Closer to One Great Pool? Evidence from Structural Breaks in Oil Price Differentials

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Our research investigates how the size of price differentials between different grades of crude oil have changed over time. We show that these price differentials have generally become smaller. We document, in particular, that many of them experienced a major structural break in or around 2008, after which there was a marked reduction in their means and volatilities. A growing ability of the global refinery sector to process lower-quality crude oil and the U.S. shale boom, which has unexpectedly boosted the supply of high-quality crude oil, are two factors consistent with these changes.

Introduction

The physical characteristics of different crude oils can vary significantly, making them imperfect substitutes for one another in the refining process and creating price differentials between the various grades of crude oil.

These price differentials are important to many oil market participants. For refiners, they can affect profitability and influence investment decisions about specific equipment, such as cokers, that could improve the profitability of processing lower grades of crude. Oil producers and fiscal authorities are concerned about these differentials because of their effect on revenues earned from producing or taxing certain types of oil. Finally, for analysts, academics and others interested in understanding the upstream and downstream oil markets, these differentials provide important signals about how supply and demand conditions change for one type of crude relative to others.

This paper investigates how the size of these quality-driven price differentials has changed over time. More specifically, we consider if these differentials have experienced permanent shifts, or structural breaks, in their average values. The research was motivated by a simple observation: in the data, many differentials between high- and low-quality crude oils appear to have significantly narrowed and become less volatile since 2008.

Data and Econometric Results

Our price data extends from 1997 to 2018 and includes 14 crude oils. The data covers a variety of geographical areas including the U.S. Gulf Coast, northwest Europe, the Middle East and Asia. A wide range of quality is considered, as our data set contains prices for high-, medium- and low-quality crude oils.

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The data is used to construct percent differentials between various pairs of prices. Our main set of results considers 27 differentials where the pairs of crude are of different qualities. These differentials are based mainly on daily price data. Some further results, based on monthly price data covering additional crudes, are presented in the appendix of the comprehensive paper and cover 42 differentials.

A structural break test, Bai (1997), is used to formally document when the mean of a price differential has changed. Our most interesting finding is that a large number of quality-related oil price differentials experienced a major structural break around the time of the Great Recession: specifically, 25 out of 27 possible differentials in our daily price data, and 38 out of 42 cases when using monthly data.

We also use the test to investigate whether oil price differentials between crudes of the same quality experienced a similar set of breaks around 2008. If so, that would suggest a broader change in the oil market not necessarily connected to crude quality. Overall, we do not find any evidence for such breaks, although we do find evidence that these differentials have experienced breaks at other times. One group of breaks occurs after the start of the U.S. shale oil boom and affects many differentials involving U.S. based, light, sweet crude oils.[1]

Visual inspection of the price differentials between various types of crude point to a marked reduction in their means and volatilities after the breaks that occur around 2008. A table in the comprehensive paper compares the pre- and post-break values for those statistics, where the pre-break sample goes from 1997 until the end of 2008 and the post-break sample runs from 2009 to the end of 2018. The average size post-break is often half that of the pre-break sample, and post-break volatilities are usually half to three-quarters the size of those before 2009.

Putting a Story to the Breaks

The econometric test does not provide a story for why a structural break occurs, let alone why we find a cluster of breaks around the time of the Great Recession. Part of our research investigates changes in the oil market that would be consistent with the emergence of smaller oil price differentials between higher- and lower-quality crude oil. This included looking at longer-term market changes, as well as potentially important events around the time of the breaks.

Given the complexity of the upstream and downstream oil sector, knowing where to look for clues was initially daunting. To guide our work, we researched how the refining process works and the role of crude quality. This turned out to be very fruitful, leading us to a handful of potentially important factors meriting further investigation.

Crude Quality and the Refining Process

While crude oil has a number of characteristics important to refiners, the two receiving the most attention are density and sulfur content. Density is formally measured by a crude oil's American Petroleum Institute gravity, hereafter API gravity. It is typically a number between 10 and 70—the lower the value, the denser the oil. Sulfur content is often measured as a percent of crude weight and can range from near 0 percent to more than 3.5 percent.

The industry has found it convenient to lump crude oils into several groups based on these properties. It is common to label oils as light, medium or heavy depending upon their API gravity and sweet or sour depending upon whether they have low or high sulfur content.

There is a price hierarchy of quality in terms of density, with light at the top and heavy at the bottom, and in terms of sulfur content, with sweet crudes preferred to sour ones. In terms of prices, light, sweet crudes usually command a premium relative to other grades, while heavy, sour crude oils usually sell at a discount.

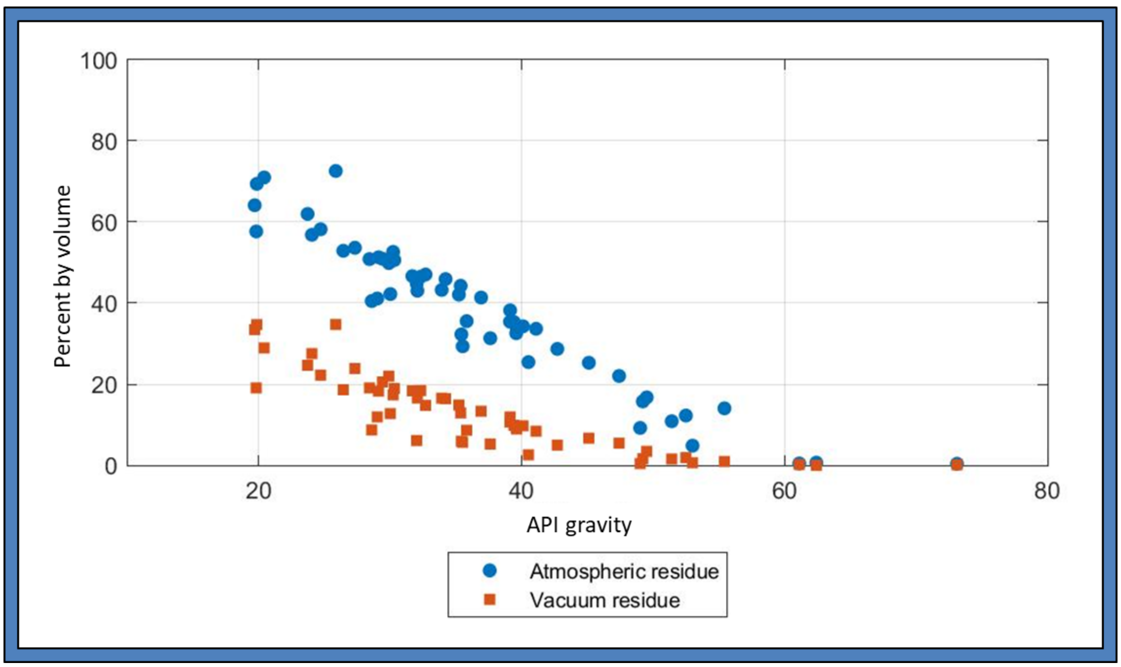
Why a Price Hierarchy?

Sulfur is a pollutant and also prevents the use of sophisticated emissions control technologies in vehicles. As a result, many countries' environmental regulations require gasoline and diesel to meet strict specifications limiting sulfur content. Removing the sulfur requires refiners to invest in costly desulfurization units, also known as hydrotreaters. This creates a premium for sweet crude oil, as it generally requires less processing than sour crude oil. While these rules only target sulfur content, they disproportionately impact lower-quality crude oil because those crudes often have higher sulfur content than do light crude streams.

Regarding density, it turns out the API gravity of a crude is related to the proportion of the different products found within a specific type of crude oil. Light crudes, i.e., those with a high API gravity, tend to have greater proportions of gasoline and diesel than residual products, while medium and heavy crude oils usually contain greater amounts of residual products. These proportions determine how much of each product is available after the first step of refining: distillation.

The residual from the first stage distillation, literally the bottom of the barrel, is often referred to as atmospheric residue. The circles in Figure 1 show the relationship between API gravity and the amount of atmospheric residue present for 54 crude oils.[2] It is possible to further distill the atmospheric residue into a product known as vacuum gas oil and vacuum residue, which is essentially residual fuel oil. The squares in the figure show the residual fuel oil content for the 54 crude oils.

Figure 1
Heavy Crude Oil Contains More Residual Content, Less Gasoline and Diesel



Note: This chart shows the amount of residual content by volume for 54 different crude oils. The x-axis is a crude oil's API gravity, a measure of its density, while the y-axis is the percent by volume of either atmospheric residue (circles) or vacuum residue (squares).

Refiners can Arbitrage across Crude Quality

Unlike gasoline or diesel, the physical properties of residual fuel oil make it impractical to use as a fuel in a wide range of settings. As a result, it sells at a much lower price than gasoline or diesel. This inherently makes medium and heavy crude less valuable than light crude.

It is here that complex refineries step into the picture. These refineries try to take advantage of the price differential between light crude and lower quality crude oil by using equipment to transform the residual content into higher-valued petroleum products. Collectively, this capital is often referred to as upgrading capacity or conversion capacity.

The most complex refineries can transform almost all of the residual fuel oil into other products. This is done using an expensive piece of equipment known as a coker. As the residual content is highest in heavy crude oil, refiners specializing in that type of crude most often use cokers. The equipment can also be used to upgrade medium crude oils.

Long Term Shifts in Refining, Crude Quality

Based on our research into the refining process and crude quality, we decided to investigate how four specific factors evolved over our sample period. The factors are: (1) environmental regulations governing sulfur content in petroleum products; (2) demand for residual fuel oil relative to lighter petroleum products; (3) the relative supplies of various types of crude oil; and (4) global refining capacity to process low-quality crude oil. Each of these could theoretically influence the long-run values of price differentials between high- and low-quality crude oil.

For each factor, we collected as much relevant data as possible and used those data to inform our understanding of oil market developments over the sample period. We find that changes in the relative supplies of different types of crude and changes in the refining sector are consistent with smaller oil price differentials, while changes in environmental regulation and in the relative demand for different fuels are not.

More specifically, the data show that the supply of light crude relative to heavy crude has increased dramatically and somewhat unexpectedly over the past 10 years due to the U.S. shale boom. At the same time, the global refining sector has become more complex due to greater upgrading capacity.

On the other hand, we find that environmental regulations on sulfur have become more stringent and cover a growing proportion of consumption of the affected fuels, which should lower the relative demand for low-quality crude oil. Likewise, consumption data show a clear negative trend in the use of residual fuel oil and significant growth in consumption of other, lighter petroleum products.

What Happened Around 2008?

Since we found a cluster of structural breaks around the start of the Great Recession, it seemed natural to take a closer look at events around that time. Consumption data show the Great Recession played a role by unexpectedly and significantly reducing global petroleum product demand in 2008 and 2009, particularly for lighter products such as gasoline and diesel. In fact, those two years are the only period when the demand of such products relative to residual fuel oil declined. At the same time, additions to global upgrading capacity begun before the downturn continued uninterrupted—the result of the long lead times for refiner expansions. Both of these outcomes would contribute to lower price differentials.

The fact that price differentials have remained smaller and less volatile since then suggests that global refining capacity additions after the Great Recession have been sufficient, in light of the other trends affecting the market, to meet growing demand for gasoline and diesel, without leading to an oversupply of residual fuel oil.

Endnotes

Dr. Plante presented on this topic at the JPMCC's 3rd Annual International Commodities Symposium during the "Economics and Policy Issues on Energy Markets" session on August 12, 2019. The symposium, in turn, was organized by Professor Jian Yang, Ph.D., CFA, the J.P. Morgan Endowed Chair and JPMCC Research Director at the University of Colorado Denver Business School.

For further coverage of the crude oil markets, one can read past *GCARD* articles on these markets.

1 The literature has previously documented and discussed the importance of some of those breaks. See, for example, Buyuksahin *et al*. (2013), Borenstein and Kellogg (2014), Scheitrum *et al*. (2018), and Agerton and Upton (2019).

2 This data comes from Exxon's crude oil assay library and can be accessed at https://corporate.exxonmobil.com/Crude-oils/Crude-trading/Assays-available-for-download.

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