Geographical limits to arbitrage in the global oil market

Michael H. Grote

Frankfurt School of Finance & Management, m.grote@fs.de

Matthew Zook

University of Kentucky, zook@uky.edu

Thomas Heidorn

Frankfurt School of Finance & Management, t.heidorn@fs.de

August, 2017

Financial Geography Working Paper #7

Geographical limits to arbitrage in the global oil market

Abstract

For more than 30 years, the world's main indices for oil prices – WTI in the US and Brent in Europe – have moved in sync. This changed dramatically in 2011, when WTI started trading at a considerable discount to Brent for almost five years. This disparity violated the "law of one price" as arbitrage between markets should quickly reduce these differences. We trace the limits to arbitrage to the specificities of the WTI oil market and highlight how geography – manifest in material infrastructure and the design and regulation of markets – can pose sizable limits to arbitrage even in globally integrated commodity markets.

Keywords: Financial geography, limits to arbitrage, oil markets, oil production

1. Introduction

The ongoing global integration of markets is one of the cornerstones of modern capitalism. There is the general notion that markets are ever more integrated and prices for identical or similar tradeable goods are becoming increasingly uniform worldwide, a proposition known as the "law of one price". In this paper we examine the decidedly material global oil market and the unexpected failure of the law of one price. Crude oil is the most traded good worldwide (UNCTAD 2016); it relies heavily on standardized forms traded on financial exchanges for pricing information. Commodity markets feature a special connection between financial markets and the "real world", namely that at one point in time, the actual good (barrels of crude oil) needs delivery for processing and consumption by manufacturing and consumer markets. As with other futures trading in commodity markets, traders use geography, i.e., control over physical delivery and storage of product, to increase their profits or even corner the market. In the oil industry, hedge funds and investment banks rent actual tankers to store oil bought cheaply on the spot market with an eye towards the higher prices on the futures market; the so called "contango" situation (see Röder 2015, Baraniuk 2016) also found in other commodities such as copper (Sanderson 2014).

Despite this key role, the treatment of geography by markets and analysts remains relatively simplistic, largely as a cost factor or discount rate within pricing models. According to the law of one price there should be no large price differences in the global oil market – beyond transportation costs – between different trading and delivery venues. And indeed, the two leading oil price benchmarks, West Texas Intermediate Crude or WTI (delivered in Cushing, Oklahoma) and Brent Crude (delivered at four ports in the North Sea), have more than 30 years of almost perfect co-movements, offering a textbook case of global market integration. However, in 2011

something happened: For the first time, prices diverged strongly with WTI trading at a substantial discount for a sustained period of close to five years (see figure 1).

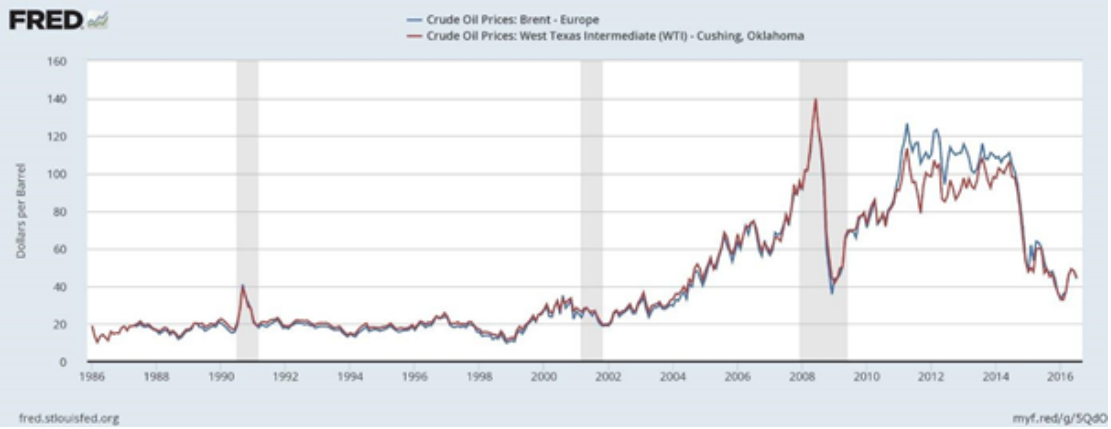

Figure 1: Crude oil prices, Brent and WTI from 1986 to 2016, Data and Graph Source: Federal Reserve Economic Data (FRED)

Given this unexpected divergence within the most heavily traded global commodity we ask the following questions: Why did things change in 2011? And change back in 2015? What caused the failure of the law of one price in such a well-established global market? How could arbitrage not set in for five years in the most-traded commodity market in the world for an almost identical product?

The answer is geography. Geography, both in its simple form – fracking in the US shifted the location of oil extraction –, as well in its complexity – the way this shift in supply flowed across the infrastructural, financial and regulatory structures of the global oil industry – allows us to trace a rich story of the modern economy. This examination demonstrates both the risks of unexplored assumptions such as the inevitability of arbitrage and the power and continued relevance of spatial specificity in the global integration of markets.

2. Arbitrage and geographic context

We use a hybrid theoretical framework combining the concerns of neoclassical economics – understanding markets and the power of arbitrage – with an economic geographic focus on how localized contexts and institutions shape markets and limit arbitrage in fundamental ways. With this approach we do not seek to develop new theories per se but instead emphasize how blending approaches provides a better understanding of real world phenomena.

An important starting point in neoclassical reasoning about markets is the central hypothesis that financial markets are efficient. Prices incorporate new information quickly so that they – most of the time – reflect the fundamental values of securities. Arbitrage, understood as “a trade that profits by exploiting the price differences of identical or similar financial instruments on different markets or in different forms” (Investopedia 2017), ensures that similar goods trade at similar prices. Arbitrage – contrasted to “noise trading”, which buys and sells on irrelevant information – is done by sophisticated market participants who drive prices back to their fundamental val-

ues by buying undervalued securities, or selling overvalued securities. Arbitrage also increases the efficiency of financial markets (Shleifer and Vishny 1997) by signaling the scarcity or abundance of products, thereby indicating opportunities for economic efforts and investments. In this way, arbitrage is essential for maintaining unambiguous market signals and well-functioning markets.

Situations in which arbitrage fails come in two broad categories: psychology and limits to arbitrage (Barberis and Thaler 2003). In the sphere of psychology, prices can remain away from their fundamental values if market participants do not assess markets rationally (see Barberis and Thaler 2003). For instance, investors may set a mental "anchor" price for securities, and do not adjust their valuation in light of new information (Tversky and Kahneman 1974). Likewise, investors might be overconfident in their abilities and trade too much (Grinblatt and Keloharju 2009). According to Kahneman and Tversky's (1979) prospect theory, investors may treat gains and losses unequally and therefore react in a non-value maximizing way. All of these psychological factors can confound the process of arbitrage.

The category of "limits to arbitrage" is not based on market participants' rationality but on specific risks or market features that hinder arbitrage. First is so-called fundamental risk: An already overvalued stock might become even more overvalued due to good news occurring during the perceived arbitrage opportunity belying the idea that arbitrage is risk-free. Second, there is the "noise trader risk", or in the famous words attributed to Keynes, "Markets can remain irrational a lot longer than you and I can remain solvent." Even if an investor rightly spots an opportunity, the mispricing could stay for a long time, or even worsen, becoming so costly that the arbitrageur-investor is forced to clear positions at a loss (see MacKenzie 2003).

A third limit is transaction costs, mostly understood as commissions, bid-ask spreads, short-sale restrictions, and the costs of actually learning and understanding the mispricing (see Barberis and Thaler 2003). While these costs make it unattractive to enter arbitrage positions they are mostly seen as rather small. Transaction costs are a particular hindrance to arbitrage for commodity markets in which costs (especially transportation) are substantial. Additionally, deviations from the neoclassical ideal – e.g., the OPEC oil cartel and the US embargo on exports – may distort prices. Indeed, the complex institutional setting of the global oil market, makes understanding market and price dynamics very difficult. As one observer notes, "Since […] 1998 no one has been able to forecast the oil price correctly, showing there is […] no comprehension by observers of its real dynamics" (Carollo 2012). In a similar way, Lutz Kilian, a key economist consulting to the WTO about oil markets, states, "There is no consensus in the academic literature on how to model the global market for crude oil" (Kilian and Murphy 2014; see Fattouh 2010 for a similar statement).

While forecasting prices is problematic even with perfect information – unpredictability is a fundamental market feature, since all available information is already incorporated in the current price – oil prices are particularly confounding. Most forecasting models rely on macro-economic factors, aggregate demand and supply, and assume a smoothly functioning system of arbitrage. However, when a geographic shift in extraction occurred during the late 2000s, this assumption was no longer true.

In order to understand this new situation, we argue that one must move beyond neoclassical models and consider a wider range of geographical, institutional and regulatory factors. Our case aptly demonstrates the value of economic geography to studies of energy markets in general and oil in particular (Bridge and Wood, 2005). Bridge (2010) reviews these approaches coming from a range of theoretical and methodological positions (see also Pasqualetti (2011) and Calvert's (2016) recent reviews of energy geographies).

Economic geography scholars emphasize the relevance of local context and social structures in which oil production and markets are embedded. Echoing Sheppard's (2005) explication of the emergence of the now global doctrine of free trade from a local epistemology in Manchester, Hemmingsen (2010) argues that the disconnection of the idea of "peak oil" from its original context has made current debates stale and unproductive. In a parallel vein, Huber (2011: 817) emphasizes geographical context in his critique of how the concepts of "over-production" and "scarcity" are constructed by the state and corporations via "specific institutional arrangements" in order "to limit the production of commodities to stabilize prices and secure profits ... In other words, scarcity has to be socially produced." To put it another way, Huber's analysis argues that oil scarcity derives from competing state and corporate strategies rather than emerging naturally from market or geological factors.

Likewise, Bridge and Wood (2010) contend that oil corporations are much less preoccupied with the geology of extraction than they are with "above-ground factors" such as reserves ownership and the evolving structure of global production. They argue, 'Big Oil' is concerned with "how to secure access to reserves that are outside their direct control, are held [sic] by national governments" meaning that "constraints on reserve growth are primarily aboveground, and not below … they are political rather than geological" (Bridge and Wood 2010: 571). In a similar manner, Kennedy's (2014) analysis finds that "uneven social relations" determine and drive the "geopolitical discourses and claims made by actors and groups" that ultimately shape the control of oil (Kennedy 2014: 272).

Thus, economic geography research on oil foregrounds the spatiality of local contexts including the political economy and institutions. For example, how do supply line constraints shape alliances and technological change, e.g., the 1950s Suez canal crisis incentivizing the use of supertankers to move oil around Africa rather than via the Suez (Calvert 2016). Applying this lens to the changes beginning in 2011 leads us to analyze the social construction of a particular kind of scarcity – the ability to transport oil efficiently – that confounded arbitrage and the law of one price. To be clear, this is not an argument that the lack or direction of pipeline capacity was intentionally engineered; rather we seek to understand how this scarcity emerged from the political economy and social expectations of the time. For example, the ways that earlier expectations of dwindling reserves in the US led to a certain kind of infrastructure, or how regulatory rules put in place during the 1970s crisis slowed response to market failure four decades later.

Using this approach, we provide a still partial view of the market for oil that explains how geographical and regulatory conditions limited the opportunities for arbi-

trage. In so doing we build on earlier work by geographers on the peculiarities of different financial markets. For instance, Clark, Wójcik and Bauer (2006) show how differences in localized knowledge cause deviations from the law of one price even for a specific stock traded in two markets, or Labban's (2010) exploration of the effects of financialization on the oil industry. In the following sections we provide a rich account of the functioning of the global oil market in order to highlight the complex and intermingled roles of regulation and geography in its development.

3. Oil Market – WTI and Brent as global standards

While oil and related products are the most traded commodity class worldwide (UNCTAD 2016), crude oil is not a homogeneous product; there are more than 300 different sorts of crude oil. The two key dimensions of crude oil are its density ("heavy" vs. "light") and its sulfur content ("sour" vs. "sweet") with light sweet crude commanding higher prices than heavy sour oils because of less energy-intensive refinery processes (USEIA 2012a). Refineries are optimized for certain kinds of crude oil and shifting to another type or source (with different characteristics) is complicated and potentially expensive (Levine *et al*. 2014). Therefore, the global market for oil actually consists of not wholly integrated networks of supply and demand, rather than a "single" commodity.

Until the early 1970s, this lack of an actual "market" for crude oil was ameliorated by large, vertically integrated companies that internalized all operations including field exploration, refining, marketing and distribution. The OPEC oil embargo in 1973 combined with the Iranian revolution in 1978 marked the end of this era as average oil prices rose from approximately three to over thirteen dollars per barrel. These changes spurred the development of new sources of petroleum, e.g., the North Sea, and state action including price controls within the US and an export ban on crude oil enacted in 1975. While the price controls were abandoned in 1981, the US export ban persisted for decades and was only lifted in December 2015 (Johnson 2015).

Also emerging from the 1970s were new approaches to markets and pricing including the expanded use of financial futures. Given the changes to the integrated corporate model, market actors sought more transparent oil pricing, an ongoing challenge. Even today it is surprisingly difficult to find the market price for crude oil; prices quoted in the media are (mostly) not spot prices of actual oil changing hands, but the cost of oil futures one month ahead. Other tactics such as shorting of oil, i.e., betting on falling prices, are impossible in physical oil markets because one cannot possess negative amounts of actual oil. As a result, the oil industry is highly reliant on the financial sector to provide a futures (or "paper") market for smooth operations and hedging against price swings.

Backing petroleum futures contracts are two similar types of crude oil, WTI and Brent crude, both "light" and "sweet" crudes with WTI having a slightly higher quality (Schieldrop 2013). Trading of WTI and Brent futures occurs on the NYMEX (New York) and the Intercontinental Exchange (ICE, in London) respectively, and by the

end of the 1980s, these indices became the main method for pricing crude oil in international trade. Most other sorts of oil are not priced in any markets, but linked to these via simple formulas:

$$\pi_\gamma := \pi_\beta \mp \delta$$

The price of the oil in question π_γ is set as the price of a benchmark crude π_β plus or minus some pre-agreed discount or premium δ (see Schieldrop 2013). Given the financial instruments developed around these indices – dictating prices of most other oil trades – WTI and Brent have become key drivers of the global oil market. This centrality is perhaps best seen in the evolving definition of Brent crude as the original oil field emptied over time and was replaced by other sources; a process which also took place with the less influential Dubai index, which today includes crude oil originating in Oman and elsewhere. Indeed, these indices now have characteristics more similar to a brand than to an exact regional specification (see Fattouh 2012). And precisely because the financial infrastructure around the major indices-cum-brands were so central to global oil markets that redefining the actual physical product delivered was preferable to adapting to a different index.

This complex structure of interlinked financial markets (or "paper markets") – including spot and also physical forwards, futures, options and other derivatives – are ultimately tied to the physical delivery of oil from field to refinery but often tenuously. This results in two distinct but interconnected parts of the market, each with a different set of actors and interests. On the financial side, hedge funds and other financial institutions are major players, whereas the physical market is the domain of oil producing countries, oil companies (some nationally owned) and oil trading companies. While images of oil derricks, offshore platforms and pipelines dominate the popular understanding of the oil industry, this misrepresents the relative scale of these two parts of the market. In actuality, trading in paper markets (of "paper barrels") is estimated to be 10 to 15 times larger than actual oil production, and 25 times larger than the physical oil trading (Carollo 2012). Most financial market participants are not interested in actual delivery, but these trades are ultimately linked to the physical product as future contracts maturing with a price identical to spot prices. Therefore, contracts can be settled financially (paying the difference from the contracted price to today's spot) on delivery at the specified point, Cushing, Oklahoma for the WTI and the North Sea for Brent Crude.

For the most part, this dominance of finance over physical is clearly manifest, with the fate and price of oil shaped by traders and matching engines in financial capitals far from the point of production or consumption. However, upon occasion the opposite occurs with physical and geographical factors confounding the financial markets, as in the case of the 2011 spread between WTI and Brent.

4. Geographies of WTI and Brent

While the paper markets loom large in the global oil market it is not possible to understand this industry without examining the specific geographies of its production and distribution. In particular, one must appreciate the spatiality and history of the

WTI and Brent indices. Despite the fact that neither had a material presence on the global market – until the end of 2015, US policy prevent any export of WTI crude oil, and the oil field that originally formed the Brent crude index is nearly exhausted –, and that the bulk of the world's oil comes from other sources, the WTI and Brent remain the key linchpins between the two parts of the oil market.

The WTI and Cushing lock-in effect

The WTI index is based on a standard of defined qualities of crude oil rather than a specific field of origin and consists of many different sources from the region. This definition by characteristics rather than a single source allowed for the development of a paper market in domestic light sweet crude by the New York Mercantile Exchange (NYMEX) in March 1983. Nevertheless, the WTI is strongly tied to geography via the small town of Cushing, Oklahoma (less than 8,000 inhabitants in 2010) that has long been the designated delivery point for WTI contracts. The self-proclaimed "pipeline crossroads of the world", Cushing acts as a key exchange and storage point with a capacity of 90 million barrels (Smith 2016).

Although oil wells were first drilled farther east in Pennsylvania and the greater Appalachia region, the central southwestern region of Texas, Oklahoma, Kansas, Arkansas and Louisiana emerged as the key site of petroleum extraction in the late 19th and early 20th century, including major discoveries at Cushing in 1912 (Kimes 2005). The initial use was for oil lamps (albeit with relatively low demand) made even lower by the invention of the electric light by Edison in 1879, setting up weak demand during the earliest era of oil exploration. This situation reversed a few decades later when gasoline powered automobiles created new (and much larger) sources of demand. This increase corresponded with the timing of oil extraction around Cushing, including the initial 1912 strikes in the Cushing-Drumright Oil Field and the resulting construction of storage tanks and related infrastructure. When production around Cushing began to taper off in 1920, this early advantage in infrastructure along with its central location to other strikes contributed to a path dependence that made Cushing a key pipeline facility.

The disjuncture between the location of oil production and demand, located in the large population and industrial centers of the Midwest and Eastern US, necessitated an inexpensive way to ship oil. Pipelines are by far the cheapest means of transportation, and with few environmental regulations, Standard Oil quickly developed an extensive network around Cushing to connect the central southwest region to the rest of the US. Once established, this transportation lock-in helped maintain Cushing as a key node via additional pipeline construction, such as the Seaway pipeline between Freeport, TX and Cushing opening in 1976 to bring imports of foreign oil (see Figure 2).

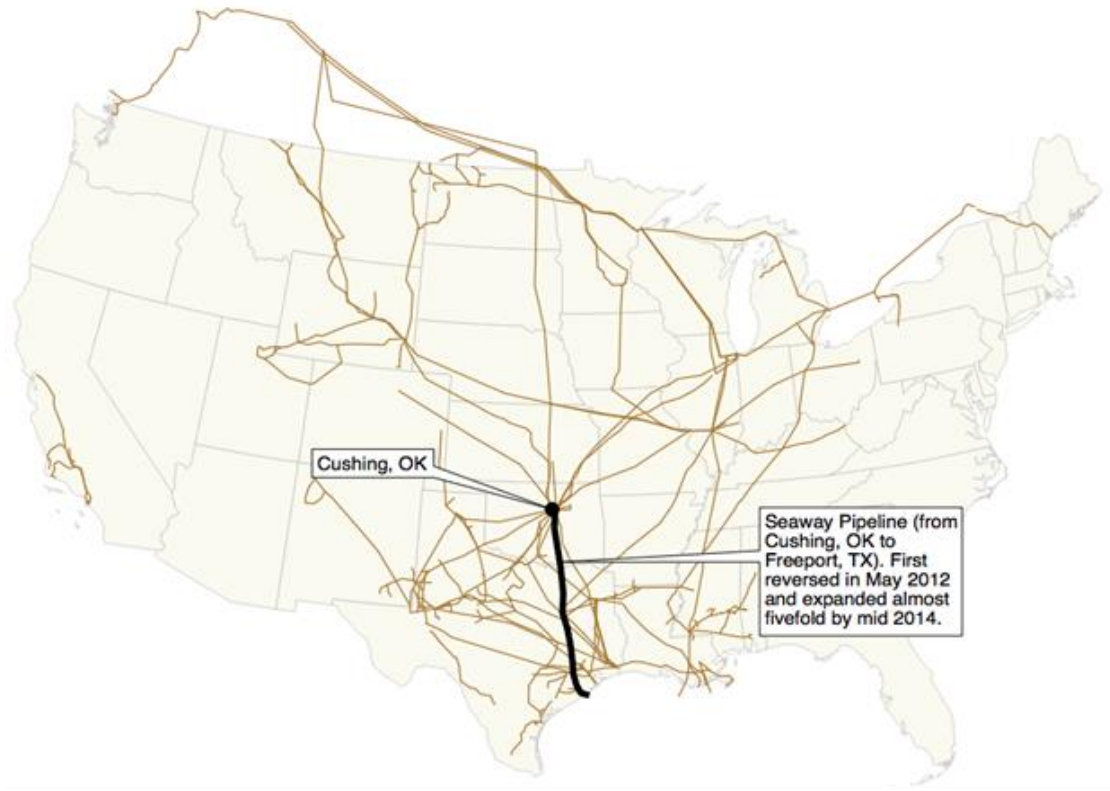

Figure 2: Major crude oil pipelines, Data Source: USEIA 2017a, Map Source: Authors

Cushing's establishment as the key transshipment node in oil transport also made it central to the financial markets as a pricing index. The combination of high volume flows from extraction points, ample storage capacity and routes to key markets made it an ideal delivery point for the paper market. Further adding to its usefulness in the global market, WTI represents a high-volume market with many buyers in a regulatory environment that makes price manipulation much more difficult relative to other indexes such as Dubai's (Fattouh 2012). With these advantages -- including lock-ins from physical infrastructure and financial markets -- the WTI index established itself as a key indicator for crude oil pricing from the late 1980s onward. This centrality, however, ultimately created a geographical bottleneck shifting the scale of relevance for the WTI index from the global to the local.

Brent Crude – a tanker market

Although petroleum deposits had been discovered (and exploited in small scale) in the North Sea, it was not until the discovery of the Groningen gas field in the Netherlands during the late 1950s, that serious commercial interest began. Oil companies began exploring the North Sea in earnest in the mid-1960s with significant finds – the Brent field, the Forties field and the Statfjord field – in the late 1960s and early 1970s. It was not, however, until the price increases from the 1973 OPEC oil crisis that commercial exploitation became lucrative.

The Brent oil field – after which the Brent index is named – was put into production in 1976 under the auspices of Shell UK. At its peak in the late 1980s, the

Brent field was sufficiently productive to support the Brent index (developed at the ICE in London) as key indicator of global oil pricing. Given this crucial role, traders wanted to ensure that future supply constraints did not render its role as a market indicator meaningless or make it overly susceptible to manipulation (current extraction from the Brent field is down to about a thousand barrels daily, from about half a million at its peak (Martén and Jiménez 2015)). Therefore, additional streams of oil from other North Sea locations were added to the Brent Crude index. Although these additions necessitated changes in the definition of Brent they were absolutely necessary in maintaining liquidity. These other streams – the North Sea Forties and the Oseberg stream starting in 2002 and the later Ekofisk stream added in 2007 – ensured the longevity of Brent futures trading. This blending brought its own problems, primarily variation in the characteristics and quality of the crude oil, resulting in quality de-escalators that triggered rebates based on the sulfur content of the delivered oil traded under the Brent index (Fielden 2015a).

Brent oil is initially sold in very large amounts, on the order of tanker loads or approximately 600,000+ barrels, limiting the number of actors who have the financial resources to participate (Fielden 2015b). Moreover, these tanker sales are generally conducted far in advance of delivery and provide relatively little help in determining price. For that, the industry relies upon futures – bundled in much smaller lots, generally 1,000 barrels, increasing the number of market participants – for price signals. Central to this process is the manner in which North Sea oil moves from the production fields to tankers and refineries. If the buyers have their own refinery, e.g., large integrated oil companies, they can simply take possession of the crude oil at one of four different terminals – Hound Point and Sullom Voe in Scotland, Teesside in England and Sture in Norway – but as this is an internal transaction, no pricing information is gained. Much more useful from the market perspective are buyers of Brent oil (generally trading companies) who resell these parcels in either the paper market, approximately a month or more away from delivery, or the “dated” or “wet” market when a three day delivery window within 25 days has been set (Fielden 2015b). These relatively well-functioning systems – particularly in the dated markets – provide key pricing signals on Brent crude that in turn are used globally to price over sixty percent of global oil (Kurt 2015).

Key geographical differences

This review of the histories and geographies associated with the WTI and Brent indices reveal key differences in the number and associated infrastructure of the delivery points. For WTI, delivery is in one location – Cushing, OK – and while this town has extensive storage facilities, shipping oil to and from Cushing is constrained by the capacity and routings of the pipelines connecting it. Moreover, this pipeline system was designed and constructed for a particular geography of oil fields and refineries and deviations from these expectations bring particular challenges.

In contrast, the Brent Crude index allows buyers to take physical possession of oil at four separate locations in the North Sea. Moreover, these points are terminals that allow loading directly onto mobile transportation resources, i.e., tankers, which

can be dispatched worldwide. The combination of four delivery points and tanker (rather than pipeline) delivery creates a more flexible system for the physical delivery of Brent index crude oil relative to WTI. As the WTI - Brent spread beginning in 2011 demonstrates, these geographical differences could not be ignored as they created a real and sustained violation of the law of one price in the global oil market.

5. Diverging local indexes in a global market

Since the late 1980s the WTI and Brent indices tracked each other closely (see Figure 1). Physically there is little difference between WTI and Brent – both are light sweet crudes – and the small difference that does exists lead to Brent normally trading slightly below WTI. Historically this negative spread has been relatively small – usually below +/- five dollars – and during the entire period from 1988 to 2010 less than 8 percent of the trading days had a lower WTI price (see Figure 3A). Whenever the spread became sizeable, physical arbitrage, shipping tankers of crude oil from Brent terminals in the North Sea to Freeport Texas for delivery to Cushing, would close the gap in pricing; a textbook example of the law of one price (see Figure 3B).

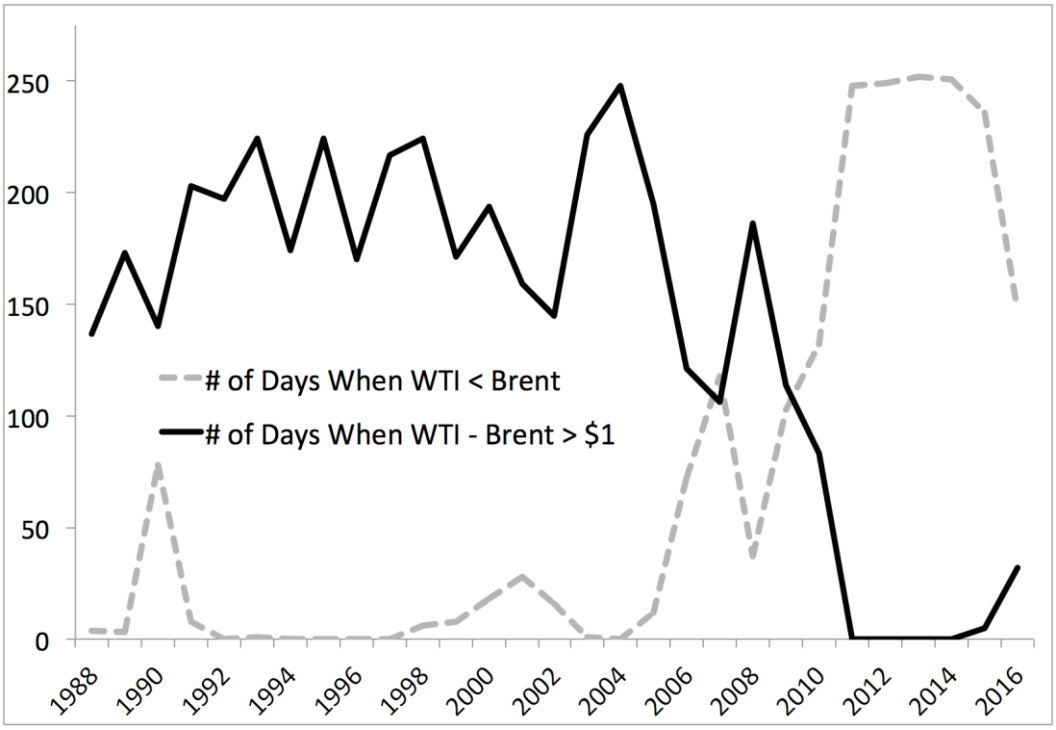

Figure 3A: Days of Price Differences between WTI and Brent, Data Source: Federal Reserve Economic Data (FRED), Graph by Authors

Beginning in the middle of 2010, however, this long-term situation changed. While not out of line with historical precedence, positive spreads were not unknown and had even been sustained over several months (see Figure 3B), the magnitude of the spread (climbing above $10 in early 2011 and peaking at $30 by late in the year) and duration (continuing for almost five years) was unprecedented (see Figures 3A and 3B). In retrospect, it is clear that the law of one price was no longer in effect but this was not clear at the time. Looking at historical precedents and expecting arbi-

trage, led to bad investment decisions in early 2011. Investment banks and analysts viewed the spread as a cyclical or short-term phenomenon (Blas 2011) and suggested shorting the spread (Strumpf 2011, Worth 2011), as it reached a historical high (at that point in time) and a reduction was likely (Hamilton 2011).

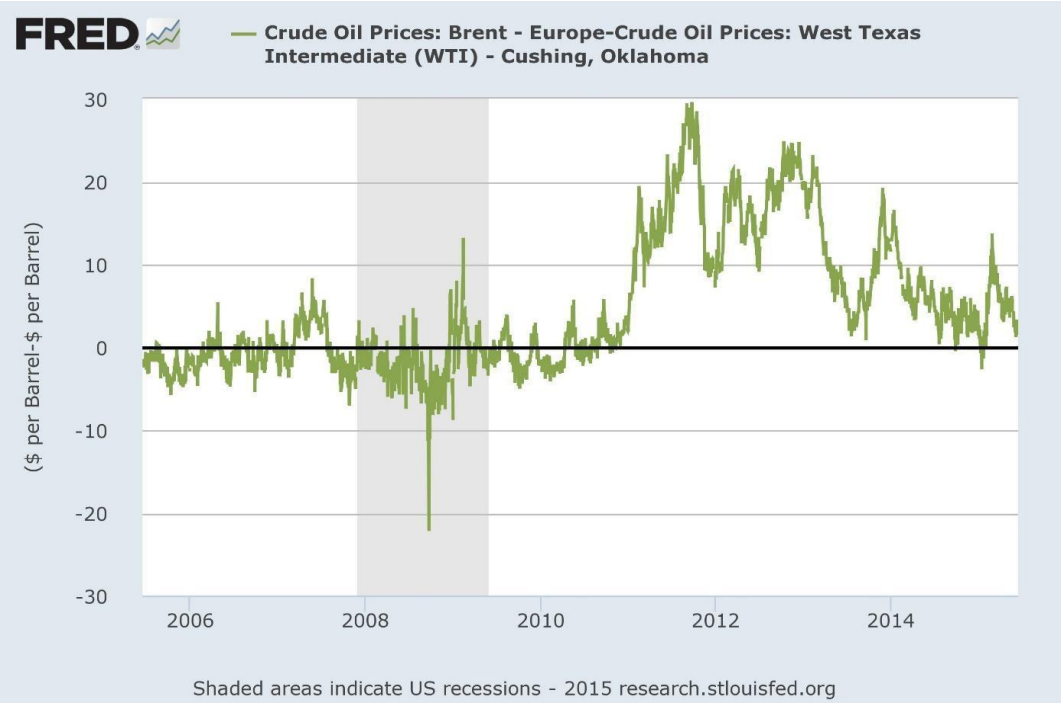

Figure 3B: Price Spread between Brent and WTI, Data and Graph Source: Federal Reserve Economic Data (FRED)

Infrastructure mismatch in the US

This failure in the law of one price comes from changes to the geography of North American oil production over the past decade. Beginning in the early 21st century, new techniques for oil extraction – horizontal drilling and multistage hydraulic fracturing ("fracking") – made oil and natural gas in shale rock formations economically accessible. As a result oil production in the US and Canada increased by 46 percent from 2008 (7.5 million barrels per day) to 2013 (11 million barrels per day) (USEIA 2016). While fracking increased oil production levels within traditional sources such as Texas, it also enabled oil production in other locations such as the Bakken formation (spread across Montana, North Dakota, Saskatchewan and Manitoba) where production increased dramatically over the course of ten years (see Figure 4). This rapid growth of production of Bakken crude (as well as the Canadian tar sands, see Pasqualetti 2009) ran counter to the design of the "midcontinent pipeline system ... configured to deliver crude oil imported to the U.S. Gulf Coast and domestic production from West Texas to the refineries in the Midwest via Cushing, Oklahoma" (USEIA 2013).

	1996		2016	
State	*Thousands of barrels*	*Share of US Production*	*Thousands of barrels*	*Share of US Production*
Texas	543,342	23.0%	1,176,041	36.2%
North Dakota	32,317	1.4%	378,439	11.7%
California	282,409	11.9%	187,565	5.8%
Alaska	509,999	21.6%	352,697	10.9%
Oklahoma	85,379	3.6%	153,653	4.7%
New Mexico	64,479	2.7%	147,302	4.5%
Colorado	24,953	1.1%	115,359	3.6%
Wyoming	73,365	3.1%	72,327	2.2%
Louisiana	132,151	5.6%	56,884	1.8%
Kansas	41,789	1.8%	37,063	1.1%
Rest	526,003	22.2%	743,444	22.9%

Figure 4: Crude Oil Production by State, Data Source: USEIA (2017b)

This geographic mismatch in pipeline design and new production points is a fundamental cause of the depressed prices in Cushing and by extension the spread show in Figures 3A and 3B. Moreover, the resulting bottleneck at Cushing (with already large existing stores) made it difficult to arbitrage away price differences in the short term. Faced with insufficient pipeline capacity, producers sought alternative transportation, shipping large quantities of oil by truck or train (see Figure 5). These substitutes, both considerably more expensive and more dangerous than pipelines, were also in high demand at the Bakken formation. As a result, arbitraging away price differences – by moving crude oil to other locations besides Cushing – was limited. In contrast, a tanker based market – as is the case for Brent – gives producers access to much cheaper transportation and makes arbitrage possible at much lower margins.

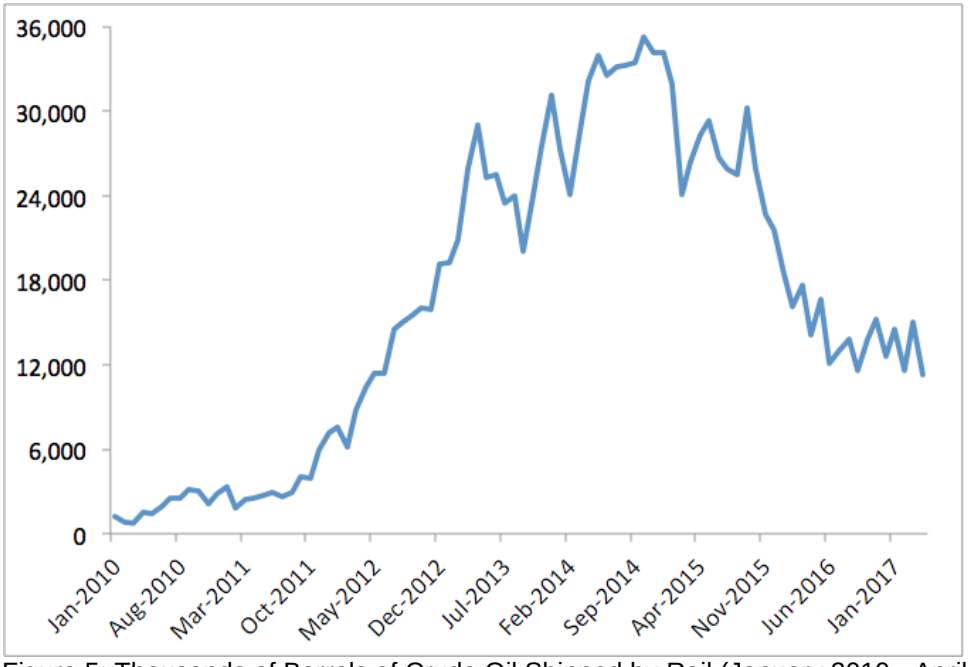

Figure 5: Thousands of Barrels of Crude Oil Shipped by Rail (January 2010 - April 2017), Data Source: USEIA (2017b)

The result of the very specific geographies of this infrastructure mismatch meant that the WTI index was no longer a good indicator of pricing in the US market (and by extension the global market). It was only an indicator of the market price in the actual locale of Cushing, Oklahoma, and its use for the larger US became defunct. Similar outcomes were also seen in other regions and associated indices – such as the Bakken formation – facing infrastructure constraints although their position (and prices) were even worse than the WTI. The USEIA (2012b) notes, "Limited pipeline capacity has made it difficult to bring crude oil out of the center of the continent, lowering all the affected benchmarks compared to prices outside the area. But within the constrained area, prices have also diverged from each other, reflecting local transmission bottlenecks within the larger constrained area." In short, in 2011 and 2012 the oil distribution system in North America confronted a historically unprecedented geography of supply with transportation capacity that was too low, or even in the wrong direction.

Ameliorating this problem in the long term, e.g. building new infrastructural capacity – be it pipeline, storage tank or tanker terminal – is expensive and time-consuming. Ultimately, the Cushing bottleneck was successfully addressed when the flow of the Seaway pipeline (see Figure 2) to Freeport Texas was reversed on May 17, 2012, and with subsequent capacity increases in January 2013 (by a factor of 2.7) and again in mid-2014 (by a factor of 2). As Mike Moeller, the Director and General Manager of Enbridge, one of the largest storage tank companies in Cushing notes:

"There's really a dynamic shift in the crude markets here in North America. We've got pipes today, the Seaway pipeline that use to bring offshore crude from tankers into Cushing and then distributed it to markets beyond Cushing. With the Shale play, the oil sands of Canada, that production, domestic production, comes down to Cushing, and now we can pipe that down to the Gulf coast through a reverse seaway pipeline" (Moeller 2013).

These changes in transportation infrastructure (including increased storage capacity) meant that stored oil in Cushing could be delivered to the coast, for refining or export, quite cheaply and ultimately removing the spread between Brent and WTI. Transportation mismatch, however, was not the only geographical factor producing the Cushing bottleneck. Other issues such as financial market lock-in for delivery points and national regulatory restrictions further confounded arbitrage in the global oil market during this period.

Financial markets lock-in

Also contributing to the Cushing lock-in effect was the nature of the future oil contracts. These financial instruments – absolutely essentially for the function of the US markets and determination of prices – are contracts focused on WTI and specifically designate Cushing as the delivery point. The NYMEX / CME where WTI-futures are traded specifies the delivery procedure as follows:

"Delivery shall be made free-on-board ("F.O.B.") at any pipeline or storage facility in Cushing, Oklahoma with pipeline access to Enterprise, Cushing storage or Enbridge, Cushing storage. Delivery shall be made in accordance with all applicable Federal executive orders and all applicable Federal, State and local laws and regulations.

At buyer's option, delivery shall be made by any of the following methods: (1) by interfacility transfer ("pumpover") into a designated pipeline or storage facility with access to seller's incoming pipeline or storage facility; (2) by in-line (or in-system) transfer, or book-out of title to the buyer; or (3) if the seller agrees to such transfer and if the facility used by the seller allows for such transfer, without physical movement of product, by in-tank transfer of title to the buyer" (CMEgroup 2017).

While extremely useful in commodifying an otherwise heterogeneous product, these futures contracts also acted as a sort of straightjacket, complicating and delaying change in a familiar system with considerable sunk costs. Changing such a complex trading system with many and competing interests is difficult. While the WTI futures market was captured by this oil glut in Cushing, OK, the rest of the world was not, and non-WTI oil futures moved on costing WTI its position relative to Brent Crude as an international benchmark. As Manescu and Van Robays (2014) note, "the WTI price has increasingly reflected US specific rather than global oil market dynamics since 2010" and "is no longer seen as the global benchmark price for oil; Brent crude oil prices have taken this role instead." In 2012, ICE Brent became the world's largest crude oil futures contract in terms of volume and ICE Brent market share has almost doubled since 2008. As a result, approximately two-thirds of the world's traded crude oil uses the Brent complex, which includes ICE Brent futures with strong liquidity and a far-reaching forward curve, as a price benchmark (ICE 2013).

During this time, however, WTI remained in constant use as an indicator for U.S. prices, despite the fact that the low WTI prices did not reflect the whole U.S. market, but rather the WTI with delivery in Cushing. After all, crude oil imports (at higher Brent related prices) continued throughout this time (see USEIA 2017b) show the very regional character of the WTI index: returning to its origins as an indicator of the very specific situation of "West Texas Intermediate" in Cushing, OK only.

And yet, the WTI persisted: trading in WTI futures remained rather constant in absolute terms between 2011 and 2016 (see Martén and Jiménez 2015) even with the loss of the international benchmark function. This is remarkable: Despite being a defunct indicator not only for the global oil market but also largely for the US market for about five years, the WTI contracts actually survived unchanged. Market participants in the US did not even change the delivery point from Cushing to, say, Port Arthur at the U.S. Gulf Coast. This shows that the financial market infrastructure "cluster" is so important and hard to change that financial market participants rather stick to a potentially misleading indicator for a long time than to abandon it and create a new one.

Regulation of US crude oil exports

Even with the evolution of the futures contracts for WTI and the reversal of the Seaway pipeline flow, cheaper WTI crude oil faced yet another barrier to arbitrage. Namely, US policy banning crude oil exports (not refined products) and thus WTI oil could not simply be brought to European (or other) refineries in the same way that North Sea Brent oil could be imported to the US. This ban originated during the 1970s oil crisis and had become increasingly unpopular among producers as they faced lower prices than the global market. Increasing the complexity of the situation is that many refineries in the US prefer imported to domestically-produced crude oil creating a mismatch between domestic supply and customer demand (Johnson, 2015).

This regulatory constraint ultimately disappeared when the ban on exports was lifted in December 2015, making it possible for the increase of crude oil from fracking to enter the global market. Since this change, the absolute growth of exports has been slow – from 465,000 barrels a day in 2015 to 520,000 barrels a day in 2016 – but the mix of destinations for this oil has changed dramatically. In 2015, 92 percent of exports went to Canada – due to an exception to the ban made by President Reagan in 1985 –, but Canada's share was less than 60 percent in 2016. Other key destinations for exports include the Netherlands (7.3 percent), Curacao (5.8 percent), China (4.4 percent), Italy (4.0 percent) and the U.K. (3.1 percent). This shift became even more pronounced over time as Canada and China received 32 and 30 percent of exports respectively in April 2017 (USEIA 2017b). These changes highlight that the third key geographic factor constraining the law of one price prior to 2016, that is, a long-standing national system of regulation, is clearly no longer shaping US producers' participation in the global oil market.

6. Conclusion

This paper demonstrates the key role played by geography in the operations of seemingly global financial markets. After a long history of almost perfect co-movement, the two leading indicators for crude oil prices, WTI and Brent, fell apart. Historically, the US's status as the largest importer of crude oil – and thus the key marginal consumer of oil in the global market – ensured price equilibrium within the US and world markets through arbitrage and created a long-standing norm. When the WTI price increased relative to Brent prices, market actors could purchase oil in the North Sea (or elsewhere adjusting for differences in quality) and ship it to the US as long as the spread was large enough to cover transportation costs and the actors' profit margin. The consistency of this norm is remarkable, with the WTI price consistently higher than Brent. It contrasts sharply with the period of 2011-2016, during which the WTI was lower 63 percent of the time, with less than two percent of all days showing a spread of a dollar or higher (see Figure 4A).

Arbitrage in reverse direction has not been possible due to three circumstances: First, an infrastructure mismatch with a pipeline system that has been built to pump crude oil from the Gulf Coast via Cushing to the refineries in the U.S., but not

the other way round. Oil from new extraction sources left Cushing, OK with an oil glut with strongly depressed prices relative to Brent. Second, financial markets have not been able to leave Cushing behind and switch to another sort of crude oil and/or to a more suitable delivery point as a base ("underlying"). This left the existing WTI financial complex, including derivatives and markets, in place. The persistence of financial markets is stupefying: While the global markets largely shifted to Brent and Brent-related instruments as a benchmark indicator, WTI continued as the leading U.S. index. After all this years as a defunct indicator not only for the global oil market but also for the U.S. market, the financial instruments surrounding WTI are still in place and traded as intensively as before. Without an alternative in place, the lock-in effect of the complex web of financial instruments and financial markets are immense. The third factor blocking is the crude oil export ban that the U.S. only lifted at the end of 2015. It is important to note, however, that in 2016, the United States exported about 0.5 million barrel per day of crude oil but at the same time it still imported 7.9 million barrel per day (USEIA 2017c): The U.S. remained and will further remain a net importer of crude oil.

In fact, WTI might face a rebound as global indicator in the future, while Brent might decline: The oil fields that feed into "Brent" crude oil are emptying, and other oil fields with different qualities might have to be included in Brent in the near future (see Platts 2016). So, a similar geography-based "fallout" could happen to Brent as well. Given, however, the stickiness of the financial instruments around a specific underlying, it is hard to imagine that the financial instruments complex surrounding "Brent" as a brand will vanish anytime soon.

While price equilibrium in the global crude oil market was ultimately restored, it took five years to achieve, a remarkable example of how market specificities – legal, institutional and geographical – matter even for the most globalized financial commodity markets. Market participants and analysts who downplay these specifics in favor of generalized and ideal assumptions risk running aground on unseen shoals of geography.

References

Baraniuk, C. (2016), Why are more and more oil ships anchoring off Singapore? BBC Future, June 29, Available at http://www.bbc.com/future/story/20160628-why-are-more-and-more-oil-ships-anchoring-off-singapore. Accessed on July 19, 2017.

Barberis, N., Thaler, R. (2003), A survey of behavioral finance, in: Constantinides, G.M., Harris, M., and Stulz, R. M. (eds.) *Handbook of the Economics of Finance 1*, pp. 1053-1128. Amsterdam: North-Holland.

Blas, J. (2011), WTI-Brent price divergence hits record $16. Financial Times, February 10, Available at http://www.ft.com/cms/s/0/3295504e-3550-11e0-aa6c-00144feabdc0.html. Accessed on May 4, 2017.

Bridge, G. (2010), Geographies of peak oil: The other carbon problem. *Geoforum*, 41(4): 523-530.

Bridge, G., & Wood, A. (2005), Geographies of knowledge, practices of globalization: learning from the oil exploration and production industry. Area, 37(2): 199-208.

Bridge, G., Wood, A. (2010), Less is more: Spectres of scarcity and the politics of resource access in the upstream oil sector. *Geoforum*, 41(4): 565-576.

Calvert, K. (2016), From 'energy geography' to 'energy geographies' Perspectives on a fertile academic borderland. *Progress in Human Geography*, 40(1): 105-125.

Carollo, S. (2012), The divorce between Brent and the oil prices, Statement at the Conference on Modeling and Forecasting Oil Prices, Oslo, March 22-23, Available at http://www.norges-bank.no/en/about/Research/Conferences/2012-Modeling-and-forecasting-oil-prices/. Accessed on July 19, 2017.

Clark, G.L., Wójcik, D. and Bauer, R. (2006), Geographically dispersed ownership and inter-market stock price arbitrage – Ahold's crisis of corporate governance and its implications for global standards. *Journal of Economic Geography*, 6(3): 303-322.

CMEgroup (2017), Crude Oil Futures Contract Specs. Available at http://www.cmegroup.com/trading/energy/crude-oil/light-sweet-crude_contractSpecs_futures.html. Accessed on July 21, 2017.

Fattouh, B. (2010), Price Formation in Oil Markets: Some Lessons from 2009, Oxford Energy Comment March 2010, www.oxfordenergy.org/wpcms/wp-content/uploads/2011/04/comment_03_02_10.pdf. Accessed on July 19, 2017.

Fattouh, B. (2012), The Dubai Benchmark and its Role in the International Oil Pricing System, Oxford Energy Comment March 2012, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2012/03/The-Dubai-Benchmark-and-its-Role-in-the-International-Pricing-System.pdf. Accessed on July 19, 2017.

Fielden, S. (2015a), Crazy Little Crude Called Brent – The Art Of Quality Maintenance. RBM Energy. March 11. Available at https://rbnenergy.com/crazy-little-crude-called-brent-the-art-of-quality-maintenance. Accessed on March 20, 2017.

Fielden, S. (2015b), Crazy Little Crude Called Brent – The Physical Trading Market. RBM Energy. February 28. Available at https://rbnenergy.com/crazy-little-crude-called-brent-the-physical-trading-market. Accessed on March 20, 2017.

Grinblatt, M., Keloharju, M. (2009), Sensation Seeking, Overconfidence, and Trading Activity. *The Journal of Finance*, 64(2): 549–578.

Hamilton, J. (2011), Brent-WTI spread. Econbrowser, Available at http://econbrowser.com/archives/2011/02/brentwti_spread. Accessed on May 4, 2017.

Hemmingsen, E. (2010), At the base of Hubbert's Peak: Grounding the debate on petroleum scarcity. *Geoforum*, 41(4): 531-540.

Huber, M. T. (2011), Enforcing scarcity: oil, violence, and the making of the market. *Annals of the Association of American Geographers*, 101(4): 816-826.

ICE (2013), ICE Brent - Key Facts and Summary, Available at https://www.theice.com/publicdocs/futures/ICE_Brent_FAQ.pdf. Accessed on July 24, 2017.

Investopedia (2017), Arbitrage, Investopedia, Available at http://www.investopedia.com/terms/a/arbitrage.asp. Accessed on March 8, 2017.

Johnson, K. (2015), U.S. Aims to Lift 40-Year-Old Oil Export Ban. Foreign Policy. December 16. Available at http://foreignpolicy.com/2015/12/16/u-s-aims-to-lift-40-year-old-oil-export-ban/. Accessed on March 15, 2017.

Kahneman, D., Tversky, A. (1979), Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, 47(2), pp. 263-291.

Kennedy, E. (2014), From Petro-States to 'new realities': Perspectives on the Geographies of oil. *Geography Compass*, 8(4): 262-276.

Kilian, L., Murphy, D.P. (2014), The role of inventories and speculative trading in the global market for crude oil. *Journal of Applied Econometrics*, 29(3): 454-478.

Kimes, B. (2005), *Pioneers, Engineers, and Scoundrels: The Dawn of the Automotive Industry in America*. Warrendale, PA: Society of Automotive Engineers Inc.

Kurt, D. (2015), Understanding Benchmark Oils: Brent Blend, WTI and Dubai. Investopedia, Available at http://www.investopedia.com/articles/investing/102314/understanding-benchmark-oils-brent-blend-wti-and-dubai.asp?lgl=rira-baseline-vertical. Accessed on July 21, 2017.

Labban, M. (2010), Oil in parallax: Scarcity, markets, and the financialization of accumulation. *Geoforum*, 41(4): 541-552.

Levine, S., Taylor, G., Arthur, D. and Tolleth, M. (2014), Understanding Crude Oil and Product Markets. American Petroleum Institute. Available at: http://www.api.org/~/media/Files/Oil-and-Natural-Gas/Crude-Oil-Product-Markets/Crude-Oil-Primer/Understanding-Crude-Oil-and-Product-Markets-Primer-Low.pdf. Accessed on May 11, 2017.

MacKenzie, D. (2003), Long-Term Capital Management and the sociology of arbitrage. *Economy And Society*, 32(3): 349-380.

Manescu, C., Van Robays, I. (2014): Forecasting the Brent Oil Price - Addressing time-variation in forecast performance. ECB Working Paper Series, No. 1735, Available at https://www.ecb.europa.eu/pub/pdf/scpwps/ecbwp1735.pdf?5b3da5f02f68ed3ba6edf6088630ab16. Accessed on July 24, 2017.

Martén, I. and Jiménez, B. (2015), Brent Crude Oil: A Benchmark in Decline?, bcg.perspectives, Available at https://www.bcgperspectives.com/content/articles/energy-environment-brent-crude-oil-benchmark-in-decline/. Accessed on July 21, 2017.

Moeller, M. (2013), Enbridge Oil Tank Farm in Cushing, Oklahoma. CNN, November 6, Available at https://www.c-span.org/video/?315800-3/enbridge-oil-tank-farm-cushing-oklahoma&start=601. Accessed on July 19, 2017.

Pasqualetti, M. J. (2009), The Alberta oil sands from both sides of the border. *Geographical Review*, 99(2): 248-267.

Pasqualetti, M. J. (2011), The Geography of Energy and the Wealth of the World. *Annals of the Association of American Geographers*, 101(4): 971-980.

Platts (2016), Platts opens formal review of additional crudes for Dated Brent. Subscriber Note, Available at https://www.platts.com/subscriber-notes-details/27722426. Accessed on July 24, 2017.

Röder, J. (2015), Die Zeit der Öltanker, Handelsblatt, January 9, Available at http://www.handelsblatt.com/finanzen/anlagestrategie/zertifikate/nachrichten/oel-investments-die-zeit-der-oeltanker/11196938.html. Accessed on July 19, 2017.

Sanderson, H. (2014), Dominant holder highlights problems in aluminium market, Financial Times, December 11, Available at https://www.ft.com/content/59ed48e6-7fb0-11e4-adff-00144feabdc0. Accessed on March 30, 2017.

Schieldrop, B. (2013), Setting the price of crude oil - SEB Commodity Research, May 2013, Available at https://www.energimyndigheten.se/contentassets/937f1766e63a4755a825229c1fa2450e/bjarne_schieldrop.pdf. Accessed on July 24, 2017.

Sheppard, E. (2005), Constructing free trade: from Manchester boosterism to global management. *Transactions of the Institute of British Geographers*, 30(2): 151-172.

Shleifer, A., Vishny, R.W. (1997), The Limits of Arbitrage. *The Journal of Finance*, 52(1): 35-55.

Smith, C. (2016), Cushing: The pipeline crossroads of the world. Tulsa World. February 21, Available at http://www.tulsaworld.com/business/energy/cushing-the-pipeline-crossroads-of-the-world/article_bba76566-248d-544b-b834-879764e90f2d.html. Accessed on March 11, 2017.

Strumpf, D. (2011), WTI, Brent Oil Set to Reconcile. Barron's, Available at http://www.barrons.com/articles/SB50001424052748704407404576651354193488820?mod=BOL_twm_mw. Accessed on May 4, 2017.

Tversky, A., Kahneman, D. (1974), Judgment under Uncertainty: Heuristics and Biases. *Science, New Series*, 185: 1124-1131.

UNCTAD (2016), *UNCTAD Handbook of Statistics 2016*, New York: United Nations. Available at http://unctad.org/en/PublicationsLibrary/tdstat41_en.pdf, Accessed on March 30, 2017.

USEIA (US Energy Information Administration). (2012a), Crude oils have different quality characteristics, Available at https://www.eia.gov/todayinenergy/detail.php?id=7110. Accessed on May 11, 2017.

USEIA (US Energy Information Administration). (2012b), North American spot crude oil benchmarks likely diverging due to bottlenecks, Available at https://www.eia.gov/todayinenergy/detail.php?id=6790, Accessed on July 20, 2017.

USEIA (US Energy Information Administration). (2013), Bakken crude oil price differential to WTI narrows over last 14 months, Available at https://www.eia.gov/todayinenergy/detail.php?id=10431. Accessed on July 20, 2017.

USEIA (US Energy Information Administration). (2016), Annual Energy Outlook 2016 (AEO2016), Available at http://www.eia.gov/pressroom/presentations/sieminski_06282016.pdf. Accessed on March 20, 2017.

USEIA (US Energy Information Administration). (2017a), Layer Information for Interactive State Maps, Available at https://www.eia.gov/maps/layer_info-m.php. Accessed on May 4, 2017.

USEIA (US Energy Information Administration). (2017b), Data Series on PETROLEUM & OTHER LIQUIDS, Available at https://www.eia.gov/petroleum/. Accessed on May 4, 2017.

USEIA (US Energy Information Administration). (2017c), Oil: Crude and Petroleum Products Explained - Oil imports and exports, Available at https://www.eia.gov/energyexplained/index.cfm?page=oil_imports. Accessed on July 24, 2017.

Worth, K. (2011), Trading The End Of The Brent-WTI Spread. SeekingAlpha, Available at https://seekingalpha.com/article/308777-trading-the-end-of-the-brent-wti-spread. Accessed on May 4, 2017.