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Physical Market Conditions, Paper Market Activity, and the WTI-Brent Spread

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Abstract

We document that, starting in the Fall of 2008, the benchmark West Texas Intermediate (WTI) crude oil has periodically traded at unheard of discounts to the corresponding Brent benchmark. We further document that this discount is not reflected in spreads between Brent and other benchmarks that are directly comparable to WTI. Drawing on extant models linking inventory conditions to the futures term structure, we test empirically several conjectures about how time and quality spreads (prompt *vs*. first-deferred WTI; prompt Brent *vs*. WTI) should move over time and be related to the inventory situation at Cushing. We then investigate whether, after controlling for macroeconomic and physical market fundamentals, spread behavior is partly predicted by the aggregate oil futures positions of commodity index traders or of commercial traders.

Keywords: Crude oil, Brent, WTI, LLS, Spread, Fundamentals, Inventories, Cushing, Paper Markets, Commodity Index Trading (CIT)

JEL codes: E31, Q4, G140.

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1. Introduction.

Oil is a heterogeneous product varying in two crucial dimensions: substance and location. Chemically and physically, crude oil is differentiated in terms of API gravity, acidity and sulfur content (Bacon and Tordo, 2004). These variations entail differences in the refining processes and in the products obtained from that processing. Location also matters, because crude oil must be transported to a refinery and the resulting output must be shipped to final users. Disparities in each dimension affect ultimate use and, therefore, may have significant price repercussions.

These complexities have motivated oil market participants to adopt reference products whose prices reflect most of the salient features for their particular markets. Those arrangements make for more efficient price discovery with respect to the reference products. Pricing for non-reference products also improves, insofar as the latter can be reliably priced off a standard reference product. The reliability of this pricing mechanism and the effectiveness of hedging strategies relying on the relevant benchmark product, however, depend on there being predictable differences between the price of a reference product and prices from markets where non-reference products are exchanged.

In this paper, we seek to better understand the features that lead to effective pricing using reference prices. Specifically, we investigate possible fundamental and financial drivers of the difference ("spread") between the two dominant oil reference prices: West Texas Intermediate sweet crude oil ("WTI"), which until recently was the "main oil benchmark" in the Americas (Fattouh, 2011 p.52); and Brent crude oil ("Brent"), a European benchmark that in recent years has been "used to assess up to 70% of the oil produced worldwide" (Platts, 2010 p.1).

By helping predict variations in this benchmark spread over time, our analysis adds to the understanding of the pricing mechanisms used by market participants engaged in establishing prices for the many varieties of oil. In particular, it isolates the impact of physical-market fundamentals and shows that oil paper-market conditions (futures market liquidity, composition of trading activity, and overall level of financial-market stress) also help forecast the movements of the main U.S. domestic oil benchmark relative to its principal international counterpart.

Historically, technology and product demand have generally favored WTI, with the latter regarded as being of slightly higher quality than Brent, generating a price differential between the two (Bentzen, 2007). Still, owing to their physical similarities and to a world oil market that is fairly global in nature (Fattouh, 2010), the two reference products have historically traded within a narrow price range – typically one to two dollars – with WTI usually priced higher than Brent. Massive increases in the magnitude and volatility of the differentials in recent years, however, suggest that something more than quality differences could now be at work.

A number of papers study crude oil price differentials – e.g., Lin and Tamvakis (2001), Bacon and Tordo (2004), Lanza, Manera and Giovannini (2005), Fattouh (2007, 2010), Pirrong (2010), Kao and Wan (2012) and Borenstein and Kellogg (2012).[1] Independently, there has been renewed interest in the importance for commodity price patterns of inventories (see, e.g., Alquist and Kilian, 2010; Gorton, Hayashi and Rouwenhorst, 2013; Kilian and Murphy, 2013; and Khan, Khoker and Simin, 2011), as well as much research about the possible impact on commodity prices and volatility of the financialization of commodity markets.[2] Our paper contributes to those three strands of prior literature: it systematically investigates WTI-Brent spreads, paying attention particularly to the respective predictive powers of the tightness of storage conditions in the WTI futures delivery point at Cushing, OK and of oil paper-market conditions.

[1] See also Alizadeh, Lin and Nomikos (2004) and Bacon and Tordo (2005) for discussions of the effectiveness of hedging different international crude oil price fluctuations using WTI or Brent crude oil futures contracts.
[2] See Büyükşahin and Robe (2012) and Fattouh, Kilian and Mahadeva (2013) for reviews of the latter literature.

On the physical side, prior work on inventory conditions focuses on shortages or stock-outs. Our analysis shows that a *dearth* of storage capacity can also affect prices in a non-linear fashion. At the practical level, our analysis helps explain why the unusually large WTI-Brent spread has not been echoed in other commodity spreads discussed in the literature such as those involving Brent *vs*. Louisiana Light Sweet ("LLS") or WTI *vs*. West Texas Sour ("WTS"). We show, as well, the importance of controlling for production constraints limiting the output of seaborne crudes and for the macroeconomic performances of the U.S. *vs*. the rest of the world.

On the financial side, it has been argued theoretically – see, e.g., Singleton (2011) – that the sharp growth of Commodity Index Trading (CIT) in the past decade may have influenced commodity price levels. Büyükşahin and Harris (2011), however, find no evidence that CIT positions Granger-cause WTI futures prices. That empirical paper, unfortunately, covers neither the wild fluctuations of the WTI-Brent spread in the Winter of 2009 nor the emergence of an extraordinarily large and persistent oil price differential after December 2010. The latter period witnessed major changes to the environment faced by CITs that might have affected Brent and WTI prices differently – including the anticipation of stricter speculative position limits in the United States (but not Britain) and the re-weighting of the main commodity price indices in favor of Brent (*vs*. WTI). It is therefore important to investigate, through the prism of oil price spreads, the predictive power of CITs' futures positions in commodity markets. By documenting the empirical relevance of trading variables in an econometric model of the WTI-Brent spread, we shed light on a heretofore unexplored dimension of energy markets' financialization.

Section 2 describes the data, provides graphical analyses of the spreads, and carries out structural break tests. Section 3 introduces our candidate explanatory variables. Section 4 presents our econometric approach and summarizes our empirical results. Section 5 concludes.

2. The WTI-Brent Spread.

In this Section, we carry out graphical analyses and structural-break tests on different commodity and time spreads in order to identify a set of candidate explanatory variables for the behavior of the WTI-Brent spread over time.

2.1. Spread decomposition.

We start from the observation that the spread between the Brent and WTI month-*t* futures price (denoted $WTI_t – BRENT_t$) can be decomposed into several time and commodity spreads. In the specific case of the WTI–Brent nearby-futures price spread, we have:

$$WTI_1 – Brent_1 = (WTI_1 – LLS_0) + (LLS_0 – BRENT_0) – (BRENT_1 – BRENT_0)$$

where $t=1$ denotes nearby futures prices; $t=0$ denotes spot prices; and "*LLS*" stands for Louisiana Light Sweet crude so that:

1. given constant U.S. interest rates, the "landlock" commodity spread $WTI_1 – LLS_0$ captures the component of the Brent-WTI spread attributable to short-term storage conditions at Cushing, OK (the physical delivery point for WTI futures) and the impact of possible difficulties in transporting crude oil from Cushing to the Gulf Coast;
2. the Transatlantic commodity spread, $LLS_0 – BRENT_0$, captures the cost of shipping light sweet crude oil across the Atlantic;
3. the Brent nearby time spread, $BRENT_1 – BRENT_0$, captures (for a fixed interest rate) the immediacy of the demand for Brent crude in international markets.

Extant studies suggest that some – but not all – time series of those three spreads could have experienced structural breaks at some point(s) in time after 2004. We draw on prior research to postulate candidate break dates and then use Chow tests to test these conjectures.

2.2. Hypotheses.

With infrastructure bottlenecks hindering the shipment of crude from Cushing to the Gulf of Mexico after February 2007 (Fattouh, 2007), North American market conditions in late Fall 2008 and Winter 2009 were characterized by large amounts of oil being stored in Cushing, OK (Fattouh, 2010; Pirrong, 2010). In such an environment, one *ceteris paribus* expects a change in price dynamics for WTI crude – but not for seaborne crudes like Brent and LLS that can easily be transported to meet world demand or stockpiled cheaply on floating storage (given a glut of oil tankers amid a worldwide recession and weak energy demand – see Plante and Yücel (2011)).

Furthermore, given that storage facilities in Cushing can be used for sour as well as sweet crudes (Pirrong, 2010), a lack of available storage capacity in Cushing should *ceteris paribus* have similar implications for all crude types stored there. If so, then the West Texas spot quality spread, $WTI_0 – WTS_0$, should not exhibit structural breaks around the end of 2008.[3]

Overall, those observations provide the basis for our first set of structural-break tests:

Hypothesis 1: The Brent-WTI ($BRENT_1 – WTI_1$) spread levels experience structural breaks in late Fall 2008; so does the "landlock" spread ($WTI_1 – LLS_0$). Neither the Transatlantic spreads ($LLS_0 – BRENT_1$ or $LLS_0 – BRENT_0$) nor the West Texas quality spreads ($WTI_1 – WTS_0$ or $WTI_0 – WTS_0$) do.

[3] Indeed, instead of a structural break in late 2008, we might expect that the differential between the two West-Texas crude grades should have widened *before* 2008 insofar as demand for sweet (low-sulfur) crude oil had risen due to environmental mandates. This is because, "in January 2000, the Environmental Protection Agency issued new rules requiring most diesel […] to contain less than 15 parts per million sulfur beginning in June 2006. Three years later, the EU set very similar standards […] in Europe to take effect in January 2009 [or] even earlier" (Verleger, 2009, p.21; see also Verleger, 2011). An investigation of the impact of such mandates is beyond the scope of our paper.

In the same vein, given that the delivery point for NYMEX crude oil futures is Cushing, OK, low spare storage capacity there should negatively impact the desirability of delivering oil for traders holding positions in expiring WTI contracts. High storage levels (relative to available capacity in Cushing) should matter less for contracts further along the futures maturity curve, because backdated contracts do not require immediate delivery. Thus, when available storage is scarce, the observed contango should be steeper for nearer-term contracts. In the late Fall 2008 and Winter 2009, therefore, annualized percentage time spreads should be a decreasing function of contract maturity, with $(WTI_2 - WTI_1)/WTI_1$ greater than $(WTI_3 - WTI_2)/WTI_2$. Post-2008, amid a persistent glut of oil in Cushing (Borenstein and Kellogg, 2012), the net cost-of-carry $(WTI_2 - WTI_1)/WTI_1$ net of 30-day LIBOR should be higher than before Lehman's demise:

Hypothesis 2: The level of the WTI time spread (measured as the slope of the near-dated term structure of crude oil futures prices, net of interest costs) experiences a structural break in Fall 2008. The structural break is less significant for contracts further along the WTI futures maturity curve.

Finally, we note that, starting toward the end of 2010, several events took place that had the potential to impact the price of Brent substantially – and differently from the price of WTI.

On the financial side, Standard and Poor's increased the 2011 weight of Brent crude oil in its S&P GSCI commodity index while lowering the weight given to WTI crude oil. In January 2012, the GSCI WTI weight was further reduced, while Brent was included for the first time in the Dow-Jones UBS commodity price index. Because these two indices provide the most widely used benchmarks for hundreds of billions of dollars invested in commodity index funds, those portfolio-weight reallocations caused large index money flows into Brent futures and away from

WTI futures. In the event that large changes in the size of commodity paper-market positions can affect commodity price levels or returns (see Singleton (2011) for a theoretical development of this hypothesis), one would expect the Brent-WTI *spread* to behave differently before and after the index weight change at the beginning of 2011.

On the physical side, starting with the Tunisian revolution in December 2010, political risk to Middle Eastern crude oil supplies increased amid the Arab Spring. In February 2011, the Libyan crisis removed a large source of sweet crude oil from the market. At the same time, Japanese demand for fossil fuel increased following a nuclear disaster in Fukushima. Combined, those events put upward pressure on the price of Brent and other seaborne crudes.

If market participants expected those paper- and physical-market changes to persist well into 2011-2012, then one should conjecture that:

Hypothesis 3: The Brent-WTI spread level experienced a structural break in December 2010.

2.3. Crude Oil Price Data.

Since the late 1980s, "physical benchmarks, such as [WTI], Dated Brent, and Dubai-Oman [have been] a central feature of the oil pricing system [used to] price cargoes under long-term contracts or in spot market transactions" (Fattouh, 2011 p.7). We focus on the relationship between the two key benchmarks – WTI and Brent. For some tests, we also use the prices of two other North American crudes: Louisiana Light Sweet ("LLS") and West Texas Sour ("WTS").

For WTI, we use futures prices because the WTI price formation "is originated by the New York Mercantile Exchange (NYMEX). The highly liquid sweet crude futures contract traded on NYMEX provides a visible real-time reference price for the market. In the (Western Hemisphere) spot market, therefore, negotiations for physical oils will typically use NYMEX as a reference point, with bids/offers and deals expressed as a differential to the futures price" (Platts, 2010 p.3). Thus, we use nearby WTI futures settlement prices from the NYMEX.

Much of the prior work on commodity prices focuses on questions best answered by abstracting from volatility around futures expiration dates. To that end, such studies generally define the "nearby futures" as the "closest-to-delivery contract with the highest open interest."[4]

In contrast, when investigating price spreads in an environment where one of the commodities under study is characterized by unusual storage conditions, it is important to pay particular attention to points in time when those conditions are most likely to matter – namely, around futures expiration dates. For the purpose of the present study, therefore, we construct two time series of WTI prices. The first price series uses the preponderance of the open interest to define the roll date. Precisely, we "roll" contracts on the ninth business day of the month through December 2004, and on the seventh thereafter. The second price series times the roll based on the calendar dates – with the "nearby" defined as the prompt contract, which typically expires three business days before the twenty-fifth day of the month.

For dated Brent crude oil, we use both spot and futures prices. Futures roll dates are chosen to coincide with the WTI calendar- or open interest-based roll dates. We obtain the prices of Brent futures (prompt, first- and second-deferred) as well as spot prices for dated Brent, West Texas Sour (WTS) and Louisiana Light Sweet (LLS) crudes from Bloomberg.

Figure 1 plots the WTI-Brent nearby spread from 2003 to 2012, with the roll based either on calendar dates (red series) or on open interest (blue series). The number plotted is positive

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[4] "Oil futures trading rarely ends in [delivery]. Two to three weeks before a contract expires, most traders close out their positions altogether or roll over their positions in the expiring contract into the first-deferred contract. This roll can entail price distortions due to liquidity issues in the paper market or storage issues in the physical market – generating a kind of seasonality. To mitigate the resulting measurement issues, [one can] construct a continuous time series of 'nearby-futures' prices by switching from the prompt contract to the first-deferred contract on the first day when the prompt open interest falls below the first-deferred open interest" (Büyükşahin *et al*, 2011 p.6).

(*negative*) when Brent trades higher (*lower*) than WTI. The red series is visibly more volatile, suggesting the importance of Cushing bottlenecks in explaining some aspects of spread behavior – especially from Fall 2008 to Spring 2009.

2.4. Structural Break Tests.

Table 1 summarizes the results of Chow tests for structural breaks in the levels of various spreads, using daily crude oil prices from June 2000 to July 2012. In line with Section 2.2, we test for breaks at the end of November 2008 and in the middle of December 2010.

Panel A of Table 1 provides the results for spreads rolled using calendar dates. Panel B summarizes the results of similar tests but with futures roll dates based on the preponderance of the open interest. In both panels, we provide results of tests with a time trend without (left-hand side columns) and with (right-hand side column) control for weekends and holidays. The results are qualitatively similar in all cases. Furthermore, Panel C shows that these commodity-spread results are generally robust to using spot prices rather than nearby futures prices, in that break points are similarly established for commodity spot spreads.

Both the Brent-WTI nearby futures spread level ($BRENT_1 - WTI_1$) and the "landlock" spread ($LLS_0 - WTI_1$) exhibit a structural break in mid-November 2008. In contrast, at the five percent level of confidence or lower, we find no statistical evidence of a break in the Cushing quality spreads ($WTS_0 - WTI_0$ or $WTS_0 - WTI_1$) or the Transatlantic spread (measured as $LLS_0 - BRENT_1$ or $LLS_0 - BRENT_0$). Together, those observations suggest that the driver of the Brent-WTI spread patterns in the Winter of 2008 and the Spring of 2009 was a glut of crude oil accumulating in Cushing, OK due to transportation bottlenecks and storage capacity constraints amid a sharp demand drop for energy following the onset of the Great Recession and an increased output capacity from the Bakken and Canadian crude oil fields.

In December 2010, we find strong statistical evidence of another structural break for the Brent-WTI ($BRENT_1$ – WTI_1) and “landlock” (LLS_0 – WTI_1) spreads. This time, though, there is at best mixed evidence of a break for Transatlantic spreads (LLS_0 – $BRENT_1$ or LLS_0 – $BRENT_0$) and no evidence of a break in West Texas crude quality spreads (WTS_0 – WTI_0 or WTS_0 – WTI_1).

These findings suggest that the source of the 2010 market shift is likely specific to seaborne crudes. Panels D and E of Table 1 support this conjecture by showing that Brent nearby *calendar* spreads exhibit structural breaks at the end of 2010 – whereas WTI calendar spreads do not. Interestingly, Panels D and E show little evidence of structural breaks in Brent calendar spreads computed using the first- and second-deferred contracts. In 2008, likewise, the structural break results for WTI calendar spreads are weaker (5% *vs*. 1% significance level) when we use deferred contracts. These findings are consistent with Hypothesis 2 in Section 2.2, suggesting that price disruptions are less substantial further along the futures maturity curves.

3. Explanatory Variables.

In this Section, we discuss potential linkages between the WTI-Brent oil price spread and macroeconomic fundamentals (3.1), physical-market conditions (3.2), and financial variables (3.3). Table 2 provides summary statistics for all the variables described in this Section.

3.1. Macroeconomic Fundamentals: Demand

If the inland U.S. WTI and the seaborne Brent crude oil were traded in segregated markets then, *ceteris paribus*, the strength of the demand for each crude stream would drive that particular stream's price. Insofar as the "link of WTI prices to other international benchmarks [is] partly dictated by infrastructure logistics" (Fattouh, 2007 p.341), the two crude benchmarks are not fully integrated. Consequently, we need to control for the relative strengths of the world and U.S. business cycles when seeking to predict time variations in the WTI-Brent spread.

3.1.1. World economy

For global real economic activity, we draw on recent work by Kilian (2009) showing that "increases in freight (shipping) rates may be used as indicators of (demand shifts) in global industrial commodity markets." The Kilian measure is a global index of single-voyage freight rates for bulk dry commodity cargoes. This index accounts for the existence of "different fixed effects for different routes, commodities and ship sizes" (Kilian, 2009 p.1056). It is deflated with the U.S. consumer price index (CPI), and linearly detrended to remove the impact of the "secular decrease in the cost of shipping dry cargo over the last forty years" (*ibidem*). This indicator, which we denote *SHIP*, is available monthly from 1968 to 2012.[5] Table 2A provides summary statistics for our sample period.

We interact the *SHIP* variable with a landlock indicator (*LAND*) to capture the difference in directionality of the infrastructure bottleneck in Cushing before and after February 2007 (see Section 3.2.4 below). This binary variable takes the value 0 *(1)* through *(after)* February 2007. Intuitively, we expect the *LAND*SHIP* coefficient to be positive because, *ceteris paribus*, a booming world economy (high *SHIP* values) should push up the Brent price while having less of an impact on the landlocked WTI.

[5] Because we are interested in the spread between benchmark oil prices (as opposed to the absolute level of either crude benchmark), we can abstract from possible endogeneity issues stemming from the fact that the shipping-cost index partly reflects the cost of the bunker fuel used to propel the freighters. We are grateful to Lutz Kilian for providing an update of his SHIP series till Spring 2012.

3.1.2. U.S. economy

To capture the possibility that the spread is affected by U.S. macroeconomic conditions, we use two variables. First, we use a daily index of U.S. business activity developed by Aruoba, Diebold and Scotti (2009). This index, which we denote *ADS*, tracks real business conditions at high (daily) frequency and is available for our entire sample period. Intuitively, a strong U.S. economy should push up demand for local crude oil, so we expect *ADS* to be positively associated with the WTI-Brent price spread.

Figure 2 depicts the evolutions of *SHIP* and *ADS* between 2000 and 2012. Several interesting facts emerge from the graph. First, these two activity measures generally move in tandem. Second, the *ADS* plot suggests that the slowdown in U.S. economic activity started earlier (in mid-2007) than the worldwide Great Recession did, although both the U.S. and the world downturns accelerated sharply after the demise of Lehman Brothers in September 2008.

In some specifications, we use a second variable to capture U.S. macroeconomic health: the U.S. Energy Information Administration's (EIA) estimate of total U.S. stocks of crude oil. Intuitively, at the beginning of an economic downturn, a weak economy should bring about high levels of petroleum storage. Hence, we expect that this nationwide storage variable should be inversely associated with the WTI-Brent spread (low WTI prices amid high US-wide storage).

3.2. Physical-Market Fundamentals: Supply and Storage

Our second set of explanatory variables seeks to summarize differential supply-demand balances for WTI and Brent crude oils. Recognizing that the WTI and Brent markets are not fully integrated, we do so by way of several variables including the effective "surplus" OPEC production capacity outside of Saudi Arabia, to capture general market conditions for seaborne crudes; the total output of Brent Blend, Forties Blend, Oseberg and Ekofisk crudes ("BFOE"), to capture specific conditions in the Brent space; and a proxy for storage conditions in Cushing, OK, to capture physical-market conditions in the WTI immediate sphere of influence.

3.2.1. OPEC surplus capacity

Büyükşahin and Robe (2011) argue that, as the demand for energy increased amid strong global economic growth in the middle of the past decade, it eventually exhausted the crude oil "surplus" or "spare" production capacity that OPEC has historically tried to maintain – leading to a sharp increase in world oil prices. Conversely, lower energy prices amid greater "surplus" production capacity reflected weak macroeconomic environments early in the past decade as well as in the aftermath of the Lehman collapse. These observations suggest, *ceteris paribus*, an inverse relationship between OPEC's spare oil output capacity and the price of Brent crude.

We use data from the EIA and from the International Energy Agency (IEA) to construct a time series of the total effective spare crude oil production capacity outside of Saudi Arabia. We focus on non-Saudi figures (measured in millions of barrels per day and denoted *SPARE*) for three main reasons. First, Büyükşahin and Robe (2011) argue that the clearest evidence of a major change in world energy market fundamentals is reflected in this variable (as opposed to, say, world oil consumption, Saudi surplus capacity, OECD stocks of crude oil, etc.). Second, Saudi crude, unlike Brent and WTI, is not light sweet oil – and refineries cannot easily switch between vastly different types of oil. Third, data on Saudi surplus production capacity is best viewed as theoretical – we are not aware of estimates of *effective* Saudi spare output capacity.

Figure 3 plots the Brent, LLS, WTS and WTI spot prices (U.S. dollars, left-hand scale) against non-Saudi OPEC surplus oil production capacity (*SPARE* in millions of barrels per day, right-hand scale). Figure 3 highlights several salient changes in the world crude oil market between 2000 and 2012.

Between 2000 and Summer 2003, *SPARE* was relatively plentiful and crude prices fluctuated in a relatively narrow dollar range below $30. From 2004 through Summer 2008, U.S. and international crude oil prices all rose massively amid a dearth of spare capacity. Some crude types topped $140 per barrel in July 2008. After the onset of the Great Recession in Fall 2008, however, oil prices collapsed whereas OPEC spare capacity surged.

Starting in late Fall 2008 and until Spring 2009, the WTI-Brent spread widened sharply in absolute terms and became very volatile – especially around WTI futures expiration dates. From mid-2009 through November 2010, the oil market was relatively less volatile, with crude prices fluctuating around $75 amid non-trivial *SPARE*. Strikingly, *SPARE* dropped sharply in 2011 and 2012 – a period coinciding with resurgent Brent prices and a large, persistent WTI-Brent price differential. The next three Subsections discuss how to account for different physical-market conditions in the North Sea and in the U.S. Midwest that contributed to this spread.

3.2.2. Oil market stress – the Arab Spring

Uncertainty beset the world's oil markets after the onset of the Arab Spring. To take into account this major, oil-market specific source of political risk and uncertainty, we carry out robustness checks with a time dummy set equal to 1 after February 11, 2011 (when Egyptian president Hosni Mubarak resigned) and equal to 0 before that date.

In further robustness checks, we also interact this Arab Spring dummy with a Brent futures open interest variable (see Section 3.3.1 below). This interaction term is designed to capture the possibility that, amid the 2011 oil market turmoil, investors positioning themselves for anticipated oil price increases would have had greater incentives to increase their long Brent futures positions and reduce their positions in futures contracts tied to the (landlocked) WTI.

3.2.3. Brent crude oil production

Amid tight supply-side conditions in the global market, shortages of one or more of the four crude oil streams (BFOE) that make up the Brent crude benchmark has the potential to push Brent prices higher than other major benchmarks. To control for this possibility, we obtain BFOE monthly production data from the International Energy Agency (IEA).

Figure 4 shows that North Sea crude oil production has fallen substantially over the course of the past decade. BFOE output, in particular, has dropped from over two million barrels per day in 2000 to less than one million in 2012. After stabilizing between mid-2006 and mid-2010, the fall in BFOE output has accelerated in the past two years. Notably, this last episode coincides with the beginning of a two-year period of unprecedentedly high WTI-Brent spreads.

3.2.4. North-American crude oil production

Whereas Brent crude oil output has been falling for over a decade, the same is not true of North-American production – which has been boosted by the so-called “shale oil revolution.” To capture the increased crude oil production capacity in North America since 2007, we must account not only for U.S. wells but also for Canadian crude flowing into the Petroleum Administration for Defense's Midwestern District ("PADD 2"), where Cushing is located. Our monthly data on crude oil imports from Canada into the PADD 2 region comes from the EIA. We proxy for U.S. production using data on operating crude oil rigs sourced by the EIA from Baker Hughes, Inc. and Weatherford International, Ltd. Specifically, the series counts the crude oil rotary rigs (used to drill wells) that are operational onshore and offshore in the fifty United

States. The rig count is reported monthly, from August 1987 to May 2012, as the average of values from a four- or five-week reporting period. Figure 5 plots the two series over time. Both variables steadily increase over much of the sample period, accelerating sharply in early 2009 (in the case of rigs) or the beginning of 2011 (in the case of Canadian imports). *Ceteris paribus*, one would expect such an increase in local crude oil supply to put downward pressure on the price of WTI crude oil – especially if the latter faces difficulties in reaching international markets.

3.2.5. Cushing storage capacity and utilization

Several studies (e.g., Fattouh, 2007, 2010; Pirrong, 2010; Borenstein and Kellogg, 2012) suggest that infrastructure constraints in Cushing have historically influenced the differential at which WTI sweet crude trades against other types of crude oil. Before 2007, "the main logistical bottleneck was how to get enough oil into Cushing (which) in many instances resulted in serious dislocations and WTI rising to very high levels compared to other benchmarks" (Fattouh, 2007, p.2). After February 2007, amid a greater flow of crude oil into Cushing from Montana, North Dakota and Canada, "the ability to shift this oil out of the region and to provide a relief valve for Cushing has been very limited" (*ibidem*).

Post-2007, Cushing bottlenecks should *ceteris paribus* be accompanied by higher crude storage. When oil tanks get filled close to their limit, though, the potential arises for an increase in cross-commodity spread levels (as Cushing oil stocks insulate the WTI market from the price pull stemming from strong world demand) and in the volatility of those spreads around futures expiration dates (as traders find it expensive to deliver oil and may exit contracts at particularly depressed prices around the expiration date).

One could apply a Hodrick-Prescott (1980) filter to identify deviations of the amount of crude oil in storage away from its long-term, possibly non-linear trend. The downside of such an approach is that it would require subjective choices to capture the trend and cyclical components.

Alternatively, one could use data on Cushing storage capacity to assess the fraction of the storage actually used. To our knowledge, the only source of public weekly or monthly data on storage capacity is Genscape, Inc. The Genscape time series, unfortunately, start in May 2009 – precluding their use to analyze the WTI-Brent spread fluctuations from late Fall 2008 to Spring 2009, which are the most likely to have been caused by storage capacity exhaustion.

We therefore follow a third approach, first suggested by Fama and French (1987, 1988):[6] we proxy the tightness of the oil storage market by way of the slope of the term structure of futures prices. We isolate the impact of interest rate fluctuations by subtracting, from the percentage calendar spread, the appropriately scaled money factor. We use the London Interbank Offered Rate (LIBOR) to compute the money factor under the assumption that it is representative of the funding costs of futures-market participants.[7] Figure 6 plots the nearby WTI futures price and the WTI-Brent nearby spread (left-hand scale, measured in U.S. dollars) *vs*. the net cost of WTI carry (right-hand scale, in annualized percentage terms).

Figure 6 shows a structural break in the stochastic process characterizing the net cost of carry (green curve) after November 2008, providing visual confirmation of the formal statistical tests in Section 2. We expect this *calendar* spread proxy for a high rate of storage utilization in Cushing to be positively related to the WTI-Brent *commodity* spread. In the econometric analyses, however, we need to minimize possible endogeneity issues – namely, the possibility

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[6] See also Geman & Ohana (2009), Khan, Khoker and Simin (2011), and Gorton, Hayashi & Rouwenhorst (2012) who confirm Fama and French's (1997, 1998) and Ng and Pirrong's (1994) intuition that the slope of the term structure is a good proxy for inventories.

[7] The money factor itself is modeled as a separate explanatory variable, denoted "*DISCOUNT*" in Tables 2 to 4.

that traders' nearby futures positions might partly reflect trading strategies related to the Brent-WTI commodity spread. The variable we use in Section 4 (denoted *WTI_SLOPE*), therefore, is the percentage difference between the prices of the first- and second-deferred futures contracts (rather than the percentage difference between the prompt and first-deferred contracts).

3.3. Financial Variables

A growing literature, reviewed by Fattouh *et al* (2012) and Büyükşahin and Robe (2012), documents how commodity markets' financialization has impacted some – but not all – moments of the distribution of commodity prices or returns. To our knowledge, the present study is the first to explore a possible relationship between the financialization of oil futures markets and the WTI-Brent spread. Our econometric analysis includes several variables to that end.

3.3.1. Paper market liquidity

Various theoretical models (Rahi and Zigrand, 2009; Başak and Croitoru, 2006) suggest that greater liquidity in commodity paper markets helps strengthen cross-market linkages and lower the magnitude of the WTI-Brent spread. We capture the changes over the past decade in the amount of trading activity in the WTI and Brent futures markets, and the resultant increase in paper market liquidity, through two variables measuring the total open interest in the three nearest-months WTI or Brent futures (denoted, respectively, *WTI_OI* and *Brent_OI*). We concentrate on near-dated contracts because our focus is on the nearby WTI-Brent spread.

Figure 7 plots these two variables from June 2000 to July 2012. It highlights two key developments in the past decade. First, oil paper-market activity has grown massively since 2001 (WTI) or 2005 (Brent), with open interest in the three nearest-dated futures tripling in both markets over the course of a just few years. Büyükşahin *et al* (2011) document that much of this increase stems from the financialization of oil markets. Second, after lagging behind WTI for many years, Brent started surging in the second half of 2009 – whereas WTI open interest mostly stagnated during that period. Following a further sharp increase since the end of 2011, the near-dated Brent open interest now exceeds its WTI counterpart.

3.3.2. Financial stress

Following theoretical work on the limits to arbitrage and contagion, we also consider the possibility that the same financial traders who might link markets in normal times often face, in periods of financial market stress, limits on their ability or willingness to engage in risky cross-market arbitraging (Gromb and Vayanos, 2010). *Ceteris paribus*, the WTI-Brent spread could thus be higher (in absolute value) during periods of elevated levels of *financial*-market stress.

To account for this possibility, we include the difference between the 30-day U.S. dollar LIBOR and 30-day Treasury bill yield (also known as the "TED spread") in our regressions. It is well known that this variable (denoted *TED*) rose sharply in August 2007, at the onset of the financial crisis, then soared after the Lehman crisis in September 2008, before falling sharply a few months into 2009 following central bank interventions to thaw or calm financial markets. Table 2.A confirms that the TED spread fluctuated greatly during our sample period, with a minimum of 0.021% and a maximum of 4.53%.

3.3.3. Trader positions in oil paper markets

Commodity Index Traders' (CITs) arrival in oil markets has garnered a lot of attention from policy makers (see, e.g., ITF 2008) and academic researchers (e.g., Büyükşahin and Harris, 2011; Irwin and Sanders, 2012; Singleton, 2011) amid a spirited debate on whether CIT activity impacts commodity price *levels*. A natural question, in light of this ongoing debate, is whether CIT positions in WTI futures or in Brent futures may help predict the WTI-Brent price *spread*.

In particular, the year 2011 saw major changes in the environment faced by CITs – with the potential to affect Brent and WTI differently. Those developments include the re-weighting of the main commodity price indices in favor of Brent (*vs*. WTI) and the anticipation of stricter speculative position limits under the Dodd-Frank Act in the United States (but not in Britain) .

Public data on CIT positions in oil paper markets exist since 2007 (WTI) or June 2011 (Brent). These data, however, have low frequency (monthly since June 2010; quarterly before). In its weekly commitments of traders (COT) reports, the U.S. Commodity Futures Trading Commission (CFTC) also tallies up commodity swap dealer positions in WTI futures. All those reports, however, combine trader positions across all maturities – whereas we wish to measure CIT activity in the three nearest-dated WTI futures. To that end a comprehensive daily dataset of trader-level positions in WTI futures was utilized. Because no such data are available for Brent futures, we impute CIT near-dated long positions in Brent futures using the relative weights of WTI and Brent crudes in Standard and Poor's GSCI commodity index (the resulting variable is denoted *CIT_Brent_Long*).

The origin of our WTI futures position data is the CFTC, which has for decades collected position-level information on the composition of open interest in most U.S. futures and options-on-futures markets. The CFTC gathers this information, for most commodities and each contract maturity, for every trader whose position exceeds a certain threshold. Importantly, it also collects information from every large trader about its underlying business (e.g., hedge fund, swap dealer, crude oil producer, refiner, etc.).

This non-public information, which underpins the CFTC's weekly COT reports, includes time series (2004-2012) of the end-of-day positions of the 54 CITs that held, as of July 2012, WTI futures positions large enough to require reporting (350 contracts or more). For this project, the positions of all 54 CITs in the three nearest-maturity WTI futures were aggregated to create three measures of CIT activity in U.S. oil futures markets: aggregate long and short positions and open interest (the average of the absolute values of the long and short positions).[8] Because commodity index trading entails long-only positions, CITs' aggregate long position is naturally much larger than their aggregate short position.[9]

The green line in Figure 7 plots the total near-dated CIT open interest from April 2004 to July 2012. It highlights the substantial increase in CIT long positions in our sample period, echoing findings in Büyükşahin *et al* (2011) regarding the financialization of oil paper markets.

In the econometric analyses of Section 4, we use CIT's aggregate long WTI futures positions (denoted *CIT_WTI_Long*) and their imputed aggregate Brent futures positions (denoted *CIT_WTI_Long*). In robustness checks, we replace the *CIT_WTI_Long* and *CIT_Brent_Long* by *CIT_WTI_OI* and *CIT_Brent_OI* (their open interest counterparts). The results with both sets of variables are qualitatively similar, so we focus the discussion in Section 4 on the *CIT_WTI_Long* variable. Table 2C provides summary statistics for all four variables.

4. Econometric Analyses.

We discuss the methodology in Section 4.1. We present our results in Section 4.2.

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8 Precisely, the raw position data and the CIT classifications on which we rely originate in the CFTC's Large Trader Reporting System (LTRS). The CFTC's Division of Market maintains that system to help the CFTC fulfill its mission of detecting and deterring market manipulation. The LTRS identifies 67 large traders (mostly commodity swap dealers) that engage in commodity index trading activities – of which 54 held non-trivial WTI futures positions. It is those 54 large traders whose long and short positions in the three nearest-dated WTI futures were aggregated to approximate total CIT positions in the WTI futures market.

9 The fact that CIT short positions are not always zero reflects the reality that some of CITs active in WTI futures also have non-CIT business that may require them to take short positions on futures exchanges.

4.1. Methodology

Before testing the explanatory power of different variables on the WTI-Brent spread, we check the order of integration of all variables using Augmented Dickey Fuller (ADF) tests. Some of the variables in our estimation equation are stationary in levels, while the others are stationary in first differences: the unit root tests are summarized in Table 2.

In order to find the long run effects of different variables on spreads, we therefore use an autoregressive distributed lag (ARDL) model estimated by ordinary least squares (OLS). In this model, the spread is predicted by p lags of itself and current and q lagged values of a number of regressors (fundamentals as well as financial variables). The lagged values of the dependent variable are included to account for slow adjustments of the dependent variable. This approach also allows us to calculate the *long-run* effect of the regressors on the spreads.

Precisely, Pesaran and Shin (1999) show that the ARDL model can be used to test the existence of a long-run relationship between underlying variables and to provide consistent, unbiased estimators of long-run parameters in the presence of I(0) and I(1) regressors. By choosing appropriate orders of the ARDL(p,q) model, the ARDL model simultaneously corrects for residual correlation and for the problem of endogenous regressors.

When estimating the long-run relationship, one of the most important issues is the choice of the orders of the distributed lag functions on the dependent (p) and explanatory (q) variables. We carry out a two-step ARDL estimation approach. First, the lag orders of p and q are selected. The results in Table 4 reflect lag lengths p=1 and q=1 (we also checked with lags lengths up to p=12 and q=12). Next, we estimate the long run coefficients using the ARDL(p,q) specification and apply a Newey-West procedure for standard errors.

4.2. Regression results

Table 3 shows the simple cross-correlations between the main variables. Table 4 presents the long-term coefficients in our main regression. The first three specifications (I-F, II-F and III-F) focus on macroeconomic, physical-market fundamentals, and financial market variables but exclude CIT positions. The next six models introduce variables that capture CIT activity in WTI and Brent futures markets. Three of those models (I-FW, II-FW, III-FW) use the relative weight of the WTI and Brent crudes in the GSCI index. The last three models (I-FC, II-FC, III-FC) investigate the predictive power of actual (WTI) or imputed (Brent) CIT futures positions.

4.2.1. Macroeconomic variables

Table 4 shows the WTI-Brent spread level linked to world macroeconomic fundamentals, proxied by *SPARE* and the interacted variable *LAND*SHIP*. Although the levels of statistical significance of these variables vary across specifications, their coefficients are consistently positive (*LAND*SHIP*) or negative (*SPARE*) – see Section 3.2.1 for a discussion.

The coefficient for *ADS* is inconsistent across specifications. When CIT activity is not included (Models I-F, II-F and III-F), the sign is statistically significant but always negative. This counterintuitive finding is reversed, however, once the model includes CIT activity – consistent with the intuition that, if the WTI and Brent markets are indeed not fully integrated, then WTI prices should fall (relative to Brent prices) when the U.S. economy is not doing well. The US-wide storage variable, *US_STOCKS*, which we use as a second proxy for the health of the U.S. economy in models III-F, III-FW and III-FC, though, is only seldom (and then only marginally) statistically significant.

4.2.2. Physical variables

All of our specifications include proxies for the directionality (inbound *vs*. outbound) of infrastructure bottlenecks in Cushing (*LAND*) as well as variables that either capture the crude oil supply from Canada and the Midwest (Models I and II) or act as a proxy for storage-market conditions in Cushing, OK (the slope of the WTI term structure in Model II, or the storage levels at this Oklahoma oil hub in Model III).

LAND is statistically significant in all models (except the simple specification III-F) and always has a negative coefficient. Likewise, the slope of the WTI futures term structure is also always significant at the 1% level of confidence, with negative coefficients. Those findings all support the conjecture that infrastructure bottlenecks in Cushing have, since 2007, hindered the shipment of oil to world markets and helped depress WTI's price relative to Brent's. We find that *SLOPE* is always statistically significant, whereas *Cushing_STOCK* is not. One possible interpretation of this result is that it may highlight the importance of taking into account not only the amount of crude oil in storage but also the degree of utilization of storage capacity.

In a landlocked context for WTI, our ARDL analyses show that the WTI-Brent spread also has, as predicted in Section 3.2.4, a statistically significant inverse long-term relationship to North-American oil supply variables. That is, greater Canadian crude oil shipments to the PADD 2 district and a higher number of oil rigs operating in the continental United States are both associated with lower WTI prices relative to Brent.

Overall, these results all suggest that infrastructure bottlenecks at Cushing contribute to the depressed state of WTI nearby futures prices relative to their Brent counterparts.

4.2.3. Financial variables and CIT activity

Table 4 shows that, besides macroeconomic and physical market fundamentals, financial variables also have predictive power. First, we find that higher WTI open interest is associated with lower values of the spread (i.e., WTI depressed relative to Brent), whereas higher Brent open interest is associated with higher values of the spread (i.e., a high WTI price compared to Brent). Second, the TED spread (our proxy for financial distress) is positively associated with the WTI-Brent spread.

Finally, one of the questions asked in the Introduction is whether CIT activity helps predict oil-benchmark price divergences. Similar to the conflicting evidence regarding whether the total near-dated futures open interest and the WTI-Brent spread (with *Brent_OI* positively associated with the spread but *WTI_OI* negatively associated with the spread), Table 4 provides mixed results for CIT long positions. After controlling for macroeconomic and physical-market fundamentals, all of our specifications do show that CIT positions in the WTI and Brent futures market help predict long-term fluctuations in the WTI-Brent spread. The signs of the WTI and Brent CIT position variables differ: the *WTI_CIT_Long* coefficient in all of the specifications is always positive, consistent with the notion that increases in the long-only positions of CITs predict increases in WTI prices relative to their Brent counterparts.[10] The opposite is true for the *Brent_CIT_Long* coefficient, which is always negative.

[10] We carried out Granger-causality tests but found no support for the notion that the aggregate activities of passive commodity investors (specifically, CITs) Granger-cause the Brent-WTI spread.

V. Conclusions.

Sporadically in Fall 2008 and Winter 2009 and persistently in 2011-2012, the West Texas Intermediate (WTI) crude oil benchmark has traded at unheard of discounts to its seaborne counterpart, Brent. This discount is not reflected in price spreads between Brent and other seaborne crude oil prices that have historically been related to WTI.

We provide empirical evidence that, between 2004 and 2012, U.S. and world business cycles, infrastructure bottlenecks affecting the transportation and storage of oil in the United States, and constraints affecting the extraction of non-US sweet crudes, all help predict the observed spread levels. Our analysis highlights, in particular, the importance of accounting for the degree of utilization of storage capacity at the WTI futures delivery point in Cushing, OK.

Armed with those results, we investigate whether the positions of some types of U.S. oil-futures traders help predict some of the observed oil-benchmark behavior. Specifically, we test whether, after controlling for macroeconomic and physical market fundamentals, the WTI-Brent spread is partly predicted by the paper-market positions of commodity index traders (CITs). Between 2004 and 2012, we find predictive power for the aggregate long position of CITs in WTI futures (as well as their imputed aggregate long position in Brent futures).

Although our econometric model fits the data well (see Figure 8), our analysis merely identifies variables that help *forecast* the WTI-Brent price spread at a daily frequency. A natural question is whether this predictive power would remain, if data on fundamentals were available at higher frequencies than weekly or monthly. In the affirmative, another natural question is whether the futures positions of CITs or other groups of traders – such as hedge funds, some subset of commercial traders, etc. – have not only predictive but also *explanatory* power. We leave these questions for further research.

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Table 1: Structural Break Tests – Levels

Panel A: Commodity Futures Spreads (*Calendar Date-Based Roll*)

	November 2008 Break		December 2010 Break	
	Constant Time Trend	Time Trend With Weekends	Constant Time Trend	Time Trend With Weekends
$\boldsymbol{Brent_1 - WTI_1}$	**8.37*** (0.0002)**	**7.56*** (0.0005)**	**8.10*** (0.0003)**	**4.25** (0.0143)**
$\boldsymbol{WTI_1 - LLS_0}$	**5.83*** (0.0030)**	**4.40** (0.0123)**	**10.78*** (0.0000)**	**8.02*** (0.0003)**
$LLS_0 - Brent_1$	0.83 (0.4365)	2.58* (0.0759)	2.96* (0.0522)	1.77 (0.1712)
$WTI_1 - WTS_0$	1.83 (0.1611)	0.75 (0.4708)	0.21 (0.8127)	0.04 (0.9571)
$\boldsymbol{Brent_1 - Brent_0}$	**13.69*** (0.00)**	**11.09*** (0.0000)**	**8.09*** (0.0003)**	**11.45*** (0.0000)**
$\boldsymbol{\frac{Brent_1 - WTI_1}{Brent_1}}$	**9.20*** (0.0001)**	**8.87*** (0.0001)**	**8.14*** (0.0003)**	**4.69*** (0.0093)**

Notes: Table 1 provides the results of structural break tests (F-tests) for several crude oil commodity spreads (levels, Panels A, B and C) and calendar spreads (percentages, Panels D and E). Hypothesized break dates are November 30, 2008 (left panel) and December 15, 2010 (right panel) – see Section 2.2. The variables LLS_0, WTI_0, WTS_0 and $Brent_0$ denote the spot prices of Louisiana Light Sweet, West Texas Intermediate, West Texas Sour and dated Brent crude oil prices (source: Bloomberg). WTI_1 and $Brent_1$ denote the settlement (closing) prices of the nearby WTI and Brent futures contracts, respectively (sources: WTI, CFTC; Brent, Bloomberg). In Panels A and D, the roll date is the calendar day on which the nearest-maturity ("prompt") futures expires. In Panels B and D, the roll date is based on the preponderance of the open interest: for consistency it is set on the 9th business day of the month through December 2004 and to the 7th business day of the month thereafter. Brent is rolled together with WTI. Statistically significant breaks are bolded: p-values are provided in parentheses, with stars (*, **, ***) indicating different levels of statistical significance for better readability (10%, 5% and 1%, respectively). The sample period is June 1, 2000 to July 15, 2012.

Table 1 (continued): Structural Break Tests – Levels

Panel B: Commodity Futures Spreads (*Open Interest-Based Roll*)

	November 2008 Break		December 2010 Break	
	Constant Time Trend	Time Trend With Weekends	Constant Time Trend	Time Trend With Weekends
$Brent_1$ – WTI_1	**6.51*** (0.0015)**	**4.71*** (0.0091)**	**10.98*** (0.0000)**	**5.85*** (0.0029)**
WTI_1 – LLS_0	**6.56*** (0.0014)**	**5.26*** (0.0053)**	**6.94*** (0.0010)**	**6.01*** (0.0025)**
LLS_0 – $Brent_1$	1.00 (0.3671)	2.71* (0.0667)	1.28 (0.2781)	0.53 (0.5869)
WTI_1 – WTS_0	1.38 (0.2519)	1.17 (0.3120)	0.38 (0.6852)	0.55 (0.5787)
$Brent_1$ – $Brent_0$	**6.20*** (0.0020)**	**3.36** (0.0266)**	**11.59*** (0.0000)**	**17.95*** (0.0000)**
$\frac{\boldsymbol{Brent_1 - WTI_1}}{\boldsymbol{Brent_1}}$	**7.00*** (0.0009)**	**5.65*** (0.0036)**	**9.78*** (0.0001)**	**4.42** (0.0121)**

Panel C: Commodity Spot Spreads

	November 2008 Break		December 2010 Break	
	Constant Time Trend	**Time Trend With Weekends**	**Constant Time Trend**	**Time Trend With Weekends**
$Brent_0$ – WTI_0	**9.31*** (0.0001)**	**10.86*** (0.0000)**	**11.19*** (0.0000)**	**10.49*** (0.000)**
WTI_0 – LLS_0	**4.11** (0.0166)**	1.87 (0.1547)	**7.64*** (0.0005)**	**5.19*** (0.0056)**
LLS_0 – $Brent_0$	0.10 (0.9017)	1.79 (0.1667)	**6.49*** (0.0015)**	**8.70*** (0.0002)**
WTI_0 – WTS_0	1.64 (0.1935)	1.29 (0.2757)	0.20 (0.8197)	0.06 (0.9435)

Notes: See Panel A.

Table 1 (continued): Structural Break Tests – Levels

Panel D: Percentage Calendar Spreads (*Calendar-date based Roll*)

	November 2008 Break		December 2010 Break	
	Constant Time Trend	Time Trend With Weekends	Constant Time Trend	Time Trend With Weekends
$\frac{WTI_2 - WTI_1}{WTI_1}$	**5.17*** (0.0050)**	**5.53*** (0.0040)**	0.35 (0.7082)	0.01 (0.9880)
$\frac{WTI_2 - WTI_1}{WTI_1} - LIBOR$	**6.62*** (0.0014)**	**7.05*** (0.0009)**	0.37 (0.6937)	0.19 (0.8293)
$\frac{WTI_3 - WTI_2}{WTI_2}$	**3.64** (0.0263)**	**3.91** (0.0202)**	0.22 (0.8054)	0.13 (0.8787)
$\frac{WTI_3 - WTI_2}{WTI_2} - LIBOR$	**3.86** (0.0213)**	**4.52** (0.0110)**	0.32 (0.7259)	0.28 (0.7563)
$\frac{Brent_2 - Brent_1}{Brent_1}$	**5.23*** (0.0054)**	**4.97*** (0.0070)**	**6.91*** (0.0010)**	**5.41*** (0.0045)**
$\frac{Brent_2 - Brent_1}{Brent_1} - LIBOR$	**7.89*** (0.0004)**	**8.11*** (0.0003)**	2.46* (0.0852)	**3.16** (0.0424)**
$\frac{Brent_3 - Brent_2}{Brent_2}$	**4.55** (0.0106)**	**5.53*** (0.0040)**	2.46* (0.0856)	0.52 (0.5962)
$\frac{Brent_3 - Brent_2}{Brent_2} - LIBOR$	**4.17** (0.0118)**	**3.89** (0.0205)**	1.25 (0.2860)	2.02 (0.1325)

Panel E: Percentage Calendar Spreads (*Open Interest-Based Roll*)

	November 2008 Break		December 2010 Break	
	Constant Time Trend	Time Trend With Weekends	Constant Time Trend	Time Trend With Weekends
$\frac{WTI_2 - WTI_1}{WTI_1}$	**4.81*** (0.0082)**	**5.22*** (0.0055)**	0.18 (0.8348)	0.43 (0.6499)
$\frac{WTI_2 - WTI_1}{WTI_1} - LIBOR$	**6.37*** (0.0017)**	**6.02*** (0.0025)**	0.43 (0.6478)	0.50 (0.6067)
$\frac{Brent_2 - Brent_1}{Brent_1}$	**7.28*** (0.0007)**	**8.26*** (0.0003)**	**3.27** (0.0381)**	1.87 (0.1547)
$\frac{Brent_2 - Brent_1}{Brent_1} - LIBOR$	**6.09*** (0.0023)**	**5.35*** (0.0048)**	2.04 (0.1297)	**3.07** (0.0466)**

Notes: See Panel A.

Table 2: Summary Statistics

Panel A: Macroeconomic Variables

	Kilian Shipping Cost Index (*SHIP*)	U.S. Business Conditions Index (*ADS*)	Discount Factor (*LIBOR*)	Financial Distress Indicator (TED Spread)	Weekly US Oil Stocks
Mean	19.12495	-0.448772	1.00092	0.499903	1730.347
Median	21.42717	-0.155276	1.000351	0.27325	1720.278
Maximum	56.46359	0.85954	1.004723	4.5315	1870.122
Minimum	-53.48168	-4.030423	1	0.0211	1560.786
Std. Dev.	23.87952	0.978369	0.001084	0.590799	65.12002
Skewness	-0.885135	-1.934566	1.280031	3.200892	0.091233
Kurtosis	3.718492	6.326196	3.679602	15.69396	2.386744
Jarque-Bera	316.493***	2257.344***	608.3259***	17525.44***	35.49635***
Sum	39799.03	-933.8947	2082.915	1040.297	3600851
Corrected SS	1186081	1990.989	0.002443	726.0103	8820483
Observations	2081	2081	2081	2081	2081
ADF p-value (Level)	0.574	0.0458**	0.8112	0.0004***	0.1074
ADF p-value (First diff.)	0.0001***	0.02600**	0.0001***	0.0001***	0.0001***

Notes: ***SHIP*** is a measure of worldwide economic activity (Kilian, 2009). ***ADS*** is a measure of U.S. economic activity (Aruoba, Diebold and Scotti, 2009). ***LIBOR*** and ***TED*** are, respectively, the discount factor to prompt-futures expiry (based on the 30-day annualized LIBOR rate) and the Ted spread, which is a measure of overall financial-markets stress (source: Bloomberg). ***Weekly U.S. Oil Stocks*** measure week-end stocks (in millions of barrels) of crude oil and petroleum products in the 50 United States and the District of Columbia, including the U.S. strategic petroleum reserve (Source: U.S. Energy Information Administration). For the augmented Dickey-Fuller (ADF) tests, we provide p-values. Stars (*, **, ***) indicate the rejection of non-stationarity at standard levels of statistical significance (10%, 5% and 1%, respectively). Sample period for all statistics: April 11, 2004 (when Cushing storage data first became available) to December 31, 2011.

Table 2: Summary Statistics

Panel B: Crude Oil Production and Storage Condition Variables

	Weekly Cushing (OK) Crude Oil Stocks	Weekly Midwest (PADD 2) Crude Oil Stocks	Non-Saudi Effective SPARE Crude Production Capacity	U.S. Rotary Rigs in Operation (Crude Oil)	Midwest (PADD 2) Imports of Crude Oil from Canada	WTI Term SLOPE	Brent Term SLOPE
Mean	25.44281	76.54859	1.076093	423.6439	36.4554	0.007742	0.005743
Median	24.429	71.931	0.42	305	35.229	0.006769	0.005965
Maximum	41.896	107.225	3.71	1307	54.614	0.09981	0.052836
Minimum	11.677	57.747	-0.03	146	27.462	-0.016103	-0.015928
Std. Dev.	7.87327	13.50397	1.142648	292.2234	5.517116	0.012763	0.010145
Skewness	0.244091	0.529594	0.719776	1.459873	1.29131	1.947789	1.249388
Kurtosis	1.851983	1.945388	2.132145	4.038581	4.781306	11.86099	6.377404
Jarque-Bera	134.941***	193.714***	244.993***	832.709***	853.468***	8123.93***	1530.47***
Sum	52946.48	159297.6	2239.35	881603	75863.69	16.11128	11.95139
Corrected SS	128935.8	379303.2	2715.741	1.78E+08	63312.22	0.33883	0.214086
Observations	2081	2081	2081	2081	2081	2081	2081
ADF p-value (Level)	0.3447	0.8212	0.7361	1.0000	0.3016	0.0002***	0.0108**
ADF p-value (First diff.)	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***

Notes: ***Weekly Crude STOCKS*** measure week-end stocks (millions of barrels) of crude oil in Cushing, OK or in the PADD2 (Midwest) district (Source: U.S. Energy Information Administration). ***SPARE*** measures the effective crude oil surplus production capacity outside of Saudi Arabia (Source: International Energy Agency and authors' computations). The ***SLOPE*** variables measure, in each oil futures market, the difference between the logged prices of the second- and third-deferred contracts. For the augmented Dickey-Fuller (ADF) tests, we provide p values. Stars (*, **, ***) indicate the rejection of non-stationarity at standard levels of statistical significance (10%, 5% and 1%, respectively). The lag length is set equal to 4 for all series. Sample period for all statistics: April 11, 2004 (when Cushing storage data first became available) to April 30, 2012.

Table 2: Summary Statistics

Panel C: Prices and Financial Variables

	WTI-Brent Futures Differential	WTI Prompt Futures Price	Brent Prompt Futures Price	WTI Near-Dated Open Interest	Brent Near-Dated Open Interest	WTI Near-Dated Long Actual (CIT only)	Brent Near-Dated Long Imputed (CIT only)	W_WTI_ Brent
Mean	-2.008486	73.83765	75.84614	506.629	317.2479	230.0344	99.05566	2.330117
Median	0.36	71.51	71.55	517.182	314.833	241.639	98.6135	2.273316
Maximum	14.88	145.29	146.08	745.999	566.264	351.848	167.2793	2.97702
Minimum	-27.88	33.87	32.46	251.366	153.482	89.731	41.19153	1.632595
Std. Dev.	6.598195	22.02451	25.28245	96.92621	95.69083	58.0002	23.48593	0.329333
Skewness	-1.935755	0.55771	0.511612	-0.258043	0.308502	-0.386574	0.032751	0.21502
Kurtosis	6.050312	3.016837	2.40779	2.291322	2.236229	2.39716	2.901413	1.925643
Jarque-Bera	2106.405***	107.9037***	121.1921***	66.6414***	83.59018***	83.34183***	1.214773***	116.118***
Sum	-4179.66	153656.1	157835.8	1054295	660192.9	478701.6	206134.8	4848.974
Corrected SS	90555.25	1008964	1329541	19540956	19046008	6997169	1147305	225.5966
Observations	2081	2081	2081	2081	2081	2081	2081	2081
ADF p-value (Level)	0.4457	0.3004	0.6016	0.0404**	0.0893*	0.0101**	0.0052***	0.8304
ADF p-value (First diff.)	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***

Notes: ***WTI_1*** and ***$Brent_1$*** denote the settlement (closing) prices of the prompt WTI and Brent futures contracts, respectively (Sources: for WTI, CFTC; for Brent, Bloomberg). ***Near-dated Open Interest*** is the total futures open interest for the three nearest-dated maturities, with roll dates set equal to the day when the prompt contract expires ("calendar roll"; Sources: for WTI, CFTC; for Brent, Bloomberg). ***WTI_CIT_Long*** is the aggregate long positions of all large traders classified as CITs by the CFTC in the three nearest-maturity WTI futures contracts (Source: CFTC and authors' computations). ***WTI_Brent_Long*** are CIT positions in Brent futures that as inferred ("imputed") from ***W_WTI_Brent***, i.e., from the relative weights of the WTI and Brent crudes in Standard and Poor's GSCI Commodity Index (Source: authors' computations). For the augmented Dickey-Fuller (ADF) tests, we provide p values. Stars (*, **, ***) indicate the rejection of non-stationarity at standard levels of statistical significance (10%, 5% and 1%, respectively). The lag length is set equal to 4 for all series. Sample period for all statistics: April 11, 2004 (when Cushing storage data first became available) to April 30, 2012.

Table 3: Correlations

	WTI_ BRENT_ SPREAD	SHIP	ADS	SPARE	RIGS	WEEKLY_ US_ ENDING_ STOCKS	WEEKLY_ CUSHING	WTI_ TERM_ SLOPE	BRENT_ TERM_ SLOPE	WTI_OI	BRENT_ OI	WTI_ CIT_ LONG	BRENT_ CIT_ LONG	W_WTI_ BRENT	TED (Financial Distress)
WTI_BRENT_ SPREAD	1														
SHIP	0.57359***	1													
ADS	-0.1188***	0.20349***	1												
SPARE	-0.2821***	-0.4443***	-0.2131***	1											
RIGS	-0.8504***	-0.6012***	0.12479***	0.34849***	1										
WEEKLY_US_ ENDING_STOCKS	-0.385***	-0.3852***	0.05275**	0.74038***	0.47185***	1									
WEEKLY_CUSHIN G	-0.6378***	-0.5614***	0.06076***	0.71556***	0.66598***	0.80561***	1								
WTI_TERM_SLOP E	-0.1279***	-0.4283***	-0.4251***	0.41327***	-0.04*	0.34593***	0.41656***	1							
BRENT_TERM_SL OPE	0.24334***	-0.2872***	-0.5843***	0.2802***	-0.2892***	0.20786***	0.11356***	0.81356***	1						
WTI_OI	-0.3509***	-0.0368*	-0.1536***	0.38978***	0.43826***	0.54677***	0.51746***	0.09228***	0.00417	1					
BRENT_OI	-0.5367***	-0.3785***	0.09381***	0.63976***	0.70495***	0.75958***	0.81401***	0.14965***	-0.0614***	0.73175***	1				
WTI_CIT_LONG	-0.2433***	-0.0069	-0.3688***	0.35408***	0.28106***	0.43096***	0.4158***	0.28871***	0.26718***	0.82716***	0.53836***	1			
BRENT_CIT_LONG	-0.6476***	-0.2492***	-0.0787***	0.19395***	0.59133***	0.41425***	0.53964***	0.24757***	0.05949***	0.73064***	0.58273***	0.81893***	1		
W_WTI_BRENT	0.48555***	0.31122***	-0.5082***	0.39832***	-0.3424***	0.19588***	-0.0412*	0.11002***	0.35358***	0.34325***	0.10244***	0.47768***	-0.1005***	1	
TED	0.2752***	0.2178***	-0.4186***	-0.2942***	-0.1587***	-0.3206***	-0.4437***	-0.2144***	0.08594***	0.09794***	-0.2323***	0.22683***	0.01667	0.35008***	1

Notes: **Table 3** shows the simple cross-correlations for between our variables. ***SPREAD*** is the WTI-Brent spread, measured as the difference between the prompt-month prices for WTI and Brent futures contracts (WTI minus Brent); the roll day is determined based on the calendar expiration day of the successive contracts (see Section 2.3). ***SHIP*** is an index for shipping rates of dry bulk cargoes on oceanic routes (Kilian, 2009). ***ADS*** is the Aruoba-Diebold-Scotti (2009) U.S. Business Conditions Index. ***SPARE*** is the non-Saudi OPEC effective spare output capacity (millions of barrels). ***RIGS*** are active oil rigs located in the USA. ***US STOCKS*** are aggregate U.S. inventories of crude and petroleum products (millions of barrels). ***Cushing STOCKS*** are inventories located at Cushing, Oklahoma (millions of barrels). ***WTI*** and ***Brent_SLOPES*** measure the log price ratio—third- *vs*. second-deferred contract prices. ***WTI OI*** is the aggregate WTI open interest in the three nearest-to-expiry contracts (millions of barrels equivalent). ***Brent_OI*** is the equivalent figure for Brent. ***CIT_WTI_LONG*** variables is the aggregate open interest in the three nearest-to-expiry WTI futures contracts of all CITs active in WTI futures. ***W_WTI_Brent*** is the relative weights of WTI and Brent in Standard and Poor's GSCI Commodity Index ***TED*** is the spread of 30-day LIBOR over the 30-day US Treasury Bill rate. Sample period: April 11, 2004 to April 30, 2012.

Table 4: Market Fundamentals, Physical Constraints and Financials as Long-run Determinants of the WTI-Brent Spread

	Public Information			Trader-Level Information			Fundamentals + Financials + CIT		
	I-F	**II-F**	**III-F**	**I-FW**	**II-FW**	**III-FW**	**I-FC**	**II-FC**	**III-FC**
Intercept	98.8187 (495.4)	221.692 (551.1)	-105.975 (565.0)	-237.925 (372.5)	-130.934 (412.6)	-136.845 (372.9)	-292.839 (259.4)	-202.840 (296.8)	-209.944 (255.8)
TIME	0.005195 (0.004278)	**0.0091927*** **(0.004849)**	**-0.0063836*** **(0.003465)**	**-0.0064868*** **(0.003827)**	-0.00329177 (0.004818)	**-0.005921***** **(0.002291)**	**-0.004779**** **(0.002437)**	-0.00319242 (0.002936)	**-0.004414***** **(0.001524)**
SHIP	0.0181879 (0.0699)	-0.00446869 (0.07727)	-0.0122422 (0.08142)	-0.0495689 (0.05273)	-0.0529670 (0.05823)	-0.0410116 (0.05391)	-0.0493147 (0.03559)	-0.0543983 (0.04083)	-0.0398034 (0.03529)
ADS	**-1.39687**** **(0.6575)**	**-2.01966***** **(0.7626)**	**-2.27678***** **(0.7169)**	0.359562 (0.5051)	-0.141815 (0.6350)	0.149058 (0.5228)	**0.655218*** **(0.3543)**	0.364546 (0.4378)	0.509077 (0.3543)
SPARE	-0.0657655 (0.9663)	-0.438393 (1.068)	1.57408 (1.007)	-0.873114 (0.7207)	-0.946569 (0.8050)	**-1.30582*** **(0.7148)**	-0.600090 (0.4885)	-0.638268 (0.5597)	**-1.02213**** **(0.4609)**
BFOE	5.96195 (4.423)	**8.33200*** **(4.855)**	8.64083 (5.751)	2.46394 (3.412)	4.00047 (3.842)	5.09798 (3.943)	-0.615093 (2.303)	0.586638 (2.663)	1.37549 (2.589)
US STOCKS	–	–	**0.0336001*** **(0.01738)**	–	–	0.0156319 (0.01220)	–	–	0.0127566 (0.007882)
LAND	**-6.10846**** **(3.047)**	**-7.55738**** **(3.383)**	-5.50301 (3.938)	**-5.54215**** **(2.261)**	**-6.37134**** **(2.503)**	**-4.2776*** **(2.594)**	**-5.92892***** **(1.526)**	**-6.55721***** **(1.751)**	**-4.84989***** **(1.696)**
LAND x SHIP	0.124108 (0.07981)	0.0918812 (0.08779)	**0.2024198**** **(0.09003)**	0.0680477 (0.05865)	0.0588898 (0.06491)	0.0592350 (0.05961)	0.0542900 (0.03958)	0.0483747 (0.4528)	0.0402615 (0.03886)
Canada Imports	-0.143609 (0.1466)	-0.0822325 (0.1611)	–	**-0.205636*** **(0.1096)**	-0.168245 (0.1217)	–	**-0.149349**** **(0.07370)**	-0.129496 (0.08416)	–
RIGS	**-0.016907***** **(0.005322)**	**-0.024499***** **(0.006305)**	–	0.00451089 (0.005540)	-0.00144904 (0.007514)	–	0.00353558 (0.003469)	0.000379972 (0.004503)	–
Cushing STOCKS	–	–	-0.196872 (0.1464)	–	–	-0.0917756 (0.09855)	–	–	-0.076846 (0.06587)
WTI SLOPE	–	**-166.808***** **(51.44)**	–	–	**-81.3112*** **(43.80)**	–	–	**-56.5533*** **(31.86)**	–

(Continued on next page)

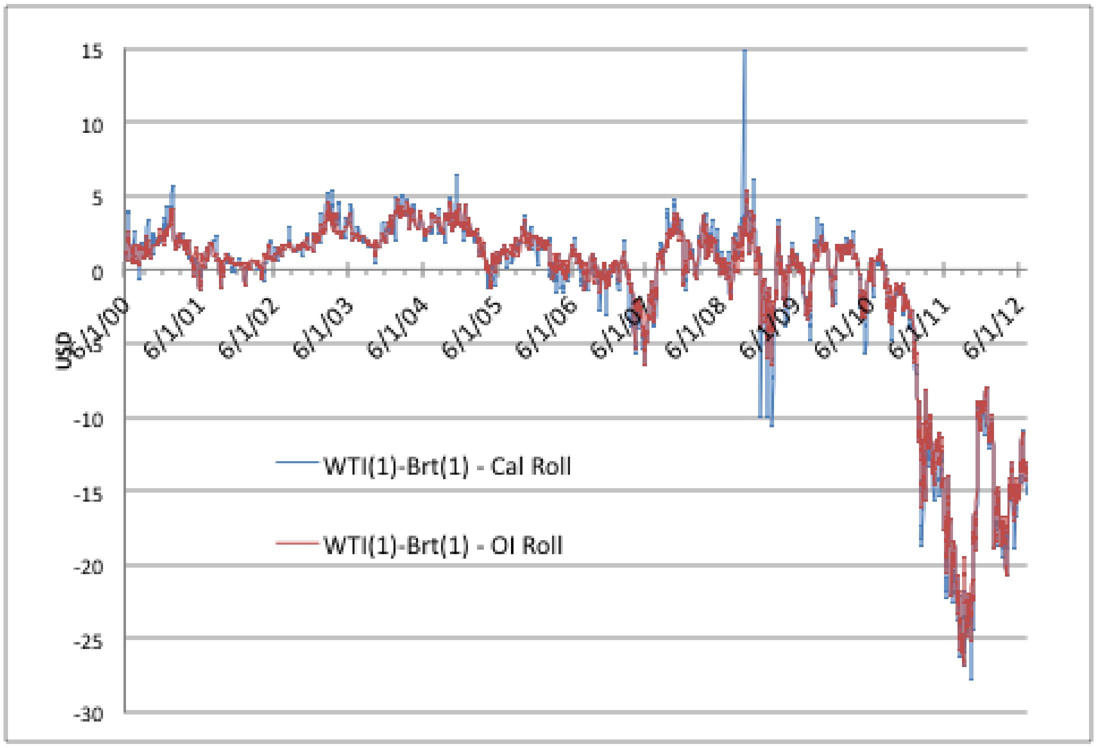
Table 4: Market Fundamentals, Physical Constraints and Financials as Long-run Determinants of the WTI-Brent Spread

(Continued from previous page)

	Fundamentals			Fundamentals + Financials			Fundamentals + Financials + CIT		
	I-F	**II-F**	**III-F**	**I-FF**	**II-FF**	**III-FF**	**I-FFS**	**II-FFS**	**III-FFS**
DISCOUNT	-95.7014 (495.0)	-228.685 (550.5)	52.6649 (565.9)	213.857 (371.7)	105.619 (411.8)	82.3511 (373.6)	311.057 (259.4)	217.412 (296.8)	200.277 (256.6)
WTI OI	**-0.038921***** **(0.009015)**	**-0.031635***** **(0.009739)**	**-0.037167***** **(0.01038)**	**-0.033770***** **(0.007096)**	**-0.030512***** **(0.007665)**	**-0.034574***** **(0.00718)**	**-0.01704***** **(0.005352)**	**-0.016209***** **(0.006245)**	**-0.017398***** **(0.005313)**
Brent OI	**0.041732***** **(0.01136)**	**0.038918***** **(0.01242)**	**0.046700***** **(0.01332)**	**0.043394***** **(0.008563)**	**0.041662***** **(0.009393)**	**0.046081***** **(0.008922)**	**0.027802***** **(0.005764)**	**0.027523***** **(0.006622)**	**0.030197***** **(0.005864)**
TED	**2.12383**** **(0.9430)**	1.54903 (1.101)	1.85238 (1.171)	0.678246 (0.7292)	0.577481 (0.8291)	0.561489 (0.7910)	**0.888889*** **(0.4866)**	0.802149 (0.5781)	0.746660 (0.5161)
WTI CIT Long	–	–	–	–	–	–	**0.173028***** **(0.01753)**	**0.167156***** **(0.02037)**	**0.160408***** **(0.01376)**
Brent CIT Long	–	–	–	–	–	–	**-0.434916***** **(0.03677)**	**-0.413675***** **(0.04566)**	**-0.405326***** **(0.03023)**
Brent *vs.* WTI Weights	–	–	–	**18.5229***** **(2.750)**	**16.4915***** **(3.442)**	**16.44883***** **(2.139)**	–	–	–

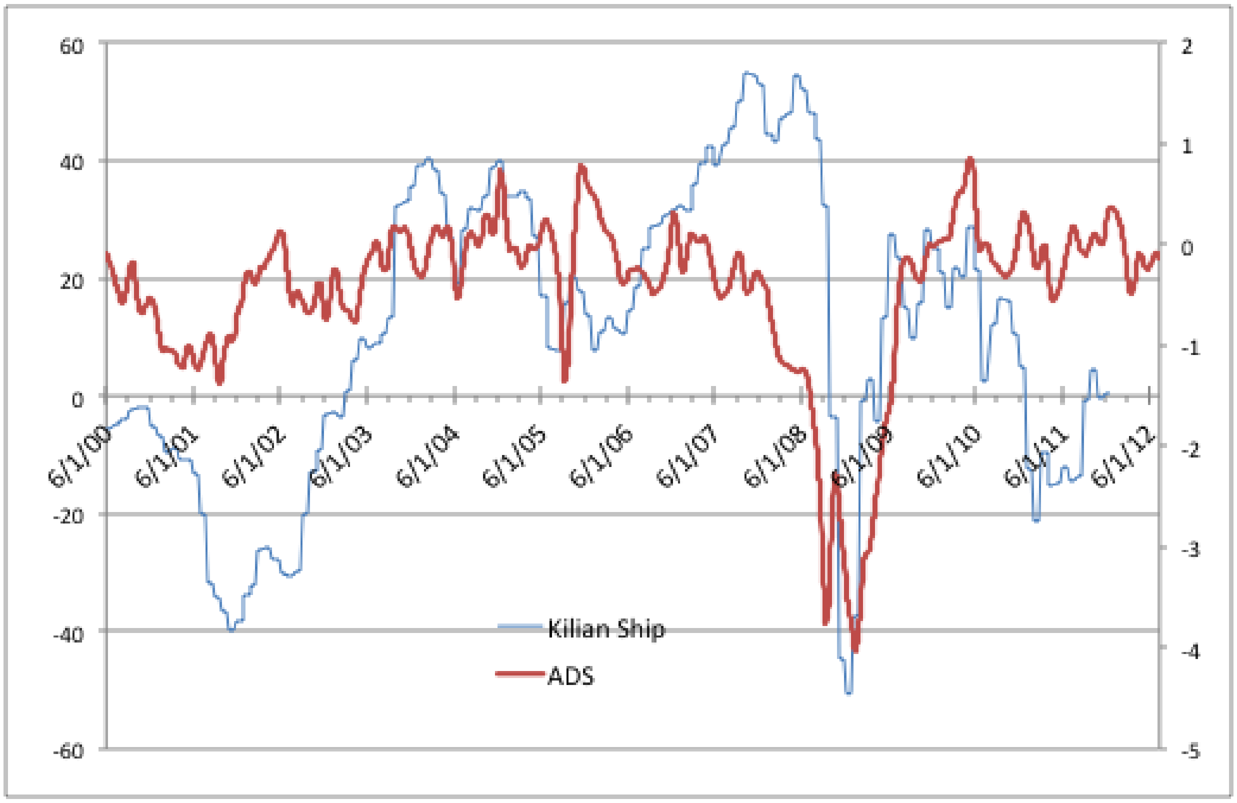
Notes: Table 4 shows the estimated long-term coefficients from nine Autoregressive-Distributed Lag (ARDL) models described in Section 4. The dependent variable is ***SPREAD,*** the WTI-Brent dollar spread measured as the difference between the prompt-month futures prices for WTI and Brent (WTI minus Brent); the roll day is determined based on the calendar expiration day of the successive contracts (Section 2.3). ***TIME*** is the order of the observation sorted by date. ***SHIP*** is an index for shipping rates of dry bulk cargoes on oceanic routes (Kilian, 2009). ***ADS*** is the Aruoba-Diebold-Scotti (2009) U.S. Business Conditions Index. ***SPARE*** is the effective non-Saudi OPEC spare crude oil output capacity (millions of barrels per day). ***BFOE*** is the monthly output of the four crude streams that make up the Brent benchmark. ***US STOCKS*** are aggregate U.S. inventories of crude and petroleum products (millions of barrels). ***LAND*** is a binary variable capturing the directionality of Cushing bottlenecks (0 through February 2007, 1 afterwards). *LAND* is interacted with *SHIP*. ***CANADA*** is the weekly crude oil imports from Canada into PADD 2 (millions of barrels). ***RIGS*** is the number of active rotary oil rigs in the 50 United States. ***Cushing_STOCKS*** is inventories located at Cushing, Oklahoma (millions of barrels). ***WTI_SLOPE*** is the log price ratio of the third- *vs*. second-deferred WTI futures prices net of ***DISCOUNT*** – the appropriately scaled money factor (based on LIBOR) until prompt–contract expiration. ***WTI_OI*** is the aggregate WTI open interest in the three nearest-to-expiry contracts (millions of barrels equivalent). ***Brent_OI*** is the equivalent figure for Brent. ***TED*** is the spread of 30-day LIBOR over the 30-day US Treasury Bill rate. ***WTI_ CIT_LONG*** is the actual aggregate open interest in the three nearest-to-expiry WTI futures contracts of all CITs active in WTI futures. ***Brent_ CIT_LONG*** is the imputed equivalent for Brent. ***W_WTI_Brent*** is the relative weight of WTI *vs*. Brent in Standard & Poor's GSCI Commodity Index. Sample period: April 11, 2004 to April 30, 2012.

Figure 1: WTI-Brent Spread, 2003-2012



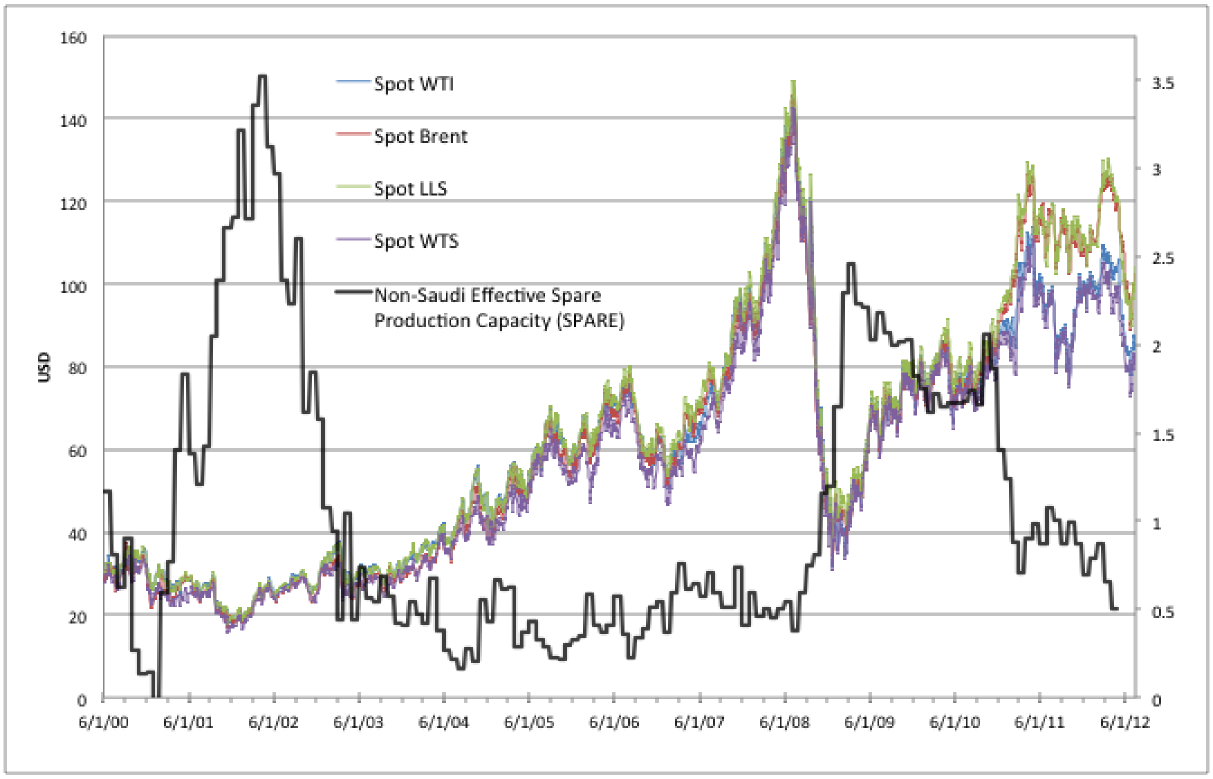
Note: Figure 1 depicts the increase in the volatility of the nearby WTI-Brent futures price spread after Fall 2008, and the large and persistent increase in the magnitude of this spread in 2011-2012. The spread is defined as the difference between the "nearby" prices of the West Texas Intermediate (WTI) and Brent crude oil futures contracts. The red series defines the nearby contracts as rolling over based on their calendar date of expiration (for WTI, this is the third business day before the 25th of the month preceding the contract month if the 25th is a business day and, if it is not, the fourth business day; for Brent, this is the 15th day before the first day of the contract month if the 15th is a business day, or the next preceding business day if it is not). The blue series defines the nearby contracts as rolling over based on the day when the WTI open interest tends to switch into the next-deferred contract; before 2006, the median day is the ninth business day of the month; after 2005 the seventh business day of the month (see Appendix 1). Sample period: June 2000-July 2012.

Figure 2: World and U.S. Macroeconomic Fundamentals



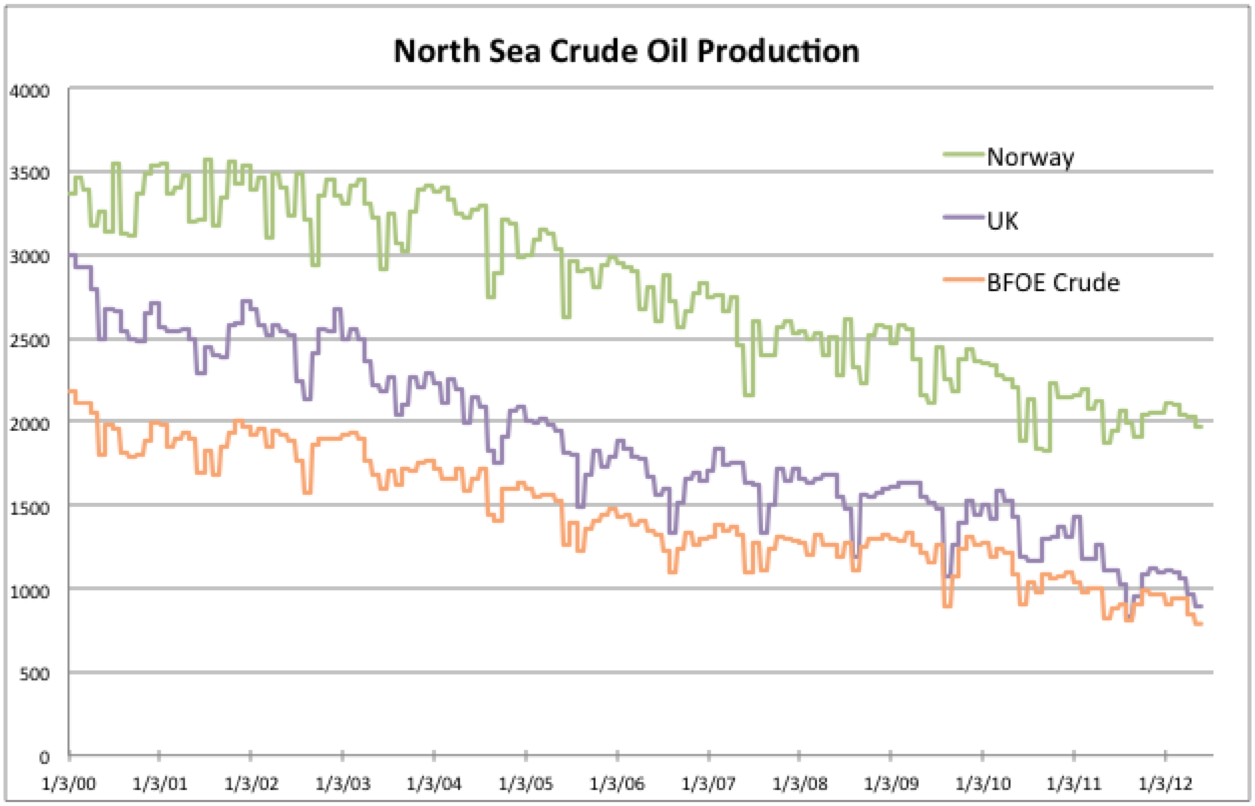
***Notes*: Figure 2** plots two indicators of macroeconomic activity. The **blue** series is the monthly Kilian (2009) Dry Bulk Shipping Cost Index, a proxy for worldwide economic demand. The **red** series is the Federal Reserve Bank of Philadelphia ADS business conditions index (Aruoba, Diebold and Scotti, 2009). This daily indicator tracks U.S. "weekly initial jobless claims; monthly payroll employment, industrial production, personal income less transfer payments, manufacturing and trade sales; and quarterly real GDP."

Figure 3: Crude Oil Prices and OPEC Effective Surplus Production Capacity



***Notes*: Figure 3** plots the spot prices (U.S. dollars per barrel) of West Texas Intermediate crude oil (WTI, in blue), Brent crude oil (in red), Light Louisiana Sweet crude oil (LLS, in green), and West Texas Sour crude oil (WTS, in purple) *as well as* the crude oil effective surplus production capacity outside of Saudi Arabia (SPARE, in million barrels per day) (in black, right hand scale). The spot price data are in USD (Source: Bloomberg). Monthly data from June 2000 to August 2010 are computed by the authors using raw data from the Energy Information Administration (U.S. Department of Energy) and the International Energy Agency (IEA).

Figure 4: Brent Output



***Notes*: Figure 4** plots the production of crude oil in the North Sea (thousands of barrels per day). Monthly data from January 2000 to May 2012 are from the International Energy Agency (IEA). The output of the four crude oil streams that make up the Brent crude benchmark (Brent Blend, Forties Blend, Oseberg and Ekofisk or "BFOE" is plotted in orange.

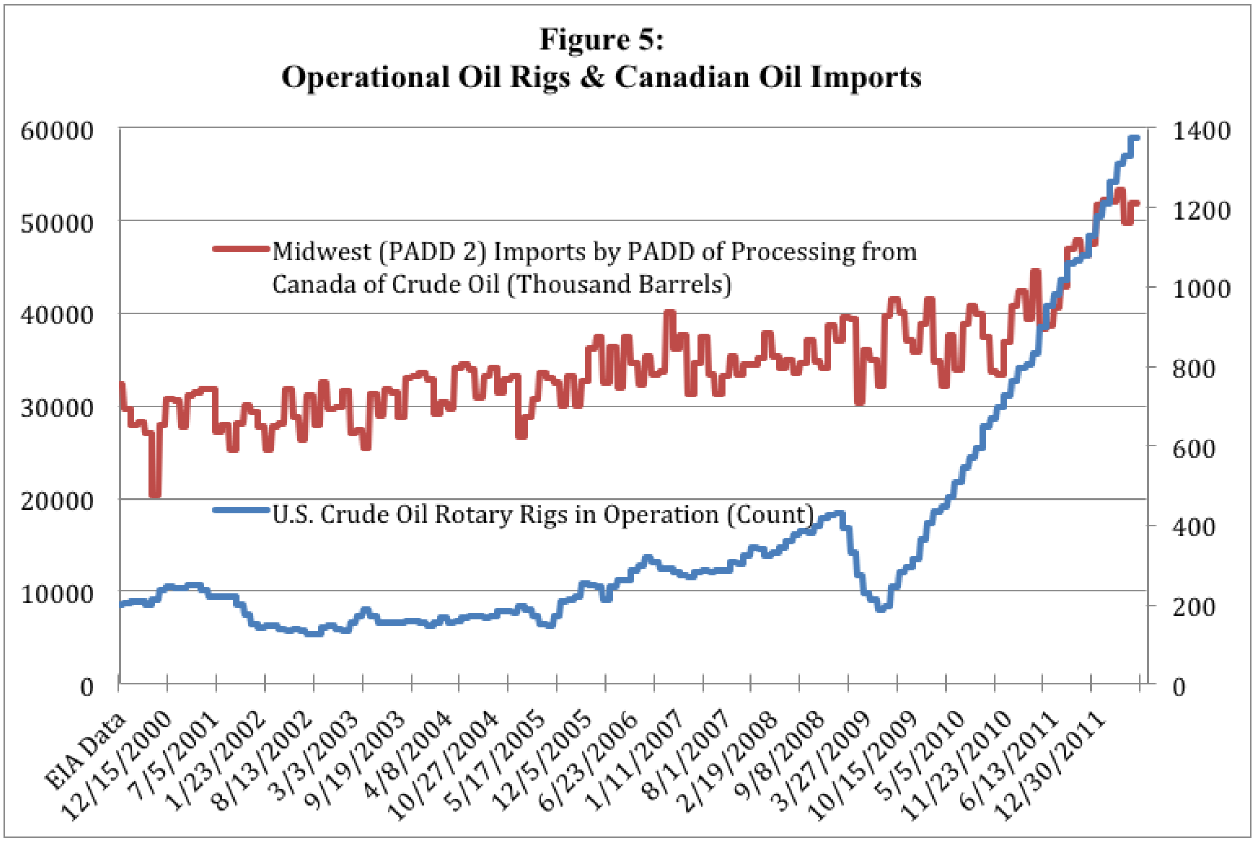
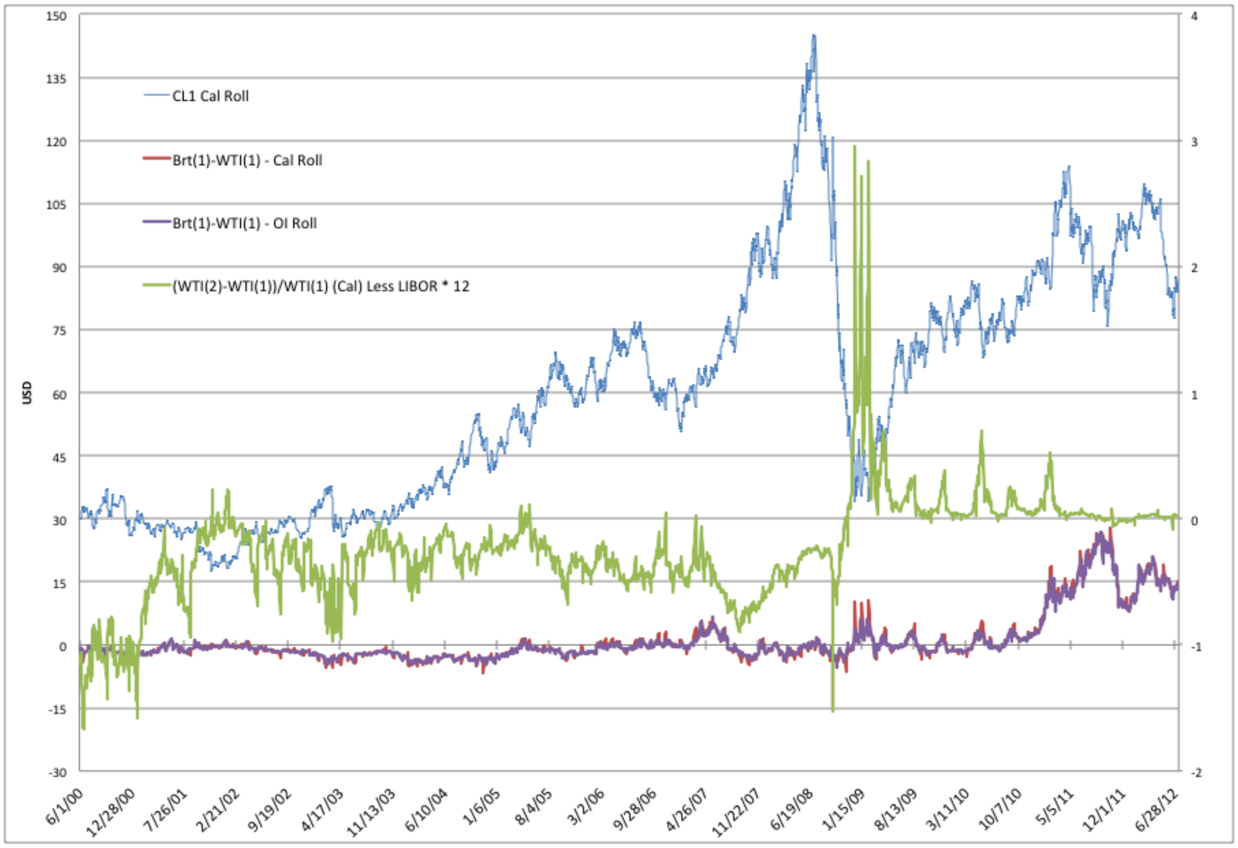


Figure 5:
Operational Oil Rigs & Canadian Oil Imports

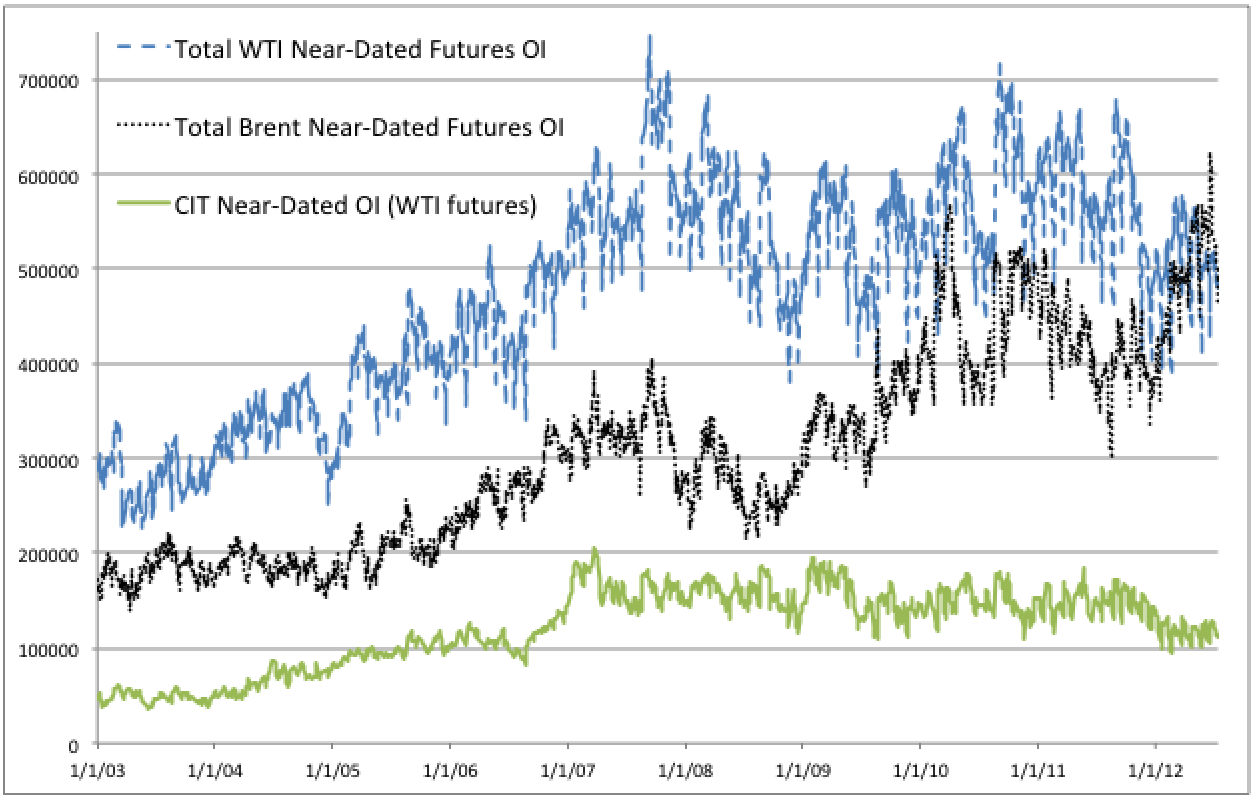
Notes: **Figure 5** plots (in **red** on the left-hand axis) imports into PADD 2 of Canadian crude oil (in thousands of barrels) and (in **blue** on the right-hand axis) the number of operational crude oil rotary rigs in the 50 United States and the District of Columbia. Data on operating crude oil rigs come from the U.S. Energy Information Administration (EIA), which sources it from Baker Hughes, Inc. and Weatherford International, Ltd. Specifically, the series provides a number of operational crude oil rotary rigs, which are used to drill wells, both onshore and offshore throughout the fifty states of the U.S. The data are reported monthly as the average of values from a four- or five-week reporting period. Data on crude oil imports (in thousands of barrels) into the Midwestern PADD 2 also come from the EIA.

Figure 6: WTI Price, Inverted WTI-Brent Spread and Calendar Spread Yield



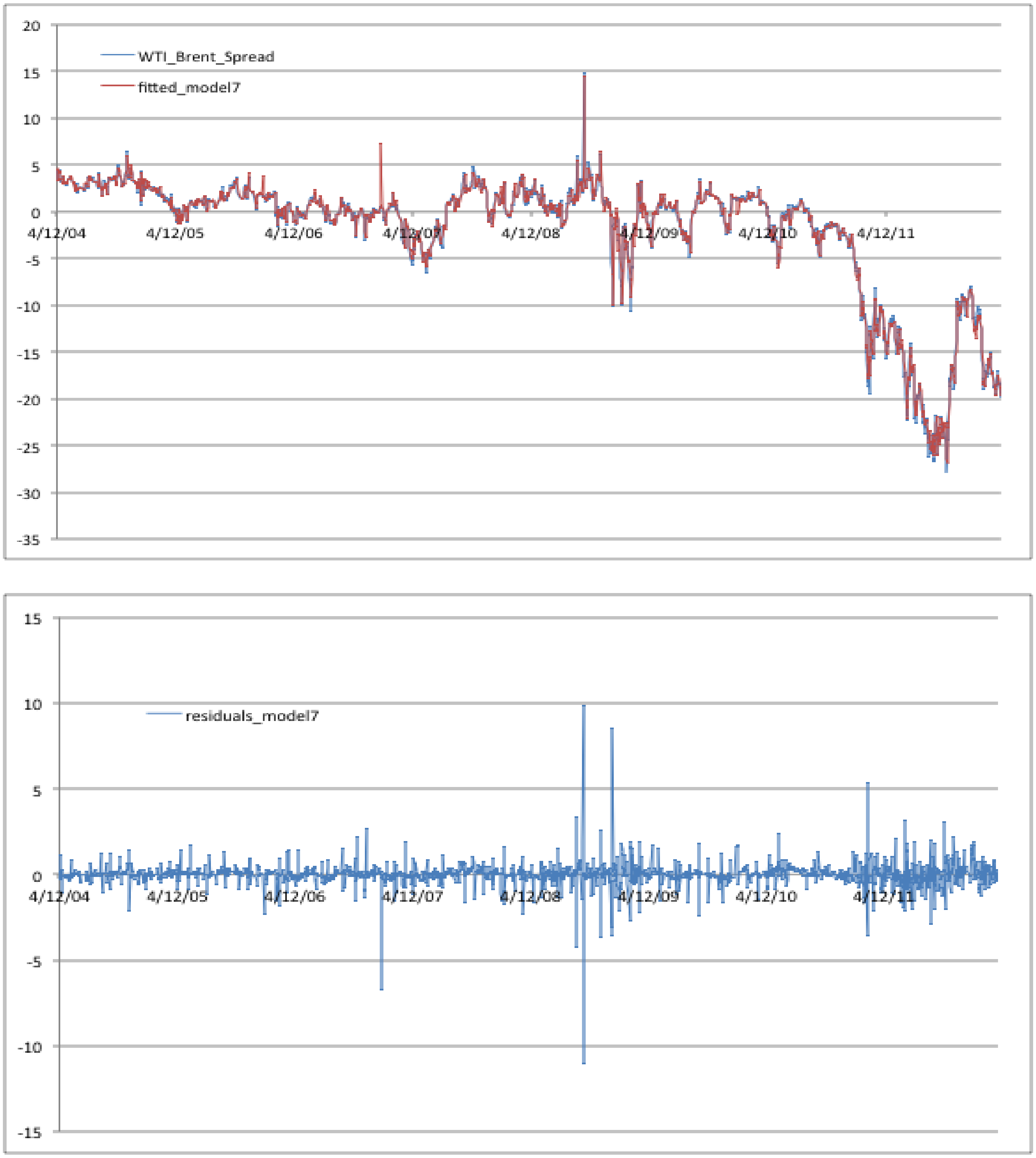
Notes: Figure 6 plots the West Texas Intermediate nearby contract price, using a calendar roll date based on the prompt contract expiration day (in blue). Figure 6 also plots the difference between Brent and WTI using two different methods to roll: the calendar roll in red highlights the increase in volatility at expiration of the prompt contract; the open-interest based roll (in purple) show a similar trend but less daily volatility. Finally, Figure 6 plots the calendar spread yield (in green) calculated as the annualized percentage difference between the prompt and first-deferred WTI contract net of LIBOR. The green curve shows a structural break in levels and volatility after November 2008. All prices are in USD.

Figure 7: WTI and Brent Near-Dated Open Interest
(First three Calendar Months)



Notes: **Figure 7** plots the overall futures open interests for the NYMEX WTI (top curve, in **blue**) and ICE Brent (dotted middle **black curve**) crude oil markets for the three nearest-dated futures. The bottom curve plots the *aggregate* "open interest" (in **green**), across the same three contracts, of 67 large futures traders classified by the U.S. CFTC as Commodity Index Traders (CITs). Precisely, WTI futures-only positions are aggregated across all 67 traders and across the three nearest-dated WTI futures contract maturities. The "open interest" is the average of the absolute values of those 67 traders' long and short positions. Source: Bloomberg (Brent) and CFTC (WTI, CIT), January 2003 to July 2012.

Figure 8: Actual and Predicted WTI-Brent Spreads



Notes: **Figure 8** plots, in the top panel, the WTI-Brent spread (in **blue**) and the values fitted using Model II-FW in Table 4 (in **red**) as well, in the bottom panel, the residuals. The largest residuals, in absolute terms, are on September 22 and 23, 2008.