Detecting abnormalities in the Brent crude oil commodities and derivatives pricing complex

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Abstract

Recent rapidly rising and volatile energy commodities prices and financial price manipulation scandals have brought the pricing mechanisms of crude oil derivatives to the fore of both popular press and policy initiatives. Among the most important of such commodities is Brent Crude. Brent Crude and its complex of derivative products make Brent Crude potentially more opaque and thus susceptible to price manipulation than other commodities. In spite of the importance of Brent to the world economy and world energy prices, and its complex of derivative pricing, relatively little work has been done to explore the potential for, and evidence of, price manipulation in the Brent Crude complex. This paper seeks to address this lack by proposing a method to test whether price squeezes have occurred in Brent Crude. This paper builds on previous work which proposed an *a priori* test for evidence of manipulation and the theory of storage. Previous work (Barrerra-Rey and Seymour 1996) posited that the very close-to-delivery end of the forward curve for Brent should not be simultaneously in contango and backwardation, while other work (Geman and Smith 2012) proposed using an econometric prediction and a model based on the theory of storage to detect manipulation in commodity markets. Our work builds on these approaches by developing a more detailed model of calendar spreads in the Brent Crude complex. In Brent, a particular area of potential manipulation is from the relatively illiquid and more opaque physical OTC forward market (where prices are 'assessed' by Platts during a short 'window' of time) and the more liquid ICE futures market. Our model relates prompt ICE futures calendar spreads to prompt-over-dated OTC forward spreads. The model then tests whether the *a priori* indicators of manipulation as suggested by Barrera-Rey and Seymour are statistically consistent with the process which drives spreads historically. We find that in most all cases, the indicated period of manipulation is statistically different. We further investigate whether other factors, such as liquidity (volume and open interest) or world oil market conditions (using WTI spreads) or other forward market conditions could be driving our results. The statistical difference is found to be invariant to the inclusion of these other explanatory variables. We conclude that the evidence is consistent with the hypothesis of price manipulation and that the test provides a model and method for detecting such cases.

1 Introduction

1.1 Rising oil prices and financial derivatives trading

The importance of crude oil and petroleum products to the world economy and population is difficult to estimate, but would perhaps be difficult to underestimate. Recent rapid rises in price levels, as well as apparently increased volatility in oil markets, therefore have been an important political and economic topic for major world oil consumer and producer economies. The importance of oil to the world economy has been perhaps increasing commensurate with price rises.

Commensurate with the trend of rising oil prices has been the general phenomenon of increased complexity in financial dealing and trading and the rapid rise of trading in more complex financial derivative products across commodities, credit, and equity financial products. A stream of scandals and financial crises, perhaps starting with Enron, the 2008 crash touched off by the bankruptcy of Lehman Bros, and subsequent financial meltdown led to increased financial regulation in the EU and USA, with legislation such as Dodd-Frank adopted in the USA.[1] More recently, evidence has emerged in the case of the London Interbank Offer Rate (LIBOR) that bankers may have reported false rates to the LIBOR reporting agency (the British Bankers Association--BBA[2]) in efforts to influence the wholesale price of credit or derivative contracts tied to LIBOR.

Energy markets have been at the fore of recent probes and investigations, with JP Morgan's alleged manipulation of power markets hitting the public press in the same weeks as the LIBOR story was in the headlines (Bloomberg 2012). In light of the scandals and also commensurate with an evolving understanding of the economics of trading, derivative contracts for commodities and financial instruments, and their pricing mechanisms also have been generating the interest of politicians, economists and regulatory agencies.

1.2 Crude oil

Refined product oil prices to the consumer ultimately follow from the prices in the complex of the underlying commodity, crude oil. In spite of the obvious importance to consumers and economies, the mechanisms by which crude oil prices are set are complex and often little-understood by non-oil market specialists. Oil prices are set via a world-wide informal system of spot prices, forward over-the-counter, and futures exchange-based trading. Added on top of these so-called 'vanilla' commodities derivatives are options, swaps, contracts-for-differences (Cfds), all with various forms and specificities.

The spot price for crude oil, the price of the underlying crude oil commodity for immediate delivery, can and does, vary by time-of-delivery (or cash settlement), location of delivery, grade,

[1] The general legislation in the EU, the Market Abuse Directive, was adopted in 2003, DIRECTIVE 2003/6/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 28 January 2003, and was adopted in the UK in 2011. http://www.fsa.gov.uk/pages/about/what/international/pdf/mad%20(pl).pdf.

[2] Thompson-Reuters handles the reporting for the BBA. http://www.bbalibor.com/

and other physical specifications (e.g., sulphur content). The variations in the spot price are driven by fundamentals of supply and demand, but also by hedging, risk sharing, speculation and arbitrage trading activity.

These fundamentals, along the with the primary function of hedging and traders' need for liquidity, has led to a few underlying grades of crude to become benchmark crudes, with other grades of crude or refined products often priced relative to the benchmark. Of the benchmark crudes, Brent is the most widely traded and most liquid. Other benchmark crudes include West Texas Intermediate (WTI) and Dubai.

1.3 Brent crude

Brent is the light sweet grade of crude originally produced in the North Sea between the UK and Norway. Brent crude remains the most important benchmark price in the world of oil commodity pricing. Brent crude has retained this position in spite of waning production. The recent events of various market manipulations (e.g. LIBOR) and waning production have caused some concern and calls for an investigation into Brent pricing has been in the press (Kemp, 2012).

Unlike some commodities, where the spot price is the price for immediate delivery, and where crude can be readily stored, the Brent crude commodity is produced at sea and delivered via pipeline to the Sullum Voe terminal, where it is loaded onto tankers. Therefore, a spot price for Brent does not exist in the strictest sense; the spot price retains an element of 'forwardness' in that it merely indicates a date for delivery that is near (23 days). The spot price, or so-called 'dated Brent' price, indicates that the crude is scheduled to be loaded within a three-day window, up to 23[3] days in advance.

1.4 Price manipulation

The financial infrastructure built around crude grades such as Brent and WTI allow for complex trading and strategies in the commodities and their derivatives, in spite of waning physical production. As financial trading has increased while production has declined, the implication is that a larger and larger amount of financial derivative contracts are being linked to an ever smaller underlying physical commodity. This historical combination of events means that small movements in the price of liquid financial markets could be engineered with trade in the more illiquid underlying physical/cash/OTC markets. The further development of the complex of derivative products based on the underlying commodity price has likely enhanced the incentives to engage in price manipulation schemes (Barrera-Rey and Seymour 1996), as potential losses from holding physical commodity contracts longer than would be economic (absent a price manipulation strategy) can be mitigated with complex derivatives trading strategies.

Evidence of price manipulation in Brent and in energy derivatives has been in the press, with a number of cases to the fore recently. In June, 2010, the Financial Services Authority (FSA)[4] fined

[3] The advance period has been changing over time, previously what was 15-day-ahead Brent became 21-day, then 23-day. The exact specification of Brent has also been changing to allow for more grades and fields' production, to account for the waning production from the original Brent fields.

[4] The FSA is the UK financial regulator.

an oil futures broker, Stephen Perkins, £72,000 for market abuse and prohibited him from the industry. He traded an extremely high volume in the Brent crude futures market on a single morning in June 2009 and the FSA determined: "As a direct result of Perkins' trading, the price of Brent increased significantly. Perkins' trading manipulated the market in Brent by giving a false and misleading impression as to the supply, demand and price of Brent and caused the price of Brent to increase to an abnormal and artificial level."[5] In another case, on April 19, 2012, the Commodities and Futures Trading Commission (CFTC) was granted a $14m settlement by the Federal Court in the *Optiver* case. The case involved market manipulation in crude oil, heating oil, and gasoline futures markets.[6]

In spite of these recent cases, and the importance of oil to the world economy, there in fact have been few cases of price manipulation proven involving the major benchmark crudes. This may be due to the difficulty in detecting and proving market manipulations, along with the lack of a clear path to testing the 'normalness' of crude markets and their pricing complexes.

Perhaps due to this difficulty, added powers and legislation have been given to the relevant authorities, and increased cooperation encouraged in the USA. The FTC and CFTC in 2011 agreed to share information and cooperate on investigations re fraud-based manipulation cases in the energy sector. On April 17, 2012, President Obama announced a new five-part plan to address oil market manipulation. He has called on Congress to approve funding for these measures. The main points of the plan are: 1) six-fold increase in surveillance and enforcement for oil futures market trading at the CFTC; 2) increased funding for the CFTC to update its IT resources for monitoring market activity; 3) ten-fold increase in civil and criminal penalties for market manipulation in the oil futures market; 4) give CFTC authority to raise margin requirements in the oil markets to help prevent manipulation and to help reduce market volatility; and 5) increase/expand access to CFTC data to examine patterns and trading activities in energy markets.[7] Outside the USA, recently in July (2012), the EU was considering making new laws criminalising commodity price distorting market behaviour (Reuters 2012).

The interest in commodities price manipulation and its difficulty in being detected thus remains an important policy context for major western policy makers.

1.5 Rest of this paper

This paper will focus on price manipulations that occur from trading in a single commodity, where there is direct trading activity among the products and players. This paper will focus on identifying evidence of potential price manipulations in the Brent crude pricing complex.

The work presented will not focus on the more general notion of speculation and financial trading causing some kind of general long-term rise in world oil prices. Pirrong (2012) likens allegations of

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[5] http://www.fsa.gov.uk/library/communication/pr/2010/109.shtml

[6] http://www.cftc.gov/PressRoom/PressReleases/pr6239-12

[7] http://www.whitehouse.gov/the-press-office/2012/04/17/fact-sheet-increasing-oversight-and-cracking-down-manipulation-oil-marke

more general price rises due to excessive speculation as "witch hunts", but notes that they are "hardy perennials" and perhaps more enduring than witch hunts.[8]

The remainder of the paper is organised as follows. The next section reviews the literature on storable commodities pricing, Brent crude, and price manipulations. Section 3 develops a model; Section 4 discusses the data and presents some preliminary data analysis. Section 5 presents results; and Section 6 gives our conclusions.

2 Review of Literature

2.1 Commodities pricing

In order to develop a model of price manipulation, it is necessary to first develop a model of what 'normal' prices are. This points towards the more general and large literature on commodities, forward, and derivatives pricing. We focus on storable commodities in general, as well as crude oil to start.

The foundations of pricing research for storable commodities is based on the "theory of storage" and the notion of intertemporal cash and carry arbitrage [Kaldor (1939), Working (1948, 1949), Telser (1958) and Williams & Wright (1991)].

Geman and Smith (2012) consider the general theory of storage and propose a model for calendar spreads in precision metals futures prices. The calendar spread is the difference between two prices for the same commodity but with different delivery dates. They derive the spread and show its relationship to the convenience yield and interest rates. They show that the interest and storage cost adjusted spread is equal to the convenience yield. Their key insight, which originated with the work of Working (1927;1933;1934;1948;1949), Kaldor (1939), and Telser (1958), is that in normal contango[9] situations, cost of carry relationships should govern the relationships between spot and forward prices, but in times of scarcity, when backwardation is likely, then convenience yield would dominate the cost of carry in the relationship.

In their lucid summary of the literature and advancement of the theory, they propose two clear testable hypotheses about the relationships between spot and futures prices and inventory levels.

Geman and Smith's proposition 1 considers when commodity markets are in backwardation, i.e., spot-price > near-dated futures price > longer-dated futures prices. In other words, the forward curve is downward-sloping. However, they propose that the normal shape of the backwardated forward curve is convex, as the likelihood is that scarcity is a short-run phenomenon. The likelihood is that the supply-demand imbalances in the current market will be resolved over time, and thus the near-term premium of the spot (or short dated futures) prices will tend to diminish with time to delivery. When markets are in contango and inventory is not scarce, cash and carry

[8] Interestingly, Pirrong (2012)[8] notes that Adam Smith in the *Wealth of Nations* considered that "forestalling" could distort prices, but likened fears of speculation to "terrors" and "fears of witchcraft."

[9] Contango is the state of the forward market where the price rises as the time-to-delivery increases. Backwardation is the opposite.

arbitrage should dominate the forward pricing. They posit that the limiting factors on a contango are cash and carry, but the limiting factors on backwardation are substitution in demand. They reproduce Working's original curve as an illustration of the relationship.

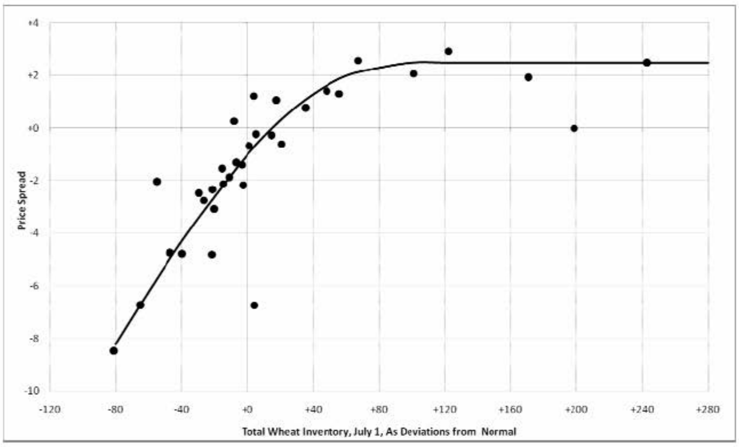

Figure 2 - Relationship between Chicago July-September Spread in June and United States Wheat Stocks on July 1 (from Working(1933))

This leads them to their proposition 2: In times of scarcity (low inventory) there should be higher volatility in spot prices, which should diminish with time to delivery. In times of non-scarcity (high inventory), volatility of spot and futures prices should be reasonably similar.

To test their theory, they reproduce Working curves for six metals categories and find reasonably good fits, which they illustrate graphically.

They further test their more innovative hypothesis about the relationship between volatility of spot prices and inventory, and again find reasonable fits, which they illustrate graphically, although the relationship between volatility and inventory appears weaker than the spread versus inventory.

They choose the following functional forms for their models. For the spread, they use:

$$\Psi_{t,T} = A^{B(I(t))} + C$$

Where, Ψ, is the spread, and A, C, and B are parameters to be estimated.

$$\sigma_{t,T} = \mathrm{A}^{\mathrm{B}(I(t))} + \mathrm{X}$$

Where sigma, σ, is the volatility, and A, B, and X are parameters to be estimated.

Finally, they propose a method for detecting market abnormalities given their (tested) hypotheses. They propose that the predicted value for the spot-futures spread and volatility from a regression[10] with inventory levels can be used to determine if the market is functioning 'normally'. They use the ratio of the actual spot price to the predicted spot price, and the actual volatility to the predicted volatility. They do not propose a formal statistical method for testing whether the two are different. They also use a graphical approach (which appears to point to some obvious spikes).

2.2 Crude price manipulation cases

Besides the academic work of Geman and Smith (2012), the work of financial regulators in crude oil cases motivates our approach. The details of the US Commodities and Futures Trading Commission's (CFTC) complaint in the Parnon/Arcadia (US CFTC v Parnon Energy, Arcadia, Wildgoose and Dyer) case are available from the CFTC.[11] The CFTC complaint asserts that the calendar spread (the differential between front month West Texas Intermediate (WTI) crude futures contract and the two-months-to-deliver contract) is the best market indicator of the relative conditions of WTI supply and demand. There is also trade in the physical oil market for WTI at Cushing, and a three-day cash window between the expiry of the prompt month futures contract plus three days. This enables market participants to further balance their needs for physical oil and delivery, but also influences the next prompt month futures contract prices and related derivatives prices. The alleged scheme of the traders in the CFTC case was that the market was in backwardation (indicating a profit from a long calendar spread position – the prompt month price is higher than the next-later-month). The traders allegedly bought up physical oil and then dumped this on the market/cash window (thus driving the spread down), while taking large short positions in the WTI calendar spreads. Thus, the traders allegedly tried to use the illiquid cash/physical market in WTI to depress the price of prompt month futures contracts in WTI (and commensurately the calendar spread).

2.3 Brent crude pricing and detecting manipulation

Barrera-Rey and Seymour (1996) propose *a priori* tests of a squeeze in Brent crude; that is to say, they do not mean to test whether the squeeze has been successful, profitable, or otherwise—merely whether the balance of the evidence supports the idea that a squeeze was likely/could have been possible. They do give detailed descriptions of how various squeezes, especially with contracts-for-differences (CfD) positions, could be profitable. Of particular note for our analysis is their description that, "Building large positions on the paper market may allow a participant to raise the value of first month relative to second month or dated Brent (or even another cargo priced off Brent),"—this sounds familiar to the CFTC Parnon/Arcadia case. The importance of the spread for potential market manipulation is that it would be rare that market participants have sufficient leverage to reverse the overall trend in the market (Barrera-Rey and Seymour 1996). Thus the spread enables participants to profit on smaller relative movements in the relative prices of adjacent month or similar contracts.

[10] They do not use classical linear regression but use an exponential fitting approach.

[11] http://www.cftc.gov/ucm/groups/public/@lrenforcementactions/documents/legalpleading/enfparnoncomplaint052411.pdf

Our focus in this paper will thus be on such cases, where the potential abuse runs from the relatively illiquid cash/physical over-the-counter market to the more liquid futures market.

Barrera-Rey and Seymour propose the following as evidence of a squeeze (whether intentional or unintentional). They take the price differential between dated Brent and first month Brent and compare this with the differential from first month Brent to second month Brent. In other words, they compare the first adjacent calendar spread to the next adjacent calendar spread prices for Brent crude oil physical contracts. They define *a priori* evidence of a squeeze as when the first-month Brent contract price rises to a premium over *both* the dated-Brent and the second-month-to deliver Brent forward prices. They add the condition that the premium of first month forward Brent over dated Brent should exceed 50cent/bbl, and also consider how the premium of first month Brent evolves over time. On the second condition, that the premium of first month Brent over dated should rise towards expiry, they note that this is not a necessary condition for a squeeze. Finally, they also consider volatility of the alleged squeeze incidents. They note that the first part of their measure was proposed by Horsnell and Mabro (1993).

They test their data and find evidence of a squeeze in at least five months where their definition of the squeeze is satisfied.

The precise hypothesis of why these conditions constitute a squeeze is not entirely described by Barrera-Rey and Seymour. We propose that the correct interpretation is that it is highly unlikely that normal market conditions could cause a 'lump' in the term structure of the forward curve at such close dates to delivery. We define 'normal' as meaning either consistent with cash and carry arbitrage or the theory of storage. The windows of time in question were between 15 and 21 days to delivery, and then a month ahead of that. 'Dated' Brent is merely front month OTC Brent that has been given a delivery date (within 21 days). It is very unlikely that there could exist an expectation of tight inventories for Brent *circa* 21 days to delivery, and simultaneously relatively ample inventories expectations for Brent being delivered from 10-21 days to delivery, *and* further out than 30 days to delivery. In other words, in order for market fundamentals to be able to explain a 'hump' in the near-term forward curve for Brent, this would require market participants to believe there was some very short-term and transient shortage that was not around in the immediate term to delivery, would appear, and then disappear rapidly. Such conditions are extremely unlikely.

3 Model and data

3.1 Commodities prices and calendar spreads

Our model is based on the fundamental models of the theory of storage and cash and carry. The cost of carry includes the opportunity cost of capital, which is the risk free rate, *r*, when cash and carry intertemporal arbitrage is possible. This simplest model for the forward pricing of a commodity is:

1) $$F_{0,T} = S_0 e^{(r+c)T}$$

Where, F_0 is the forward price today, for delivery at time T, S_0 is the spot price today, *r* is the risk free rate, *c* is the storage cost, and *T* is the time-to-delivery (and *e* is the exponential function operator). Thus, the equation says that the forward price should equal the spot price, which increases over time-to-delivery at the risk-free cost of funds plus storage cost.

In this simple case, the forward curve of prices for future delivery will rise with time at the rate *r +c*. Thus, in the case of normal cash and carry arbitrage, the forward price should be greater than the spot price with time, and contracts for delivery further into the future should be priced above contracts for delivery closer to the present. The state is called contango. The alternative, where the forward curve slopes downward with time-to-maturity, is called backwardation.

Empirically, we observe that markets can be in either contango or backwardation, so the basic cash and carry model must be extended. The most common extension is to add "convenience yield". Convenience yield is the extra value market players give to having the commodity on hand, to avoid stockouts, production process interruptions, etc. Convenience yield is an alternative factor that explains that having physical possession of the commodity might be more valuable than having a contractual right only to the commodity. In our formula, convenience yield, c*y*, has the opposite effect of storage cost – it can be thought of as an inverse of storage costs.

2) $$F_{0,T} = S_0 e^{(r+c-cy)T}$$

When convenience yield is larger than the risk-free rate and storage costs, then the slope of the forward curve will be negative with time to delivery; in other words, the market will be in backwardation.

In general, the above framework can be adopted for the relationships between different parts on the forward curve (introducing the price at time t>0 for delivery at time T), risk and the cost of carry. We can at *t* and *w*, the risk-adjusted interest rate to the model.[12]

3) $$F_{t,T} = S_t e^{(w+c-cy)(T-t)}$$

It is useful to work in logs, and so taking the log of the above gives:

4) $$lnF_{t,T} = lnS_t + (w + c - cy)(T - t)$$

The calendar spread is then the difference between (usually adjacent) points on the forward curve:

5) $$lnSprd_{t,T+1\_T} \equiv lnF_{t,T+1} - lnF_{t,T} = (w + c - cy)$$

This is similar to Geman and Smith (2012), who show the spread plus the cost of carry is equal the convenience yield.

Where the above notation indicates the spread between products for delivery between *T+1_T*. It is notable that the above model implies that the forward curve has a constant slope in its log-price form (prices grow/shrink at a constant rate in the levels). This is at odds with empirical observation, which shows that the forward curve can switch from contango to backwardation, and can even display both at different maturities. It is necessary then to allow for differences in the

[12] The convenience yield can be negative or positive empirically; here we have put it in as a negative, because it is a negative "cost", i.e., enters in the opposite way as the opportunity cost of capital.

convenience yield and the risk adjusted rate. Over short periods of time, i.e., months, and on the front end of the forward curve, we can assume that the cost of storage is constant. Let us therefore focus on convenience yield, and allow that to be time variant, and also allow for a terms structure of interest rates.

6) $$lnSpd_{t,T+1\_T} \equiv lnF_{t,T+1} - lnF_{t,T} = w(t \ldots T+1) + c - cy(X_t, t \ldots T+1)$$

Essentially, convenience yield is assumed to be a function of exogenous factors, X, during the time between t and T+1. Note that equation 5) rearranges to the formula derived by Geman and Smith (2012)[13], i.e., that the spread, adjusted for interest and the cost of carry, is a measure of the convenience yield.

7) $$lnSpd_{t,T+1\_T} \equiv lnF_{t,T+1} - lnF_{t,T} - w(t \ldots T+1) - c = -cy(X_t, t \ldots T+1)$$

Essentially, convenience yield is assumed to be a function of exogenous factors, X, during the time between t and T+1. Note that 5a) rearranges to the formula derived by Geman and Smith (2012) (5b)[14], i.e., that the spread, adjusted for interest and the cost of carry, is a measure of the convenience yield.

It is useful also to consider the difference between adjacent calendar log-spreads:

8) $$lnSpd_{t,T+2\_T+1} - lnSpd_{t,T+1\_T} = \Delta w(t \ldots T+2) - \Delta cy(X_t, t \ldots T+2)$$

In other words, the difference between adjacent calendar spreads is equal to the difference between interest rates (risk adjusted) on the yield curve and the change in convenience yield over the time period. Since for short time periods, interest rates and the cost of storage should be nearly identical, the differences in calendar spreads represent differences in convenience yield over time.

Rearranging, gives and more formal model whose intuition is derived from the work of Barrera-Rey as previously discussed:

9) $$lnSpd_{t,T+2\_T+1} = lnSpd_{t,T+1\_T} + \Delta w(t \ldots T+2) - \Delta cy(X_t, t \ldots T+2)$$

The model above says that the calendar spread of the second month over the first month futures/forward prices should equal the spread on the first month-to-deliver over the spot or immediate delivery price spread, plus an adjustment for the differential in the term structure of interest rates[15] and the convenience yield (assuming that over the short time periods, physical storage costs are approximately constant).

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[13] They define a slightly different measure of the spread as the percentage change in the futures price over the spot price; we use the log-differential, which is the continuous constant growth rate.

[14] They define a slightly different measure of the spread as the percentage change in the futures price over the spot price; we use the log-differential, which is the continuous constant growth rate.

[15] Technically, the differential should be the difference between to implied forward rate from T to T+1, less the spot rate from today, t, to T (if t is in fact forward, such as the first month to delivery, then this should also be the forward rate from t to T, although the difference at such a short-dated portion of the yield curve is likely to be minimal.

We wish to develop an empirical model for the above, and note that the convenience yield itself is not observable directly, whereas the spread can be calculated directly from market data on forward prices.

A final development of our model is motivated by the work of Barrera-Rey and Seymour, and also by the case-details from the US CFTC and the Parnon/Arcadia case for WTI, where the alleged manipulation involved use of the physical market and 'cash window' to try and manipulate spreads in the futures markets. The Brent crude complex includes a similar structure, with cash-physical crude OTC trading near to delivery, and linked to the ICE futures market. We therefore want to pose the model in terms of the physical OTC forward and cash markets (forward dated and 21-day forward market spread in the case of Brent) and the impact of this market on the front month calendar spread in ICE Brent futures. We further allow a constant elasticity parameter between the log-spread from the OTC-forward-physical market to the futures market. The model becomes:

10) $$lnSpd_{f2\_f1} = \alpha + \beta lnSpd_{BFOE1\_BFOEdtd} + \epsilon$$

Essentially, the spread is a measure of the convenience yield (adjusted for interest rates). The spread one period ahead is the expected change in the convenience yield between the current delivery period and the next delivery period. Current inventory levels should be fully reflected in the closest-to-delivery (prompt) spread. Thus our measure of the spreads is in effect a measure of two convenience yields.

11) $$cy_{f2\_f1} = \alpha + \beta cy_{BFOE1\_BFOEdtd} + \epsilon$$

3.2 *A priori* evidence of manipulation

As discussed in the literature review section, there are relatively few papers proposing tests of market manipulation. Notable exceptions are Barrera-Rey and Seymour (1996) and Geman and Smith (2012).

Barrera-Rey and Seymour (1996) propose the test of *a priori* price manipulation in the Brent complex as a test of whether the very short-dated forwards market appears to have an aberration in displaying both backwardation and contango. In other words, if the front-month 21-day-BFOE price is greater than the price of dated BFOE and 2nd-month BFOE, then they propose this is evidence of potential price manipulation. We use this same test to identify periods of potential manipulation; the test explicitly is:

12) $$P_{BFOE\_2} < P_{BFOE\_1} > P_{BFOE\_dtd}$$

And

$$P_{BFOE\_1} - P_{BFOE\_dtd} > \$0.50$$

In other words, if the price of forward Brent for prompt delivery is greater than the price of Brent dated for delivery (more immediate delivery than the 21-day Brent), and greater than the price of Brent for 2-month-forward delivery; the different between the short-dated prices should exceed 50 cents per barrel, as an added filter on small aberrations due to illiquidity or other random factors.

Barrera-Rey and Seymour do not explicitly articulate the mechanism as to why this is an indication of manipulation, but we hypothesize that the explanation is that the market cannot be consistent with the theory of storage. In other words, the models of Geman and Smith (2012), following the work of others, suggests that calendar spreads, which measure convenience yield which dominates the cost of carry when the market is backwardated, should be explained by storage. It is highly unlikely that the market for Brent crude could be in contango in the two closest to expiry forward contracts while in backwardation between the next two expiry dates.

We propose to test the *a priori* evidence of manipulation, as identified using the Barrera-Rey and Seymour test, using a test of the convenience yields and the theory of storage. The method proposed is to create time-specific dummy variables for alleged manipulations and then test whether the relationship between the convenience yields is statistically different for those identified periods.

Because we do not have data on the storage and pipeline flows, loading programmes, etc, for all the market participants in the Brent Crude complex, we cannot test the theory of storage directly. We, however, propose that the test of the two convenience yields as proposed in equations and can form an alternative test. More specifically, we propose the test:

13) $$lnSpd_{f2\_f1} = \alpha + D_\tau + \beta lnSpd_{BFOE1\_BFOEdtd} + \gamma D_\tau lnSpd_{BFOE1\_BFOEdtd} + \epsilon,$$

where the D_τ is a dummy variable identifying the period of the alleged manipulation (i.e., given equation 11 holds). The test of manipulation is then the statistical test: $\beta=\gamma$.

3.3 Data

The data used for the analysis are daily close futures prices and daily assessment prices for Brent crude. The Futures prices are closing prices ICE prompt (first month), second month, and third month ICE Brent crude futures contracts. The forwards prices are over-the-counter cash contracts for Brent, Forties blend, Oseberg and Ekofisk (BFOE) crudes, and are Platts Brent forward pricing data for the first three time-to-expiry contracts: dated Brent/BFOE, first month Brent/BFOE and second month Brent/BFOE. Note that the first month Brent/BFOE simply becomes dated Brent at expiry.

The period chosen includes all of the available time for which Brent futures prices have been available since October 2008 to the end of April 2012 (first and last trading days). We chose the period beginning in October 2008 because this was the first period available after the financial crisis.

For subsequent analysis, we also included data from ICE on Brent open interest and volume for the prompt (first month) contract. We also used data for NYMEX West Texas Intermediate (WTI) crude futures contract prices, for the prompt and next month-to-delivery.

Variable	Obs	Mean	Std. Dev.	Min	Max
f1	1376	87.10	23.97	36.61	146.08
f2	1376	87.41	23.48	39.17	146.60
bfoe_dtd	650	79.74	21.12	39.67	126.64
bfoe1	650	80.07	21.03	39.41	126.43
bfoe2	650	80.55	20.58	40.01	126.22
vol_f1	1331	126988.50	57047.04	8085.00	463810.00
oi_f1	1299	129070.00	60888.25	8518.00	277256.00

4 Results

4.1 Periods of potential manipulation

We first ran the test proposed by Barrera-Rey and Seymour on the data for all BFOE forward contract prices in the dated, 1st-month, and 2nd-month-to-delivery complex. We chose the time-period from October 2008 to the present (April 2012), as prior to the financial crisis, there was considerable volatility and other drivers prevailing in world commodity markets. This analysis identified the following periods for the *a priori evidence* of potential manipulation:

Period	bfoe_dtd	bfoe1	bfoe2
12/07/09 - 15/07/09	59.44	60.45	60.27
27/07/09 - 31/07/09	67.89	68.59	68.50
09/09/10- 14/09/09	78.00	78.57	78.51
15/12/10 - 25/12/10	92.46	93.06	92.97
10/01/11 - 21/01/11	97.77	98.60	98.01
28/02/11 - 05/03/11	114.90	115.58	115.42
16/06/11 - 02/07/11	109.84	110.48	110.16
19/07/11 - 30/07/11	118.16	119.15	118.22

The methodology was then to estimate Equation **13** econometrically and test the results of whether the coefficient on the alleged time period was different.

4.2 Regression results

We estimated a number of regression models with inclusion of various explanatory variables. We first added a general time trend to Equation **13**. We estimated Equation **13** for each identified time periods separately (i.e., a separate dummy variable), and then overall for a model including all the time periods in the same model. In other words, the slope coefficient estimates on the BFOE_1 to BFOE_dated calendar spread were restricted to just two parameters: one indicating a period of the alleged infraction; and one during a normal state for the near-to-delivery forward curve.

The results of these regressions are found below in Table 1.

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

VARIABLES	(1) D0	(2) D1	(3) D2	(4) D3	(5) D4	(6) D5	(7) D6	(8) D7	(9) D_all
lnsprd_bfoe1_dtd	0.216533***	0.219551***	0.215330***	0.215349***	0.220204***	0.215285***	0.214900***	0.214434***	0.232484***
	(0.038)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)	(0.039)
td	-0.000031***	-0.000031***	-0.000031***	-0.000031***	-0.000030***	-0.000031***	-0.000031***	-0.000031***	-0.000030***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
d0	0.218147								
	(0.542)								
d0_lnsprd_bfoe1_dtd	-0.540388								
	(1.288)								
d1		0.195150							
		(0.579)							
d1_lnsprd_bfoe1_dtd		-0.477411							
		(1.391)							
d2			-3.296022						
			(7.646)						
d2_lnsprd_bfoe1_dtd			7.983354						
			(18.527)						
d3				0.097088					
				(0.393)					
d3_lnsprd_bfoe1_dtd				-0.240237					
				(0.954)					
d4					0.406854				
					(0.339)				
d4_lnsprd_bfoe1_dtd					-0.991563				
					(0.821)				
d5						0.466335			
						(1.083)			
d5_lnsprd_bfoe1_dtd						-1.135225			
						(2.630)			
d6							0.118667		
							(0.356)		
d6_lnsprd_bfoe1_dtd							-0.287880		
							(0.865)		
d7								0.041272	
								(0.333)	
d7_lnsprd_bfoe1_dtd								-0.098485	
								(0.809)	
d_all									0.267508**
									(0.119)
d_all_lnsprd_bfoe1_dtd									-0.652445**
									(0.287)
Constant	0.483895***	0.480950***	0.483215***	0.482919***	0.479988***	[illegible]278***	0.483630***	0.483949***	0.472468***
	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)	([illegible]035)	(0.035)	(0.035)	(0.035)
Observations	903	903	903	903	903	903	903	903	903
R-squared	0.398443	0.400592	0.398535	0.399305	0.401014	0.398761	0.398811	0.398698	0.403156

VARIABLES	(1) D0	(2) D1	(3) D2	(4) D3	(5) D4	(6) D5	(7) D6	(8) D7	(9) D_a_vol	(10) D_a_wti
lnsprd_bfoe1_dtd	0.135702***	0.131767***	0.131680***	0.137272***	0.128496***	0.125412***	0.130413***	0.130103***	0.145660***	0.155433***
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.035)	(0.032)
td	-0.000034***	-0.000034***	-0.000034***	-0.000034***	-0.000034***	-0.000034***	-0.000034***	-0.000034***	-0.000034***	-0.000018***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
d1	0.165689									
	(0.454)									
d1_lnsprd_bfoe1_dtd	-0.404459									
	(1.091)									
lnvol_f1	0.000636**	0.000631**	0.000616**	0.000660**	0.000632**	0.000635**	0.000635**	0.000640**	0.000614**	0.000685**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
lnoi_f1	-0.000155	-0.000141	-0.000136	-0.000190	-0.000154	-0.000153	-0.000154	-0.000159	-0.000117	-0.000083
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
winter	0.006021***	0.006015***	0.006059***	0.006066***	0.006540***	0.006483***	0.006061***	0.006057***	0.005925***	0.003743***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
d2		-2.951843								
		(6.120)								
d2_lnsprd_bfoe1_dtd		7.150828								
		(14.830)								
d3			0.060288							
			(0.310)							
d3_lnsprd_bfoe1_dtd			-0.149719							
			(0.754)							
d4				0.401245						
				(0.267)						
d4_lnsprd_bfoe1_dtd				-0.977254	-0.006632					
				(0.647)	(0.006)					
d5					0.005645	0.384008				
					(0.003)	(0.859)				
d5_lnsprd_bfoe1_dtd						-0.919015				
						(2.085)				
d6							0.032194			
							(0.284)			
d6_lnsprd_bfoe1_dtd							-0.074446			
							(0.691)			
d7								-0.034872		
								(0.272)		
d7_lnsprd_bfoe1_dtd								0.089247		
								(0.662)		
d_all									0.254750***	0.263956***
									(0.095)	(0.093)
d_all_lnsprd_bfoe1_dtd									-0.618749***	-0.641424***
									(0.230)	(0.225)
lnsprd_wti2_1										0.452066***
										(0.039)
lnsprdf3bfoe2										0.040206***
										(0.008)
Constant	0.576649***	0.578848***	0.578589***	0.575197***	0.581192***	0.583650***	0.580836***	0.580911***	0.570747***	0.259272***
	(0.035)	(0.035)	(0.035)	(0.034)	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)	(0.039)

Table 1 shows the modelling results where only variables involving the spreads are included. Table 2 includes additional variables in the model which proxy and control for other factors, such as world oil market supply and demand conditions, as well as potential idiosyncrasies between the ICE Brent futures contract (and the on-exchange daily close prices) and the over-the-counter BFOE forward cash market (and the Platts assessment prices).

The results in tables show a number of things. First, in all the models, the coefficient on the log-calendar spread of BFOE1-to-BFOE_dated is statistically significant in all the nine models estimated, in each of the two tables. The magnitude of the coefficient estimate ranges from about 0.21 to 0.23 in table 1, and 0.136 to 0.16 in table 2. The sign of the coefficient on the log-calendar spread of BFOE1-to-BFOE_dated is positive as expected; a contango market in the short-dated cash OTC market (BFOE) indicates a contango market in the ICE Futures nearest-to-expiry markets. The spread coefficient is an estimate of the convenience yield, on average, over the period.

The coefficient estimates on the slope-dummy variables for the BFOE1-to-BFOE_dated calendar spread (d0_lnBFOE1_dtd,….,d7_lnBFOE1_dtd, dall_lnBFOE1_dtd) are of particular interest, as they estimate the degree to which the periods identified by the Barrera-Rey Seymour test deviate from the theory of storage. They are not statistically significant for any of the individual-period models, but for the model with all the eight identified periods grouped together (d_all_lnBFOE1_dtd) the variable is significant and of the expected sign (negative). The indication is that the direction of the forward curve for the nearest-to-delivery OTC cash-physical market (BFOE), being either contango or backwardation, impacts the ICE Brent Crude front month spreads in the opposite direction to what would be expected given the theory of storage.

In table 2, the same set of regressions was run with added variables. Regressions including volume and open interest as explanatory variables are included. The volume variable has a positive as expected and significant coefficient in all the models, while open interest has an insignificant coefficient in all the models. It is still important to include these variables as sensitivities in the models. Volumes and open interest together are a good proxy of liquidity[16] in the ICE Brent futures market. It is conceivable *a priori* that the normal cycle of rolling over contracts at the end of the month and other liquidity factors could be driving our results, but the insensitivity of the coefficients and models to including volume and open interest point to the conclusion that liquidity and normal trading cycles are not likely explanations of our results on the calendar spread variables. We note that volume and open interest for BFOE contracts, an OTC market, are not generally available.

In addition to including added variables on volume and open interest of prompt-month ICE Brent, we also added variables on the spread between 3rd month-to-delivery ICE Brent over 2nd month to delivery BFOE and the calendar spread for 2nd month WTI over prompt WTI. The first variable, lnsprd_f3_BFOE2, is included as a proxy for any market conditions in the forward curve that might be 'normal' between the ICE futures and BFOE OTC markets (and their price reporting methodologies—recall the ICE price data are daily close-mid prices, and the BFOE are Platts window assessment prices). The second variable, the WTI prompt month calendar spread,

[16] We also tried a model of the ratio of volume to open interest, but the results were very similar and so we do not report these.

controls for world crude oil market supply and demand conditions that are common to the two most widely used benchmark crude futures, namely, Brent and WTI. In other words, to the extent that world crude and petroleum refining supply and demand conditions impact both of these spreads together, then these conditions are held constant when estimating the other coefficients in the model.

Quite interestingly, inclusion of the two added variables has virtually no effect on the coefficient estimates of the main spread variable (lnBFOE1_dtd) and it remains significant and of the expected sign in all models. Likewise, the slope dummy on the front month BFOE to dated spread (d_lnBFOE1_dtd) is not significantly impacted by inclusion of what might be expected to be *a priori* collinear variables. The slope dummy variable is itself insignificant in all the sub-models, where the number of observations is limited, but is significant in the 'all-in' model where all periods are grouped in the one dummy.

Finally, the table below shows the results of the statistical test of whether the two coefficients are equal on the spread for BFOE, where the period of question has been dummied. The test is whether the slopes are equal for the general model versus the period in question. For all but the first period, we find that the slopes are significantly different. Thus the test of Berrara-Rey and Seymour is confirmed more rigorously using the theory of storage and appropriate time-series estimation techniques.

Dummy 0	lnsprd_bfoe1_dtd - d0_lnsprd_bfoe1_dtd = 0	F(1, 645) = 0.48
		Prob > F = 0.4893
Dummy 1	lnsprd_bfoe1_dtd - d1_lnsprd_bfoe1_dtd = 0	F(1, 645) = 12.03
		Prob > F = 0.0006
Dummy 2	lnsprd_bfoe1_dtd - d2_lnsprd_bfoe1_dtd = 0	F(1, 645) = 11.75
		Prob > F = 0.0006
Dummy 3	lnsprd_bfoe1_dtd - d3_lnsprd_bfoe1_dtd = 0	F(1, 645) = 11.75
		Prob > F = 0.0006
Dummy 4	lnsprd_bfoe1_dtd - d4_lnsprd_bfoe1_dtd = 0	F(1, 645) = 11.89
		Prob > F = 0.0006

Dummy 5	lnsprd_bfoe1_dtd - d5_lnsprd_bfoe1_dtd = 0	F(1, 645) = 11.73
		Prob > F = 0.0007
Dummy 6	lnsprd_bfoe1_dtd - d6_lnsprd_bfoe1_dtd = 0	F(1, 645) = 11.70
		Prob > F = 0.0007
Dummy 7	lnsprd_bfoe1_dtd - d7_lnsprd_bfoe1_dtd = 0	F(1, 645) = 11.70
		Prob > F = 0.0007

The conclusion is that the data and model suggest that world oil market conditions or idiosyncrasies that are generally in the ICE Brent futures to BFOE Platts forward curve do not account for the a) relationship between ICE and BFOE spreads, and b) the different relationships in the periods of the alleged squeezes.

5 Conclusions and future research

This paper is a study of potential market abuse in the Brent crude oil derivatives complex. Brent crude oil is one of the most important commodities in the world; the economies of the world depend on petroleum products and Brent is the most important benchmark price for crude oil.

Brent crude oil prices are set by a range of different methods and markets, and the reporting of these prices is done either via exchanges or via assessments from market reporting agencies such as Platts and Argus.

The physical production of Brent crude has been waning over time, and in spite of the addition of other grades and fields' production to the contract, over-the-counter trades in physical-dated or 'wet' Brent crude remain at least somewhat illiquid and therefore open to potential abuse.

Recent legal action and cases, such as the CFTC case against Parnon/Arcadia/Wildgoose, involving WTI OTC physical trades and NYMEX futures, suggest that there is potential for abuse via using the more illiquid physical-dated markets to influence more liquid markets such as on-exchange futures.

The case for proving market manipulations is difficult, however, and a lack of a clear path for testing such manipulations is no doubt part of the difficulty. This paper seeks to address this lack.

The literature on the theory of storage and cash and carry arbitrage in combination gives a fairly robust description of commodity prices, and crude oil prices in general. When there is an absence of scarcity, then cash and carry arbitrage should drive the functional relationship between commodity price and time-to-delivery—a positive cost of carry indicates a contango, or prices increasing with time-to-delivery. In the case of scarcity, or potential scarcity, convenience yield dominates the cost of carry, and backwardation, a downward-sloping forward curve, is observed.

There has been little published on the subject of price squeezes in oil and crude oil markets, but one exception is the paper by Barrera-Rey and Seymour. They propose a test for *a priori* evidence of a price squeeze in the Brent crude complex, as being when the dated Brent crude price (nearest to delivery) and the 2nd month Brent crude price are both less than the 1st month Brent price (all Platt's BFOE OTC forward contract prices). Thus the indication is that the front month contract has had its price driven up artificially. We interpret this as being unlikely that such as pricing anomaly could be consistent with the theory of storage and/or cash and carry.

Using the test and data from Bloomberg on ICE Brent futures and Platts Brent forwards, we identified the periods since October 2008 for which a squeeze might be indicated. We then propose a test of whether the alleged squeezes are statistically significant. The test involves a test of whether the historical relationship between adjacent products on the forward curve, calendar spreads, holds.

We therefore regressed ICE futures 2nd month over 1st month calendar spreads on the Platts BFOE 1st month-over-dated spread. The method was then to allow the slope and intercept parameter estimates to vary for the period of the alleged manipulation, by using a slope and intercept dummy variable approach, and then testing whether the slope and intercept dummy parameter estimates were statistically different from the 'normal' period parameter estimates.

The results showed a statistically significant relationship between the spread of front month BFOE spreads and its impact on the front month ICE Brent futures spread. The individual periods identified, and their slope dummy coefficients, in all cases showed a coefficient that was statistically different from the 'normal' coefficient. When including all the alleged periods in one regression with one slope dummy variable, the alleged price squeeze coefficient became statistically significant from zero, as well as being different from the 'normal' coefficient estimate.

We then included other variables in the regression to account for potentially unmodelled effects that might be driving the result. We included a winter dummy variable, plus variables on the volume and open interest on the ICE front month Brent contract. We also included the front month calendar spread for NYMEX WTI futures and the spread between 3rd month ICE Brent futures over 2nd month Platts BFOE forwards. The volume and open interest variables proxy for the liquidity and market conditions in ICE Brent futures. The WTI front month calendar spread's inclusion controls for world oil market supply and demand conditions – to the extent that these are present in both NYMEX WTI and ICE Brent futures markets. Finally, the spread of ICE 3rd month futures over Platts BFOE 2nd month controls for common forward curve conditions in Brent and any deviations between the ICE and Platts price data that would be non-transitory/anticipated by the market (at least from spot to the third month out). The relationships estimated and the qualitative conclusions on the statistical significance and difference of the coefficients estimates were not sensitive to inclusion of any of the above additional variables.

Thus our conclusion is that the identified periods are consistent with the notion of a price squeeze in Brent, and that the alleged squeeze potentially could impact from the OTC BFOE forwards market (which is relatively illiquid) onto the more liquid ICE futures market. The alleged squeezes are unlikely to be explainable by the theory of storage or the theory of cash and carry, or some combination. The standard conditions of the world oil market's supply and demand and persistent and anticipated differences between the ICE and Platts pricing data are also not likely be driving the results.

While we believe that the evidence supporting our conclusions is clear, we wish to urge caution in their interpretation, in that the evidence and conclusions are considerably limited. The evidence merely has identified periods where the price complex is statistically different from the historical relationship, and argued that this is unlikely to be driven by storage, scarcity, world supply and demand, or persistent and anticipated differences between the futures and forwards pricing methodologies. There is no evidence, and none should be inferred, as to intent or deliberateness of a squeeze, whether the alleged squeeze had material impacts on other prices in the complex, or other markets.

Further research in the field is warranted before the generalness of the results can be confirmed. For example, a similar approach could be used for other crude benchmarks such as WTI and/or Dubai-Oman crudes. It would be interesting as well to apply the model to other energy markets such as natural gas or refined petroleum products. Still further, other authors such and Geman and Smith have suggested a similar regression approach, but that the predicted forward prices and predicted volatilities from a regression using supply and demand variables (e.g., stocks and usage), and that a comparison of the predicted prices would indicate market abnormalities. Applying both approaches to a market such as WTI (where stocks and usage data can be obtained more readily), and comparing the results would be of interest.

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