The Dynamics of Storage Costs

Andrei Stancu[⋆], **Lazaros Symeonidis**[†], Chardin Wese Simen[⋆⋆], and Lei Zhao[§]

[⋆]Newcastle University Business School, UK
[†]Essex Business School, University of Essex, UK
[⋆⋆]University of Liverpool Management School, UK
[§]ESCP Business School, France

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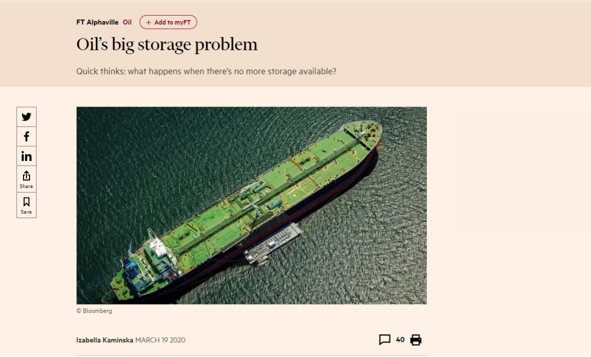
Motivation

- Inventories play a central role in commodity theories, such as the theory of storage (Kaldor, 1939; Working, 1949).
- A growing literature on inventory data (Symeonidis et al., 2012; Gorton et al., 2013; Armstrong et al., 2021; Ederington et al., 2021)



What do we Know About Oil Storage Costs?

Not much!

- Average storage cost: It is difficult to say!
  - Ross (1997): 1.67%
  - Routledge et al. (2000): 0.25%
  - Baker (2020): 1%
- Volatility: Assumed to exhibit little variation over time (Gu et al., 2020; Ederington et al., 2021).
  - If true, this is unusual for real-estate!
  - No direct test in the literature.
- Information content of storage costs for key variables:
  - Futures pricing?
  - Inventory growth rates?
  - Spot returns?

⚠ Challenge: Limited data on storage costs

Contributions

- We use a novel dataset of the Louisiana Offshore Oil Port (LOOP) sour crude oil storage futures (SFC) to construct a new storage cost measure.
- We provide answers to several important questions, such as:
  1. What is the cost of storing oil for 1-month?
  2. Is the storage cost really constant as assumed by the literature?
  3. What are the key economic implications of the storage cost for:
     - The futures–spot price spread (i.e. the basis)?
     - The predictability of inventory growth?
     - The predictability of spot returns?

Methodology

- We begin with the cost-of-carry model

$$F_{t,t+1} = S_t + \underbrace{E_t\left(Storage_{t,t\to t+1} + X_{t,t\to t+1} - CY_{t,t\to t+1}\right)}_{\text{Carrying Costs}}$$

$$F_{t,t+1} = S_t + \underbrace{SFC_{t,t\to t+1}(1 + r_{t,t\to t+1})^{1/12} + E_t\left(X_{t,t\to t+1} - CY_{t,t\to t+1}\right)}_{\text{Carrying Costs}}$$

- Re-arranging we obtain the basis

$$\underbrace{\frac{F_{t,t+1} - S_t}{S_t}}_{basis_t} = \underbrace{\frac{SFC_{t,t\to t+1}(1 + r_{t,t\to t+1})^{1/12}}{S_t}}_{scc_t} - \underbrace{E_t\left(\frac{CY_{t,t\to t+1} - X_{t,t\to t+1}}{S_t}\right)}_{acyc_t}$$

$$basis_t = scc_t - acyc_t$$

Dissecting the Basis

- **Mean** of the basis

$$
\begin{aligned}
E(basis_t) &= E(scc_t) - E(acyc_t) \\
100\% &= \frac{E(scc_t)}{E(basis_t)} - \frac{E(acyc_t)}{E(basis_t)}
\end{aligned}
$$

- **Variance** of the basis

$$
\begin{aligned}
Var(basis_t) &= Var(scc_t - acyc_t) \\
100\% &= \underbrace{\frac{Var(scc_t) - 2 \times Cov(scc_t, acyc_t)}{Var(basis_t)}}_{\text{Var Cont}_{scc}} + \underbrace{\frac{Var(acyc_t)}{Var(basis_t)}}_{\text{Var Cont}_{acyc}}
\end{aligned}
$$

Computation of Core Variables

- **Basis**

$$basis_t = \frac{F_{t,t+1} - S_t}{S_t}$$

- **Storage Cost**

$$scc_t = \frac{SFC_{t,t\rightarrow t+1}(1 + r_{t,t\rightarrow t+1})^{1/12}}{S_t}$$

- **Adjusted Convenience Yield**

$$\text{Recall that } basis_t = scc_t - acyc_t$$
$$acyc_t = scc_t - basis_t$$

Data

✓ **Storage Futures Contracts (SFC)** from Refinitv Tick History

- Monthly expiration cycle
- Same maturity with crude oil futures

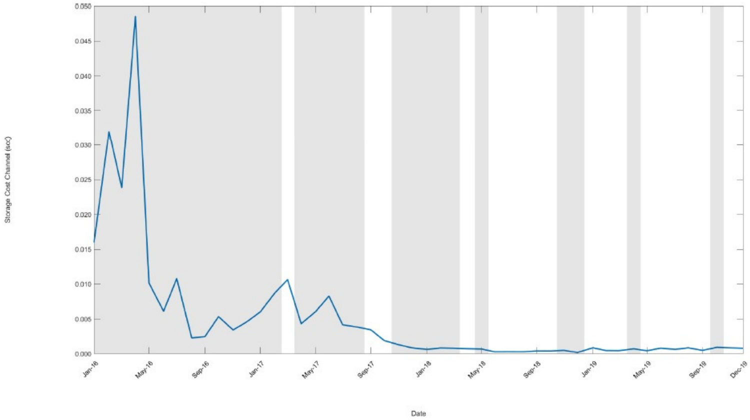
✓ **Gulf Coast Sour Crude Oil Futures** from Refinitv Tick History

- Sampling on the last trading day to obtain spot price (Fama and French, 1987)
- Sample period: January 2016 – December 2019

Storage Futures

- Right to store 1,000 barrels of LOOP sour crude oil at the Clovelly hub (largest privately-owned facilities in the US) during the delivery month
- Commercial traders (e.g. refiners) as well as cash-and-carry arbitrageurs
- Important innovation in the oil market:
  - Pricing of storage transparent to all participants
  - Great flexibility (monthly expirations over 15 consecutive months)
  - Storage risk management

Time Series of the Storage Cost



Comparison with Fama and French (1987)

TABLE 2 **Regressions of the 6-Month Basis on the 6-Month Interest Rate and Monthly Seasonal Dummies:**

$$\frac{F(t,T) - S(t)}{S(t)} = \sum_{m=1}^{12} \alpha_m d_m + \beta R(t,T) + e(t,T)$$

Commodity	Obs.	SD	β	$s(\beta)$	F	df	R_1^2	R_2^2	Storage (%)	Handling (%)
Agricultural products:										
Cocoa	35	8.1	1.16	1.44	.00	1	.00	.03	.16	.35
Coffee	30	9.6	.29	1.57	1.72	4	.06	.03	.12	.26
Corn	35	4.6	.86	.52	.01	1	.05	.07	1.41	1.73
Cotton	36	4.9	.84	1.46	1.14	2	−.02	−.02	.32	.13
Oats	34	9.7	1.06	1.27	6.55	1	.16	.01	2.65	3.26
Orange juice	102	9.2	1.39	1.21	3.32	5	.14	.04	.30	.32
Soybeans	105	7.8	1.88	.71	5.72	5	.30	.14	.64	.78
Soy meal	70	7.2	2.03	.84	.20	5	.16	.21	...	...
Soy oil	74	8.9	1.73	1.28	.79	5	.06	.07	.27	.30
Wheat	35	6.8	1.05	.86	9.03	1	.24	.05	1.39	1.71
Wood products:										
Lumber	86	13.6	2.41	2.21	1.86	5	.12	.07	1.96	3.82
Plywood	82	7.4	1.23	1.17	.71	5	.04	.06	...	...
Animal products:										
Broilers	64	10.1	1.39	1.65	5.43	11	.44	.00	...	...
Cattle	70	5.6	−.06	.57	4.48	5	.19	−.01	...	...
Eggs	80	22.2	−4.32	3.34	4.96	11	.38	.04	...	...
Hogs	102	10.9	2.21	1.36	1.79	9	.14	.08	...	...
Pork bellies	34	14.3	2.71	1.66	5.86	1	.19	.07	.98	2.54
Metals:										
Copper	89	6.5	1.39	.85	1.05	5	.14	.13	.12	.49
Gold	57	2.0	1.07	.13	.29	6	.81	.83	.01	.03
Platinum	66	4.2	1.18	.63	.28	3	.15	.18	.01	.01
Silver	101	1.5	.77	.16	.31	5	.58	.60	.03	.06

NOTE.—Obs. is the number of observations. SD is the standard deviation of the 6-month basis. df is the numerator degrees of freedom for the F-statistic test of the hypothesis that all the seasonal dummies in a regression are equal. R_2^2 is the coefficient of determination in the simple regression of the basis on the interest rate, and R_1^2 is for the regression that includes the seasonal dummies. Storage is the monthly warehousing cost per dollar of the June 1984 spot price. Handling is the total cost of loading and unloading the commodity at the warehouse per dollar of the June 1984 spot price. Storage and handling charges are from futures exchanges, dealers, elevators, and warehouses. These charges are reported only for commodities that have standard storage arrangements. The absence of such arrangements implies high storage costs. The 6-month maturity is not available for cotton. The 3-month maturity is used.

Basis Decomposition

Panel A: Unconditional

	scc	acyc
Mean	281.05%	181.05%
Variance	45.35%	54.65%

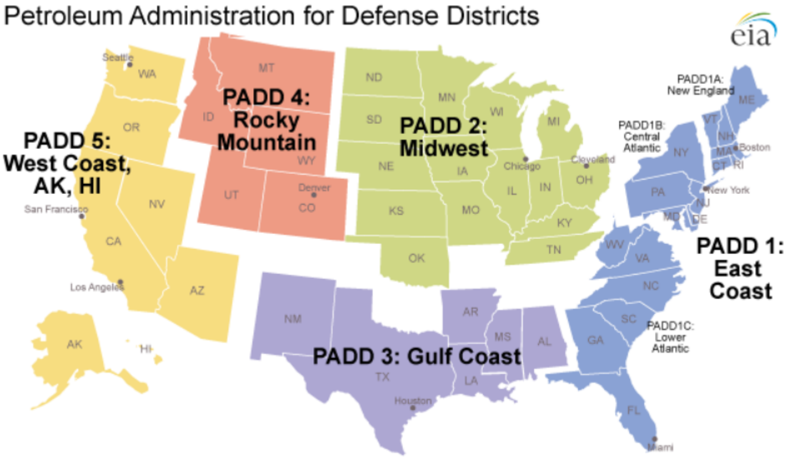
Panel B: Backwardation

	scc	acyc
Mean	-9.70%	-109.70%
Variance	-3.45%	103.45%

Panel C: Contango

	scc	acyc
Mean	62.36%	-37.64%
Variance	76.34%	23.66%

Inventory Data: Petroleum Administration for Defense



Source: U.S. Energy Information Administration.

Predictability of Inventory Growth

$\%\Delta scc_t$	0.020	0.021	0.020				
	(2.802)	(2.728)	(2.157)				
$\%\Delta scc_t \times I_{\text{contango},t}$				0.042	0.042		
				(4.379)	(4.286)		
$\%\Delta scc_t \times I_{\text{backwardation},t}$				0.009	0.007		
				(1.877)	(1.376)		
$\%\Delta scc_t \times I_{\text{spare capacity}<q_{50},t}$						0.045	0.048
						(3.641)	(3.541)
$\%\Delta scc_t \times I_{\text{spare capacity}>q_{50},t}$						0.007	0.006
						(1.440)	(0.929)
$\%\Delta acyc_t$			-0.001		-0.001		-0.001
			(-3.951)		(-3.288)		(-3.527)
$\%\Delta imports_t$			0.015		0.011		-0.011
			(0.499)		(0.379)		(-0.377)
$\%\Delta refinery_t$			-0.179		-0.204		-0.180
			(-1.864)		(-2.334)		(-2.060)
$\%\Delta production_t$			0.331		0.283		0.180
			(2.751)		(2.358)		(1.373)
$\%\Delta I_t$		-0.060	0.042	-0.138	-0.033	-0.016	0.066
		(-0.491)	(0.290)	(-1.001)	(-0.215)	(-0.143)	(0.539)
R^2	0.091	0.095	0.246	0.172	0.322	0.185	0.331
Adj R^2	0.071	0.053	0.130	0.091	0.176	0.106	0.187

Return Predictability

- The theory of storage (Fama and French, 1987) implies that: $E_t(S_{t+1}) = F_{t,t+1}$
- It can easily be shown that:

$$E_t\left(\underbrace{\frac{S_{t+1}-S_t}{S_t}}_{R_{t+1}}\right) = \frac{F_{t,t+1}-S_t}{S_t} = basis_t$$

- We thus estimate the following predictive regressions:

$$\begin{aligned} R_{t+1} &= \alpha + \beta \times basis_t + \epsilon_{t+1} \\ \text{Recall that } basis_t &= scc_t - acyc_t \\ R_{t+1} &= \alpha + \gamma \times scc_t + \delta \times acyc_t + \epsilon_{t+1} \end{aligned}$$

Return Predictability: LOOP Sour Crude Oil

α	0.022	0.005	0.034	0.012	0.016	0.039	0.024
	(1.814)	(0.365)	(1.978)	(0.795)	(0.923)	(2.158)	(1.160)
basis	2.241						
	(2.382)						
scc		4.475		3.800	3.034		2.647
		(3.014)		(3.334)	(2.958)		(2.805)
acyc			-2.196	-1.420		-2.605	-2.335
			(-1.654)	(-1.292)		(-1.585)	(-1.445)
relbasis					-0.009	1.710	1.814
					(-0.014)	(1.102)	(1.207)
mom					-0.079	-0.105	-0.067
					(-1.458)	(-2.295)	(-1.354)
basmom					-0.050	-0.002	-0.013
					(-0.152)	(-0.006)	(-0.038)
R^2	0.169	0.157	0.088	0.191	0.198	0.208	0.245
Adj R^2	0.150	0.139	0.068	0.154	0.122	0.132	0.153

Return Predictability: WTI Crude Oil

α	0.019	0.002	0.024	0.001	0.008	0.029	0.011
	(1.597)	(0.155)	(1.545)	(0.096)	(0.537)	(1.806)	(0.649)
basis	1.295						
	(1.654)						
scc		3.920		3.976	3.153		3.023
		(2.739)		(2.903)	(2.679)		(2.675)
acyc			-0.695	0.117		-1.096	-0.788
			(-0.806)	(0.186)		(-1.019)	(-0.790)
relbasis					1.107	1.604	1.722
					(1.661)	(1.329)	(1.406)
mom					-0.059	-0.099	-0.055
					(-1.403)	(-2.221)	(-1.325)
basmom					0.018	0.043	0.030
					(0.058)	(0.134)	(0.096)
R^2	7.14%	15.31%	1.12%	15.34%	20.07%	14.58%	20.75%
Adj R^2	5.08%	13.43%	-1.08%	11.49%	12.46%	6.44%	11.09%

Return Predictability: Mid-Stream ETFs

	ENFR	EINC	AMLP
α	0.001	-0.003	-0.003
	(0.130)	(-0.424)	(-0.425)
scc	2.365	2.628	2.405
	(2.511)	(3.468)	(2.592)
R^2	15.66%	18.24%	11.17%
Adj R^2	13.78%	16.43%	9.20%

What About...

- Statistical inference based on bootstrap (dependent wild bootstrap of Shao, 2010)?
- Winsorization?
- Alternative interest rate proxy?
- Information leakage ahead of inventory announcements (Rousse and Sévi, 2019)?
- Predictability of the (log) changes of inventory?
- Definition of market states based on spare capacity?

Conclusions

- Using a novel dataset on LOOP sour crude oil storage futures, we construct a new measure of storage costs (SC) and explore its dynamics
- The level of the storage cost is economically large and varies over time and over different market states
- We decompose the basis into a storage cost channel (*scc)* and an adjusted convenience yield channel (*acyc*)
  - The *scc* dominates the level of the basis
  - It explains about 45% of variations in the basis
- We document the information content of the *scc* for:
  - Future inventory growth
  - Future spot return

Thank You!

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Appendix

Controls in Predictive Regressions for Spot Returns

- **Relative basis** (Gu et al., 2020)

$$relbasis_t = \frac{S_t - F_{t,t+1}}{F_{t,t+1}} - \frac{F_{t,t+1} - F_{t,t+2}}{F_{t,t+2}}$$

- **Momentum**

$$mom_t = \Pi_{i=t-11}^{t} \left(\frac{S_i}{F_{i-1,i}} \right) - 1$$

- **Basis–momentum** (Boons and Prado, 2019)

$$basmom_t = \Pi_{i=t-11}^{t} \left(\frac{S_i}{F_{i-1,i}} \right) - \Pi_{i=t-11}^{t} \left(\frac{F_{i,i+1}}{F_{i-1,i+2}} \right)$$

Summary Statistics

	basis	*scc*	acyc
Mean	0.18%	0.50%	0.32%
Median	0.20%	0.09%	0.09%
Std	1.87%	0.89%	1.38%
Skew	0.37	3.28	1.07
Kurt	5.40	14.64	5.51
Min	-4.93%	0.02%	-3.20%
Max	6.16%	4.85%	4.99%
$AR(1)$	0.56	0.63	0.36
Nobs	48	48	48

Alternative Market States

Panel A. Low Spare Capacity

	Storage Channel	Adjusted Convenience Channel
Mean	83.16%	-16.84%
Variance	64.70%	-35.30%

Panel B. High Spare Capacity

	Storage Channel	Adjusted Convenience Channel
Mean	-9.16%	-109.16%
Variance	0.08%	-99.92%

Prediction of the Logarithmic Growth of Inventory

$\%\Delta scc_{t-1}$	0.030	0.031	0.032				
	(4.462)	(4.287)	(4.059)				
$\%\Delta scc_{t-1} \times I_{\text{contango},t}$				0.038	0.037		
				(4.228)	(4.312)		
$\%\Delta scc_{t-1} \times I_{\text{backwardation},t}$				0.017	0.021		
				(1.481)	(1.753)		
$\%\Delta scc_{t-1} \times I_{\text{spare capacity}<q_{50},t}$						0.037	0.038
						(3.139)	(3.056)
$\%\Delta scc_{t-1} \times I_{\text{spare capacity}>q_{50},t}$						0.020	0.021
						(2.061)	(1.961)
$\%\Delta acyc_t$			-0.001		-0.001		-0.001
			(-5.376)		(-4.531)		(-4.392)
$\%\Delta imports_{t+1}$			0.009		0.008		-0.001
			(0.325)		(0.262)		(-0.032)
$\%\Delta refinery_{t+1}$			-0.176		-0.172		-0.174
			(-2.191)		(-2.124)		(-2.208)
$\%\Delta production_{t+1}$			0.359		0.321		0.269
			(3.135)		(2.806)		(2.011)
$\%\Delta I_t$		-0.089	0.023	-0.145	-0.036	-0.050	0.040
		(-0.752)	(0.167)	(-1.112)	(-0.241)	(-0.472)	(0.316)
R^2	0.148	0.156	0.328	0.196	0.358	0.189	0.349
Adj R^2	0.129	0.117	0.225	0.118	0.219	0.109	0.208