

Theoretical Results (Existing Model, New Application)

- A dynamic, rational expectations model of commodity storage: stable relationships among variables
- The key is demand for oil and its interaction with the supply regime:
  - When supply is unrestricted, demand growth will cause price to rise only temporarily, and inventories should **drop**
  - When supply is restricted, demand growth will cause a persistent rise in price, and inventories should **rise**

Empirical Results (This Paper)

- Monthly series of crude oil supply, demand, inventories, and price; cannot reject a unit root for any of them
- Therefore the model's predicted stable relationship translate empirically to predicted cointegrating vectors among these variables
- We show that these vectors exist in the data, and that the signs of coefficients in the estimated cointegrating equations are consistent with the model's predictions

Theory: A Commodity Storage Model

- We write a theoretical model of the oil market:
  - Extension of canonical commodity storage model à la Deaton and Laroque (1992, 1996)
  - We introduce growth dynamics into the canonical model
  - Model accommodate both stationary and non-stationary stochastic processes
  - Focus on intermediaries: how does their behavior change?
- Important features:
  - Supply of oil is either restricted (increases with technology development) or flexible (accommodates demand shocks fully)
  - Cost of storage is positive and fixed

An Extended Commodity Storage Model

- Oil availability A_t: amount of oil that can potentially be consumed at time t

$$A_t = X_{t-1} + Z_t,$$

- Where X_{t-1} is oil stored from last period, Z_t oil extracted this period (supply)
- Inverse demand function for oil:

$$P_t = P(Q_t, Y_t)$$

- Where $Q_t = A_t - X_t$ is consumption, Y_t is an income variable
- Assume only ratio of consumption to income matters:

$$P_t = P(Q_t, Y_t) = P(\frac{Q_t}{Y_t}, 1) = p(q_t)$$

- Where lowercase letters denote variables normalized by Y_t ("effective" variables)

Demand: Two Alternative Income Processes

- A simple AR(1) process:

$$\frac{Y_{t+1}}{\overline{Y}_{t+1}} = \left(\frac{Y_t}{\overline{Y}_t}\right)^{\rho} e^{\varepsilon_{t+1}},$$

where $\varepsilon_{t+1} \sim N(0, \sigma_\varepsilon^2)$ is an iid shock, and $\overline{Y}_t$ is trend income, increasing over time at rate $\overline{\mu} > 0$

- Alternative assumption: income is subject to growth shocks

$$Y_{t+1} = e^{\mu_{t+1}} Y_t,$$

such that

$$\mu_{t+1} = (1-\phi)\overline{\mu} + \phi\mu_t + v_{t+1},$$

where $\phi \in (0,1)$ is a persistence parameter and $v_{t+1} \sim N(0, \sigma_v^2)$ is an iid shock.

Supply: Two Alternative Regimes

- Supply in our model is non-stochastic
- Under a "restricted" regime, it grows at the trend income rate $\overline{\mu}$:

$$Z_{t+1} = \widetilde{Z}\overline{Y}_t$$

  where $\widetilde{Z}$ is a capacity parameter
- Trend income $\overline{Y_t}$ captures the effects of technological progress:
  - Global ratio of oil production to known reserves has been actually dropping since 1980, currently below 2%.
- Under a "flexible" regime supply fully accommodates demand shocks:
  - AR(1) shocks:

$$Z_{t+1} = \widetilde{Z}\overline{Y}_t \left(\frac{Y_t}{\overline{Y}_t}\right)^{\rho}$$

  - Growth shocks:

$$Z_{t+1} = \widetilde{Z}e^{(1-\phi)\overline{\mu}+\phi\mu_t}Y_t$$

Determination of Storage

- Storage X_t and equilibrium price P_t are determined together in equilibrium:

$$X_t \geq 0 \Leftrightarrow P_t = \beta E_t[P_{t+1}] - C$$

where $\beta = 1/\left(1+r\right)$ is the discount factor, $r > 0$ is the exogenously given interest rate, and $C > 0$ denotes per barrel cost of storage

- Equilibrium price P_t must be such that there is no incentive to increase or decrease X_t.
- Alternatively, there could be a stockout:

$$X_t = 0 \Leftrightarrow P_t > \beta E_t[P_{t+1}] - C$$

- In a stockout the storage non-negativity constraint is binding
- The model therefore has to be solved numerically

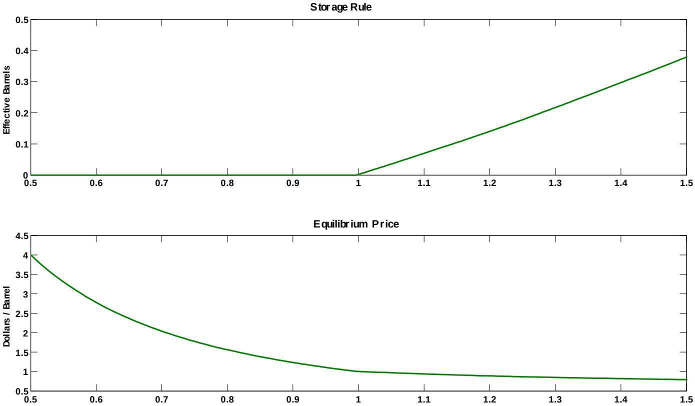
Model Equations

$$
\begin{aligned}
a_{t+1} &= (x_t + z_{t+1}) / e^{\mu_{t+1}}, \\
\frac{Y_{t+1}}{\overline{Y}_{t+1}} &= e^{\mu_{t+1} - \overline{\mu}} \frac{Y_t}{\overline{Y}_t}, \\
\mu_{t+1} &= (1 - \varphi)\overline{\mu} + \varphi \mu_t + v_t, \\
(a_t - x_t)^{-\gamma} &= \beta E_t [P_{t+1}] - C.
\end{aligned}
$$

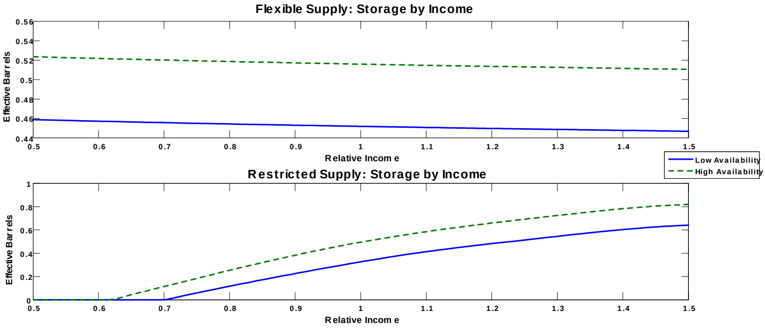
The Rational Expectations Equilibrium

- Under all four sets of assumptions, equilibrium maintains classic features:
  - Storage rises with effective availability
  - Price declines with effective availability
- We can also see the effect of **income growth** on storage
- Where supply is **unrestricted**:
  - Agents calculate that supply will quickly catch up with demand $\implies P > E[P]$
  - Storage will decrease, flooding the market with extra oil, mitigating price increase
- Where supply is **restricted:**
  - There is no prospect for supply to accommodate $\implies P < E[P]$
  - Storage will increase, withdrawing oil from the market, exacerbating price rise

Effect of Availability on Storage Choice and Price



Effect of Income and Availability on Storage Choice



Predictions of the Model:

- The model solution provides a description of a stable equilibrium, even in the presence of growth shocks.
- This implies that a stable relationship between supply, demand, stocks, and price should be present in the data.
- If these series are I(1), then we should be able to find a stationary cointegrating vector.
- Moreover, there should be different cointegrating vectors for periods with restricted vs. unrestricted supply.

Data Description

- All series are monthly (1931/1 - 2011/12) and pertain to the U.S.
- Oil supply: crude oil production (EIA)
- Oil demand: index of overall industrial production (Federal Reserve)
- Oil stocks: commercial inventories of crude oil (EIA)
- Oil price: composite price series of Texas and Oklahoma oil
- We split the series at 1972/12, since our previous work shows a break in both persistence and volatility in either 1972 or 1973.
- We test all series, and cannot reject a unit root in any of them (DF-GLS, at 5%)

Figure 3: 1920/1 - 1972/12

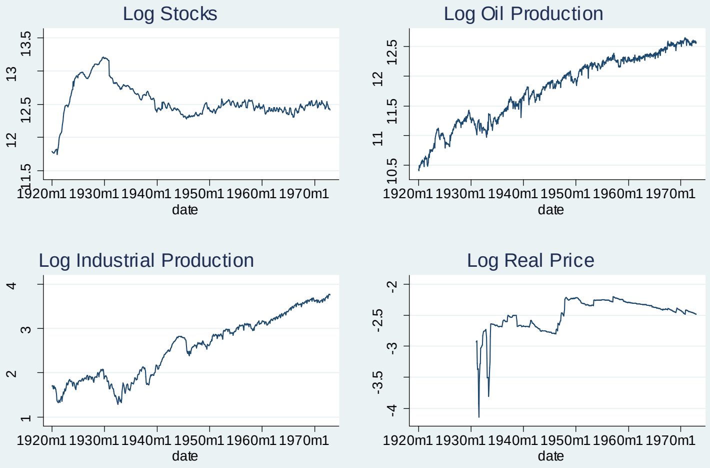
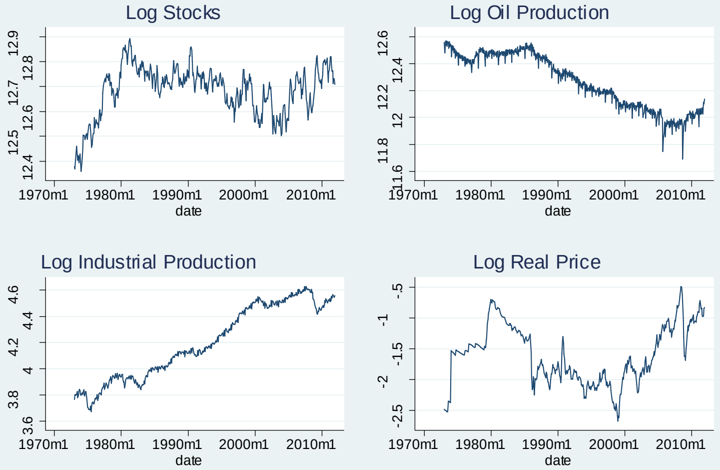


Figure 4: 1973/1 - 2011/12



Johanssen Tests for the Existence of Coinegration Vectors

	Column I		Column II	
Period	1931/5 - 1972/12		1975/1 - 2011/12	
Coinegrating Rank	0	1	0	1
Trace Statistic	98.89***	28.86	54.70***	31.93**
5% Critical Value	47.21	29.68	47.21	29.68
1% Critical Value	54.46	35.65	54.26	35.65
Obs.	500		444	
Differenced Lags	3		1	

Tests include a constant and seasonal dummies. Number of lags chosen by HQ information criterion. (***) denotes that the trace statistic for the applicable rank is larger than the 1% critical value. (**) denotes that the trace statistic for the applicable rank is larger than the 5% critical value.

Long-Run Relationships of Stocks, Production, Demand, and Price

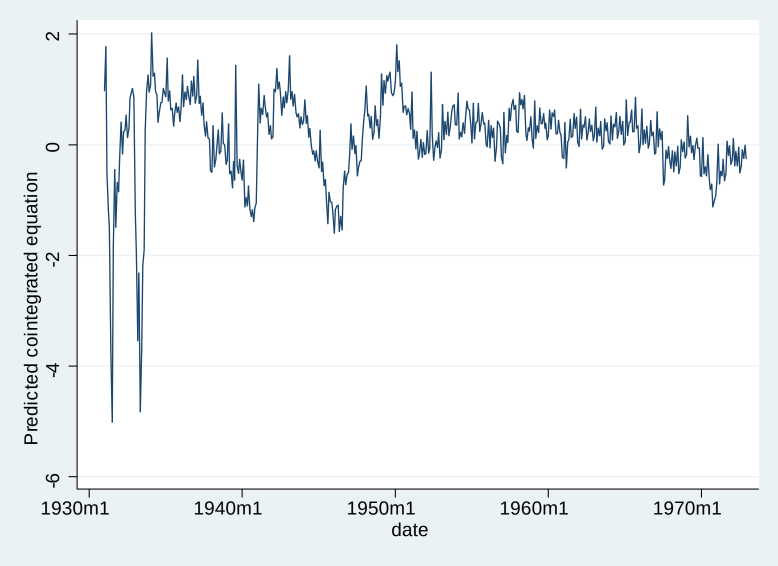
	Column I	Column II
Period	1931/5 - 1972/12	1975/1 - 2011/12
ln $Stocks_t$	1	1
ln $Oil\_Production_t$	-6.80*** (1.12)	-1.02*** (0.27)
ln $Indutrial\_Production_t$	3.58*** (0.68)	-0.65*** (0.20)
ln $Price_t$	3.98*** (0.47)	-0.10** (0.04)
Obs.	500	444
Differenced Lags	3	1
χ^2(p-value)	75.54 (<0.0001)	18.27 (0.0004)

Data sources: see text. Three asterisks (***) denote significance at the 1% level, two asterisks(**) denote significance at the 5% level. Standard errors are shown in parentheses. See text for definition of variables. All regressions include a constant and seasonal dummies (not shown).

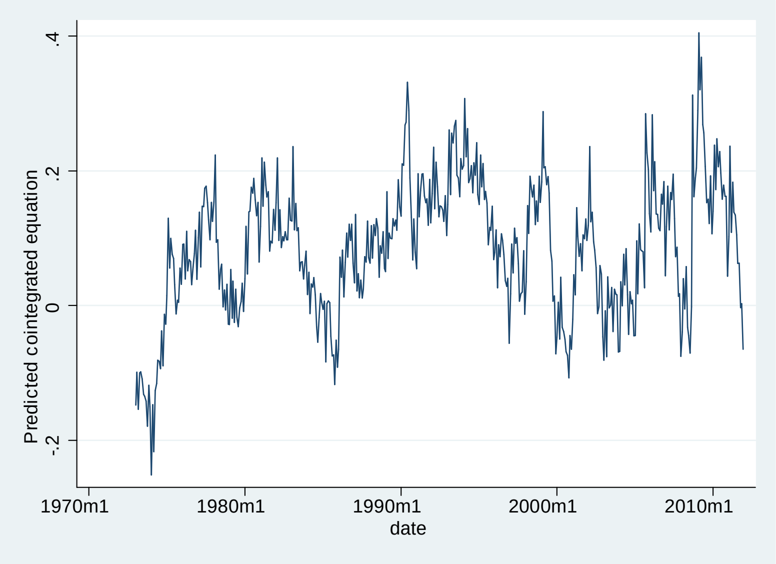
Discussion of Results

- The existence of a stationary framework for the U.S. oil market seems consistent with the data:
  - Stable long-run relationships between the main variables do appear in monthly data
  - Signs of coefficients in estimated cointegration equations consistent with model's predictions
    - Before 1973/1 stocks **decrease** as income and price increase
    - After 1975/1 stocks **increase** as income and price increase
    - In both periods stocks decrease as supply increases.
- We can reject the null of I(1) for both cointegrating vectors
- These results are robust to changing lag length, beginning and end months

Estimated Cointegrating Relationship 1931/1 - 1972/12



Estimated Cointegrating Relationship 1973/1 - 2011/12



Robustness Check: Long-Run Relationships of Stocks, Production, Demand (Excluding Price)

	Column I	Column II
Period	1931/5 - 1972/12	1975/1 - 2011/12
ln $Stocks_t$	1	1
ln $Oil\_Production_t$	-2.22*** (0.60)	-1.35*** (0.33)
ln $Indutrial\_Production_t$	1.47*** (0.40)	-0.86*** (0.25)
Obs.	500	444
Differenced Lags	3	1
χ^2(p-value)	13.86 (0.001)	16.93 (0.0002)

Data sources: see text. Three asterisks (***) denote significance at the 1% level, two asterisks(**) denote significance at the 5% level. Standard errors are shown in parentheses. See text for definition of variables. All regressions include a constant and seasonal dummies (not shown).

Robustness Check: Global Long-Run Relationships

	Column I	Column II
Period	1975/4 - 2011/12	1975/1 - 2011/12
ln OECD_Stocks$_t$	1	1
ln World_Oil_Prod$_t$	0.56*** (0.18)	-
ln Non_Opec_Oil_Prod$_t$	-	0.02 (0.15)
ln OECD_Ind_Prod$_t$	-0.65*** (0.08)	-0.34*** (0.07)
ln Price$_t$	-0.02 (0.02)	-0.01 (0.02)
Obs.	441	441
Differenced Lags	2	2
χ^2(p-value)	196.80 ($<$0.0001)	87.76 ($<$0.0001)

Data sources: see text. Three asterisks (***) denote significance at the 1% level, two asterisks(**) denote significance at the 5% level. Standard errors are shown in parentheses. See text for definition of variables. All regressions include a constant and seasonal dummies (not shown).

Conclusion

- We build on our extended storage model which features non-stationary processes and supply regime changes
- The model predicts the existence stable long-run relationships among oil market variables: production, inventories, and demand, with price co-determined.
- An application to the U.S. oil market: stable long-run relationships show up in monthly data
- Relationship changes with the 1973 crisis, in a way that is consistent with the model:
  -
    - Before 1973/1 crude oil inventories **decrease** as income (and price) increase
    - After 1975/1 crude oil inventories **increase** as income (and price) increase
- Results are robust to changes in specification (changes in lag order, start and end dates, exclusion of price variable)
- OECD stocks and industrial production also exhibit a long-run relationship with the expected signs