The role of market fundamentals and speculation in recent price changes for crude oil

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Abstract

I hypothesize that the price spike and collapse of 2007–2008 are driven by both changes in both market fundamentals and speculative pressures. Contrary to arguments for a demand shock, I hypothesize that prices rise sharply in 2007–2008 because ongoing growth in Chinese oil demand runs into a sudden and unexpected halt to a decade long increase in non-OPEC production. This caused a loss of OPEC spare capacity because increased demand for OPEC production runs ahead of increases in OPEC capacity. These changes are reinforced by speculative expectations. Although difficult to measure directly, I argue for the role of speculation based on the following: (1) a significant increase in private US crude oil inventories since 2004; (2) repeated and extended break-downs (starting in 2004) in the cointegrating relationship between spot and far month future prices that are inconsistent with the law of one price and arbitrage opportunities; and (3) statistical and predictive failures by an econometric model of oil prices that is based on market fundamentals. These changes are related to the behavior and impact of noise traders on asset prices to sketch mechanisms by which speculative expectations can affect crude oil prices.

1. Introduction

Compared to other commodities, the price of crude oil is not exceptionally volatile (Regnier, 2007). Therefore, volatility alone may not explain the large price changes in 2007 and 2008. In August 2007, the near-month contract for West Texas Intermediate (WTI) crude oil sold for just under $70 per barrel on the New York Mercantile Exchange. A little less than a year later, July 3, 2008, the near month contract sold for $148 per barrel. And after another 6 months, the near month contract sold for a little more than $35 per barrel on December 24, 2008.

Such large changes during an 18 month period beg a cause. Analysts offer two general explanations; speculative expectations and market forces. An emphasis on market forces postulates that rapid changes in oil prices are needed to clear the market for a good that has relatively small (absolute) short-run supply and demand elasticities and is subject to large and/or unexpected changes in supply and/or demand. An alternative explanation attributes the large changes in price to speculative expectations. Of course, these two explanations are not mutually exclusive, and both market forces and speculative expenditures may be responsible.

A role for speculation in the sharp price rise is described by Masters (2008). He attributes the increase to speculators who buy oil as a financial asset. Speculators profit from expectations for higher prices by taking a long position on a far month contract, selling it at a higher price before the contract expires, and reinvesting the proceeds in a new far month contract. Financial gains from this strategy can become a self-fulfilling prophecy if the perception of rising prices is shared widely. Consistent with this hypothesis, the role of extrapolative expectations in the recent price rise is confirmed empirically (Cifarelli and Paladino, 2010).

The importance of speculation is disputed by others, including government agencies (CFTC, 2008) and academics. Hamilton (2009) argues against an important role for speculation by highlighting the absence of an observable stock build that is predicted by a simple model for an oil refiner who takes a long position on future prices. Instead, Hamilton (2009) and others focus on market fundamentals. Both Hamilton (2009) and Kilian (2009a) attribute much of the 2008 price increase to a demand shock that originates in China.

Here, I argue that the large price changes of 2007–2008 are driven by changes in both market fundamentals and speculative pressures. Prices rise sharply in 2007–2008 because ongoing growth in Chinese oil demand runs into two changes on the supply side:

- Non-OPEC oil production unexpectedly stops growing in 2004.
- OPEC loses much of its spare capacity due to a 2004 halt in ongoing gains in non-OPEC crude oil production.

Prices decline in late 2008 when the financial crisis lowers global demand, which restores significant amounts of spare capacity.
But price movements associated with these supply-side fundamentals are reinforced by speculative expectations. Although speculative expectations cannot be measured directly like supply and demand, I argue that speculation plays a significant role in the recent rise and collapse in oil prices based on three indicators:

- A significant increase in private US crude oil inventories that reverses more than 20 years of steady reductions.
- A break-down in the cointegrating relationship between spot and far month future prices that is inconsistent with the arbitrage opportunities that support the law of one price.
- Statistical and predictive failures by an econometric model of oil prices that is based on market fundamentals.

Evidence for the effect of market fundamentals and speculative expectations in the recent spike and collapse in oil prices is presented in four sections. Section 2 highlights inconsistencies in analyses that argue for the importance of a demand shock. Instead the markets forces that raise crude oil prices originate on the supply side. Section 3 describes three indicators that suggest supply-driven changes in oil prices may have been exacerbated by speculative expectations, and finally, Section 4 concludes with a description of how speculative pressures may operate in the oil market.

2. Market fundamentals

Empirical tests of the hypothesis that market forces are responsible for the large changes in oil prices over the last 2 years focus in supply and demand. But unlike recent efforts to attribute price shocks to demand growth (e.g. Kilian, 2009b), I postulate that the recent spike was caused largely by a supply shock—a sudden end to on-going increases in non-OPEC production. When non-OPEC production fails to grow after 2004, on-going increases in global (Chinese) oil demand are satisfied by increasing production by OPEC nations. However OPEC capacity grows less rapidly than demand during this period, and therefore increasing output reduces spare capacity. The loss of spare capacity pushes prices ever higher. Price decline when the 2008 financial crisis reduces oil demand, which reestablishes spare capacity.

2.1. Demand

Several analysts argue that strong growth in oil demand in general, and rapid growth in Chinese oil demand in particular, are responsible for the rapid rise in oil prices (e.g. Hamilton, 2009; Kilian, 2009b). But this argument is not consistent with data for global oil demand (Fig. 1). There is a small rise in the growth rate of world oil demand in 2003 and 2004. However, after 2004, rates of demand growth diminish. In 2005, world oil demand averages 84.04 million barrels per day (MBD)—in 2007 oil demand averages 86.14 MBD. This 2 MBD increase represents an annual growth rate of 1.2%. Demand growth is not any faster during the first three quarters of 2008. Demand remains below 87 MBD in all quarters of 2008. Demand in the second quarter of 2008 is nearly identical to the 2007 average, and demand in the third quarter of 2008, when prices reach $148 per barrel, drops to 85.3 MBD.

Slow rates of growth seem to undermine the hypothesis that rapid growth in world oil demand is responsible for the large increase in prices. This seeming contradiction begs the question, what is the basis for the hypothesis that the 2005–2008 rise in prices is a ‘demand shock.’ Kilian (2009a, b) argues for the preeminence of demand based on the results of a vector autoregression (VAR) in which global economic activity (and oil demand) is proxied using a monthly measure of dry cargo bulk freight rates (herein termed SHIP). According to Kilian (2009b), SHIP is a ‘measure of the component of worldwide real economic activity that drives demand for industrial commodities in global markets.’ According to this logic, changes in the dry cargo bulk rates reflect changes in economic activities that drive oil demand.

A visual examination of SHIP seems to belie any relationship to oil demand (Fig. 2). The SHIP index, which is a de-trended time series of the log values of the aggregated dry cargo bulk freight rates, rises sharply in 2004 and remains high through 2008. Conversely, a de-trended time series of the log values for global oil demand shows no appreciable increase since the mid-1980s. In other words, global oil demand grows at trend between the mid-1980s and the present, which is consistent with the visual impression from Fig. 1. Furthermore, there is no statistically measurable relationship between the two series, as indicated by a t-test (t = 1.04, p > 0.30) on the regression coefficient (β) that is generated by an OLS estimate of the following regression (Oil Demandt = a + β SHIPCt + µt).

The mismatch between global oil demand and SHIP begs a cause. Perhaps, economic activity, as measured by dry cargo bulk rates, increases demand ceteris paribus, but oil demand fails to grow because oil prices also rise. But this explanation would imply a small income elasticity for oil relative to its own price elasticity. Such values are inconsistent with a large literature of empirical estimates, which indicate that the income elasticity for oil demand is much larger (in absolute terms) than its own price elasticity of demand (e.g. Dargay and Gately, 1995).

Alternatively, the positive relationship between SHIP and crude oil prices that Kilian (2009b) attributes to the effect of economic activity on oil demand may simply represent the effect of oil prices on dry cargo bulk rates. As described by Büyüksahin et al. (2008) at typical 2005 (mid-2008) charter rates, the bunker fuel used to propel ships accounted for approximately one-third (one-half) of dry-cargo shipping costs. Despite this relationship, Büyüksahin et al. (2008) dismiss the hypothesis that the effect of oil prices on shipping costs is responsible for the VAR results that suggest the recent price spike is caused by a demand shock. Visual inspection of the Ship and crude oil price series however, suggests that the shipping cost increases predated, by more than six months, the start of a sustained increase in crude oil prices.  

I test this visual assessment by examining causal relationships among variables in the VAR estimated by Kilian (2009b), which includes detrended logged values of SHIP, the percentage change in global oil production, and logged values of the real US refiner’s acquisition cost for imported oil. Observations are available between January 1974 and February 2009. Results reject the null hypothesis that real crude oil prices do not ‘Granger cause’ SHIP (F(3,400) = 4.52, p < 0.01). This result implies that innovations in crude oil prices have an immediate and lagged effect on SHIP in the structural VAR. Such an effect is consistent with the hypothesis that rising crude oil prices elicit bunker adjustment factor surcharges, which increase container shipping costs (USDA, 2005). As such, the rise in SHIP after 2002 may simply reflect on-going increases in oil prices, and not an increase in oil demand, which is not present in the observational record.

To obtain the innovations that represent the demand shock, Kilian (2009a, b) orders the VAR such that innovations to SHIP have an immediate effect on crude oil prices but crude oil price innovations do not have an immediate effect on SHIP. The latter is inconsistent with the finding of Granger causality from prices to...
SHIP described above. Nonetheless, the ordering is consistent with a weak \( F(3,407) = 2.71, p < 0.05 \) finding of Granger causality from SHIP to oil prices.

But this finding may be misleading—Granger causality from SHIP to oil prices may be created \textit{a priori} based on the measure of oil prices used by Kilian (2009b). As defined by the US Energy Information Administration, which is the source of the data, the refiner acquisition cost for imported oil is ‘the cost of crude oil, \textit{including transportation} (italics added) and other fees paid by the refiner.’ By definition, the refiner acquisition cost for imported oil includes transportation costs. Because much of the oil imported by the US arrives by ship, innovations in shipping costs should appear simultaneously in prices of crude oil that include transportation costs.\(^2\)

To evaluate the effect that the inclusion/exclusion of transportation costs in the price of crude oil has on findings of Granger causality, tests of Granger causality are repeated with landed prices of crude oil that do include shipping costs (the refiner’s acquisition cost of foreign oil, the US average landed price of crude oil from non-OPEC nations, and the US average landed price of crude oil from OPEC nations) and freight on board (fob) prices that do not include transportation costs (the average fob price for US oil imports, the fob price for crude oil from non-OPEC nations, and the fob price for OPEC nations).

For all measures of crude oil prices, the \( F \) test strongly rejects the null hypothesis that real oil prices do not ‘Granger cause’ SHIP (Table 1). This result is consistent with the hypothesis that oil price innovations have an immediate and lagged effect on SHIP in the structural VAR. For measures of crude oil prices that do not

\(^2\) There is a statistically significant correlation, as measured by a \( t \)-test \((t = 8.22, p < 0.001)\) on the regression coefficient (\( \beta \)) that is generated by an OLS estimate of the following regression (SHIP = \( a + \beta (\text{transportation}) \mu_t \)) in which Transportation is the de-trended series of the natural log of the difference between real landed and freight on board (fob) prices for US oil imports from non-OPEC nations.
include transportation costs, the lack of evidence for ‘Granger causality’ from SHIP to oil prices (Table 1) is inconsistent with the ordering of the VAR used to quantify demand shock (i.e. that innovations in the SHIP variable have an immediate and/or lagged effect on oil prices in the structural VAR). This inconsistency, along with an explanation for the positive relationship between SHIP and oil prices (as deflated by the PPI). 

Table 1
Tests of Granger causality for a VAR that specifies the same three variables used by Kilian (2009b): the SHIP index (measure in logs), the percent change in global crude oil production, and logged real oil prices (as deflated by the PPI).

<table>
<thead>
<tr>
<th>Crude oil price variable</th>
<th>Price → SHIP index</th>
<th>Ship index → price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refiner acquisition foreign</td>
<td>$f(3,400)=4.52^{**}$</td>
<td>$f(2,405)=2.58^{*}$</td>
</tr>
<tr>
<td>Non-OPEC landed price</td>
<td>$f(3,400)=5.13^{**}$</td>
<td>$f(3,402)=1.91$</td>
</tr>
<tr>
<td>OPEC landed price</td>
<td>$f(3,400)=6.89^{**}$</td>
<td>$f(3,402)=1.12$</td>
</tr>
<tr>
<td>Average fob US imports</td>
<td>$f(3,400)=5.67^{**}$</td>
<td>$f(3,402)=1.25$</td>
</tr>
<tr>
<td>Non-OPEC fob price</td>
<td>$f(3,400)=4.77^{**}$</td>
<td>$f(2,405)=2.02$</td>
</tr>
<tr>
<td>OPEC fob price</td>
<td>$f(3,400)=6.57^{**}$</td>
<td>$f(2,405)=1.66$</td>
</tr>
</tbody>
</table>

Test statistics are statistically significantly different from zero at the **1%, *5%, and +10% levels. 

Although there is a general consensus for a unified global market for crude oil, many argue that oil prices are affected by source of crude oil (e.g. Gately et al., 1977; Kaufmann, 1995). This source effect often is associated with behavior by two producer groups; non-OPEC and OPEC nations. Firms that produce oil from fields located in non-OPEC nations generally are viewed as price takers. Consistent with this view, non-OPEC output is negatively related to the cost of production and is positively related to its price (e.g. Kaufmann and Cleveland, 2001; Dees et al., 2007). Similarly, there is little evidence for strategic considerations by non-OPEC producers (e.g. Kaufmann et al., 2004).

Conversely, the state run oil companies (e.g. Saudi Aramco) that produce nearly all of the crude oil from fields in OPEC nations are viewed as following some form of strategic behavior. Empirical results indicate that production levels by OPEC nations are influenced by production quotas and are consistent with production sharing (e.g. Kaufmann et al., 2008a). Strategic behavior by OPEC producers is simulated using a variety of assumptions, including models for a dominant firm, revenue targets, and bureaucratic syndicates (e.g. Smith, 2005).

These behavioral differences imply that non-OPEC nations are infra-marginal suppliers while OPEC is the marginal supplier. If these differences in behavior are correct, then changes in production between non-OPEC and OPEC nations will have an important effect on price. Specifically, any change in non-OPEC production that strengthens OPEC’s control over the marginal barrel of oil will tend to increase prices. As such, unanticipated or large changes in the market share of OPEC producers could generate a supply shock.

2.2.2. OPEC production

The sudden, unexpected, and prolonged hiatus in rising rates of non-OPEC production is important because it causes the slow but steady increase in global oil demand to increase demand from the marginal supplier OPEC. This changes the balance between OPEC and non-OPEC producers that exists before 2004. Between 1997 and 2003, the 6.3 MB/D increase in global oil demand is satisfied in large part by ongoing increases in non-OPEC production. As a result, there is little increase in crude oil production by OPEC nations between 1997 (27.29 MB/D) and 2003 (27.98 MB/D).

Without a significant supply increase by non-OPEC producers after 2004, further gains in oil demand are satisfied from two sources—OPEC production of natural gas liquids, which are liquids that are brought to the surface in the process of producing natural gas, and OPEC production of crude oil. OPEC increases its production of natural gas liquids by about 0.5 MB/D between 2004 and 2008 while crude oil production increases from 30.5 MB/D in 2004, to 32.5 MB/D in 2008. OPEC production grows about 2.4 MB/D and this accounts for more than the 2.3 MB/D increase in global production of liquid fuels.

The increase in OPEC production of crude oil is important because it is not quite matched by increases in operable capacity. As a result, there is a loss in spare capacity and an overall increase in the rate of capacity utilization. These two changes are important because empirical models indicate that OPEC production quotas and/or OPEC capacity utilization rates have a statistically measurable effect on real oil prices (Kaufmann et al., 2004, 2008b; Chevillon and Riffart, 2009).

Changes in OPEC and non-OPEC production beg the question, why do these supply-side changes have little effect on the results described by Kilian (2009b). The simple answer is that these supply-side changes are not represented in the VAR. The variable for crude oil production aggregates output from OPEC and non-OPEC nations. Furthermore, the VAR specifies supply as a percentage change in production as opposed to the level of production. Conversely, the time series for real crude oil prices and the shipping index are specified in levels. Given this specification, it is not surprising that the percentage change in global oil production is not an important driver of real oil prices. As such, the model that purports to measure the effects of


The sudden and unexpected halt in output growth by non-OPEC production is notable. Prior to 2004, there is only one extended period in which non-OPEC production fails to grow: 1988–1993. This period is associated with a collapse in production by the former Soviet Union, where production shrinks from 12.1 MB/D in 1988 to 7.0 MB/D in 1994. Outside the former Soviet Union, non-OPEC production continues to grow. This allows non-OPEC production to grow steadily between 1994 and 2004 once the former Soviet Union is able to stabilize production.

The post 2004 period is marked by production declines across a wide geographical area that includes the US, Mexico, and Western Europe. And unlike 1988–1993, when real oil prices are low and relatively stable, the on-going period of stagnant non-OPEC production occurs during an extended period of rising real oil prices. In 2004, real oil prices average $43.76 per barrel—prices average $62.90 between 2005:Q1—2007:Q4 and $70.17 2005:Q1 through 2008:Q4. Without taking a position on the issue of peak oil (Sorrell et al., 2009), the lack of a supply response to a very large and sustained price increase suggests an important change in the infra-marginal supply of oil.
demand-side shocks diminishes the effects of a supply-side shock a priori.

3. Speculation

The changes in OPEC and non-OPEC production that are described above seem small relative to the large changes in real oil prices between 2004 and 2008. Nonetheless, it may be possible to explain these price changes based on market fundamentals if the relevant supply and/or demand effects are assumed to be highly inelastic (Hamilton, 2009). But this hypothesis is difficult to test empirically. For example, the argument about demand side effects depends in part on whether the short run own price elasticity for oil is $-0.06$ or $-0.10$ (Hamilton, 2009).

Unfortunately, the role of speculation is equally difficult to evaluate quantitatively. Instead, analysts look for important changes in market behavior. For example, Parsons (2009) argues that speculation plays a role in the recent spike in oil prices based on changes in the term structure for oil futures on the New York Mercantile Exchange. Here, I expand the list of changes that suggest a role for speculation with the following three indicators:

- A significant increase in private US crude oil inventories since 2004.
- Repeated and extended break-downs in the cointegrating relationship between spot and far month future prices (starting in 2004) that are inconsistent with the arbitrage opportunities that enforce the law of one price.
- Statistical and predictive failures by an econometric model of oil prices that is based on market fundamentals.

No single piece of evidence is proof-positive that speculation plays a significant role in the recent rise and collapse in oil prices, one would expect corresponding changes in inventories of crude oil. Anticipation of future increases in oil prices should induce speculators to increase inventories so long as the expected gains in price exceed the time value of money and the cost of physical storage. Based on this notion, Hamilton (2009) argues 'If the price increases between 2005 and the first half of 2008 was greater than needed to equate supply with demand, inventories would have been piling up...'. Hamilton's hypothesis provides a ‘smell test’ for the role of speculation—the absence of an inventory build would argue against a significant role for speculators in the recent price spike. The importance of this ‘smell test’ is disputed by Parsons (2009), who argues that ‘an elevated level of the entire term structure should not produce a growing stockpile of oil stored in above-ground tanks.’

To test the hypothesis that speculative expectations generate an inventory build, Hamilton (2009) compares historical averages (1999–2007) for monthly stocks of crude oil held by US refiners to observed values for 2007 and 2008. The comparison (Hamilton’s Fig. 11) shows little change relative to historical averages, which is inconsistent with the hypothesis that speculation plays a significant role in the recent price spike. But the lack of a stock build by refiners may be explained by industry behavior. The US Commodity Futures Trading Commission (CFTC) (2008) considers refiners to be commercial traders. This classification includes those ‘engaged in business activities hedged by the use of futures or option markets.’ As such, refiners are unlikely to take a large long position by building physical stocks on speculative expectations of a price increase. As such, refiner inventory levels are unlikely to be a clear indicator of speculative pressure. Nor is there an a priori reason to suppose that a speculative stock build start in 2007 or 2008 and that 1999–2007 monthly averages are the relevant historical period against which changes in crude oil inventories should be judged.

To evaluate the degree to which the results reported by Hamilton (2009) constitute evidence for an absence of a stock build, I examine changes in US private (does not include the strategic petroleum reserve) inventories of crude oil, which includes those held by refiners, tank farms and pipelines, leases, and Alaskan oil in transit (EIA, 2009) from January 1973 (the first date at which monthly data are available) through October 2009, which is the most recent observation at the time of this writing. Measured both in absolute quantities (million barrels) and days of forward consumption (inventories divided by US consumption of oil).
refined petroleum products), this measure for private inventories reaches an all-time high in 1981 (Fig. 4a and b). This increase is consistent with both the fear of and the experience with oil supply disruptions.

Starting in 1982, both measures decline steadily through 2004. Beyond 2004, both series start a steady increase. The reversal in the 22 year downward trend in US inventories of crude oil coincides with the start of the recent rise in real oil prices.

Visual suggestions of a reversal in the long-term downward movement of crude oil inventories are evaluated formally with a Quandt Likelihood Ratio (QLR), which is used to test whether there is a structural break in a simple model that specifies monthly crude oil inventories as a function of a constant and a time trend ($\text{Inventories}_t = \alpha + \beta \text{Time}_t + \mu_t$). This equation is fit to both measures of oil inventories for the sample period from January 1982 to October 2009 (5% trimming). The QLR strongly rejects the null hypothesis of no break in the simple model for the quantity of crude oil in storage (QLR = 99.3, $p < 0.001$) and for the days of forward consumption (QLR = 127, $p < 0.001$).

Despite the very high significance levels, conclusions about a break in these time series could be affected by their time series properties—crude oil inventories may be I(1). To investigate this possibility, I use the procedure developed by Perron (1997) to test the null hypothesis that the time series for US crude oil inventories contains a stochastic trend, against the alternative hypothesis that the time series is trend stationary with a change in the slope only and that both segments of the trend function are joined at the time break. The test statistic rejects the null hypothesis that the time series for the quantity of oil held in Figure 4. (a) Private inventories of crude oil held in the US (black line) and the best fit deterministic trend (red line) with a break (joined) generated by the procedure developed by Perron (1997). Data from US Energy Information Administration. (b) Days of forward consumption (private inventories of crude oil held in the US/daily US demand for refined petroleum products–black line) and the best-fit deterministic trend (red line) with a break (joined) generated by the procedure developed by Perron (1997). Data from US Energy Information Administration (for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

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4 The results described below do not change significantly if the equation is fit to the entire sample period that starts in January 1973 or if the equation includes monthly dummy variables.
storage \((-5.88, p < 0.01)\) or days of consumption \((-6.03, p < 0.01)\) is \(f(1)\). For both time series, the break occurs in 2004. March for quantity of oil stored and June for days of forward consumption.

Clearly, these statistical tests are not definitive—I do not argue that crude oil inventories are determined exogenously by a time trend. Rather, visual examination of the data and some simple statistical tests suggest that the factor(s) that lowers US inventories between 1982 and 2004 is offset by a new factor (or the effect of an on-going factor is reduced) such that inventories start to rise in 2004. One such factor could be speculative expectations of higher oil prices. As such, the post 2004 rise in inventories passes a ‘smell test’ for a significant role of speculation.

### 3.2. Law of one price

There is a consensus among analysts that the crude oil market is unified. The working hypothesis that the world oil market is unified originates with Adelman (1984, 1992). His hypothesis is confirmed repeatedly by studies that find prices for various grades of crude oil from different parts of the globe cointegrate (e.g. Cullen, 1999, 1999; Ewing and Harter, 2000; Bachmeier and Griffin, 2006; Hammoudeh et al., 2008). This unified price is generated by arbitrage opportunities that increase over time due to lower transaction costs (Kleit, 2001).

If the world oil market is unified, the Law of One Price implies that arbitrage opportunities will realign prices for different grades of crude oil if their prices diverge by amounts greater than the spread that is implied by physical measures of quality (e.g. sulfur content, API gravity index) and arbitrage transaction costs. This conclusion is re-inforced by results that indicate crude oil prices ‘error correct’ faster when their price spread exceeds some threshold, which presumably represents the costs of arbitrage (Fattouh, 2010).

If speculative expectations play a significant role in price formation, the law of one price may break down. Specifically, one may see a separation between prices for crude oil on spot markets, where the purchaser is expected to take possession, and futures markets, where a contract may be bought and sold several times before the contract expires.

The origination for such a break down may be identified by an analysis of the price discovery process for ten crude oil contracts (spot prices for five crude oils and five future price contracts for three crude oils) (Kaufmann and Ullman, 2009). Their analysis suggests that new information about supply/demand enters the market through the spot price for Dubai-Fateh while information about expected prices enters the market through the 5-month forward contract for WTI. Market fundamentals dictate that these crude oils have a different price because they have a different specific gravity. Specifically, WTI has a higher price because WTI (39.6°) is ‘lighter’ than Dubai-Fateh (32°). Nonetheless, the law of one price implies that the price difference between these two crude oils (or any two crude oils) should be stationary around a constant ‘spread.’ Furthermore, large deviations from the price spread should be eliminated fairly quickly because large deviations enhance arbitrage opportunities (Fattouh, 2010). As such the cointegrating relationship between the price for WTI and Dubai-Fateh (\(WTI_t = \alpha + \beta DuFa_t + \mu_t\)) should be stable if the law of one price holds.

If speculative expectations play an important role in price formation, the cointegrating relationship dictated by the law of one price could break down for extended periods. This hypothesis seems consistent with a visual examination of the residual from the cointegrating relationship between the spot price for Dubai-Fateh and the 5 month forward contract for WTI (Fig. 5). The residual fluctuates within a relatively small range until 2004, but becomes increasingly volatile thereafter.

To test for a break down in the long-run cointegrating relationship between the five month contract for WTI and the spot price for Dubai-Fateh, I use a test statistic developed by Andrews and Kim (2006):  

\[
R = \sum_{t=T+1}^{T+m} \left( \sum_{t-t}^{T+m} \mu_t \right)^2
\]

in which \(( \mu_t)\) is the residual from the cointegrating relationship for the price of the two crude oils, \(m\) is the length of the post break sample period (12 weeks), and \(T\) is the end of the pre-break period during which the prices for the two crude oils cointegrate. The test statistic evaluates the null hypothesis that the cointegrating relationship does not change in the post break down period relative to the pre break period. As described by Andrews and Kim (2006), the test statistic is evaluated against an asymptotic null distribution that is generated from 12-week break down periods estimated from the pre-break sample period. These values are ranked by size and the value at the 95 percentile is used as the critical value \((p < 0.05)\). Values that exceed the critical threshold indicate the cointegrating relationship between weekly prices for the 5-month forward contract for WTI and the spot price for Dubai-Fateh changes in the 12 week post break sample period relative to the pre-break sample period.

Using this methodology, I iteratively test for a break-down in the long-run relationship during the last 12 weeks of post-break sample periods, the first of which ends the week of December 31, 1999. That is, the first 12 week post break sample starts the week of January 7, 2000 and ends the week of March 24, 2000—the pre break period runs from the week of March 7, 1997 through December 31, 1999. Next, I extend the full sample by one week such that the pre break period runs from the week of March 7, 1997 to the week of January 7, 2000 and the post break period runs from January 14, 2000 to the week of March 31, 2000. This process is repeated until the pre break sample period runs from the week of March 7, 1997 to the week of July 10, 2009 and the post break period runs from July 17, 2009 to the week of October 2, 2009, which is the last observation available as of this writing.

The power of the test depends on the size of \(m\) and \(T\), therefore failure to reject the null hypothesis should not be interpreted as strong evidence in favor of stable cointegration. Furthermore, the iterative testing described above will increase the likelihood of finding a break down in the cointegrating relationship. To avoid this source of confusion, analysis of the results focuses on consecutive 12-week periods that reject the null hypothesis. Monte Carlo simulations (1000 experimental data sets with a sample length identical to the historical period) indicate that there only three instances in which the \(R\) statistic rejects the null hypothesis for 15 (or more) consecutive weekly periods—there are no instances in which the null hypothesis is rejected in 20 consecutive weekly post break periods. Based on these results, the discussion ignores break downs in the cointegrating relationship that do not persist for at least 15 consecutive 12 week post break periods.

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6 Weekly data are available from January 3, 1997 to December 4, 2009. There are 675 observations. I test for a maximum of nine lags and leads for the DOLS regression, so this implies a full sample that supports testing from March 7, 1997 to October 2, 2009.
Consistent with the behavior of a unified market, there are only a few periods for which the cointegrating relationship breaks down for two or more consecutive 12 week post break periods before 2004 (Fig. 5). Starting then, there are four periods during which the long-run relationship between the five-month forward contract for WTI and the spot price for Dubai-Fateh breaks down for 15 or more consecutive 12 week periods. The shortest of these five periods is sixteen consecutive 12 week periods (more than one quarter). The longest of these periods (March 23, 2007–December 28, 2007) is forty consecutive 12 week periods (about three consecutive quarters). Together, these results suggest that the law of one price does not describe the world oil market for extended periods starting in 2004.

These results beg the question, why would the law of one price fail for extended periods. One possible cause is changes unique to a crude oil that diminishes its ability to serve as a benchmark. For example, Fattouh (2007) argues that the ability of WTI to serve as a crude oil that diminishes its ability to serve as a benchmark breaks down for extended periods due to infrastructure logistics and/or local changes in inventories. I test this hypothesis by adding weekly data for PADD 2 crude oil inventories (data available for the entire sample period), which includes the point of delivery for WTI, or inventories at Cushing OK (data available starting April 9, 2004), which is the point of delivery for WTI, to the cointegrating relationship \( WTI_1 = a + \beta DuFa + \gamma \text{Inv}_t + \mu_t \) and testing the residual \( \mu_t \) from the cointegrating relationship with the procedure described above. The results generally are consistent with those described above—starting in 2004, there are several periods when the cointegrating relationship between the five month forward contract for WTI and the spot price for Dubai-Fateh breaks down for 15 or more consecutive 12 week post sample periods. This suggests that conditions unique to WTI are not solely responsible for the extended periods during which the relationship between the prices of the two crude oils breaks down. Rather, the break-downs described above identify extended periods when arbitrage opportunities for not preserve the law of one price.

3.3. Performance of price models based on market fundamentals

The effects of market fundamentals on real oil prices during the last quarter century are quantified statistically by several empirical models (e.g. Kaufmann et al., 2008b; Chevillon and Rifflart, 2009). The ability of these models to simulate crude oil prices should be relatively unchanged if market fundamentals are responsible for the recent spike and collapse. But if the spike and collapse cannot be simulated accurately, the models’ failure would be consistent with the hypothesis that speculative expectations change oil prices relative to the price dictated by market fundamentals or that speculative expectations change the way in which oil prices react to market fundamentals. This notion generates an empirically testable hypothesis; if speculative expectations play a significant role in the recent rise and collapse in crude oil prices, this period should be marked by a statistically meaningful change in the performance by empirical models of real oil prices.

I test this hypothesis using the model described by Kaufmann et al. (2008b). This model specifies real oil prices (either the near month contract for WTI on the New York Mercantile Exchange or the average fob price for crude oil imported by the US) as a function of capacity utilization by OPEC producers, capacity utilization of US refiners, which represents changes in the use of light and heavy crude oils, inventories of crude oil held by OECD nations, and the difference between the four month and near month contract for WTI on the New York Mercantile Exchange. Kaufmann et al. (2008b) estimate the cointegrating relationship among these variables from quarterly data between 1986:Q1 and 2006:Q3 using dynamic ordinary least squares (Stock and Watson, 1993). Results indicate that the variables cointegrate, elements of the cointegrating vector have the expected sign, and an error correction model indicates that disequilibrium in the cointegrating relationship moves the real price of crude oil towards the value that is implied by the cointegrating relationship.

To evaluate this empirical model’s ability to simulate recent changes in real oil prices, the data set is extended through the second quarter of 2009 and these data are used to examine two aspects of model performance; a breakdown in the model’s cointegrating relationship for real oil prices and the accuracy of a one-step ahead out of sample forecast.

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Fig. 5. Residual from the cointegrating relationship between the five month forward contract for WTI and the spot price for Dubai-Fateh (black line) as fit for the entire sample period. Values are extended before March 7, 1997 and after October 2, 2009 by subtracting the value calculated by the full sample cointegrating relationship from observed values. Dates inside the red columns identify a period when the cointegrating relationship breaks down for a 12-week post period. Dates identify the last date of the post break period (for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).
The stability of the model’s cointegrating relationship is examined using the same iterative methodology that is described in the previous section. Using this procedure, I test for a breakdown in the cointegrating relationship between real oil prices and market fundamentals during a six quarter \((m=6)\) post break sample period. The shorter postbreak period is dictated by the quarterly frequency and the shorter sample period, which includes 95 observations. The first pre-break period ends in 1996:Q4 and the last pre-break period ends in 2007:Q3—the last observation of this post break period is 2009:Q2.

The results indicate that there is little evidence for a breakdown in the model’s cointegrating relationship between market fundamentals and the near month contract for WTI (this price is used because more recent observations are available) until 2007:Q3 (Fig. 6a). This date marks the start of five consecutive periods 2007:Q3 through 2007:Q3, in which a six quarter post break period changes relative to the pre-break period. These six consecutive quarters include the price spike and collapse. Monte Carlo simulations indicate that it is statistically unlikely \((p=0.135)\) that the \(R\) statistic will reject the null hypothesis for five consecutive post break sample periods due to random chance.

The nature of the breakdown in the cointegrating relationship can be explored by examining the one step ahead out-of-sample forecast for real oil prices simulated by the cointegration/error correction model (Fig. 6b). The first out of sample forecast is generated by estimating the cointegrating relationship and error correction model from a sample that starts 1986:Q1 and ends 1996:Q1 and using the statistical results to generate a one-step ahead out-of-sample forecast for 1996:Q2. The out-of-sample forecast for 1996:Q3 is generated by estimating the models with a sample that extends through 1996:Q2. This process is repeated, extending the sample period by one quarter with data through 2009:Q1 to forecast prices in 2009:Q2. The methodology uses observed values for the independent variables only—real prices are simulated starting in 1996:Q2 and forecast values are used to extend the simulation beyond 1996:Q2 i.e. the simulation has no information about observed oil prices after the first quarter of 1996.

The results indicate that the one-step ahead forecast captures the much of the price variability from 1996:Q2 to 2003:Q4 (Fig. 6b). During this period, it captures the price decline associated with the Asian financial crisis (demand reduction) and the subsequent price recovery. The model also captures much of the price increase from about $36 in 2004:Q1 to $57 in

![Fig. 6. (a) Residual from the cointegrating relationship for real oil prices as fit for the entire sample period (black bars). The most recent values (last three observations) are calculated as the difference between observed real oil prices and the value generated by the cointegrating relationship estimated through 2008:Q4 Areas shaded in red identify period when the cointegrating relationship break down for a six quarter post sample period. Dates identify the last date of the post break period. (b) Observed value for the real price of the near month contract for WTI (blue line) and one-step ahead out of sample forecast generated by an empirical model for crude oil prices (red line) (for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).](image-url)
2006:Q4. During this period, the one step ahead forecast is about one quarter ‘behind’ the observed value. But its ability to ‘catch-up’ is associated with market fundamentals—by 2006:Q4 and 2007:Q1, the observed price and the one-step ahead forecast are nearly identical.

Beyond 2007:Q1, the model’s ability to forecast prices deteriorates sharply. Observed prices rise from $71 in 2007:Q3 to $115 in 2008:Q2, but the model forecasts little gain in prices. Indeed, the model simulates a price decline from 2007:Q2 to 2008:Q1. As a result, the forecast error is very large relative to previous errors. Similarly, the forecast errors are large (in absolute terms) during in 2008:Q4 and 2009:Q1. During this period, large negative forecast errors indicate that the model cannot simulate the price collapse.

The break down in the cointegrating relationship and the nature of the one step ahead out of sample forecast errors have at least two explanations. Perhaps the model’s stability and out-of-sample accuracy prior to 2007 are ‘luck.’ Although possible, statistical criteria suggest that the model did capture important aspects of the relationship between oil prices and market fundamentals between 1986:Q1 and 2007:Q1.

Alternatively, the break down in the cointegrating relationship and the increased (absolute) size of the one-step ahead out of sample forecast errors that start in 2007:Q2 are consistent with the hypothesis that speculation plays a significant role in the recent price spike and collapse. A cointegrating relationship for real oil prices based largely on market fundamentals will break down as speculative expectations play an increasingly important role in the formation of real oil prices. Furthermore, if speculative expectations drive prices higher in 2008, the model would be expected to under-predict observed prices—this is the failure indicated in Fig. 6a and b. Similarly, if speculative expectations accelerate the price collapse, the model would be expected to over-predict observed prices, this failure also is indicated in Fig. 6a and b.

4. Conclusion

By definition, it is nearly impossible to measure speculative expectations. As such, it is very difficult to provide a ‘smoking gun’ that would establish speculation as an important contributor to the recent spike and collapse in real oil prices. Nonetheless, the previous section identifies several indicators that strongly suggest that there is a significant change in the price discovery process. This change may be caused in part by speculative expectations.

Of the three indicators, the break down in the cointegrating relationship between spot and future price is the most evocative of speculative expectations. Without changes to a specific crude oil, the law of one price implies that changes in the spread between spot and future prices, which exceed transaction costs, should be eliminated by arbitrage. Given this mechanism for self-correction, why does the cointegrating relationship between the 5-month future price WTI and the spot price for Dubai-Fateh break down for extended periods?

I hypothesize that the break downs in the cointegrating relationship between the spot price for Dubai-Fateh and the 5 month contract for WTI are caused by noise traders, who are defined as traders that falsely believe that they have special information about the future price of a noisy asset (De Long et al., 1990). De Long et al. (1990) use a simple overlapping generation model to evaluate the ability of noise traders to disrupt prices generated by market fundamentals. Simulations indicate that expectations held by noise traders create a risk that deters rational arbitrageurs from betting against them. The model also indicates that noise traders may earn a higher rate of return than rational traders. These results are extended by Kogan et al. (2006), who find that noise traders can affect asset prices even when their wealth shrinks to low levels and that their impact does not depend on their long-run survival.

General principles gleaned from these simulations may shed some light on the recent spike and collapse in crude oil prices. First, many non-commercial traders probably can be considered noise traders. Quoting Weiner (2002), ‘of the hundreds of fund managers and commodity traders, the vast majorities are systems traders relying upon the analysis of price trends for their trading decisions, and paying little if any attention to the fundamentals of the markets in which they are trading.’ The role of noise traders in oil markets is confirmed empirically using a capital asset pricing model (Cifarelli and Paladino, 2010).

Second, the importance of speculative traders, which the CFTC defines as an individual who does not hedge, but who trades with the objective of achieving profits through the successful anticipation of price movements (http://www.cftc.gov/educationcenter/glossary/glossary_s.html#speculator), increases over the last ten years. For example, the percentage of WTI futures open interest (all maturities) that originates from noncommercial traders (hedge funds, floor brokers and traders, and non-registered participants), increases from less than 20% in July 2000 to more than 40% in August 2008 (Buyukshahin et al., 2008).

An increase in the number of noise traders relative to sophisticated investors should increase volatility (De Long et al., 1990). Consistent with this hypothesis, there is a noticeable increase in the volatility of the residual from the cointegrating relationship between the spot price of Dubai-Fateh and the five month contract for WTI (Fig. 5). This increased volatility may be partially responsible for the break down in the cointegrating relationship between the prices of the two crude oils.

This effect can be exacerbated by the fact that the average misperception by noise traders is not zero (De Long et al., 1990). In their model, a bullish outlook by noise raises the price of the risky asset, which in this case is the futures contract. Conversely, a bearish outlook by noise traders lowers the price of the risky asset. These effects are consistent with 2007–2008 predictive failures of the price model based on market fundamentals (Fig. 6a and b).

But the ability to connect these failures to market sentiments is difficult. For example, empirical evidence about the cause-effect relationship between noise trader sentiment and price movements is ambiguous. Sanders et al. (2004) find that positive futures returns ‘Granger cause’ a net increase in the percent long position by noncommercial traders. Conversely, they find no evidence that the positions held by noncommercial traders have information about market returns.

But speculative expectations are not solely responsible for the rapid rise and collapse in prices. The empirical model of oil prices is able to simulate the tripling of real oil prices from just under $20 in 1999 to nearly $60 in 2007 (Fig. 6b). This rise is associated with a rise in capacity utilization by OPEC producers due in part to the abrupt, unexpected, and prolonged hiatus in rising non-OPEC production after 2004. This hiatus, along with trend growth in oil demand, and slow expansion of OPEC capacity, causes OPEC capacity utilization to rise. And it is this growth in OPEC capacity utilization, and not demand growth per se, that causes oil prices to rise. To paraphrase the monetarist argument about inflation, ‘oil price shocks are always and everywhere a supply-side phenomenon.’

References