An Analysis of the Relationship Between U.S. Gasoline Prices and Crude Oil Prices

Prepared by:

John B. O’Brien
Charles G. Kemp
Dileep N. Sirur
Kevin G. Waguespack

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Baker & O’Brien, Inc.
1333 West Loop South
Suite 1350
Houston, TX 77027
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1. EXECUTIVE SUMMARY

Beginning in 2011, robust growth in United States (U.S.) light tight oil (LTO) production led to heavily discounted prices for mid-continent crude oils. These discounts were primarily the result of limited capacity to transport the new crude oils from the point of production to the large refining centers on the U.S. Gulf and East Coasts. However, infrastructure investments have now largely eliminated the mid-continent transportation bottlenecks.

Unlike the situation in 2011, the decline in global crude oil prices that began in mid-2014 has been attributed to a global oversupply of crude oil, driven in significant part by the aforementioned production growth in the U.S., as well as the absence of any concerted production cutbacks by the Organization of the Petroleum Exporting Countries (OPEC). These developments have increased scrutiny of the long-standing ban on the export of U.S. crude oil, and raised questions about whether lifting the ban would be in the interest of the nation and that of the U.S. consumer. With regard to the latter, there are important questions as to what impact lifting the ban might have on domestic gasoline prices.

In order to provide additional insight into the relationship between domestic gasoline prices and crude oil prices, and what the impact of lifting the export ban might have, Baker & O’Brien Inc. (Baker & O’Brien) was engaged to investigate what the key price setting mechanisms are for U.S. gasoline prices and how gasoline prices have been impacted by domestic crude oil discounts relative to comparable global crude oils.

APPROACH

To address how domestic gasoline prices may have been impacted by discounted U.S. crude oils, three U.S. gasoline markets were selected for analysis: New York Harbor (NYH), the U.S. Gulf Coast (USGC), and Chicago. Three distinct time periods were considered: (1) the 5-year period prior to the commencement of price discounts for West Texas Intermediate (WTI) crude oil; (2) the 2 ½-year period from 2011 through June 2013 when these price discounts were most pronounced; and (3) the period from July 2013 through June 2015 following the expansion of Cushing-to-Houston crude oil pipeline capacity.
We used regression analysis to evaluate the relationship between domestic spot gasoline prices in the three U.S. markets with: (1) crude oil benchmark prices for WTI, LLS, and Brent; and (2) gasoline prices in Western Europe (Rotterdam). Western European refineries are typically in surplus with respect to gasoline components and the difference between East Coast and Rotterdam gasoline prices has a major influence on product flows across the Atlantic.

**KEY FINDINGS**

Our analysis suggests that during the period when price discounts on U.S. mid-continent crude oils were at their highest, these discounts were passed through—in varying proportions—to domestic gasoline prices. For example, in the USGC and Chicago markets, approximately 25 percent (%) of the crude oil price discounts appear to have been passed through to gasoline in the form of lower spot prices. This means that spot buyers of gasoline were able to purchase product at prices in the range of 10-11 cents per gallon (cpg) lower than would otherwise have been the case.\(^1\) In NYH, approximately 14% of the domestic crude oil discount appears to have been passed through, equal to about 6 cpg.\(^2\) These results tend to support the conclusion that U.S. consumers enjoyed somewhat lower gasoline prices as a direct flow-through from the lower-priced domestic crude oils.\(^3\)

Interestingly, our results show that the apparent gasoline price benefits continued even after the mid-continent transportation bottlenecks were eased, and the level of domestic crude oil price discounts had moderated. This was likely driven by structural changes in the U.S. market, which included not only generally lower crude prices, but also low natural gas prices, flat gasoline demand,\(^4\) and increases in refining capacity to process lighter crude oils. Also, over the past five years, the U.S. has transitioned from being a net importer of gasoline in the range of 500 thousand barrels/day (MB/D), to a near-balanced market, with net exports in the winter months, and net imports during the summer months. Thus, increased refining capacity,

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\(^1\) With PADD 2 (Midwest) and PADD 3 (Gulf Coast) regions together representing almost 4 million barrels per day of gasoline demand, the approximate savings passed through from domestic crude oil discounts would be in the range of $6.1 to $6.7 billion dollars per year.

\(^2\) With PADD 1 (East Coast) representing 3.1 million barrels per day of gasoline demand, the approximate pass through in this region alone would be nearly $2.9 billion per year.

\(^3\) Retail consumers of gasoline typically benefit from lower spot prices, provided sufficient competition is available at the wholesale and retail points of sale.

\(^4\) Indications are that U.S. gasoline demand has recently increased, perhaps due to lower prices.
processing of more low-cost light, gasoline-laden crude oil, improved refinery efficiency, and moderating gasoline demand have all contributed to generally lower gasoline prices for the consumer. Moreover, because the U.S. is now much less reliant on gasoline imports, certain U.S. markets have periodically transitioned away from their historical relationship to global crude oil prices.

Our study confirmed that all three benchmark crude oil grades—WTI, LLS, and Brent—have been highly correlated with gasoline prices in each of the three U.S. markets studied. However, starting in 2011, and until mid-2013, the period when WTI prices weakened considerably compared to international pricing (i.e., relative to Brent), the historic correlations between gasoline prices and crude oil prices weakened considerably. The link to WTI weakened the most, followed by Brent and LLS. Weakness in the Brent correlation was most notable in Chicago, where the correlation coefficient of the regression declined from 0.860 (prior to 2011) to 0.279. However, we also found that the degree of correlation between gasoline and crude oil prices depended, to some degree, on the absolute range of crude oil prices during the particular time period considered. For example, during periods in which crude oil traded in a relatively narrow price range—as was the case during 2011 - 2013—the correlation between gasoline and crude oil prices was weaker than in periods in which crude oil prices were more volatile. Thus, the weakening of the gasoline-to-crude oil price relationship in the period 2011 - 2013 cannot be attributed entirely to the discounts that existed in the WTI price.

During the last five years, all three of the U.S. markets studied have gradually transitioned from exhibiting gasoline price premiums relative to Europe, to gasoline price discounts. This change has coincided with the commencement of increasing WTI price discounts in 2011, as well as the U.S. transition away from being a significant gasoline importer. Prior to 2011, changes in Western European gasoline prices were strongly correlated to changes in U.S. gasoline market prices, with regression factors of 0.94, 0.96, and 0.98 for Chicago, USGC, and NYH, respectively. However, this correlation weakened considerably during the period 2011 – 2103, with the respective regression factors falling to 0.66, 0.88, and 0.94. These results suggest a partial “de-linking” of domestic gasoline prices from European prices (which

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5 This is not an unexpected result, since the cost of crude oil is the largest component in the cost of gasoline.
are largely set by global crude oil prices) with the U.S. gasoline price setting mechanism moving
toward a more balanced situation in which the U.S. is less reliant on foreign gasoline supplies
and more reliant on gasoline produced from lower-cost domestic crude oils. Thus, it is likely
that U.S. gasoline markets—especially those in Chicago and the USGC—will remain advantaged
compared to foreign markets, as long as the current domestic crude discounts favor U.S. gasoline
production over foreign production. This situation should persist as long as the crude oil export
ban remains. As long as U.S. gasoline markets stay partially de-linked from foreign markets,
changes in the Brent crude oil price should have a lesser impact on domestic gasoline prices than
changes in domestic crude oil prices.
2. **INTRODUCTION**

In September 2014, Baker & O’Brien, Inc. (Baker & O’Brien) conducted a study that analyzed the technical ability of the United States (U.S.) refining system to absorb increasing amounts of domestically-produced light tight oil (LTO).\(^6\) That study indicated that the U.S. refining industry should have the potential to absorb an additional 3.1 to 4.3 million barrels per day (MMB/D) of LTO by 2020, relative to the fourth quarter of 2013. The mechanisms by which those incremental barrels could be processed include: (a) displacement of crude oil imports (2 MMB/D); (b) capacity expansion (1.3 MMB/D); and (c) higher utilization of existing capacity (0.3 MMB/D). These total incremental volumes exceeded the U.S. Energy Information Agency’s (EIA’s) long-term production forecast (at the time) to 2020, for both its “reference” and “high-resource” cases.

Since the time of our previous study, global crude oil prices have declined more than 50 percent (%), and expectations have changed to reflect a future scenario where LTO production volumes are likely to plateau and decline over the short to medium term—although, at the time of this report, shale-based oil production has shown to be resilient despite the decline of oil prices. A number of studies have been commissioned to assess the impact of lifting the current ban on U.S. crude oil exports, and these studies were completed at various times before, during and after last year’s collapse in crude oil prices. Such studies often reached different conclusions regarding the impact on U.S. gasoline prices if the ban were to be lifted. For example, some analysts opine that lifting the export ban would lower domestic gasoline prices, arguing that global—not domestic—crude oil prices are the main determinant of U.S gasoline prices.\(^7\) Other studies suggest that the domestic crude oil price is the most important driver of gasoline prices, and lifting the export ban would increase domestic crude oil prices, and raise spot gasoline prices.\(^8\)

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Baker & O’Brien was asked\(^9\) to provide insight into the potential effects of lifting the crude oil export ban by analyzing the historic relationship between domestic gasoline prices and crude oil prices, and what impact, if any, heavily-discounted domestic crude oil prices have had on domestic gasoline prices. Our approach was to address the following two questions:

1. How have gasoline prices been impacted by lower domestic crude prices?

2. What portion, if any, of refiners’ lower crude oil costs have been passed through to consumers as reduced gasoline prices?

\(^9\) Consumers and Refiners United for Domestic Energy commissioned Baker & O’Brien to complete this study.
3. **U.S. GASOLINE PRICE RESPONSE TO WTI PRICE DISCOUNTS**

**BACKGROUND**

Petroleum refineries in the U.S. are owned by both integrated oil companies, who produce and refine crude oil (e.g., ExxonMobil, Shell), and independent refiners, who focus primarily on refining (e.g., Valero, Phillips 66). Independent refiners capture the profit margin between sales of refined products and the cost of crude oil. Over a business cycle, market prices for petroleum products must be sufficient for refineries to recover feedstock costs, operating costs, and sustaining capital expenditures, as well as provide an acceptable return on the capital employed in the business.

It is well-accepted that refined product prices in general, and motor gasoline prices in particular, are highly dependent on crude oil pricing, given that the cost of crude oil accounts for approximately 91% of total feedstock costs and 86% of total refining cash costs (including feedstocks).\(^\text{10}\) Gasoline prices and their key determinants have long been the focus of numerous studies tending to validate the strong linkage between gasoline and crude oil prices. A recent study by the U.S. EIA\(^\text{11}\) cites: “Other factors equal, a $1-per-barrel change in the price of crude oil will result in a $1-per-barrel, or $0.024-per-gallon...change in the price of wholesale and retail gasoline.”

Baker & O’Brien examined the relationships between crude oil prices and gasoline prices in three key U.S. markets during several market periods—including the period 2011-2013, when significant discounts (relative to global crude oil prices) existed for WTI, as well as other domestic grades such as LTO in the mid-continent.

**ANALYSIS APPROACH**

Baker & O’Brien analyzed historical gasoline prices (at the “spot”/bulk point of sale)\(^\text{12}\) in three U.S. markets east of the Rocky Mountains—New York Harbor (NYH), the U.S. Gulf Coast

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\(^{10}\) Baker & O’Brien *PRISM* refining database, U.S. refineries, calendar year 2014.  
\(^{12}\) Prices for these transactions typically involve relatively large batches of product, such as for product tankers or pipeline batches. Independent pricing services assess and report the spot price for these transactions.
(USGC), and Chicago—and evaluated how these prices responded to changes in the prices of three crude oil benchmarks: West Texas Intermediate (WTI) at Cushing, Oklahoma; Light Louisiana Sweet (LLS) at St. James, Louisiana; and Dated Brent (Brent) at Sullom Voe, Scotland. We also evaluated the relationship between gasoline prices in each of the three U.S. markets and Northwest Europe (Rotterdam). Refer to Appendix A for a listing of the price sources used in the analysis.

Three distinct periods were evaluated: (1) the 5-year period (2006-2010) preceding the drop in domestic crude oil prices in the mid-continent;¹³ (2) the 2 ½-year period of 2011 through June 2013, when mid-continent crude oils were deeply discounted due to transportation bottlenecks that restricted the movement of crude oil from the mid-continent to large refining centers on the Gulf and East coasts; and (3) the 2-year period from July 2013 through June 2015, after pipeline transportation capacity to the USGC had been expanded and logistical bottlenecks had mostly been eliminated.

The degree of “fit” between U.S. gasoline pricing and crude oil pricing, as well as U.S. gasoline pricing and European gasoline pricing, was determined using linear regression analysis. Using linear regression, the degree of fit (R² or “R Squared”) was measured whereby the benchmark crude oil prices and the Rotterdam gasoline prices were the independent variables, and the U.S. market-specific gasoline prices were the dependent variables.¹⁴ The objective was to determine how much of the change in domestic gasoline prices can be explained simply by changes in the benchmark crude oil prices (or European gasoline prices) and how much is due to other factors.

**CRUDE OIL PRICES**

Table 1 summarizes the crude oil price differentials during these three periods. The previous 10-year history is also provided for additional context. While prices of WTI and Brent in Period 1 were not significantly different, the WTI discount to Brent averaged more than $16

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¹³ This period is generally consistent with longer-term U.S. price history.  
¹⁴ R² is a measure of the correlation between an independent and a dependent variable. It is an indication of how much a change in the dependent variable (in this case, gasoline price) can be explained by changes in the independent variable (in this case, the benchmark crude oil grade or the Rotterdam gasoline price) being evaluated. For example, an R² of 0.80 means that 80% of the change in gasoline price can be explained by the change in crude oil price, and the rest of the difference has to do with other factors.
per barrel (/B) in Period 2, when domestic crude oils were transportation limited. During the same periods, the average LLS premium to Brent was $3.26/B in Period 1, and fell to only $0.82/B in Period 2. Period 3 compares crude oil price discounts, following the expansion of pipeline capacity from the mid-continent to the USGC (i.e., Cushing-to-Houston). During Period 3, the relative WTI price strengthened with an average price of $6.16/B lower than Brent, but the relative LLS price weakened further, trading at an average discount of $2.20/B to Brent. The Period 3 difference between WTI and LLS prices (about $4/B) is generally reflective of incremental pipeline tariffs required to move barrels from Cushing to the USGC. The relevant crude oil price differential trends (LLS and WTI vs. Brent) for the three time periods are shown in Figure 1.

### TABLE 1
**BENCHMARK CRUDE OIL PRICES AND DIFFERENTIALS**

<table>
<thead>
<tr>
<th>Averages, $/B</th>
<th>1996-2005 (10 years)</th>
<th>Period 1 2006-2010 (5 years)</th>
<th>Period 2 2011- Jun 2013 (2.5 years)</th>
<th>Period 3 Jul 2013-Jun 2015 (2 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brent</td>
<td>26.94</td>
<td>75.12</td>
<td>110.64</td>
<td>91.44</td>
</tr>
<tr>
<td>WTI</td>
<td>28.76</td>
<td>75.78</td>
<td>94.52</td>
<td>85.28</td>
</tr>
<tr>
<td>LLS</td>
<td>28.81</td>
<td>78.40</td>
<td>111.46</td>
<td>89.24</td>
</tr>
<tr>
<td><strong>Range, Low-High</strong></td>
<td><strong>9.85-64.09</strong></td>
<td><strong>39.14-133.91</strong></td>
<td><strong>82.32-109.88</strong></td>
<td><strong>47.23-106.54</strong></td>
</tr>
<tr>
<td><strong>Standard Deviation (monthly)</strong></td>
<td><strong>11.9</strong></td>
<td><strong>20.4</strong></td>
<td><strong>6.7</strong></td>
<td><strong>21.7</strong></td>
</tr>
<tr>
<td><strong>WTI minus Brent</strong></td>
<td>1.82</td>
<td>0.65</td>
<td>(16.12)</td>
<td>(6.16)</td>
</tr>
<tr>
<td><strong>LLS minus Brent</strong></td>
<td>1.86</td>
<td>3.26</td>
<td>0.82</td>
<td>(2.20)</td>
</tr>
</tbody>
</table>

Source: Platts; Baker & O’Brien analysis
FIGURE 1
WTI AND LLS DIFFERENTIALS TO BRENT

U.S. Crude Oil Pricing Differentials to Brent, $/barrel

Source: Platts; Baker & O’Brien analysis

U.S. GASOLINE PRICES AND DIFFERENTIALS TO EUROPE

U.S. and European gasoline prices trended as shown in Figure 2. It is apparent that gasoline prices in the three markets (colored lines) are interrelated. It is also apparent that these prices generally tracked the Brent crude oil price (shaded gray area).
Figure 3 illustrates the historical price differences between gasoline in Europe (zero line) and U.S. gasoline prices. In Period 2, U.S. gasoline prices switched from being “price premium” markets (higher than Europe) to “price-discounted” markets (lower than Europe). This transition coincides with high growth in LTO production and large WTI price discounts to Brent.

Several economic drivers underlying this transition appear to support this observation. Prior to 2011, most U.S. refineries did not have a considerable cost advantage to Europe, were not the lowest-cost producers of refined products, and could not meet total domestic demand. Thus, the U.S. imported relatively large quantities of gasoline and the gasoline price structure was generally reflective of import parity with Europe (i.e., Rotterdam plus transportation).
Since 2011, however, low-cost natural gas, low-cost crude oil, growth in refining capacity and flat-to-negative trends in gasoline demand growth have resulted in the U.S. becoming balanced-to-surplus in gasoline supply. Of the factors mentioned, lower natural gas and crude oil prices for a large and expanding segment of the U.S. refining base were key, allowing many U.S. refineries to significantly lower their costs and realize higher margins. Lower domestic crude oil prices also encouraged refiners to increase utilization, and enjoy

15 The natural gas cost advantage versus Western Europe, for example, reduces cash operating costs by about $0.50 - $1/B, due to lower costs for heat generation and hydrogen production. Crude oil price discounts directly impact refinery cash operating costs on one-for-one basis.
16 For example, several refineries in the U.S. northeast were provided an impetus to continue operating, even with high, rail-based transport costs for Bakken crude oil. Refineries in the U.S. mid-continent that could not process heavy crude oil grades were only marginally profitable prior to growth in Bakken crude supply.
additional economies of scale. During the past four years, the gasoline trade has shifted from one in which the U.S. was a net importer to one which is more balanced, with net exports during certain times of the year. Figure 4 illustrates these trends of gasoline imports and exports.

### FIGURE 4
**U.S. GASOLINE IMPORTS AND EXPORTS**

By examining the sources of imports and destinations for exports, an even clearer picture emerges and helps explain the shifting price differentials. Table 2 summarizes the changes by country or region for both imports and exports between 2010 and 2014. Imports to the U.S. declined by 157 MB/D since 2010, while exports from the U.S. increased by 154 MB/D, resulting in a positive net change of 311 MB/D over the four years. The largest shifts from U.S.
imports to U.S. exports occurred in markets in South and Central America, Europe, and the Virgin Islands.17

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Changes in Imported and Exported Gasoline Volumes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in Volume from 2010 to 2014, MB/D</td>
<td></td>
</tr>
<tr>
<td><strong>Country/Region</strong></td>
<td><strong>Imports</strong></td>
</tr>
<tr>
<td>Canada</td>
<td>(24)</td>
</tr>
<tr>
<td>Mexico</td>
<td>-</td>
</tr>
<tr>
<td>Virgin Islands</td>
<td>(107)</td>
</tr>
<tr>
<td>South and Central America</td>
<td>(21)</td>
</tr>
<tr>
<td>Europe</td>
<td>(123)</td>
</tr>
<tr>
<td>Africa</td>
<td>(3)</td>
</tr>
<tr>
<td>Mid-East</td>
<td>(5)</td>
</tr>
<tr>
<td>Asia</td>
<td>(3)</td>
</tr>
<tr>
<td>Others</td>
<td>(2)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>(157)</td>
</tr>
</tbody>
</table>

Source: U.S. EIA, Baker & O’Brien analysis

The gasoline price differentials over the three periods of interest are summarized in Table 3. In Period 1, the price premiums in the three U.S. markets averaged between 5 cpg and 7 cpg. In Period 2, the differentials changed significantly, with all three markets exhibiting prices below Rotterdam. Chicago and the USGC markets showed the greatest decline, reflecting price differentials ranging from 4 cpg (Chicago) to over 7 cpg (USGC). Despite the debottlenecking of crude pipelines leaving Cushing, Period 3 gasoline price differentials did not revert back to those observed in Period 1. Instead, Period 3 gasoline differentials were similar to those in Period 2. This indicates that U.S. gasoline markets are now priced closer to export parity, with freight-related discounts to Europe, rather than at import parity—where prices are more linked to the global market (freight-related premiums) and global crude oil prices.

17 The large HOVENSA refinery, located in St. Croix, Virgin Islands, closed in early 2012, was responsible for 107 MB/D of gasoline imported to the U.S. in 2010.
### TABLE 3
SUMMARY OF GASOLINE PRICE DIFFERENTIALS

<table>
<thead>
<tr>
<th>Differentials to Rotterdam, c/gal</th>
<th>Period 1 2006-2010 (5 years)</th>
<th>Period 2 2011-Jun 2013 (2.5 years)</th>
<th>Period 3 Jul 2013-Jun 2015 (2 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYH</td>
<td>4.55</td>
<td>(0.95)</td>
<td>0.13</td>
</tr>
<tr>
<td>USGC</td>
<td>4.30</td>
<td>(5.84)</td>
<td>(7.15)</td>
</tr>
<tr>
<td>Chicago</td>
<td>6.41</td>
<td>(4.52)</td>
<td>(7.18)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crude Oil Price Differentials, $/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>WTI minus Brent</td>
</tr>
<tr>
<td>LLS minus Brent</td>
</tr>
</tbody>
</table>

Source: Platts; Baker & O’Brien analysis

### REGRESSION ANALYSIS: U.S. GASOLINE PRICES VS. BENCHMARK CRUDE OILS

U.S. historical gasoline prices were compared with the three benchmark crude oils, using a linear regression. Practically, this means that prices for gasoline in each of the three markets were plotted against each of the crude oil benchmarks (scatter diagram) for each of the three defined time periods, and a line of best fit was determined for each case. In total, 27 unique regressions were run, representing three gasoline markets, three benchmark crude oils and three time periods. The regression analyses for Chicago and Brent for Periods 1, 2, and 3 are shown in Figures 5, 6, and 7, respectively. The scatter diagrams for all regressions are provided in Appendix B. Table 4 summarizes the results of these regressions over the three time periods of interest.
An Analysis of the Relationship Between U.S. Gasoline Prices and Crude Oil Prices

FIGURE 5
STATISTICAL REGRESSION: CHICAGO GASOLINE VS. BRENT-PERIOD 1

Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. Brent
(Monthly Spot: 2006-2010)

\[ y = 2.3613x + 26.494 \]
\[ R^2 = 0.8597 \]

FIGURE 6
STATISTICAL REGRESSION: CHICAGO GASOLINE VS. BRENT-PERIOD 2

Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. Brent

\[ y = 1.864x + 76.025 \]
\[ R^2 = 0.2791 \]
FIGURE 7
STATISTICAL REGRESSION: CHICAGO GASOLINE VS. BRENT-PERIOD 3

TABLE 4
REGRESSION RESULTS:
U.S. GASOLINE PRICES VS. CRUDE OIL PRICES

<table>
<thead>
<tr>
<th></th>
<th>Period 1 2006-2010 (5 years)</th>
<th>Period 2 2011- Jun 2013 (2.5 years)</th>
<th>Period 3 Jul 2013-Jun 2015 (2 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NY Harbor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brent</td>
<td>0.930</td>
<td>0.699</td>
<td>0.957</td>
</tr>
<tr>
<td>LLS</td>
<td>0.922</td>
<td>0.670</td>
<td>0.977</td>
</tr>
<tr>
<td>WTI</td>
<td>0.906</td>
<td>0.362</td>
<td>0.971</td>
</tr>
<tr>
<td>USGC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brent</td>
<td>0.890</td>
<td>0.539</td>
<td>0.866</td>
</tr>
<tr>
<td>LLS</td>
<td>0.886</td>
<td>0.554</td>
<td>0.905</td>
</tr>
<tr>
<td>WTI</td>
<td>0.870</td>
<td>0.444</td>
<td>0.891</td>
</tr>
<tr>
<td>Chicago</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brent</td>
<td>0.860</td>
<td>0.279</td>
<td>0.885</td>
</tr>
<tr>
<td>LLS</td>
<td>0.856</td>
<td>0.286</td>
<td>0.925</td>
</tr>
<tr>
<td>WTI</td>
<td>0.839</td>
<td>0.264</td>
<td>0.918</td>
</tr>
<tr>
<td>WTI minus Brent, $/B</td>
<td>0.65</td>
<td>(16.12)</td>
<td>(6.16)</td>
</tr>
<tr>
<td>LLS minus Brent, $/B</td>
<td>3.26</td>
<td>0.82</td>
<td>(2.20)</td>
</tr>
</tbody>
</table>
The following observations can be made about the gasoline/crude oil price relationships.

**PERIOD 1**

- In Period 1, prior to the deep WTI price discounts, a large portion of the variation in gasoline prices in all three markets can be attributed simply to crude oil price changes.

- The relationship was strongest in the NYH where changes in the Brent price appear to explain 93% of the changes in gasoline price. Strong, but slightly weaker relationships are noted for LLS (92.2%) and WTI (90.6%), consistent with the fact that Europe and the USGC were key sources of gasoline supply to the Northeast U.S. during this period.

- The relationship between gasoline prices and crude oil prices was slightly lower in the USGC and Chicago markets. On the USGC, correlations ($R^2$ values) ranged from 89% (Brent) to 87% (WTI). Chicago relationships were somewhat weaker, ranging from 86% (Brent) to 84% (WTI). These findings are consistent with the location and product supply situation for these markets, with Chicago (and PADD 2) being structurally short of gasoline, and incremental supply being provided from the USGC via pipeline, and the USGC having excess gasoline supplies for transport to the U.S. Northeast.

**PERIOD 2**

- Period 2 demonstrated much weaker correlations between gasoline prices and crude oil, as indicated by the middle column in Table 3. As one might expect, the correlation between gasoline and crude prices in the more isolated inland Chicago market was low during this period, with the WTI relationship showing the biggest decline in correlation among the three crude grades. However, the relationship between gasoline prices and Brent also declined considerably in all markets, suggesting that other variables (e.g., refining capacity utilization and pipeline utilization) were impacting gasoline prices during Period 2. In Chicago, the
statistical analysis suggests that changes in crude oil price accounted for less than 30% of the change in gasoline prices.\textsuperscript{18}

- In addition to the foregoing, our results show that the correlation between gasoline prices and crude oil prices also depended, to some degree, on the range of absolute crude oil prices during the time period studied. For example, during periods when crude oil traded in a relatively narrow range (as was the case during the period 2011 – 2013\textsuperscript{19}), regression correlations were generally weaker than during periods when crude oil prices were more volatile. Thus, the weakening of the gasoline-to-crude oil price relationship during the period 2011 - 2013 cannot be attributed entirely to the discounted WTI prices. Other factors, including changes in regional refinery utilization and utilization of pipelines supplying the region, are likely impacting the relationships.

**PERIOD 3**

- During Period 3, when most—but not all—of the WTI price discount dissipated and gasoline markets settled into a new equilibrium, strong price correlations between gasoline and crude oil were reestablished. However, the steep decline in crude oil prices resulted in a wide absolute range of price levels imbedded in the correlation, and this may be a partial cause of the high correlation coefficients observed.\textsuperscript{20}

**REGRESSION ANALYSIS: U.S. VS. ROTTERDAM GASOLINE PRICES**

A similar analysis was conducted using the Rotterdam gasoline price as the independent variable and U.S. gasoline prices in the three markets as the dependent variables. This analysis

\textsuperscript{18} Crude oil prices in Period 2 are generally higher and trend in a more narrow range, compared to Period 1, which may also weaken the correlation, given the relatively lack of crude oil price movement. Additional testing of the correlation of subsets of data indicates that something other than the level and range of crude oil are driving the low correlations in Period 2.

\textsuperscript{19} As Table 1 indicates, the range of crude oil prices in Period 2 was over $27.56/B, compared to $94.77/B in Period 1 and $59.31/B in Period 3. The standard deviation (monthly basis) in Period 2 was 6.7, compared to 20.4 in Period 1 and almost 21.7 in Period 3.

\textsuperscript{20} A wide range of crude oil prices will generally help to support a high correlation coefficient. The natural statistical variation of the independent variable (gasoline) is dampened by large movements in the independent variable (crude oil price).
aimed to capture how gasoline price relationships in the U.S. and Western Europe changed, if at all, during the period of deep WTI price discounts. Table 5 summarizes the results of this analysis.

### Table 5

**Regression Results:**

**U.S. vs. Rotterdam Gasoline Prices**

<table>
<thead>
<tr>
<th></th>
<th>Period 1 2006-2010 (5 years)</th>
<th>Period 2 2011- Jun 2013 (2.5 years)</th>
<th>Period 3 Jul 2013-Jun 2015 (2 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R Squared</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NY Harbor</td>
<td>0.980</td>
<td>0.945</td>
<td>0.993</td>
</tr>
<tr>
<td>USGC</td>
<td>0.957</td>
<td>0.885</td>
<td>0.969</td>
</tr>
<tr>
<td>Chicago</td>
<td>0.935</td>
<td>0.662</td>
<td>0.970</td>
</tr>
<tr>
<td><strong>WTI minus Brent, $/B</strong></td>
<td>0.65 (16.12)</td>
<td></td>
<td>(6.16)</td>
</tr>
<tr>
<td><strong>LLS minus Brent, $/B</strong></td>
<td>3.26 (2.20)</td>
<td></td>
<td>(2.20)</td>
</tr>
</tbody>
</table>

The following observations can be made:

- **During Period 1,** all three U.S. markets appear to be highly correlated with gasoline prices in Europe. This result was generally expected, given the high degree of physical connectivity and observed gasoline trade between these markets. In Period 1, prior to the deep WTI price discounts, Rotterdam gasoline prices were positively correlated with NYH (98.1%), USGC (95.7%), and Chicago (93.5%). The Chicago market’s relationship to Rotterdam involves two key transportation segments—waterborne to the USGC and pipeline to Chicago—which likely accounts for its slightly lower correlation.

- **During Period 2,** the correlation between NYH and Rotterdam gasoline prices declined only slightly, while correlations were weaker in Chicago (down to 66%)

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21 An active trading market exists between the markets where price arbitrage provides incentive to move products to the highest priced markets as long as the price differences are expected to exceed transportation costs. For example, price differences between NYH and Rotterdam can be easily observed and trading activities coordinated to capture arbitrage opportunities. Within the U.S., the USGC supplies a large share of gasoline demand in the eastern half of the U.S. via the large Colonial and Plantation pipeline systems. The USGC also supplies gasoline (and other refined products) to markets in the U.S. mid-continent via Explorer and other interstate pipelines.
and the USGC (88%). During this period, gasoline prices in the Chicago market appear to have been less influenced by other markets in the Atlantic Basin.

- During Period 3, correlations returned to levels witnessed prior to the high crude oil discount period.

**SUMMARY OF FINDINGS**

Our analyses confirm that the market equilibrium and level of gasoline prices in U.S. markets changed in 2011 due to the burgeoning LTO production and corresponding price discounts for domestic crude oils, such as WTI and various LTO grades. U.S. gasoline markets in Chicago and the USGC are now priced at export parity with freight-related discounts to Europe, rather than at import parity prices with freight-related premiums.

A summary of the prevailing gasoline price differentials during Periods 1 and 2 is provided on both a cents-per-gallon and dollar-per-barrel basis in Table 6. During Period 2, gasoline prices in NYH, the USGC and Chicago declined considerably compared to Rotterdam, and relationships between crude oil prices and Rotterdam prices weakened measurably, suggesting a disconnect between domestic and foreign gasoline pricing.

**TABLE 6**

**INDICATIONS OF CRUDE OIL PRICE DISCOUNT PASS-THROUGH TO GASOLINE**

<table>
<thead>
<tr>
<th>U.S. Gasoline Differentials to Rotterdam, cpg</th>
<th>Period 1 2006-2010 (5 years)</th>
<th>Period 2 2011- Jun 2013 (2.5 years)</th>
<th>Difference: Period 2 minus Period 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYH</td>
<td>4.6</td>
<td>(1.0)</td>
<td>(5.5)</td>
</tr>
<tr>
<td>USGC</td>
<td>4.3</td>
<td>(5.8)</td>
<td>(10.1)</td>
</tr>
<tr>
<td>Chicago</td>
<td>6.4</td>
<td>(4.5)</td>
<td>(10.9)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Differentials to Rotterdam, $/B</th>
<th>Period 1 2006-2010 (5 years)</th>
<th>Period 2 2011- Jun 2013 (2.5 years)</th>
<th>Difference: Period 2 minus Period 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYH</td>
<td>1.91</td>
<td>(0.40)</td>
<td>(2.31)</td>
</tr>
<tr>
<td>USGC</td>
<td>1.81</td>
<td>(2.45)</td>
<td>(4.26)</td>
</tr>
<tr>
<td>Chicago</td>
<td>2.69</td>
<td>(1.90)</td>
<td>(4.59)</td>
</tr>
</tbody>
</table>

| WTI minus Brent, $/B                         | 0.65                        | (16.12)                           | (16.77)                           |
| LLS minus Brent, $/B                         | 3.26                        | 0.82                              | (2.45)                            |

**Gasoline Price Differences, % of WTI Discount**

- NYH: 14%
- USGC: 25%
- Chicago: 27%
During Period 2, U.S. gasoline prices—relative to Rotterdam—declined by 5.5 cpg, 10.1 cpg and 10.9 cpg, in the NYH, USGC, and Chicago markets, respectively. As a percentage of the WTI to Brent price change, these gasoline price declines indicate that approximately 14% of the WTI discount was passed along to gasoline prices at the spot/bulk point of sale in NYH. In the USGC and Chicago, approximately 25% and 27%, respectively, of the discount was passed through to the spot/bulk point of sale.

These findings would indicate that a significant portion of the discount in domestic crude oil prices was directly passed through to spot gasoline prices and, therefore, it appears likely that U.S. consumers benefited from lower-priced domestic crude oils.22

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22 Retail consumers of gasoline typically benefit from lower spot prices in large, competitive markets, where sufficient competition exists at the wholesale and retail points of sale.
5. **ADDITIONAL INFORMATION**

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Appendix A
Price Sources Used in the Analysis

Monthly price data were sourced from Platts.
Platts code shown in parentheses.

Crude Oil
- WTI Cushing (1st Month) (PCACG00)
- Dated Brent (PCAAS00)
- LLS St. James (PCABN00)

Gasoline
- Gasoline Unl 87 USGC Prompt Pipeline (low) (PGACT00)
- Gasoline Unl 87 NY Cargo (low) (AAMHG00)
- Gasoline Unl 87 Chicago Pipeline (low) (PGACR00)
- Gasoline Prem Unleaded 10 ppmS FOB AR Barge (low) (AAXFQ00)
Appendix B
Statistical Regression Charts
U.S. Gasoline vs. Crude Oil Prices

Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. Brent
(Monthly Spot: 2006-2010)

\[ y = 2.3613x + 26.494 \]
\[ R^2 = 0.8597 \]

Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. Brent
(Monthly Spot: 2011-Jun 2013)

\[ y = 1.8694x + 76.025 \]
\[ R^2 = 0.2791 \]
Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. Brent
(Monthly Spot: Jul 2013 - Jun 2015)

\[ y = 2.1551x + 39.545 \]
\[ R^2 = 0.8851 \]

Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. WTI
(Monthly Spot: 2006-2010)

\[ y = 2.2662x + 32.166 \]
\[ R^2 = 0.8392 \]
**Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. WTI**
(Monthly Spot: 2011-Jun 2013)

\[ y = 1.9278x + 100.64 \]
\[ R^2 = 0.2636 \]

**Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. WTI**
(Monthly Spot: Jul 2013-Jun 2015)

\[ y = 2.3271x + 38.146 \]
\[ R^2 = 0.9179 \]
Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. LLS
(Monthly Spot: 2006-2010)

\[ y = 2.2683x + 26.082 \]
\[ R^2 = 0.8556 \]

Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. LLS
(Monthly Spot: 2011-Jun 2013)

\[ y = 1.8572x + 75.86 \]
\[ R^2 = 0.2862 \]
Gasoline Prices vs. Crude Prices: Chicago Unl Reg v. LLS
(Monthly Spot: Jul 2013-Jun 2015)

\[ y = 2.3581x + 26.176 \]
\[ R^2 = 0.9246 \]

Gasoline Prices vs. Crude Prices: USGC Unl Reg v. Brent
(Monthly Spot: 2006-2010)

\[ y = 2.3901x + 22.222 \]
\[ R^2 = 0.8905 \]
Gasoline Prices vs. Crude Prices: USGC Unl Reg v. WTI
(Monthly Spot: 2006-2010)

\[ y = 2.2954x + 27.842 \]
\[ R^2 = 0.8705 \]

Gasoline Prices vs. Crude Prices: USGC Unl Reg v. WTI
(Monthly Spot: 2011-Jun 2013)

\[ y = 2.2638x + 67.562 \]
\[ R^2 = 0.4443 \]
Gasoline Prices vs. Crude Prices: USGC Unl Reg v. WTI
(Monthly Spot: Jul 2013-Jun 2015)

\[ y = 2.2446x + 45.21 \]
\[ R^2 = 0.8907 \]

Gasoline Prices vs. Crude Prices: USGC Unl Reg v. LLS
(Monthly Spot: 2006-2010)

\[ y = 2.296x + 21.804 \]
\[ R^2 = 0.8862 \]
Gasoline Prices vs. Crude Prices: USGC Unl Reg v. LLS
(Monthly Spot: 2011-Jun 2013)

\[ y = 2.3379x + 20.967 \]
\[ R^2 = 0.5544 \]

Gasoline Price, cents/gal
Crude Oil Price, $/B

Gasoline Prices vs. Crude Prices: USGC Unl Reg v. LLS
(Monthly Spot: Jul 2013-Jun 2015)

\[ y = 2.2838x + 32.836 \]
\[ R^2 = 0.9046 \]
Gasoline Prices vs. Crude Prices: NYH Unl Reg v. Brent

(Monthly Spot: 2006-2010)

\[ y = 2.3254x + 27.332 \]
\[ R^2 = 0.9296 \]

Gasoline Prices vs. Crude Prices: NYH Unl Reg v. Brent

(Monthly Spot: 2011-Jun 2013)

\[ y = 2.3005x + 31.911 \]
\[ R^2 = 0.6986 \]
Gasoline Prices vs. Crude Prices: NYH Unl Reg v. Brent
(Monthly Spot: Jul 2013 - Jun 2015)

\[ y = 2.3475x + 47.55 \]
\[ R^2 = 0.9574 \]

Gasoline Prices vs. Crude Prices: NYH Unl Reg v. WTI
(Monthly Spot: 2006-2010)

\[ y = 2.2295x + 33.086 \]
\[ R^2 = 0.9057 \]
Gasoline Prices vs. Crude Prices: NYH Unl Reg v. WTI
(Monthly Spot: 2011-Jun 2013)

\[ y = 1.757x + 120.36 \]
\[ R^2 = 0.3618 \]

Gasoline Prices vs. Crude Prices: NYH Unl Reg v. WTI
(Monthly Spot: Jul 2013-Jun 2015)

\[ y = 2.2926x + 48.395 \]
\[ R^2 = 0.9706 \]
Gasoline Prices vs. Crude Prices: NYH Unl Reg v. WTI
(Monthly Spot: Jul 2013-Jun 2015)

\[ y = 2.2936x + 48.395 \]
\[ R^2 = 0.9706 \]

Gasoline Prices vs. Crude Prices: NYH Unl Reg v. LLS
(Monthly Spot: 2011-Jun 2013)

\[ y = 2.2108x + 40.029 \]
\[ R^2 = 0.6702 \]
Gasoline Prices vs. Crude Prices: NHY Unl Reg v. LLS
(Monthly Spot: Jul 2013-Jun 2015)

\[ y = 2.3219x + 36.713 \]

\[ R^2 = 0.9766 \]
U.S. Gasoline vs. Rotterdam Gasoline

NYH Gasoline Prices vs. Rotterdam Gasoline Prices
(Monthly Spot: Period 1 2006-2010)

\[ y = 1.027x + 6.5632 \]
\[ R^2 = 0.9797 \]

NYH Gasoline Prices vs. Rotterdam Gasoline Prices
(Monthly Spot: Period 2 2011-Jun 2013)

\[ y = 0.988x + 8.5701 \]
\[ R^2 = 0.9454 \]
Chicago Gasoline Prices vs. Rotterdam Gasoline Prices

(Monthly Spot: Period 1 2006-2010)

\[ y = 1.0595x + 2.2346 \]

\[ R^2 = 0.9352 \]

Chicago Gasoline Prices vs. Rotterdam Gasoline Prices

(Monthly Spot: Period 2 2011-Jun 2013)

\[ y = 1.0629x - 16.057 \]

\[ R^2 = 0.6621 \]
Chicago Gasoline Prices vs. Rotterdam Gasoline Prices

\[ y = 1.0208x - 10.487 \]

\[ R^2 = 0.9702 \]