Why do Firms Hold Oil Stockpiles?

Charles F. Mason

H.A. True Chair in Petroleum and Natural Gas Economics
Department of Economics
University of Wyoming
Laramie, Wyoming

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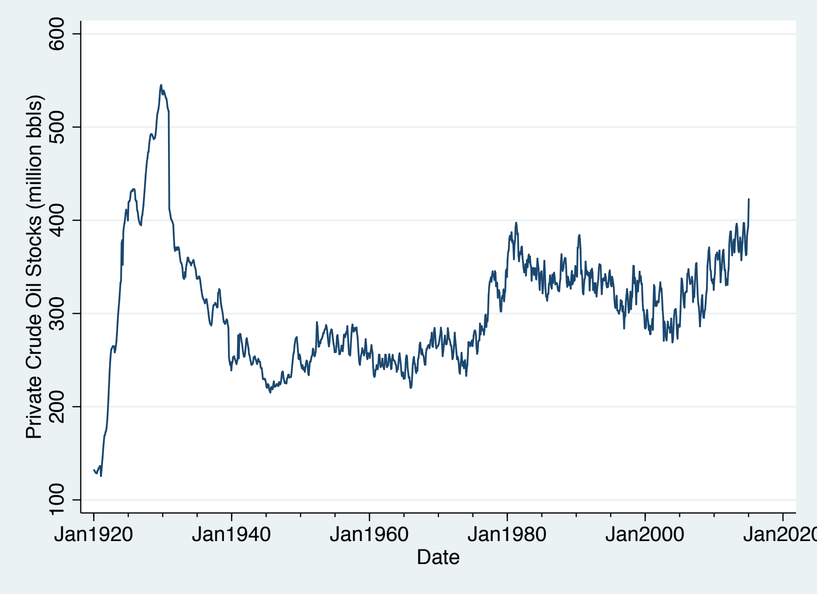
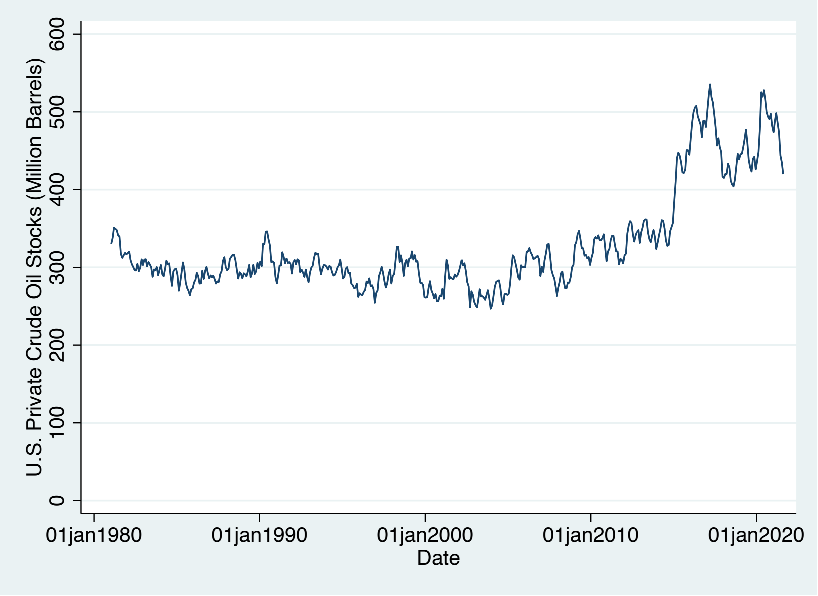
Motivation

- Since at least the 1920s, private interests in the US have held significant petroleum inventories
  - averaged ≈ 325 million barrels
  - fluctuated from 215 million to roughly 400 million barrels
- inventories only mildly responsive to current, future prices
  - roughly constant for long periods of time
    - though big run-up of reserves from mid-70s into early 80s
    - steady increase over past two decades
  - some inventories liquidated when prices collapsed in 2008
    - similar to experience in mid- to late-80s

Monthly U.S. Petroleum Stocks, 1920 - 2015



Weekly U.S. Petroleum Stocks, 1980 - 2021



Vertical integration

- petroleum industry has at least 4 channels
  - extraction, transportation, refining, marketing
- many firms have presence in multiple areas

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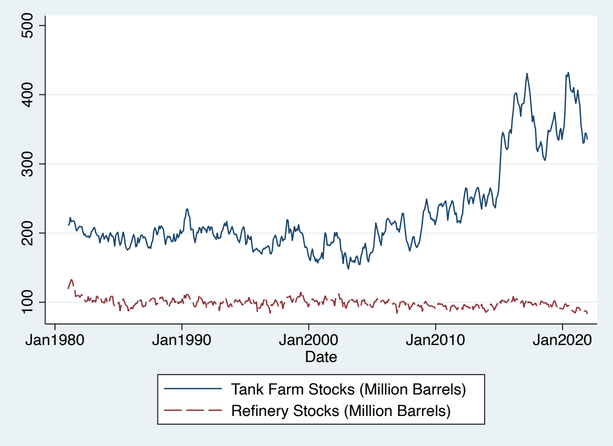
rank	company	assets	Refinery cap
1, 3	ExxonMobil	362.597	1762.8
2, 5	Chevron	237.428	1037.7
3, 1	Marathon	98.556	2870
4, 4	Phillips 66	58.72	1694.3
5	ConocoPhillips*	70.514	
6, 2	Valero[a]	53.864	2181.3
7	Occidental[b]	109.93	
8	EOG [b]	37.125	
9, 12	HollyFrontier[a]	12.165	466.6
10, 6	PBF Energy[a]	9.132	950.2

Notes: rank: # emp, cap; assets: 10^9 USD; cap: 10^3 barrels per day;
*: divested Phillips 66 in 2005, a: refining only, b: production only

Decomposing Stocks



- stocks reported for refineries, tank farms
- ‘tank farm’ stocks are more significant
  - particularly in last few decades

Why hold inventories?

- Potential motives:
  - speculation?
    - hold inventories anticipating price run-ups, then cash in
    - alleged culprit summer of 2008 (Saudis; some in U.S. Congress – Senator Barasso; Rep J.P. Kennedy II)
    - has implications for relation of stockpiles to prices
  - stock-out?
    - hold inventories to avoid running out
    - daily throughput at U.S. refiners $\approx$ 15 million bpd
    - so typical inventory = roughly 21 days' worth of throughput
  - production smoothing?
    - hold inventories to minimize impact of rapid variation in costs
    - requires upward-sloping MC
    - also requires sufficient volatility in prices
- difficult to rationalize in deterministic world
  - inter-temporal optimization of production $\rightarrow$ rents rise at r
  - inventory holding requires price rises at rate r
  - incompatible unless costs are stock dependent (still hard)

Assumptions

A1 costless to hold inventories

A2 $dP_t/P_t = \mu dt + \sigma dz$ (geometric Brownian motion)

- dz increment of standard Wiener process
- require $\mu < r$ for convergence

- Instantaneous profits are $\pi_t = P_t[y_t - w_t] - c(y_t, R_t)$
- Let $V(t, R_t, S_t, P_t) =$ optimal value function for firm
  - depends on *in situ* reserves, R_t, inventories, S_t, price, P_t
- Fundamental equation of optimality is then

$$\max_{y_t, w_t} \left\{ \pi_t e^{-rt} + \partial V/\partial t - y_t \partial V/\partial R + w_t \partial V/\partial S + \mu P_t \partial V/\partial P + (\sigma^2 P_t^2/2) \partial^2 V/\partial P^2 \right\} = 0$$

Stochastic control results

Optimal levels of extraction, inventory additions satisfy:

$$P_t - \frac{\partial c}{\partial y}(y_t^*, R_t) - \partial V/\partial R = 0 \quad (y_t^*)$$

$$-P_t + \partial V/\partial S \geq 0 \quad (w_t^*)$$

- if LHS negative then stockpile is liquidated
  - withdrawal, delivery constraints would limit this result
- if LHS positive then all extraction is stockpiled
  - injection constraints would limit this result
- if LHS zero then w_t is indeterminate
  - only outcome that does not violate market clearing?

Stochastic control results, cont.

- proceed by 'time-differentiating' FOC (using Ito's operator)

$$\frac{1}{\mathrm{dt}}E\Big[\mathrm{d}(P)\Big] - \frac{1}{\mathrm{dt}}E\Big[\mathrm{d}(\frac{\partial c}{\partial y})\Big] = \frac{1}{\mathrm{dt}}E\Big[\mathrm{d}(\partial V/\partial R)\Big] = r\partial V/\partial R + \partial c(y, R$$

$$= r(P - \frac{\partial c}{\partial y}) + \partial c(y,R)/\partial R$$

- rents anticipated to rise at rate r (subject to stock effects on extraction costs)

$$\frac{1}{\mathrm{dt}}E\Big[\mathrm{d}(P)\Big] = \mu P$$

- combined:

$$\frac{1}{\mathrm{dt}}E\Big[\mathrm{d}(\frac{\partial c}{\partial y})\Big] = -(r-\mu)P + r\frac{\partial c}{\partial y} - \partial c(y,R)/\partial R$$

condition on variance

Proceed further by assuming $c(y,R) = y^2/R$
$\rightarrow \frac{\partial^3 c}{\partial y^3} = 0; \partial c(y,R)/\partial R = -c/R)$

Condition for holding inventories reduces to

$$\frac{\partial c}{\partial y}\left\{\frac{y}{R} - \frac{\partial y}{\partial R} + \sigma^2\left(\frac{\sigma^2 P^2}{2y}\right)\frac{\partial^2 y}{\partial P^2} - r\right\} = 0$$

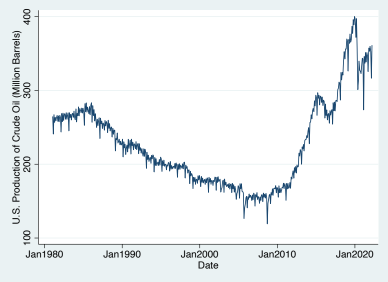
$$\Leftrightarrow \frac{y}{R} - \frac{\partial y}{\partial R} + \sigma^2\left(\frac{P^2}{2y}\right)\frac{\partial^2 y}{\partial P^2} - r = 0$$

- so require sufficient price volatility ($\sigma^2 \geq \underline{\sigma}^2$)
- still true if inventory holding is costly
  - lower bound on price volatility would be somewhat larger

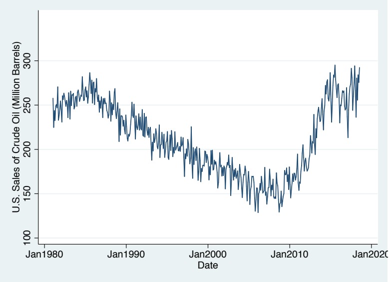
extraction vs. sales

- model predicts greater variation in sales than extraction
- comparison of monthly values for these variables confirms this prediction

extraction



sales



Data

Sources:

1. U.S Energy Information Administration (EIA) website
   - data on spot prices, production, inventories, oil stocks (monthly); reserves (annual)
2. Baker-Hughes
   - data on number of rigs actively drilling for oil (weekly)

- changes in reserves related to production, finds
  - hence drilling

$$R_t = R_{t-1} - y_t + F_t$$

- true at both monthly and annual level
- $R_t - R_{t-1} + y_t$ highly correlated with number of rigs (annual)
- apply at monthly level
  - pro-rate annual reserve change prop'n'l to monthly drilling
- assume spot prices exogenous w.r.t. firm decisions
- aggregate firm decisions to national level

Production as a function of price, reserves and stocks

- use preceding results to form fitted value of reserves at monthly level, $\hat{R}$
- observed production should depend on price, reserves and stocks
- use linear, squared terms and cross-effects
  - non-linear relation
  - important to consider second-order effects
  - think of Taylor's series approximation
- monthly data from January 1986 – December 2009 (289 obs.)
- allow for serial correlation
- use results to estimate $\frac{\partial y}{\partial R}$ and $\frac{\partial^2 y}{\partial P^2}$
- can then calculate lower bound on price variance

Regression results

variable	coefficient	std. err.
P	-4.456*	2.551
PR	.00035**	.0018
PR^2	-7.01e-09**	3.0e-09
PRS	-2.06e-09*	1.09e-09
PR^2S	3.95e-14**	1.55e-14
$\hat{\rho}$ = .926		
R-squared = .685		
SSE = 4.869		

Implied lower bound on σ^2

statistic	$\underline{\sigma}^2(.01)$	$\underline{\sigma}^2(.02)$	$\underline{\sigma}^2(.03)$
25%	0.0297	0.0600	0.0918
mean	0.0695	0.1417	0.2141
median	0.0642	0.1295	0.1927
75%	0.0922	0.1874	0.2825
90%	0.1248	0.2577	0.3911
s.d.	0.0525	0.1086	0.1649

note: $\underline{\sigma}^2$(r) listed for annual discount rates: r = .01, r = .02 and r = .03
variance of monthly real spot price during sample period = .2086

Implications

- variance in spot prices during sample period is .2086
- lower bound on variance is smaller than sample variance
  - for over 50% at relatively conventional real interest rate
  - for over 75% at low real interest rates
- evidence supports production smoothing as motive for inventories

extensions

- above model employs some simplifying assumptions
  - GBM
  - costless delivery to market
  - no constraints on delivery
  - costless inventory holding
- central results is robust to these assumptions
  - price movements likely influenced by ‘jumps’
    - these would increase value of holding inventories as hedge against cost variations
  - costly delivery to market exerts similar impacts on production and inventory addition paths
  - delivery constraints induces stock-out motive
  - costly inventory holdings raises critical value of price variance