KAPSARC
مركز الملك عبدالله للدراسات والبحوث البترولية
King Abdullah Petroleum Studies and Research Center

Balancing World Oil Markets and Understanding Contango and Inventories: The Changing Nature of World Oil Markets

Jennifer I. Considine and Abdullah Al Dayel

June 2020

Doi: 10.30573/KS--2020-DP15

About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

This publication is also available in Arabic.

Legal Notice

Key Points

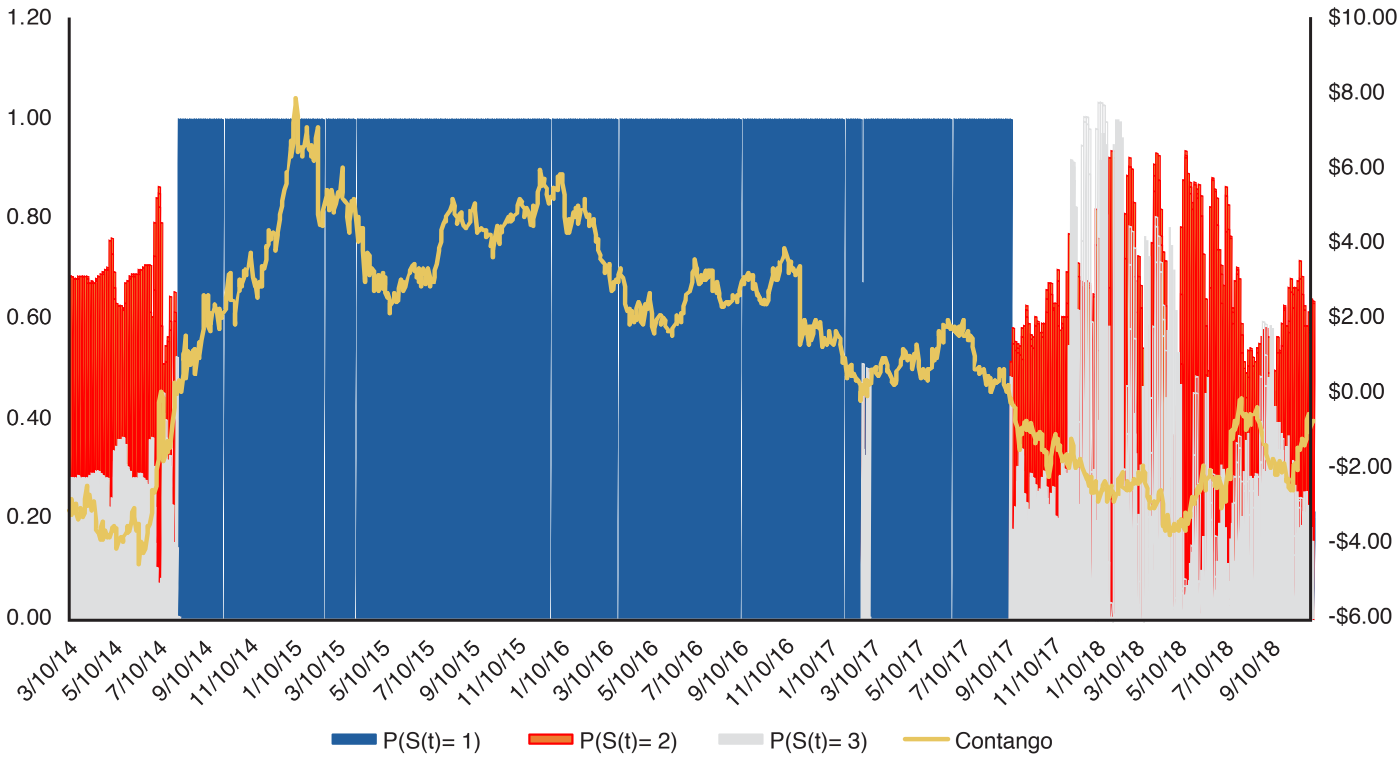
Given the volatile nature of global oil markets and their sensitivity to geopolitical and economic shocks, at any given time there may be a 'well balanced' oil market, or surpluses or shortages of crude oil supplies. In this dynamic environment, even the suggestion of changes to crude oil demand, supply, or inventories can trigger a price reaction and a subsequent rebalancing of world oil markets.

This paper examines the dynamic relationship between the futures price and the spot price (the basis) spread, and inventories. The basis is modeled as a Markov regime switching (MRS) process, which helps to identify the number of systems that govern the dynamics of world oil inventories and the market structure. Our results show that there are three separate market states: contango, backwardation, and extreme backwardation (Key Points Figure 1).

> The analysis confirms the general theory of storage, which suggests a positive relationship between the level of contango and inventories.

> Changes in crude oil inventories have a greater impact on the market structure when prices are in backwardation. This is in line with conventional storage theory, which predicts that if stocks are in scarce supply, a reduction in inventories will increase the convenience yield, resulting in lower futures prices and large movements in the basis.

Key Points Figure 1. Probability of being in a particular state vs. the level of contango.



Where P(S(t)) is the filtered probability of being in regime t, for t=1,2 and 3.
Note: The filtrations are used to model the information that is available at a given point in time.

Source: KAPSARC calculation, 2019.

Key Points

> When inventories are at sufficiently low levels and prices are volatile, the risk premium can be higher than the convenience yield, resulting in a negative relationship between contango and inventories. In other words, stocks can increase when the level of contango falls.

> The oil market exhibits the greatest volatility during periods of extreme backwardation. This is due to the fact that backwardation is generally associated with just-in-time inventories, or low and falling stock levels, and can be quite sensitive to shocks, or new developments in the marketplace.

The results suggest that OPEC has a significant role to play in balancing world oil markets. Increasing production quotas when stock levels are low can push down spot prices, bringing prices back to contango, and preventing extreme periods of price volatility and backwardation.

Summary

The general theory of storage suggests that the level of inventories is a key factor in determining the structure of the oil futures curve, or the basis, over time. The basis is the difference between the price of oil in the futures market and the price of oil in the spot market. As an indicator of future price movements, the basis follows a different dynamic when inventories are in scarce supply or in surplus. This means that there are several different market states that reflect different underlying crude oil market conditions.

This paper examines the changing nature of these market states and their implications for policymakers. We set out to answer the following questions:

> What are the market characteristics that determine which market state we are in? Is there more than one market state governing changes in the level of crude oil inventories? Is there a stable path between different market states?

> How high or low do inventories have to be before the markets can be said to be stable?

We use a Markov regime switching (MRS) process to model the complex relationship between world crude oil inventories and market structures. 'Market structure' is defined in this study as the basis and corresponding degree of contango or backwardation in the market. Our results show that three well-defined and distinct market regimes govern potential changes in the level of crude oil inventories: contango, backwardation, and extreme backwardation.

Their main characteristics are as follows:

1. Contango:

- The basis is positive: The mode value of contango is $3.20 per barrel.
- The distribution is skewed slightly positively but is fairly evenly distributed overall.
- Average market volatility.

2. Backwardation:

- The basis is negative: The mode value of backwardation is -$2.43 per barrel.
- The distribution is skewed slightly negatively but is fairly evenly distributed overall.
- Low market volatility.

3. Extreme backwardation:

- The basis is negative: The mode value of backwardation is -$2.67 per barrel.
- The distribution is positively skewed.
- High market volatility.

The analysis confirms the general theory of storage (Fama and French 1987), which suggests a negative relationship between the spread options value of storage and inventories. In addition, the empirical results of this study suggest the market structure is sensitive to inventory levels. Changes in crude oil inventories have a greater impact on the market structure when stocks are in backwardation. This is in line with conventional storage theory, which predicts reduced inventories increase the convenience yield, resulting in a reduction in futures prices relative to the basis and large movements in the basis.

Whether there is a stable path between market states can be determined by a detailed inspection of the transition probabilities. When the market is in backwardation, a reversal in the price trend — specifically an increase in the level of contango — tends to increase the probability of moving from backwardation to extreme backwardation and high volatility. This, combined with extreme volatility in oil prices and a short period of time spent in extreme backwardation, suggests that the transition to extreme backwardation is highly volatile.

When inventories are at sufficiently low levels and prices are volatile, the risk premium can be higher than the convenience yield, resulting in a positive relationship between inventories and the spread options value (market structure). The results of this paper suggest that OPEC has a significant role to play in balancing world oil markets. Increasing production quotas when stocks are at low levels can push down spot prices, bringing prices back to contango and preventing extreme periods of price volatility and backwardation in oil markets.

Note: The term market structure has been defined for the purpose of this study as the basis and corresponding degree of contango or backwardation.

Introduction

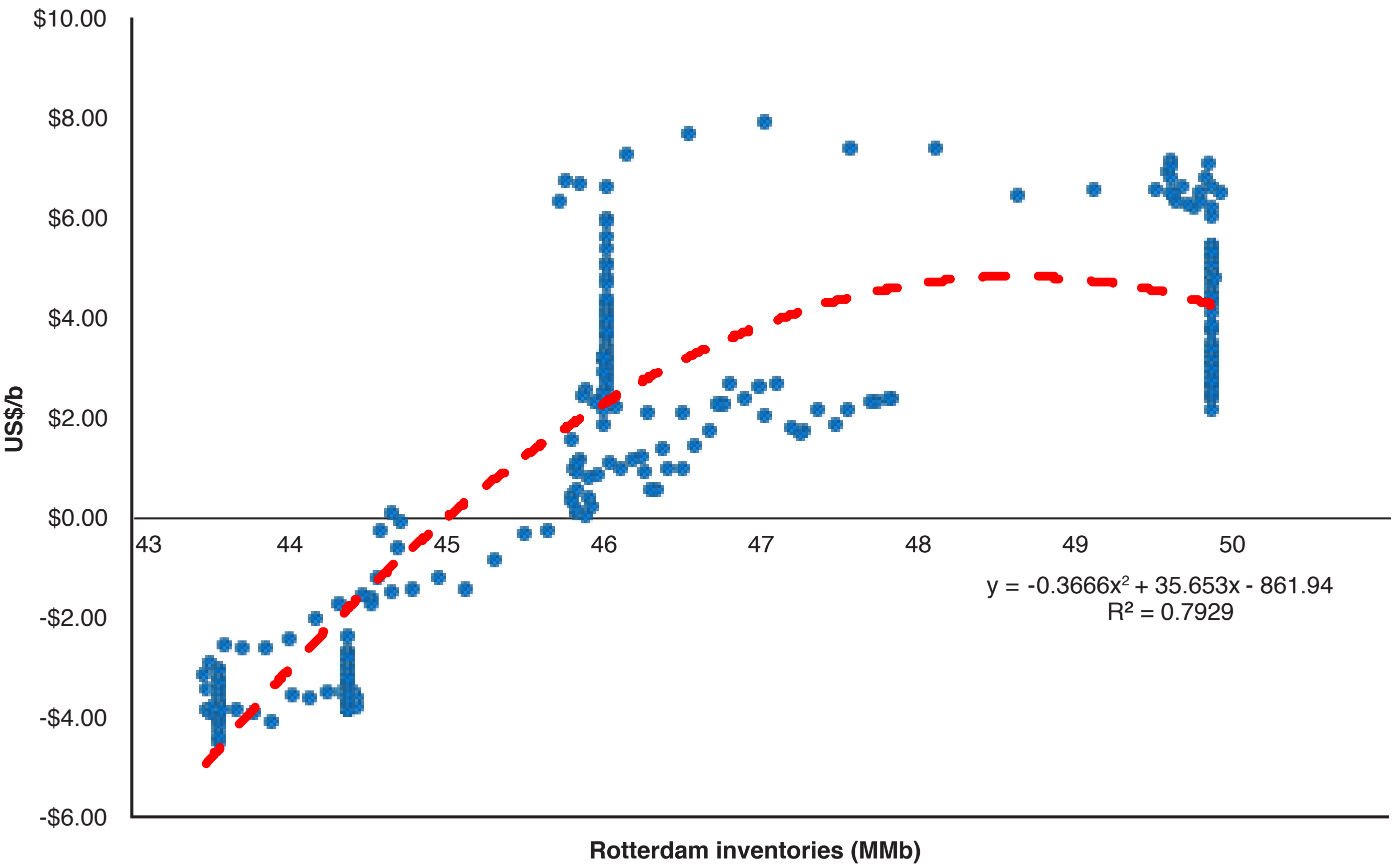
Given the volatile nature of oil markets and their sensitivity to geopolitical and economic shocks, at any given time it may be 'well balanced' or have supply surpluses or shortages. In this dynamic environment, even the suggestion of changes to crude oil demand, supply, or inventories can trigger a price reaction and a subsequent rebalancing of world oil markets. The potential consequences of any specific political or economic disturbance are unclear and would appear to depend on the market conditions, and the exact nature of the supply or demand shock, at the time.

As Figure 1 illustrates, the qualitative relationships between market structure, contango and crude oil inventories change across time and in different market states (Considine, Galkin and Aldayel, 2020). This paper examines the changing nature of these relationships and the implications of this for policymakers. We use several scenarios of market changes — excess supply and/or demand — to answer the following questions:

> What are the characteristics that determine which market state we are in? Is there more than one market state, or regime, governing potential changes in crude oil inventories? Is there a stable path between different market states?

> How high or low do crude oil inventories have to be before the markets can be said to be stable?

Figure 1. Brent contango vs. Rotterdam inventories.



The estimated trendline: Contango = y; S-G inventories = x; number of observations = 550; $R^2 = 0.386$. The sample is daily satellite data from 03/2014 to 10/2018; y = -5E-12x2 + 1E-05x - 6.7599. The trendline (curve) was chosen to provide the best fit with the data.
Sources: Orbital Insights satellite data; Bloomberg; KAPSARC calculations.

Introduction

The general theory of storage suggests that the level of inventories is a key factor in determining market structure, or the basis, over time. The shadow price of inventories or the basis is expected to follow a different dynamic when inventories are in scarce supply, suggesting a number of different 'regimes' reflecting different underlying conditions on crude oil markets.

This paper examines the dynamic relationship between the futures price and the spot price (basis) spread, and crude oil inventories. The basis is modeled as a Markov regime switching (MRS) process, which helps to identify the number of regimes that govern the dynamics of world oil inventories and the market structure.

We also test whether the level of crude oil stocks has any implications for the probability of world oil markets being in, and remaining in, one of the three distinct regimes.

The study is divided into three sections. The first section, "Market structure and crude oil inventories: A complex relationship," provides a brief history of contemporary storage theory and a literature review.

Section two, "Data and methodology," describes the data used in the analysis and the construction of the key variables, including the level of inventories, the market structure, and the spread options value.

The third section, "Empirical results," presents the results of the statistical analysis and robustness tests. Finally, the conclusion summarizes the results and outlines areas for future research.

This study defines the term 'market structure' as the basis and corresponding degree of contango or backwardation. This definition reflects the efficient markets hypothesis that spot and futures market prices fully reflect all available information about a commodity, including all factors affecting supply and demand and the level of competition in the marketplace.

The shadow price is a term used in economics to refer to the price of an item that is not necessarily priced or sold in a marketplace, or when the price of an item is not transparent. It is used to value intangible assets, and/or to reveal the true price of a commodity that is currently unknowable or difficult-to-calculate, such as storage. Most storage transactions of inventories are done through bilateral contracts or agreements and are not publicly available.

Market Structure and Crude Oil Inventories: A Complex Relationship

The relationship between market structure and crude oil inventories has been well documented. According to the conventional theory of storage, under normal market conditions, when the crude oil market is balanced, prices are generally in a state of contango. The price that futures trade above the spot price accounts for the costs of storing a commodity, including warehousing costs, the costs of foregone interest, and a convenience yield on inventories (Fama and French 1987). When this is not the case, and futures prices trade below the spot price, the market is said to be in backwardation. Firms hold minimal or just-in-time inventories, and they tend to increase production to meet demand (Working 1933; Brennan 1958; Telser 1958).

In short, conventional storage theory predicts a positive relationship between inventories and the basis (or cost of carry), or a negative relationship between the marginal convenience yield and inventories. The relationship is dynamic and changes according to the conditions in world oil markets. The convenience yield falls with inventory levels but at a decreasing rate. When stocks are scarce, the marginal convenience yield will likely be higher than the convenience yield, and the basis will be negative (backwardation). As the level of inventories rises, the convenience yield falls to levels below the cost of carry, and the basis becomes positive (contango) (Fattouh 2009; Pindyck 2004).

For example, in refineries, where crude oil is needed for the production of gasoline, there is a negative relationship between the level of inventories and the marginal convenience yield of holding a physical barrel of oil. When inventories are high, crude oil supplies will be readily available to produce gasoline. This reflects the inconvenience of holding physical barrels when storage tanks are nearing full capacity. The convenience yield is an aggregate of this relationship for all firms in the industry.

Note on terminology:

The **convenience yield** is a benefit (or cost) that accrues to the owner of a physical asset such as a barrel of crude oil, but not of a futures contract. It reflects the convenience of owning the physical commodity, which is an input for the production of another commodity, such as gasoline, or to meet an unanticipated increase in demand. The yield can reflect the ability of producers to meet contractual obligations and minimize disruptions from supply shocks, among other benefits and/or costs.

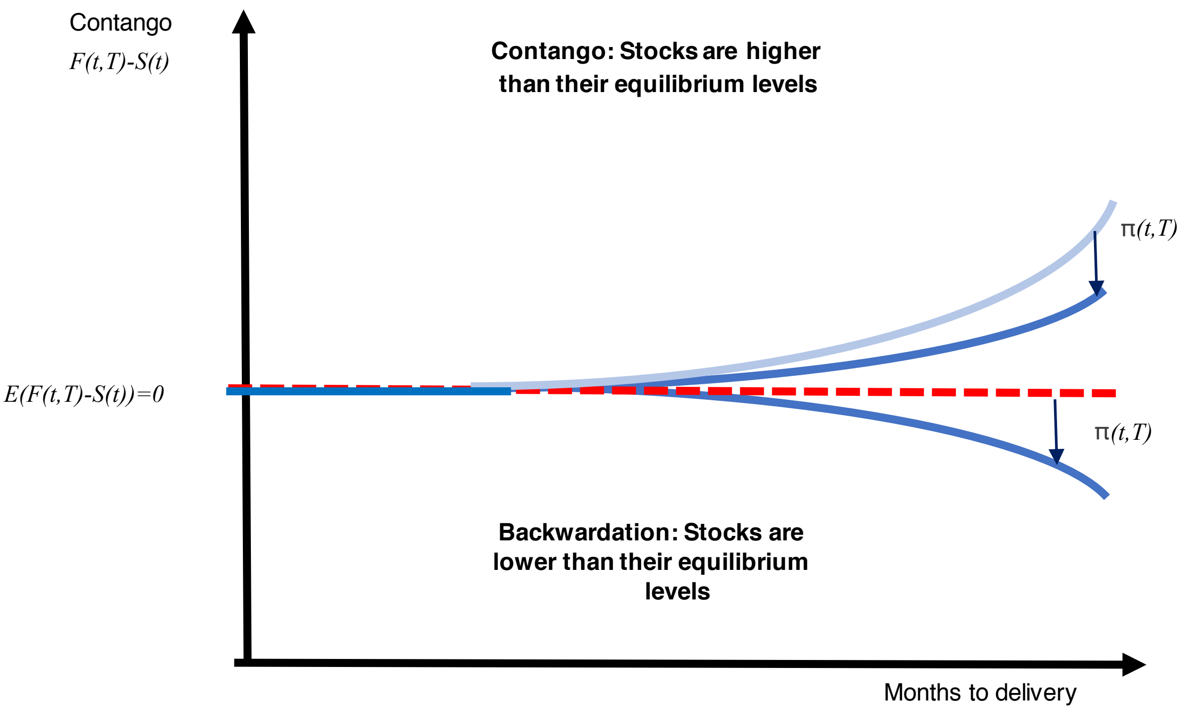
The **cost of carry** refers to the total costs incurred as a result of holding crude oil in storage or the net yield from carrying the underlying asset. The cost of carry includes the physical expenses of storing the commodity at a given point in time plus costs, including interest on bonds, margin accounts, loans, and opportunity costs associated with taking the position.

An alternative theory suggests that the basis, the difference between the futures price and the spot price, can be explained in terms of a risk premium and a forecast of future oil prices (Bailey and Chan 1993). The risk premium π(t,T) reflects all of the systematic factors affecting futures prices, including demand and supply shocks, political risk, and net hedging pressure (Hicks 1939).

Figure 2 illustrates the risk premium theory of storage. When the difference between the futures price and the spot price F(t,T) - S(t) is higher than the best industry forecasts of the forward price E(F(t,T) - S(t)), plus a measure of compensation for the risk of holding a barrel of crude oil or a futures contract, π(t,T), then it will pay to buy a barrel of crude (on the physical or futures market) and sell it forward, and stocks will be above their equilibrium levels. The purchase of spot oil and the sale of futures will reduce the level of contango, F(t,T) - S(t), until the market returns to equilibrium (Bailey and Chan 1993; Fama and French 1987). Backwardation is explained by the fact that a buyer of futures contracts will earn a positive risk premium when futures prices are trading below the spot price.

The theory can be extended to include the implications of hedging against commodity price risk and storage costs. When storage is expensive, economic agents can reduce risk by taking long hedging positions in crude oil, effectively hedging against storage costs, rather than selling inventories short. Hedging against the costs of producing crude oil promotes upward price bias, or contango in the futures market, while hedging against rising storage costs promotes downward price bias or backwardation (Hirshleifer 1989).

Figure 2. The risk premium theory of storage.



Source: KAPSARC 2019.

Larson (1991) suggests a similar non-linear formulation of the theory, positing that the basis or shadow price of inventories is convex in inventories:

> "Just as the price of a call option contains a premium based on price variability, so the shadow price of inventories contains a dispersion premium associated with the unplanned component of inventories. When inventory levels are low, the value of the premium increases to the point where inventories will be held even in the face of a fully anticipated fall in price." (Larson 1991).

A number of studies have shown that an options-based approach to storage valuation models is superior to the traditional cost of carry and convenience yield models (Omura and West 2015). These studies model the convenience yield as a financial call option that has value in market settings subject to supply shocks (Milonas and Thomadakis 1997; Heinkel, Howe, and Hughes 1990). As before, the positive value of the option, which increases with volatility, provides an explanation for backwardation in crude oil futures prices (Heaney 2002; Sorensen 2002).

While most of these studies are based on a calendar-style spread option, an alternative formulation suggests that a location-based spread option approach improves the accuracy and precision of models that define the quantitative relationship between market structure and inventories. This is because this methodology uses all of the information in the forward curves for every possible competing crude, thereby incorporating more information about market expectations and accounting for the implied volatility of commodity prices across the entire spectrum of forward curves. See Considine and Galkin (2019).

Conventional storage theory has been criticized for being a product of pure econometric analysis, rather than traditional economic theory and competitive optimization models. An alternative rational expectations approach models the convenience yield as an embedded timing option. An economic agent that has a long position in crude oil can decide to store the commodity, in which case it will be priced as an ordinary asset, and the forward price will reflect the total cost of storage. Alternatively, the agent can decide to consume it or sell it in the spot market. In this case, the commodity is priced as a consumption good, and the forward price will reflect the convenience yield (Routledge, Seppi and Spatt 2000; Deaton and Laroque 1990).

Once again, these formulations suggest that the level of inventories is a key factor in determining the market structure, or the basis, over time. The shadow price of inventories, or the basis, is expected to follow a different dynamic when inventories are in scarce supply, suggesting a number of different 'price regimes' reflecting different underlying conditions on crude oil markets. Fattouh (2009) investigates this assertion in his paper "Basis Variation and the Role of Inventories: Evidence From the Crude Oil Market" and finds two distinct market regimes. One is characterized by low price volatility when the market is in contango, and an alternative regime is characterized by high volatility when the market is in backwardation (Fattouh 2009). The approach adopts the Markov switching modeling approach, which can be extended to include seasonality and jumps in the pricing process for futures with different maturities (Leonhardt, Ware and Zagst 2017).

In a more recent study, "Modelling Nonlinear Dynamics of Oil Futures Market," Ayben Koy uses a Markov switching autoregressive model to investigate the recession and growth periods of oil futures markets. The study finds that oil futures prices follow a non-linear pattern that can be divided accurately into three distinct price regimes: (i) slight backwardation, with high volatility; (ii) slight contango, with low volatility, and (iii) sharp backwardation, with high volatility (Koy 2017).

While all of these studies suggest that there is, in fact, a well-defined quantitative relationship between the level of inventories and the basis, the exact nature of this relationship is unclear and would appear to change at different times, depending on the market structure at the time of the forecast.

This paper examines the dynamic relationship between the market structure and inventories, using the locational spread option approach. The spread option approach utilizes a more complete dataset, including a number of futures curves, and transportation costs for relevant competing crudes, and, as a result, can be shown to improve the accuracy of the quantitative storage models (Considine and Galkin 2019). The market structure is modeled as a Markov regime switching process, which allows us to identify the number of regimes that govern the dynamics of world oil inventories.

Data and Methodology

This section describes the data used in the analysis, and the construction of key variables, including a simple measure of contango, inventories and the spread options value. We estimate these variables, the main drivers behind crude oil inventories, on a daily basis for Rotterdam, and for competing crudes from eight major international storage hubs located at major seaports. They include Fujairah in the United Arab Emirates, Jamnagar (India), Kagoshima (Japan), Louisiana Offshore Oil Port (LOOP) (United States [U.S.]), Ningbo (China), Saldanha Bay (South Africa), Singapore Port (Singapore) and Ulsan (South Korea). For LOOP, where the daily storage rates are available, we add the monthly storage rate on a particular day to the delivery costs. A more detailed description of the key variables, contango, the level of inventories and the real options value, is given in Appendix A. See also Considine and Galkin (2019).

The daily future nine- and two-month values for the Brent benchmark were used for the contango variable (Bloomberg 2019). The daily inventory data was provided by Orbital Insight (2019).

The spot prices for all of the crudes used in the analysis were taken from the Bloomberg Terminal (Bloomberg 2019), and the shipping costs from Clarksons Research (2019). We applied various national central banks' interest rates, effective on a particular day of the estimation period from December 21, 2015 to January 25, 2019, as a proxy for the cost of capital. These rates were taken from the websites of relevant national central banks and from Triami Media (2019). For the Netherlands, we used a one-year zero-coupon bond rate, and for Japan, we used the Japanese yen Libor rate. Both these datasets were taken from the Bloomberg Terminal (Bloomberg 2019). The expiry date chosen for the spread options was one month from the date of valuation.

The shipping costs were calculated using the weekly spot freight rates taken from Clarksons Research (2019) for crude oil tankers on matching or similar routes. The resulting weekly shipping costs in dollars per barrel ($/b) were interpolated to obtain daily values using a cubic spline multiplicative procedure from EViews. For the cost of carry calculations, we used the same proxies of capital cost to estimate the convenience yield.

For a detailed description of the data sources and equations used in the specific estimations of this study, please refer to appendices A and D.

Empirical Results

To determine the relationship between the market structure and inventories, we postulate the following regression equation of the market structure as measured by the spread options value (the dependent variable) on inventories and seasonal dummies. We use daily data from March 10, 2014 to November 30, 2018. This shorter time frame was used to accommodate lags in the reporting of inventory data.

$$MS_t = \alpha_o + \beta_1 \Delta Inv_t + \sum_i^N \left(\gamma_{i_t} * D_{i_t}\right) + \varepsilon_t \qquad 1$$

Where:

$MS_t \equiv$ Market structure as defined by the spread options value.

$\Delta Inv_t \equiv$ Rotterdam inventories as reported by Orbital Insights.

$D_{i_t} \equiv$ A vector of dummy variables, including monthly seasonal dummy variables, and a dummy variable for 2014 to 2015, to accommodate the evolution of the data collection process from Orbital Insights.

$\alpha_o, \beta_1, \gamma_{i_t} \equiv$ Estimated parameters

The equation was estimated using a Markov regime switching (MRS) analysis. Markov switching models are used to describe situations where the behavior of the variables, or stochastic processes, change from one regime to another. The model captures the behavior of a 'state variable' that cannot be directly observed (s_t), such as a recession, or a depression, in gross domestic product (GDP) growth. The state variables for the oil industry that cannot be observed would be a state of excess supply (an oversupplied market), excess demand (an undersupplied market), or balanced world oil markets.

The results of the MRS analysis using equation 1 are illustrated in Tables 1, 2 and 3, and are reported in detail in Appendix D. As expected, the model finds clear evidence of three distinct regimes, regime 1 – contango, regime 2 – backwardation, and regime 3 – extreme backwardation.

> In regime 1, contango, the average value of contango is \$2.98, and there is a 90% probability of the values ranging between \$0.43 and \$5.66. The standard deviation of the time series for the contango regime is \$1.69.

> In regime 2, backwardation, the mode value of backwardation is -\$2.43, and the standard deviation estimated for regime 2 is \$0.41. This regime is the most stable in terms of volatility.

> In regime 3, extreme backwardation, the mode value of backwardation is -2.67, and there is a 40% probability that the level of backwardation will be lower than -\$2.50 \$/b. The standard deviation is \$8.70, by far the highest of any of the three regimes.

In short, the market structure exhibits the greatest volatility when the market is in regime 3, extreme backwardation. This is because backwardation is generally associated with just-in-time inventories, or low and falling stock levels, and can be quite sensitive to shocks, or new developments in the marketplace.

In the MRS analysis, transition probabilities measure the probability of moving from one regime to the next, for example, the probability of moving from contango to backwardation. The mean value of the transition probabilities is given in Table 2. These results are similar to those obtained by Fattouh (1999) and show that it is more likely for

Table 1. Markov regime switching results.

	Coefficient	Std. Error	z-Statistic	Prob.
Regime 1				
ΔInv_t	-0.5444	0.2194	-2.4812	0.0131
Regime 2				
ΔInv_t	-2.0745	0.4857	-4.2715	0.0000
Regime 3				
	1.9793	0.3849	5.1426	0.0000

Source: KAPSARC calculations.

Table 2. Time-varying Markov transition probabilities and expected durations.

Time-varying transition probabilities:				
P(i, k) = P(s(t) = k I s(t-1) = i)				
(row = i / column = j)				
		1	2	3
Mean	1	0.6681	0.0872	0.2447
	2	0.0479	0.2859	0.6662
	3	0.6681	0.0636	0.2683

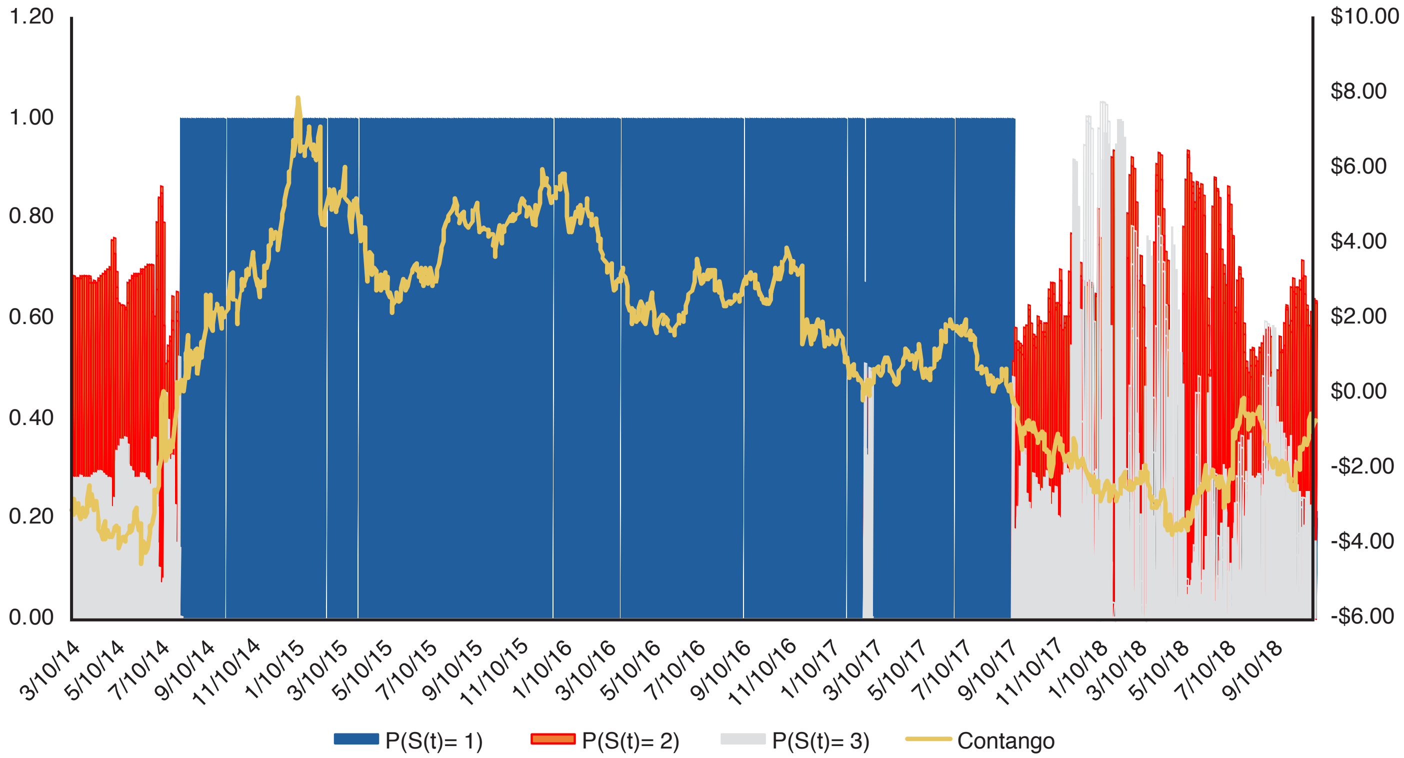
Source: KAPSARC calculations.

the basis to remain in contango P(1,1)=0.6681, or to move from extreme backwardation to contango P(3,1)=0.6681, than from contango to extreme backwardation P(1,3)=0.2447. Unsurprisingly, the market regime was most often in a state of contango during the period under investigation. The expected time duration of backwardation and extreme backwardation is only five and three days, respectively, throughout the observation period.

Figure 3 illustrates the filtered probability of being in regimes 1, 2, and 3, and the level of contango in Brent crude oil prices. The probability of being in a particular regime ranges from 0 to 1 and is represented on the left vertical axis. The level of contango or backwardation ranges from -$4.5 to $7.9 and is represented on the right vertical axis. The probability of the markets being in regime 1 (contango) is represented in blue, and the probabilities of the markets being in regimes 2 (backwardation) and 3 (extreme backwardation) are given in red and grey, respectively. The level of contango (backwardation) is given by the yellow line.

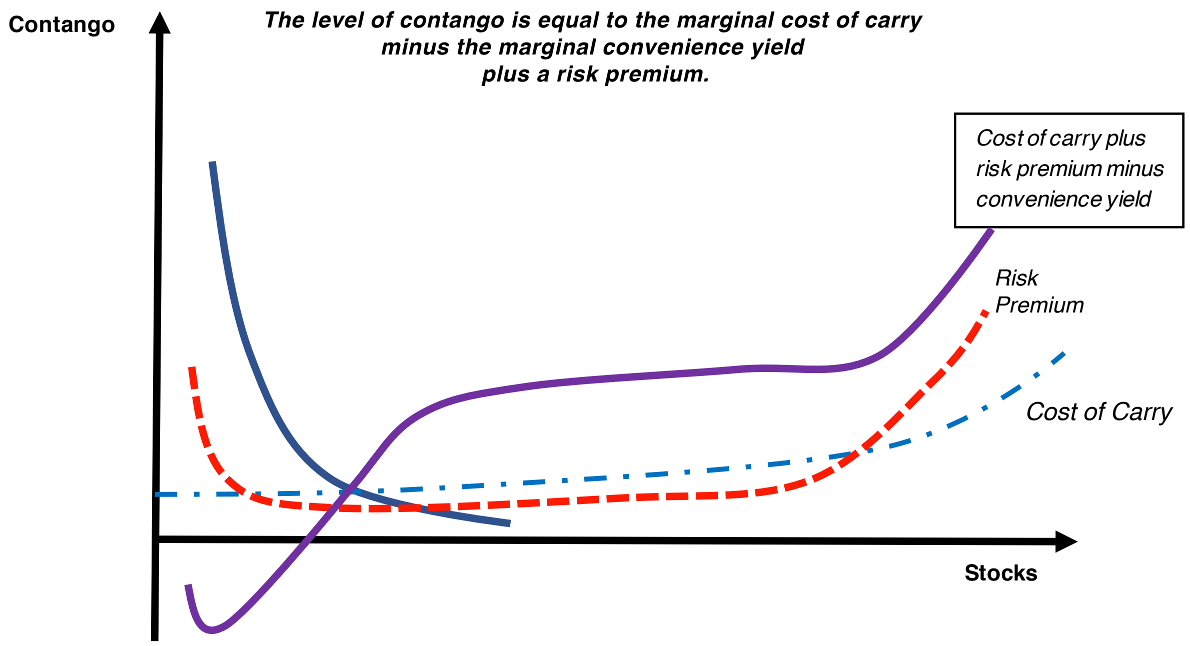
As expected, the MRS estimates of the market structure in the three regimes – as measured by the spread options value – is captured by the actual level of the basis or contango in the marketplace. The probability of the market being in regime 1 almost exactly matches the actual value of the basis. The model captures long periods of contango in the marketplace, and the shifts between backwardation (low volatility) and extreme periods of backwardation (high volatility). The shift back to contango at the end of the sample period, in October 2018, is clearly represented.

Figure 3. Filtered regime probabilities.



Where P(S(t)) is the filtered probability of being in regime t, for t=1,2 and 3.
Note: The filtrations are used to model the information that is available at a given point in time.
Source: KAPSARC calculations.

Figure 4. The general theory of storage.



Sources: Brennan (1958); KAPSARC.

As predicted, the level of inventories varies significantly across the three states. The mean, or average, level of inventories is approximately 61.36 million barrels (MMb) in regime 1, 58.10 MMb in regime 2, and 60.10 MMb in regime 3.

The estimated coefficients of the Markov switching model are all statistically significant at the 1% confidence level. Unsurprisingly, the sensitivity of the market structure – as measured by the changes in the options value – to changes in inventories varies significantly across regimes. The estimated coefficients for the three regimes are: (i) -0.54 for contango; (ii) -2.07 for backwardation, and (iii) 1.98 for extreme backwardation.

Changes in crude oil inventories have a greater impact on the market structure when stocks are in backwardation. This is in line with conventional storage theory, which predicts that if stocks are in scarce supply, a reduction in inventories will increase the convenience yield, resulting in a reduction in the futures prices and large movements in the basis.

Note: The general theory of storage states that the marginal return to storage – the level of contango or the futures basis – is equal to the marginal cost of carry minus the marginal convenience yield plus a risk premium (Brennan 1958).

In extreme periods of backwardation with high volatility, the Markov switching model suggests a positive relationship between the market structure and changes in the level of inventories, and generally heralds a change in the direction of the movement of the basis, from falling to increasing. This can be explained by a slight variation to the risk premium theory of storage, which suggests that the risk premium in times of low storage levels and extremely high levels of volatility will be sufficiently high to induce an increase in the level of the basis when inventories rise (see Figure 4). This supports the results obtained by Wei and Zhu (2008) that the “determination of convenience yield is largely consistent with economic theories, [but that] the evidence regarding the determination of the risk premium is mixed.”

Inventories are higher in the contango regime, and there is little incentive to hold more stocks. As such, the convenience yield is lower (or zero), as is the volatility of crude oil prices, which suggests a lower risk premium. In this case, the cost of holding inventories reflects only storage costs and the costs of carry, which are less sensitive to changes in inventories than the convenience yield.

Table 3. Markov regime transition matrix parameters.

Transition Matrix Parameters

Variable	Coefficient	Std. Error	z-Statistic	Prob.
P11-CONTANGO__BRENT	447.5613	133510.3	0.003352	0.9973
P12-CONTANGO__BRENT	0.490343	0.909485	0.539143	0.5898
P21-CONTANGO__BRENT	-23.42116	57.10263	-0.410159	0.6817
P22-CONTANGO__BRENT	-24.38101	57.10312	-0.426965	0.6694
P31-CONTANGO__BRENT	388.7821	41003.48	0.009482	0.9924
P32-CONTANGO__BRENT	0.720326	0.20128	3.578721	0.0003

Source: KAPSARC calculations.

The results suggest that the level of contango does not have a significant impact on the transition probabilities for most regimes. The sole exception to this general rule is the switch from regime 2 (backwardation) to regime 3 (extreme backwardation). In this case, a change in the direction of the price movement of the basis — an increase in the level of contango — tends to increase the probability of moving from backwardation to extreme backwardation and high volatility. The estimated coefficient of 0.72 is significant at the 1% level. This result is consistent with the theory of storage, in that an increase in the volatility of the basis will increase both the risk premium and the options value of storage.

Finally, we test the proposition that the level of inventories affects the probability of being in each of the individual regimes. To accomplish this, we model the probabilities of remaining in a given regime as a logistics function of the level of inventories. The estimated coefficients for the inventory variable in each regime are statistically significant at the 1% level. As expected, an increase in the level of inventories increases the probability of remaining in regime 1, contango. Similarly, a reduction in the level of inventories increases the probability of remaining in backwardation. These results are in line with a priori expectations and agree with the general theory of storage.

Table 4. Probability of being in a regime versus the level of stocks.

Regime 1: Contango				
Time Varying Probability of Remaining in Regime 1				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	-4.0412	1.0890	-3.7108	0.0002
Inventories	0.0520	0.0190	2.7410	0.0062

Regime 2: Backwardation				
Time Varying Probability of Remaining in Regime 2				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	4.1415	5.2469	0.7893	0.4301
Inventories	-0.2956	0.0904	-3.2706	0.0011

Regime 3: Extreme Backwardation				
Time Varying Probability of Remaining in Regime 3				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	3.0464	5.0248	0.6063	0.5445
Inventories	-0.2796	0.0867	-3.2240	0.0013

Source: KAPSARC calculations.

Conclusion

The past few years have seen considerable variation in the futures curves and shifts from backwardation to contango and back again. This was primarily due to the fundamental factors facing world oil markets, including the rise of shale oil in the U.S., global trade wars and the renegotiation of major trade deals, and increased geopolitical tensions in the Middle East, particularly in the Strait of Hormuz (Figure 5).

Conventional storage theory suggests that the level of inventories is a key factor in determining market structure, or the basis, over time. The shadow price of inventories, or the basis, is expected to follow a different dynamic when inventories are in scarce supply, suggesting a number of different 'price regimes' reflecting different underlying conditions on crude oil markets.

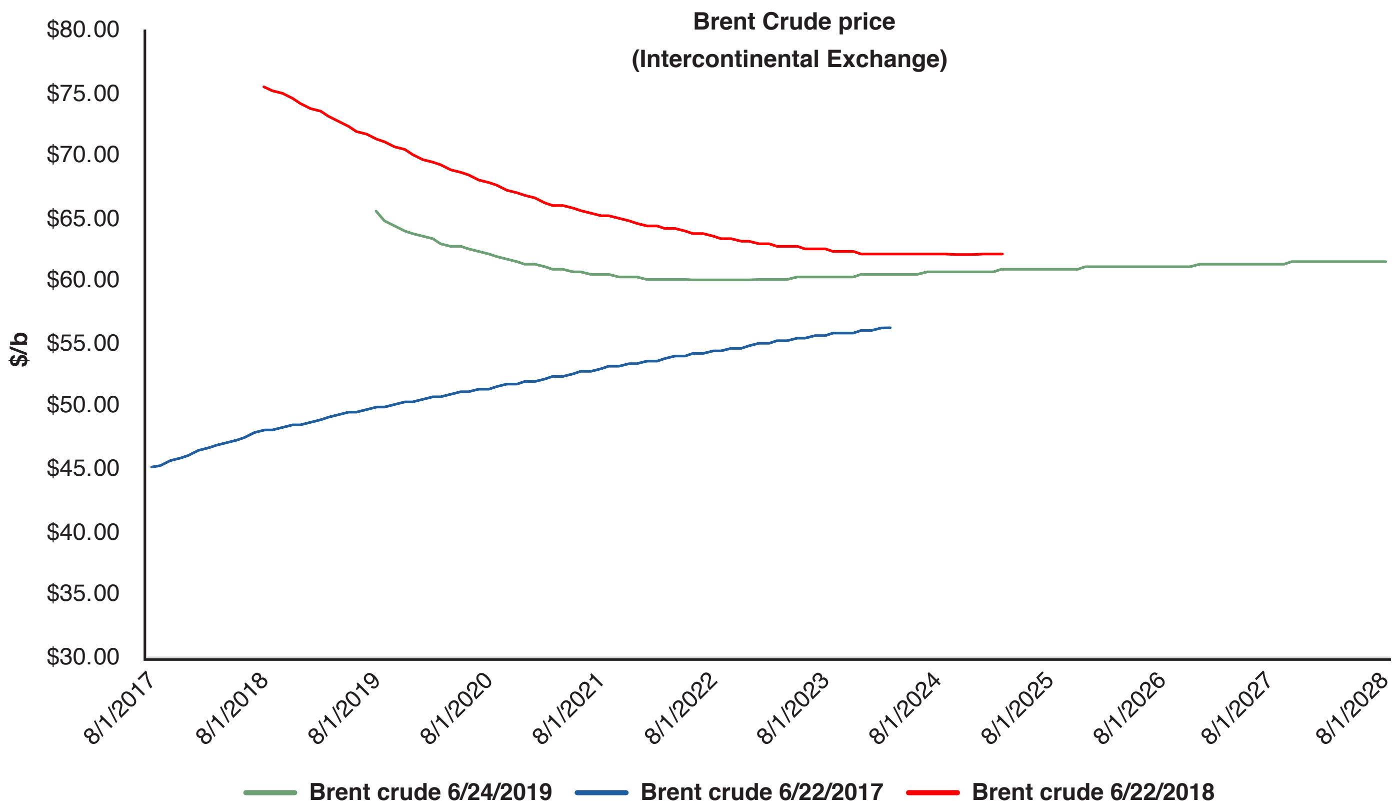
Our results show that there are three well-defined and distinct market regimes that govern potential changes in the level of crude oil inventories: contango, backwardation, and extreme backwardation.

Their main characteristics are as follows:

1. Contango:

- Positive basis: The average value of contango is $2.98, the mode is $3.20.
- There is a 90% probability of the values ranging between $0.43 and $5.66.
- There is a slight positive skew, but it is fairly evenly distributed. The skewness is 0.2786, so the distribution is fairly symmetrical.

Figure 5. From backwardation to contango and back again.



Source: Bloomberg; KAPSARC.

- Average volatility: The standard deviation of the time series for the contango regime is $1.69.

2. Backwardation:

- Negative basis: The mode value of backwardation is -$2.43.
- There is a slight negative skew, but it is fairly evenly distributed. The skewness is -0.2824, so the data has a slight negative skew, but it is fairly symmetrical.
- Low volatility: The standard deviation estimated for regime 2 is $0.41. This regime is the most stable in terms of volatility.

3. Extreme backwardation:

- Negative basis: The mode value of backwardation is -$2.67.
- There is a 40% probability that the level of backwardation will be lower than -$2.50 $/b.
- Positive skew: The skewness is 0.8853, so the data has a distinct positive skew.
- High volatility: The standard deviation is $8.70, by far the highest of any of the regimes.

The answer to the question of whether there is a stable path between states is slightly more complex, but it can be derived through a detailed inspection of the transition probabilities. We find that the level of contango does not have a significant impact on the transition probabilities for most regimes. However, when the market is in backwardation, a reversal in the price trend — or an increase in the level of contango — tends to increase the probability of moving from backwardation to extreme backwardation and high volatility. This, combined with extreme volatility in oil prices and the short duration spent in extreme backwardation, suggests that the transition to the extreme backwardation regime is highly volatile.

The final question of how high or low do inventories have to be before the markets can be said to be stable, or in a state of contango, can be answered by observing the average level of inventories in each regime. As noted above, the mean, or average, level of inventories is approximately 61.36 MMb in regime 1, 58.10 MMb in regime 2, and 60.10 MMb in regime 3. Using storage data from 2016 to the present, there is a 69.7% probability of being in the stable contango regime if inventories are above 60 MMb.

It is interesting to note that the level of inventories does not appear to be as effective as the level of contango in explaining the stability of world oil markets. In regime 1, there is a 40% probability of inventories being below 60 MMb, but only a 5% chance of the level of contango being below $0.43, and a 15.5% chance of the volatility being higher than 1.4, the average level of volatility expected in the unstable, extreme backwardation, regime.

Unsurprisingly, our analysis confirms the general theory that there is a negative relationship between the spread options value of storage and inventories. In addition, the empirical results suggest that the actual levels of inventories have significant implications for the sensitivity of the market structure to changes in the levels of inventories. Specifically, changes in crude oil inventories have a greater impact on the market structure when stocks are in backwardation. This is in line with conventional storage theory, which predicts that if stocks are in scarce supply, a reduction in inventories will increase the convenience yield, resulting in a reduction in the futures prices and large movements in the basis.

When inventories are at sufficiently low levels, and prices are volatile, the risk premium can be higher than the convenience yield, resulting in a positive relationship between inventories and the spread options value (the market structure). The results suggest that OPEC has a significant role to play in balancing world oil markets. Specifically, increasing production quotas when stocks are at low levels can push down spot prices, bringing prices back to contango and preventing extreme periods of price volatility and backwardation.

This policy prescription warrants a further investigation of the determination of the risk premium, and the complex relationship between the level of inventories and market structure.

Future research could focus on identifying the regimes, the major drivers and their sensitivities for a number of major global crude oil storage and consumption nodes (besides Rotterdam) and alternative crudes (besides Brent). This would help to identify regional differences and create a more comprehensive picture of the global oil market.

The approach developed in this study provides market participants and policymakers with a tool that could be used to track developments in the global oil market and assess a variety of potential future scenarios. Specifically, large producers and exporters can estimate the amount of crude that would have to be stored (delivered) to a particular location in order to trigger a regime switch in the oil market. For exporters, this can provide an excellent estimate of the additional shipments they can deliver to any particular location without causing significant pressure on prices. For those interested in balancing the oil market (e.g., OPEC), this approach also provides a more precise measure of the additional supply required to bring the markets to a stable, or equilibrial, position.

References

Bailey, Warren, and K. C. Chan. 1993. “Macroeconomic Influences and the Variability of the Commodity Futures Basis.” *The Journal of Finance* 48 (2): 555–73. https://doi.org/10.1111/j.1540-6261.1993.tb04727.x.

Bazzi, Marco, Francisco Blasques, Siem Jan Koopman, and Andre Lucas. 2017. “Time-Varying Transition Probabilities for Markov Regime Switching Models.” *Journal of Time Series Analysis* 38 (3): 458–78. https://doi.org/10.1111/jtsa.12211.

Bekiros, Stelios D., and Alessia Paccagnini. 2015. “Macroprudential Policy and Forecasting Using Hybrid DSGE Models With Financial Frictions and State Space Markov-Switching TVP-VARS.” *Macroeconomic Dynamics* 19 (7): 1565–92. https://doi.org/10.1017/S1365100513000953.

Bergmeir, Christoph, Isaac Triguero, Daniel Molina, José Luis Aznarte, and José Manuel Benitez. 2012. “Time Series Modeling and Forecasting Using Memetic Algorithms for Regime-Switching Models.” *IEEE Transactions on Neural Networks and Learning Systems* 23 (11): 1841–47. https://doi.org/10.1109/TNNLS.2012.2216898.

Brennan, M.J. 1958. “The Supply of Storage.” *The American Economic Review* 48: 50–72.

Considine, Jennifer, Philipp Galkin, and Abdullah Aldayel. 2020. “Market Structure, Inventories and Oil Prices: An Empirical Analysis.” KAPSARC Discussion Paper. https://www.kapsarc.org/research/publications/market-structure-inventories-and-oil-prices-an-empirical-analysis/

Deaton, Angus, and Guy Laroque. 1990. “On the Behavior of Commodity Prices.” SSRN Scholarly Paper ID 269628. Social Science Research Network. https://papers.ssrn.com/abstract=269628.

Diebold, Francis X., and Atsushi Inoue. 1999. “Long Memory and Structural Change.” SSRN Scholarly Paper ID 267789. Social Science Research Network. https://papers.ssrn.com/abstract=267789.

Fama, Eugene F., and Kenneth R. French. 1987. “Commodity Futures Prices: Some Evidence on Forecast Power, Premiums, and the Theory of Storage.” *The Journal of Business* 60 (1): 55–73.

Fattouh, Bassam. 2009. “Basis Variation and the Role of Inventories: Evidence from the Crude Oil Market.” *Oxford Institue for Energy Studies* WPM 38 (January): 23.

Filardo, Andrew J. 1994. “Business-Cycle Phases and Their Transitional Dynamics.” *Journal of Business and Economic Statistics* 12 (3): 299–308. https://doi.org/10.2307/1392086.

Heaney, Richard. 2002. “Approximation for Convenience Yield in Commodity Futures Pricing.” *The Journal of Futures Markets*, August 13. https://onlinelibrary.wiley.com/doi/abs/10.1002/fut.10036.

Heinkel, Robert, Maurine Howe, and John Hughes. 1990. “Commodity Convenience Yields as an Option Profit.” *Journal of Futures Markets*. https://onlinelibrary.wiley.com/doi/abs/10.1002/fut.3990100508.

Hicks, J.R. 1939. Value And Capital. Second Edition. Oxford: Oxford University Press/Oxford Institute for Energy Studies. https://archive.org/details/in.ernet.dli.2015.223876/page/n3.

Hirshleifer, David. 1989. “Futures Trading, Storage, and the Division of Risk: A Multiperiod Analysis.” *Economic Journal* 99 (397): 700–719.

Koy, Ayben. 2017. “Modelling Nonlinear Dynamics of Oil Futures Market.” *Economic Research in Finance* (March). https://www.researchgate.net/publication/315728754_Modelling_Nonlinear_Dynamics_of_Oil_Futures_Market.

Kucher, Oleg, and Alexander Kurov. 2014. “Business Cycle, Storage, and Energy Prices.” *Review of Financial Economics* 23 (4): 217–26. https://doi.org/10.1016/j.rfe.2014.09.001.

Larson, Donald F. 1991. *Copper and the Negative Price of Storage*. World Bank Publications.

Leonhardt, Daniel, Antony Ware, and Rudi Zagst. 2017. “A Cointegrated Regime-Switching Model Approach with Jumps Applied to Natural Gas Futures Prices.” *Risks* 5 (3): 48. https://doi.org/10.3390/risks5030048.

Milonas, Nikolaos T., and Stavros B. Thomadakis. 1997. “Convenience Yields as Call Options: An Empirical Analysis.” *Journal of Futures Markets* 17 (1): 1–15. https://doi.org/10.1002/(SICI)1096-9934(199702)17:1<1::AID-FUT1>3.0.CO;2-P.

Omura, Akihiro, and Jason West. 2015. “Convenience Yield and the Theory of Storage: Applying an Option-Based Approach.” *Australian Journal of Agricultural and Resource Economics* 59 (3): 355–74. https://doi.org/10.1111/1467-8489.12092.

Pindyck, Robert S. 2004. “Volatility and Commodity Price Dynamics.” *Journal of Futures Markets* 24 (11): 1029–47. https://doi.org/10.1002/fut.20120.

Press, William H., ed. 1996. *FORTRAN Numerical Recipes*. 2nd ed. Cambridge, U.K. and New York: Cambridge University Press.

Sorensen, Carsten. 2002. “Modeling Seasonality in Agricultural Commodity Futures.” *Journal of Futures Markets*, March. https://onlinelibrary.wiley.com/doi/abs/10.1002/fut.10017.

Telser, Lester G. 1958. “Futures Trading and the Storage of Cotton and Wheat.” *Journal of Political Economy* 66. https://econpapers.repec.org/article/ucpjpolec/v_3a66_3ay_3a1958_3ap_3a233.htm.

Wei, Song Zan Chiou, and Zhen Zhu. 2006. “Commodity Convenience Yield and Risk Premium Determination: The Case of the U.S. Natural Gas Market.” *Energy Economics*, no. 28: 523–34. https://doi.org/10.1016/j.eneco.2005.10.002

Working, Holbrook. 1933. “Price Relations Between July And September Wheat Futures At Chicago Since 1885.” *Wheat Studies* 09 (06). https://ideas.repec.org/a/ags/frisws/142876.html.

Appendix A: Data and Key Variables

Inventory data: Savitzky-Golay smoothing filters

The analysis (INV) used daily inventory data from September 18, 2013 to January 25, 2019. The time series used is the daily floating tank top storage volumes in Rotterdam provided by Orbital Insight (2019).

The Savitzky-Golay filter was used to smooth the noise introduced by the satellite data gathering procedure and maximize the signal-to-noise ratio (Press 1996). Figure A.1. shows the resulting time series, the Savitzky-Golay smoothed inventories (SG_ROV).

The general equation for the Savitzky-Golay filter is given by:

$$Filtx_t = \frac{1}{h}\left[\sum_{i=-\frac{n_{p-1}}{2}}^{\frac{n_{p-1}}{2}} (a_i x_{t-i})\right] \qquad \text{A.1}$$

Where:

$Filtx_t$ = the filtered value of x_t

h = given in Table A.4

a_i = the coefficients of the polynomial

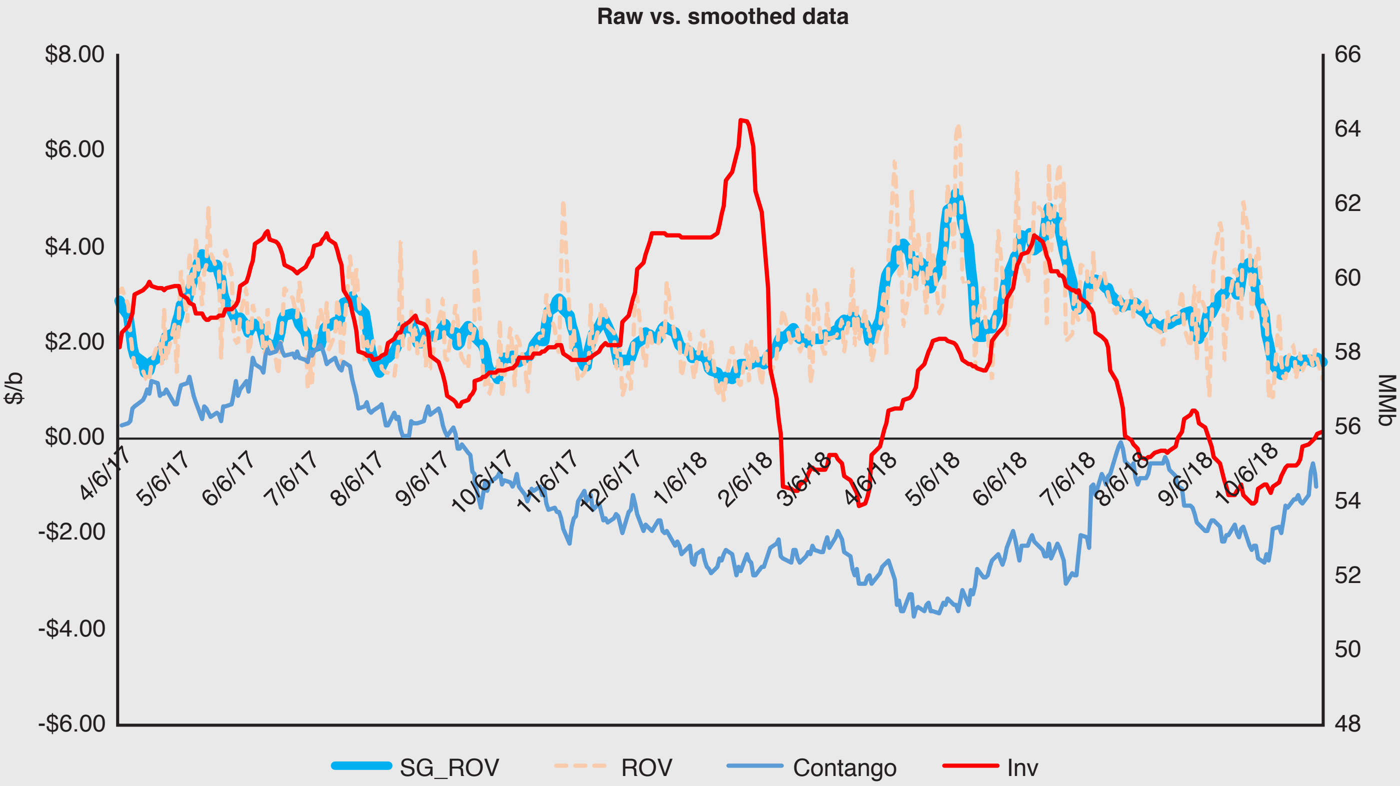
n_p = the number of data points used for the smoothing

x_t = the unfiltered time series

The spread options value (ROV) is calculated according to the methodology outlined in Considine, Galkin, and Aldayel (2020), and based on daily reported data from Orbital Insights for Rotterdam. Once again, the Savitzky-Golay filter (SG_ROV) was used to smooth the data and maximize the signal-to-noise ratio (Press 1996). The contango variable was calculated using daily future nine-month and two-month values for the Brent benchmarks sourced from the Bloomberg Terminal (Bloomberg 2019).

The time series used in this analysis, from April 6, 2017 to November 29, 2018, including both raw and smoothed datasets, are illustrated in Figure A.1.

Figure A.1 Inventories, contango and spread options values.



Sources: Orbital Insights; Bloomberg; KAPSARC calculations.

Appendix B: Summary Statistics

Table B1 reports some basic statistics for crude oil inventories and the spread options value for the daily time series from March 10, 2014 to November 30, 2018.

For both, the means are positive and have very high standard deviations. The skewness of the spread option is positive, suggesting a heavier right tail, while the skewness for inventories is negative, suggesting a heavier left tail.

For all of the time series, the kurtosis is quite high, suggesting fat-tailed distributions for all of the variables. The Jarque-Bera test rejects the null hypothesis that either of the time series is distributed normally.

Table B.1 Summary statistics for daily time series.

	Inventories	Spread option
Mean	56.1516	2.7735
Median	58.2295	2.5612
Maximum	65.0878	6.5948
Minimum	43.4588	-0.0921
Std. Dev.	6.5167	1.1137
Skewness	-0.6311	0.5570
Kurtosis	2.0291	3.2327
Jarque-Bera	123.2032	62.9153
Probability	0.0000	0.0000
Sum	65472.7900	3233.9540
Sum Sq. Dev.	49474.2100	1444.9330
Observations	1166	1166

Note: The spread option, and inventories values are smoothed and filtered for noise using the Savitzky-Golay filter described in Appendix A.
Source: KAPSARC calculations.

For both time series, the kurtosis is quite high, suggesting fat-tailed distributions for all of the variables.

Appendix C: Unit Root Tests

The first step in the econometric analysis is to conduct unit root tests on all the variables. Table C.1 reports the results of these tests for the level of crude oil inventories and the spread options value for daily data from March 10, 2014 to November 30, 2018. The lag lengths for the Augmented Dickey-Fuller (ADF) tests are selected according to the Schwartz information criteria. The results show that the inventory variable has unit roots at the 1%, 5% and 10% significance levels.

The first difference was taken for the inventory variable, and the time series were retested before their inclusion in the regression analysis. The first difference of the inventory variable was found to be stationary at the 1%, 5% and 10% significance levels.

The results for the spread options variable suggest that we can reject the null hypothesis of a unit root at the 5% significance level.

Table C.1 Unit root tests.

Daily	Inventories	Spread option	Critical values	ADF	PP
Augmented Dickey-Fuller	-2.0065	-4.0761	1% level	-3.4358	-3.4357
Prob.*	0.2842	0.0011	5% level	-2.8638	-2.8638
Philips-Perron	-1.9802	-5.6618	10% level	-2.5680	-2.5680
Prob.*	0.2958	0.0000			

Note: The reported values are the test statistics and the probability of the null hypothesis of a unit root.
*MacKinnon (1996) one-sided p-values.

Source: KAPSARC calculations.

Appendix D: Methodology and Detailed Empirical Results

To determine the relationship between the market structure and inventories, we postulate the following regression equation of the market structure, as measured by the spread options value (the dependent variable) on inventories and seasonal dummies, using daily data from March 10, 2014 to November 30, 2018.

The regression equation follows the work done by Omura and West (2015), Kucher and Kurov (2014), Fattouh (2009) and Considine, Galkin, and Aldayel (2020), and is represented as:

$$MS_t = \alpha_o + \beta_1 \Delta Inv_t + \sum_i^N \left(\gamma_{i_t} * D_{i_t}\right) + \varepsilon_t \qquad \text{D.1}$$

Where:

MS_t ≡ Market structure as defined by the spread option value.

ΔInv_t ≡ Rotterdam inventories as reported by Orbital Insight.

D_{i_t} ≡ A vector of dummy variables, including monthly seasonal dummy variables and a dummy variable for 2014 to 2015, to accommodate the evolution of the data collection process from Orbital Insights.

$\alpha_o, \beta_1, \gamma_{i_t}$ ≡ Estimated parameters

The regression was estimated for the different market states or regimes using the Markov regime switching model. Markov switching models are used to describe situations where the behavior of the variables, or stochastic processes, change from one regime to another. The model captures the behavior of a 'state variable' that cannot be directly observed (s_t), such as a recession or depression in GDP growth. For the oil industry, the state variables that cannot be observed are a state of excess supply (an oversupplied market), excess demand (an undersupplied market), or balanced world oil markets.

$$p(MS_t|Inv_t; D_t; s_t) = \begin{cases} p(MS_t|Inv_t; D_t; \theta_1) \; if \; s_t = 1 \\ p(MS_t|Inv_t; D_t; \theta_2) \; if \; s_t = 2 \\ p(MS_t|Inv_t; D_t; \theta_3) \; if \; s_t = 3 \end{cases} \qquad \text{D.2}$$

Where:

$\theta_m = \alpha_{om}, \beta_{1m}, \gamma_{i_m}$ ≡ Estimated parameters associated with regime m, with three distinct regimes (1, 2 and 3). The state variable evolves according to a Markov chain process. That is, the probability of being in any particular regime, or state of the oil market, in period t depends only on the state of the oil market in time (t-1) and not any other time (t-2) or (t-3).

The Markov chain process for the oil market has the following transition probabilities:

$$P([s_t = 1]|s_{t-1} = 1) = p_{11}$$
$$P([s_t = 1]|s_{t-1} = 2) = p_{12}$$
$$P([s_t = 1]|s_{t-1} = 3) = p_{13}$$
$$P([s_t = 2]|s_{t-1} = 1) = p_{21}$$
$$P([s_t = 2]|s_{t-1} = 2) = p_{22}$$
$$P([s_t = 2]|s_{t-1} = 3) = p_{23} \qquad \text{D.3}$$
$$P([s_t = 3]|s_{t-1} = 1) = p_{31}$$
$$P([s_t = 3]|s_{t-1} = 2) = p_{32}$$
$$P([s_t = 3]|s_{t-1} = 3) = p_{33}$$

Where p_{ii} is the probability of remaining in state i, given that the world oil market was in state i in the last period, and p_{ij} is the transition probability of the markets changing to state i, given that the world oil market was in state j in the last period.

While some representations assume that the transition probabilities are fixed, this would appear to be an overly restrictive assumption for the energy markets. We permit the transition probabilities to vary through time (Bazzi et al. 2017; Diebold and Inoue 1999; Filardo 1994; Fattouh 2009).

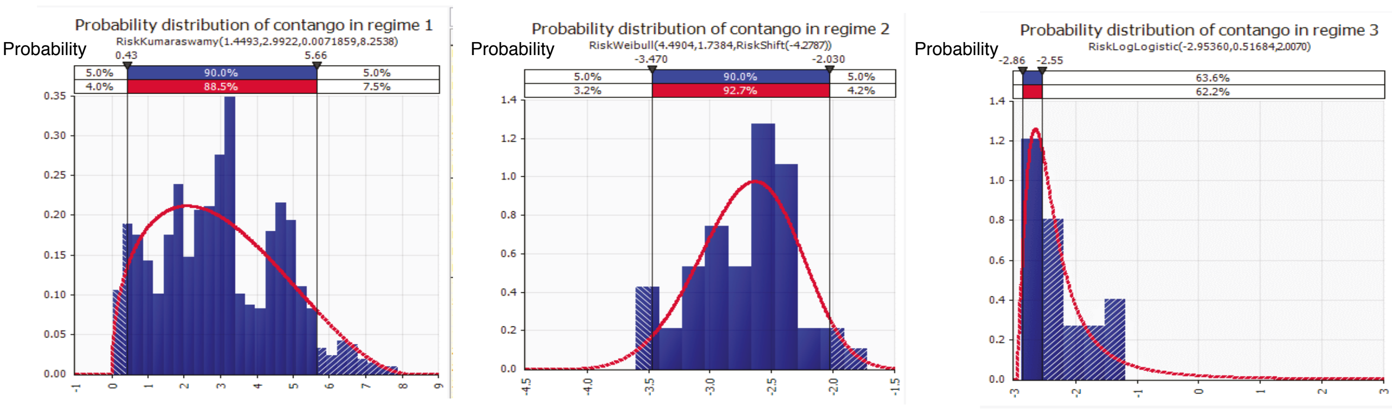
In this formulation, the probability of switching from one regime to another is a function of the level of contango in world oil markets. The level of contango (c_{t-1}) for Brent crude oil prices is a conditioning vector that contains vital economic information affecting the transition probabilities.

$$P([s_t = i]|s_{t-1} = j) = p_{ij(c_{t-1})} \text{ for i = 1,2,3, and j = 1,2,3.} \qquad \text{D.4}$$

The estimated parameters for the MRS structure in equation D.4 are estimated using a Markov switching regression, a non-linear optimization technique that uses the Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm and Marquardt steps to estimate all of the parameters of the complex non-linear system simultaneously.

Note: The BFGS method belongs to quasi-Newton methods, a class of hill-climbing optimization techniques that seek a stationary point of a (preferably twice continuously differentiable) function (Bergmeir et al. 2012; Bekiros and Paccagnini 2015).

Figure D.1 Probability distribution of contango in the three regimes.



Sources: KAPSARC calculations; Palisade @Risk.

The results of the Markov regime switching (MRS) analysis are reported in detail in tables D.1 and D.2. As expected, the model finds clear evidence of three distinct regimes, regime 1 – contango, regime 2 – backwardation, and regime 3 – extreme backwardation. The probability distributions for the basis, or level, of contango in the three regimes are chosen from a number of potential probability distributions according to the Anderson-Darling test statistic and are illustrated in Figure D1.

In regime 1, the average value of contango is $2.98, the mode is $3.20, and there is a 90% probability of the values ranging between $0.43 and $5.66. The estimated distribution is Kumaraswarmy, with a standard deviation of $1.69. In regime two, the backwardation regime, the mode value of contango is -$2.43, and the probability distribution is normal. The standard deviation estimated for regime 2 is $0.41. This regime is the most stable in terms of volatility. In regime 3, extreme backwardation, the estimated distribution is log logistic, the mode is -$2.67, and there is a 40% probability that the level of contango will be lower than -$2.50 $/b. The standard deviation is $8.70, by far the highest of any of the regimes.

The variance in the error terms for the estimated MRS model is 1.56 in regime 1, 1.12 in regime 2, and 2.30 in regime 3. In short, the basis exhibits the greatest volatility when the market is in regime 3, extreme backwardation. This is because backwardation is generally associated with just-in-time inventories, or low and falling stock levels.

The estimated coefficients of the Markov switching model are all statistically significant at the 1% confidence level. Unsurprisingly, the sensitivity of the market structure, as measured by the options value to changes in stocks, changes across regimes. The estimated coefficients for the three regimes are (i) -0.54 for the contango regime; (ii) -2.07 for the backwardation regime; and (iii) 1.98 for the extreme backwardation regime.

Table D.1 Markov regime switching results.

Variable	Coefficient	Std. Error	z-Statistic	Prob.
Regime 1				
ΔInv_t	-0.5444	0.2194	-2.4812	0.0131
Regime 2				
ΔInv_t	-2.0745	0.4857	-4.2715	0.0000
Regime 3				
ΔInv_t	1.9793	0.3849	5.1426	0.0000
Common				
DUMMY2	3.9217	0.1504	26.0820	0.0000
DUMMY3	3.0460	0.1299	23.4567	0.0000
DUMMY4	3.2648	0.1303	25.0631	0.0000
DUMMY5	2.9996	0.1282	23.4038	0.0000
DUMMY6	2.9896	0.1262	23.6836	0.0000
DUMMY7	2.2934	0.1263	18.1583	0.0000
DUMMY8	2.6081	0.1270	20.5398	0.0000
DUMMY9	2.7311	0.1288	21.2006	0.0000
DUMMY10	2.3364	0.1260	18.5486	0.0000
DUMMY11	2.3764	0.1434	16.5682	0.0000
DUMMYORB	0.2456	0.0733	3.3513	0.0008
LOG(SIGMA)	0.2057	0.0212	9.7076	0.0000
Mean dependent var	2.7741	S.D. dependent var		1.1140
S.E. of regression	1.2501	Sum squared resid		1797.2360
Akaike info criterion	3.3120	Log likelihood		-1908.2460

Source: KAPSARC calculations.

Table D.2 Time-varying Markov transition probabilities and expected durations.

Time-varying transition probabilities:				
P(i, k) = P(s(t) = k I s(t-1) = i)				
(row = i / column = j)				
		1	2	3
Mean	1	0.6681	0.0872	0.2447
	2	0.0479	0.2859	0.6662
	3	0.6681	0.0636	0.2683
		1	2	3
Std. Dev.	1	0.4709	0.1354	0.3516
	2	0.0934	0.4093	0.4696
	3	0.4709	0.1106	0.3861
Time-varying expected durations:				
		1	2	3
Mean	NA		5.3316	3.1206
Std. Dev.	NA		9.2946	3.9702

Source: KAPSARC calculations.

Table D.3 Markov regime transition matrix parameters.

Transition Matrix Parameters				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
P11-CONTANGO__BRENT	447.5613	133510.3000	0.0034	0.9973
P12-CONTANGO__BRENT	0.4903	0.9095	0.5391	0.5898
P21-CONTANGO__BRENT	-23.4212	57.1026	-0.4102	0.6817
P22-CONTANGO__BRENT	-24.3810	57.1031	-0.4270	0.6694
P31-CONTANGO__BRENT	388.7821	41003.4800	0.0095	0.9924
P32-CONTANGO__BRENT	0.7203	0.2013	3.5787	0.0003

Source: KAPSARC calculations.

Notes

Notes

About the Authors

Jennifer Considine

Jennifer is a visiting researcher at KAPSARC and a senior research fellow at the Centre for Energy, Petroleum and Mineral Law and Policy (CEPMLP) in Dundee, Scotland. She has led a number of research projects involving options pricing, real options valuations of physical assets, including electricity generation facilities, storage companies, and natural gas pipelines and contracts, risk management and hedging techniques, and trading strategies for a variety of commodities including natural gas, electricity and crude oil.

Abdullah Aldayel

Abdullah is a research analyst in KAPSARC's Markets and Industrial Development program, with a focus on oil markets and energy policies. Before joining KAPSARC he completed an internship at Halliburton's research and development center in Dhahran, Saudi Arabia.

About the Project

The purpose of this project is to provide a snapshot of global oil inventories at any given time and to identify whether the global or regional markets can be considered balanced. This will help to identify potential regional or global surpluses or shortages of crude oil supplies and inventories that could trigger a price reaction and a subsequent rebalancing of world oil markets.

The equilibrium 'market balancing' level of world oil inventories could have changed significantly in recent decades due to various factors. These include (a) the shale revolution and the resulting rapid response of shale oil supplies to changes in world oil prices; (b) the expansion of global oil refining and consuming centers; and (c) the buildup of strategic petroleum reserves in non-OECD countries. It is therefore essential to be able to determine the optimal inventory levels that would rebalance world oil markets under this new market paradigm. The project aims to answer the following questions:

1. How high do inventory levels have to be before world oil markets become over-supplied?
2. Are current inventory levels so high that they have put the market at risk of another price shock?

KAPSARC

مركز الملك عبدالله للدراسات والبحوث البترولية

King Abdullah Petroleum Studies and Research Center

www.kapsarc.org