Journal of Banking and Finance 95 (2018) 27–43

Contents lists available at ScienceDirect

Journal of Banking and Finance

journal homepage: www.elsevier.com/locate/jbf

The impact of commodity benchmarks on derivatives markets: The case of the dated Brent assessment and Brent futures

Alex Frino[a,d,1], Gbenga Ibikunle[b,e,f,*], Vito Mollica[c,d,2], Tom Steffen[b,c,d,3]

[a] University of Wollongong, Australia
[b] University of Edinburgh Business School, United Kingdom
[c] Macquarie Graduate School of Management, Sydney, Australia
[d] Capital Markets Cooperative Research Centre (CMCRC), Sydney, Australia
[e] European Capital Markets Cooperative Research Centre (ECMCRC), Pescara, Italy
[f] Centre for Responsible Banking and Finance, University of St Andrews, United Kingdom

ARTICLE INFO

Article history:
Received 15 September 2016
Accepted 25 August 2017
Available online 26 August 2017

JEL classification:
G13
G14
Q02
Q41

Keywords:
Dated Brent
Physical crude oil
Benchmark assessment
Brent futures

ABSTRACT

We examine the response of ICE Brent Crude futures to the spot Dated Brent benchmark published by Platts. Trading activity in the futures market intensifies during the benchmark assessment. We also find trading in the direction of the published benchmark during the price assessment window. Aligned positions and a substantially increased arrival rate of informed traders suggest that sophisticated traders, taking advantage of a rise in uninformed trading activity, induce the price run-up in Brent futures, ahead of the Dated Brent assessment end. The general increase in the arrival rate of both informed and uninformed traders during the assessment window underlines the benchmark's relevance and its potential for attracting liquidity. Our results are robust to alternative specifications and underscore the significance of physical commodity benchmarks as critical elements of the financial market infrastructure.

1. Introduction

Benchmarks occupy a central role in stimulating the flow of information between exchange-traded and over-the-counter (OTC) instruments by establishing settlement prices and improving transparency (see Duffie et al., 2016). Due to their importance, benchmarks and their administration are increasingly gaining the attention of regulatory bodies in relation to their architecture and the regulatory oversight they are or should be subjected to (see FCA, 2015).[4] With regards to oil, the most actively traded and one

* Corresponding author at: University of Edinburgh Business School, 29 Buccleuch Place, EH8 9JS, Edinburgh, UK.

E-mail addresses: afrino@uow.edu.au (A. Frino), gbenga.ibikunle@ed.ac.uk (G. Ibikunle), vito.mollica@mgsm.edu.au (V. Mollica), tsteffen@cmcrc.com, gibikunle@yahoo.com (T. Steffen).

[1] University of Wollongong, NSW 2522, Wollongong, AU.

[2] Macquarie Graduate School of Management, NSW 2109, Sydney.

[3] University of Edinburgh Business School, 29 Buccleuch Place, EH8 9JS, Edinburgh, UK

The Capital Markets Cooperative Research Centre (CMCRC) funded this research. We thank Platts Singapore and the Securities Industry Research Centre of Asia-Pacific (SIRCA) for facilitating the acquisition of the data. We thank two anonymous referees, the managing editor, Carol Alexander, and the special issue guest editors, Marcel Prokopczuk, Andrea Roncoroni and Ehud Ronn for their constructive and helpful feedback. We are grateful to conference participants at the SGF Conference 2016 (Zurich), International Conference on Capital Markets and Innovation, Systemic Risk and Supervision (Tianjin), 2016 Commodity Markets Conference (Hannover), Energy and Commodity Finance Conference 2016 (Paris), European Financial Management Association 2016 Doctoral Seminar (Basel), 2016 Financial Management Association Annual Meeting (Las Vegas), Jo Danbolt, Sean Foley, Richard Heaney, Stefan Hunt, Can Inci, Alexander Kurov, David Lesmond, Peter O'Neill, Bill Rees, Pierangelo Rosati, Felix Suntheim, Terry Walter, Chardin Wese-Simen, and colleagues at the CMCRC and the University of Edinburgh for helpful comments and discussions. The views expressed in the paper are those of the authors. All remaining errors are our own.

[4] In 2012, the International Organization of Securities Commissions (IOSCO) published the *Principles for Oil Price Reporting Agencies*. Starting with the LIBOR, the Financial Conduct Authority (FCA) introduced the first regulatory benchmark regime in April 2013. Two years later, in April 2015, the FCA expanded its regulatory supervision to seven other key benchmarks: LIBOR, SONIA, RONIA, WM/Reuters London 4pm Closing Spot Rate, ISDAFIX, LBMA Gold Price Fixing, LBMA Silver Price Fixing and the ICE Brent Index (FCA, 2015). The 2015 and 2016 *Fair and Effective Markets Review,* conducted by the Bank of England (BoE), HM Treasury (HMT), and the FCA, identify several shortcomings in the Fixed Income, Currencies and Commodities (FICC) markets and from July 2016, the *Market Abuse Regulation* (MAR) regards the manipulation of benchmarks as a civil offence across the EU. The *EU Benchmarks Regulation* will enter into force at the beginning of 2018.

http://dx.doi.org/10.1016/j.jbankfin.2017.08.017

of the most economically important commodities in the world, the International Organization of Securities Commissions (IOSCO) has set out recommendations aimed at enhancing the quality and reliability of its price benchmarks. Nevertheless, the administration of spot oil benchmarks currently remains unregulated. The EU legislation on benchmarks, to be applied from January 2018 onwards, will be the first comprehensive regulatory framework under which physical commodity benchmarks can be considered for direct supervision. Several price reporting agencies (PRA)[5] currently assess and publish oil benchmark prices, however the Dated Brent benchmark, operated by S&P Global's Platts, has come to dominate this space. The Platts Dated Brent benchmark prices approximately 67% of the global physical (spot) oil traded (Davis, 2012). This dominance also underscores its importance to the derivatives/financial (paper) markets for oil.

Following unannounced searches of the offices of several crude oil market participants by the European Commission and the European Free Trade Association (EFTA)[6] in early 2013, reports of price distortion of the Platts Dated Brent benchmark began to emerge in the financial press (see as examples Kemp, 2013; Mackey and Lawler, 2013; Makan et al., 2013; Van Voris et al., 2013). More recent news suggests that trading activities at the interface between the physical and financial oil market are still controversial (see as examples Cooper, 2017; Hurst and Blas, 2017). Despite these reports, a limited number of studies have analyzed the impact of the Dated Brent benchmark assessment on financial oil markets more generally. To the best of our knowledge, only Inci and Seyhun (2015) and Swinand and O'Mahoney (2014) have utilized Platts benchmark data. Inci and Seyhun (2015) examine the market dynamics between the spot and futures markets and report a high level of integration, while Swinand and O'Mahoney (2014) examine calendar spreads in order to identify instances of price anomalies in the Brent crude complex. The difficulty in using calendar spreads lies in the increasing level of spread mispricing as the front month futures contract approaches maturity (see Frino and McKenzie, 2002).

In this paper, we examine trading behavior in the ICE Brent Crude futures contract around the assessment of the Dated Brent benchmark price, computed daily by Platts based on the trading activity in the North Sea spot oil market. Of particular interest is the 30 min window from the start to the end of the daily Dated Brent price assessment at precisely 16:30 London time — otherwise known as the *Platts Window*. Specifically, based on the assumption of a pricing error-correction relationship (e.g., Hasbrouck, 1995) between the physical and financial oil markets, we hypothesize that both markets are integrally linked such that Brent futures will be sensitive to the Platts Dated Brent benchmark assessment. Secondly, based on the informational relevance of the intersection of the two crude oil market dimensions (i.e. the physical and the financial oil markets), we investigate whether participants in the Platts Dated Brent benchmark assessment, having become privy to the trading pressure evidenced during the assessment, drive the Brent futures price in the direction of the Dated Brent benchmark assessment.

Our results provide evidence of a significant increase in trading activity in the ICE Brent Crude futures contract during the Dated Brent price assessment. We also show that an informed trader could earn average profits of between 8 bps and 24 bps during the 30 min benchmark assessment, as Brent futures experience a significant price run-up in the direction of the impending benchmark price. The price run-up is followed by a price reversal. Furthermore, benchmark-aligned trade order imbalances and acceleration in the arrival rate of informed traders during the Platts Window suggest that the directional trading behavior is at least partly information-driven.[7] Nevertheless, uninformed traders also participate in the Brent futures market during the Platts Window. Indeed the presence of uninformed traders is critical to the price discovery process in the futures market. Glosten and Milgrom (1985) and Kyle (1985) show that informed traders earn arbitrage gains when trading with uninformed traders. This form of price discovery ensures the transfer of private information from informed traders to the rest of the market.

This study makes two key contributions to the literature. Firstly, we undertake an empirical analysis of the fundamental spot crude oil event, the Dated Brent benchmark assessment, and the intraday response of Brent futures traded on ICE Futures Europe. Our results underscore the significance of physical commodity benchmarks as integral elements of the global financial market infrastructure and price discovery in commodity markets. Secondly, our analysis of information-related interactions between two market structures is unique in that the benchmark assessment window by Platts provides a natural experiment to examine the dynamics between the oil spot and derivatives markets. This differs from other fixing events such as in the precious metals market, where the benchmark fixing period length is indeterminate (see Caminschi and Heaney, 2014), or in the case of information events that do not have a precise release timestamp (see Vega, 2006; Tetlock, 2010; Bernile et al., 2016).

The remainder of this article is organized as follows: the next section presents the institutional background to the study and discusses the existing related literature; section three introduces the data; section four sets out the methodology and results; and section five concludes.

2. Background

2.1. Institutional details

Variability in the grades of oil available for trade at any point in time compels spot traders to apply 'formula pricing' to value any contracted cargo of crude oil, by adding or subtracting a spread to an agreed benchmark price as calculated by a PRA (Dunn and Holloway, 2012). The PRA publishing the industry-leading benchmark price for Dated Brent is Platts.[8] Dated Brent refers to the price of a physical cargo of North Sea Brent, Forties, Oseberg or Ekofisk (BFOE) crude oil with an assigned loading date for shipping — a *dated* cargo. Platts operates an online data-entry and communications system called *eWindow* that is used to establish the Dated Brent benchmark price in the Market on Close (MOC) process.[9] The MOC methodology has the advantage of promoting liquidity, as it concentrates spot market activity over a short timeframe at the end of the day (Barret, 2012a). Our investigation focuses on the daily half-hour (16:00 – 16:30) window during which the Dated Brent is computed. During this half-hour assessment window, Platts considers a combination of three

[5] PRAs classify themselves as media organizations and information providers, collecting and channeling commodity market intelligence into independent benchmark prices. The four major PRAs are Platts, Argus, ICIS and OPIS.

[6] Please refer to http://www.shellnews.net/documents/WhiteOaksFund.pdf and http://www.businessweek.com/pdfs/crude-complaint-11-6.pdf for further information.

[7] Data limitations complicate our attempts to disentangle the trading practices leading to directional trading behavior. However, the common feature making the directional trading worthwhile is, arguably, an informational advantage, most plausibly gained in the physical crude oil market. In this paper, given our findings, we reason in favor of informed trading activity leading to a 'correct' futures price adjustment during the ongoing physical benchmark assessment.

[8] Dated Brent is estimated to serve as a price marker for anywhere between 50% and 80% of the world's physical crude oil trade (see Barret, 2012a; Barret, 2012b; Davis, 2012; Dunn and Holloway, 2012; Mathur, 2013; Tuson, 2014).

[9] Please refer to Appendix 1 for more details.

physical OTC variables: (i) physical North Sea cargoes; (ii) short-term swaps between Dated Brent and Forward Brent (i.e. Contracts for Difference, CFD); and (iii) outright Forward Brent (also called cash BFOE). The window itself can be divided into three phases, determined by cut-off periods. During the first phase, market participants submit new bids/offers for physical North Sea cargoes, traded as a differential to Dated Brent or Forward Brent; the new entry cut-off for this is 16:10:00. New bids/offers for CFD contracts are assessed in the second phase, with a new entry cut-off of 16:15:00. The third cut-off for new outright cash BFOE bids/offers is 16:25:00. Notwithstanding the specified cut-offs for new entries, existing physical North Sea bids/offers and CFD bids/offers may be amended until 16:25:00. Finally, prices for cash BFOE can be changed until the window close at 16:30:00. This last phase is judged to be of critical importance and described as particularly stressful for both Platts and the physical market participants, not least because cash BFOE is the last and only element of the assessment traded at a flat price. Based on these three inputs, Platts calculates a price for each of the four North Sea grades (Brent, Forties, Oseberg, Ekofisk),[10] with the cheapest grade setting the daily Dated Brent price. The Dated Brent price reflects the transactable value precisely at 16:30:00 London time.

Only a limited number of companies, mastering the operational and logistical requirements of trading spot oil, participate in physical oil trading via eWindow. The firms are also required to satisfy Platts' due diligence requirements. According to multiple sources and discussions with the industry, there is only a handful of active trading companies participating each day (see also Fattouh, 2011; Barret, 2012a). In addition to the trading participants, a larger but still limited number of subscribers to Platts' fee-based *Global Alert* (PGA) real-time information service can follow the live physical trading activity and order-flow information (transactions, bids, asks) throughout the benchmark assessment period.[11]

2.2. Related literature

Recent theoretical research by Duffie et al. (2016) highlights the key role benchmarks play in enhancing price transparency and liquidity in the underlying market. Several empirical studies examine the effects of benchmarks and their operation on the trading behavior of related derivatives, some reporting a positive and others a negative impact. This literature is limited and restricted to the precious metals, fixed income and foreign exchange markets. The assessment procedures of these markets differ significantly from that of the oil market.

In the precious metals market, Caminschi and Heaney (2014) examine the short-term reaction of gold futures and exchange-traded funds (ETF) to the London PM Gold price fixing, and conclude that information from the benchmark assessment proceeding (for example, price direction) leaks into the gold derivatives market well before the official price publication. Similarly, Aspris et al. (2015) investigate the effects of the replacement of a traditional closed fixing auction for precious metals with a more transparent and enhanced electronic-based auction platform on related futures contracts. They show that the new regulated regime leads to a significant improvement in market quality. In terms of the fixed income market, several studies examine market dynamics around the London Interbank Offered Rate (LIBOR). Abrantes-Metz et al., (2012) describe patterns suggestive of collusion and manipulation of the 1-month LIBOR rate, while Fouquau and Spieser (2015) find that their identification of manipulating banks corresponds to those classified by the regulator as having played a major role in the 2012 LIBOR scandal. Monticini and Thornton (2013) show that the underreporting of LIBOR quotes by certain participating banks likely led to reduced rates. Additionally, Evans (2016) reports asymmetric behavior in price changes and volatility for 21 currency pairs during the WM/Reuters London 4pm FX benchmark fixing vis-à-vis normal trading periods. Contrary to the expectations of dealers sharing risks, Evans (2016) identifies trading strategies consistent with collusive and manipulative behavior that lend themselves to significant economic trading opportunities. More recently, several studies focus on the reformation of financial benchmarks in light of a number of regulatory investigations (e.g., Duffie and Stein, 2015; Perkins and Mortby, 2015).

The benchmark structure, process and operation in these markets are, however, different to those in place for oil markets in terms of design, transparency and regulation. The question remains: what is the observed response of the paper oil market to the assessment of the key spot oil benchmark?

2.3. Directional trading

Directional trading — the adoption of a futures position during the assessment window that is aligned with the benchmark outcome,[12] can result from a number of different trading practices by different participant groups. For example, such trading behavior could be due to an intention to manipulate the market by influencing the benchmark price direction, and simultaneously executing an aligned futures position. Makan (2013) cites an anonymous trader in an interview with the Financial Times, stating that "[*t*]he game of having a leveraged position in the futures market and then trying to change the Platts price by a few cents is as old as the market itself". While alleged manipulation may be one possibility, it is not within the scope of this study. Secondly, a trader could also anticipate the benchmark direction through Brent futures speculation based on intelligence gained in the physical spot market, through either commercial participation or proprietary commodities trading, for example. A third reason is linked to spot-futures arbitrage activity based on the fundamental value relationship between spot and futures. Arbitrageurs are strictly defined as being informed from a market microstructure perspective (e.g., Chordia et al., 2008; Moore and Payne, 2011), and thus contribute to the futures price discovery during the Platts assessment window by speedily translating information from the spot market into futures prices. Fourthly, trading in futures could further arise due to natural hedging activity of commercial users in order to cover physical exposure. The common feature making any of the above worthwhile is arguably an informational advantage, most plausibly gained in the physical crude oil market. As an example, consider a physical market participant such as a commercial user who is closely monitoring the oil market and is thus informed of the spot market fundamentals such as demand and supply. The informed trader can try to anticipate the dynamics during the Platts Window, and aligns his futures positions accordingly. Benchmark submitters naturally belong to this category of traders. Alternatively, as physical trade and order flow is revealed during the Platts assessment, an informed trader can continuously judge the extent to which the information is incorporated into the futures price, and act if he identifies a divergence from the fundamental spot-futures relationship. Both examples would lead to a futures price adjustment in the direction of the Dated Brent fixing outcome ahead of its assessment end.

[10] Prices for the four grades vary due to differing oil qualities.

[11] We interchangeably refer to the Platts process as the assessment or fixing. Unlike several other commodities, such as the precious metals market, the physical oil market has no official fixing system. However, over time a few PRAs have adopted the role of benchmark administrators.

[12] In the context of this paper directional trading strictly refers to this definition, and not to other strategies such as directional options trading.

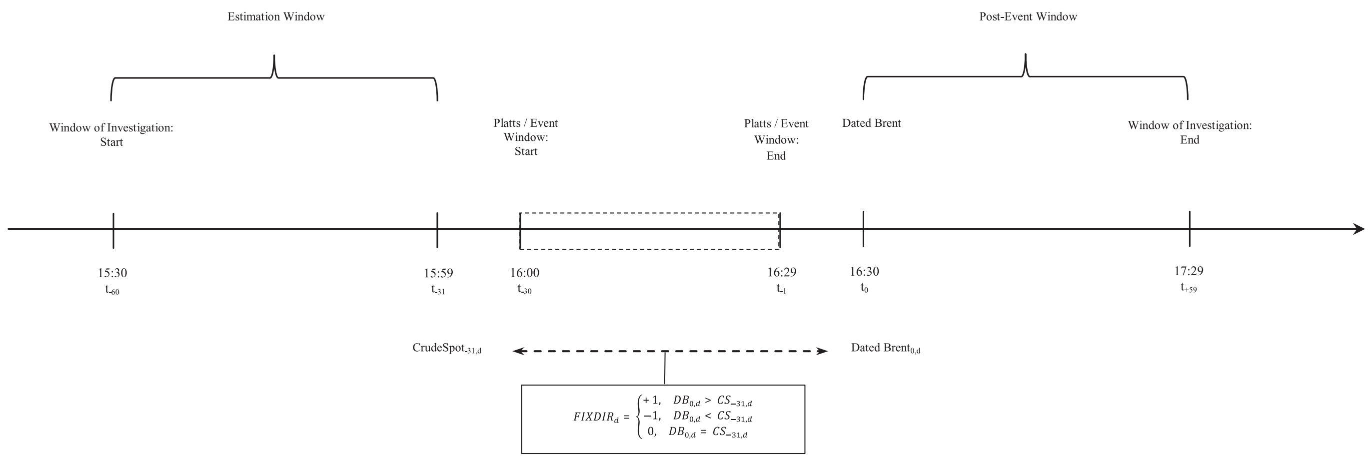

Fig. 1. Window of investigation.
Notes: This figure illustrates the event study design applied to analyze trading behavior surrounding the Platts Dated Brent price assessment. *DB* and *CS* represent the price of Dated Brent and the BFO crude spot in interval *t* on trading day *d*, respectively. Timestamps represent interval start times. The estimation window covers interval t_{-60} to t_{-31} [15:30:00, 15:59:59]. The event window covers t_{-30} to t_{-1} [16:00:00, 16:29:59]. The post-event window covers t_0 to t_{+59} [16:30:00, 17:29:59].

Wang (2002) and Frino et al. (2016) argue that hedgers may indeed be informed, given their proximity to the underlying good or customer, and this may also hold true for the spot oil market. In our case, however, the hedging theory does not align with the results presented in this paper. In order to hedge a physical transaction executed during the Platts Dated Brent benchmark assessment, a futures position in the opposing direction to the spot fixing would need to be adopted. As illustrated above, the more plausible explanations are physical market-informed futures speculation or spot-futures arbitrage.

3. Data and study design

Intraday data for the ICE Brent Crude futures and the Brent-Forties-Oseberg (BFO) crude oil spot, with identifiers LCOc1 and BFO- respectively, are obtained from the Thomson Reuters Tick History (TRTH) database. Both datasets include trade and quote information time stamped to the nearest millisecond. The Brent Crude futures are listed for each month 7 years forward, and are cash settled against the ICE Brent Index.[13] We sample only the front month, closest-to-maturity futures contract and rollover to the next contract at expiry.[14] The BFO spot price, constructed by Thomson Reuters, is based on a combination of the futures price (either ICE Brent or NYMEX WTI, depending on the time of the day), Exchange Futures for Physical (EFP)[15] values, and the ICE close. The BFO serves as a public estimate of the intraday oil price in light of the OTC nature of oil markets. We use the BFO series as an approximation of the Brent crude oil spot price immediately ahead of the Platts Window start at $t_{-31} = 15{:}59$ (see Fig. 1). Finally, we acquire price data for the daily Dated Brent benchmark, with identifier PCAAS00, from Platts Singapore. The Platts data contain daily Dated Brent prices timestamped at 16:30 London time. Our full period of investigation comprises of observations from 9th January 2012 to 31st March 2016 inclusive, some 1056 trading days.

[13] Our analysis does not focus on the ICE Brent Index that is published only on a monthly basis for cash settlement purposes, following the expiry of the ICE Brent Crude futures front month contract.

[14] Using only the nearest maturity contracts is consistent with the literature on commodity derivatives. This is mainly because the nearby futures contract is typically the most liquid, whereas the longer-dated contracts are predominantly thinly traded.

[15] An EFP allows traders to exchange a Brent futures position for a cash BFOE (forward) position and vice versa.

We sample data over the 120 min window of investigation [$t_{-60} = 15{:}30$, $t_{59} = 17{:}29$] covering an hour before and after the Dated Brent assessment end for each trading day *d*, as depicted in Fig. 1. The pre-benchmark *estimation window* extends [$t_{-60} = 15{:}30$, $t_{-31} = 15{:}59$] and the *post-event window* covers [$t_0 = 16{:}30$, $t_{+59} = 17{:}29$]. The *event time*, $t_0 = 16{:}30$ London local time, refers to the start of the interval covering the 16:30:00 Platts Dated Brent price. The Platts assessment or *event window* encompasses [$t_{-30} = 16{:}00$, $t_{-1} = 16{:}29$].[16]

4. Empirical analysis, results and discussions

4.1. Relative volume and volatility evolution around the dated Brent benchmark assessment

Consistent with Caminschi and Heaney (2014), we begin our analysis by examining the evolution of ICE Brent Crude futures intraday relative volume and volatility around the Dated Brent benchmark assessment window. We compute these measures for each interval *t* during the window of investigation, relative to a reference value measured over the 30 min estimation window, [$t_{-60} = 15{:}30$, $t_{-31} = 15{:}59$], for each trading day *d*, and then average across all sample trading days *D*. The 30 min estimation window reflects the average level of activity on *d*, independent of the benchmark assessment process.

The average relative volume per interval *t* is computed as follows:

$$VMref_d = \frac{1}{30}\sum_{t=-60}^{-31} \ln\left(VM_{t,d}\right) \tag{1}$$

$$\overline{VM_t} = \frac{1}{D}\sum_{d\in D} \frac{\left(\ln\left(VM_{t,d}\right) - VMref_d\right)}{VMref_d} \tag{2}$$

where $VM_{t,d}$ is defined as the total trading volume in Brent futures during any given 1-minute interval *t* on day *d*. $\overline{VM_t}$ is the average difference for each 1-minute interval *t*, between the log volume and the reference volume on day *d*, scaled by the reference volume on *d* such that it yields the percentage volume increase

[16] All time specifications are in London local time. During summer time, London local time corresponds to British Summer Time (BST = GMT + 1), whereas during the winter, London local time corresponds to GMT. BST begins at 01:00 GMT on the last Sunday of March and ends at 01:00 GMT on the last Sunday of October.

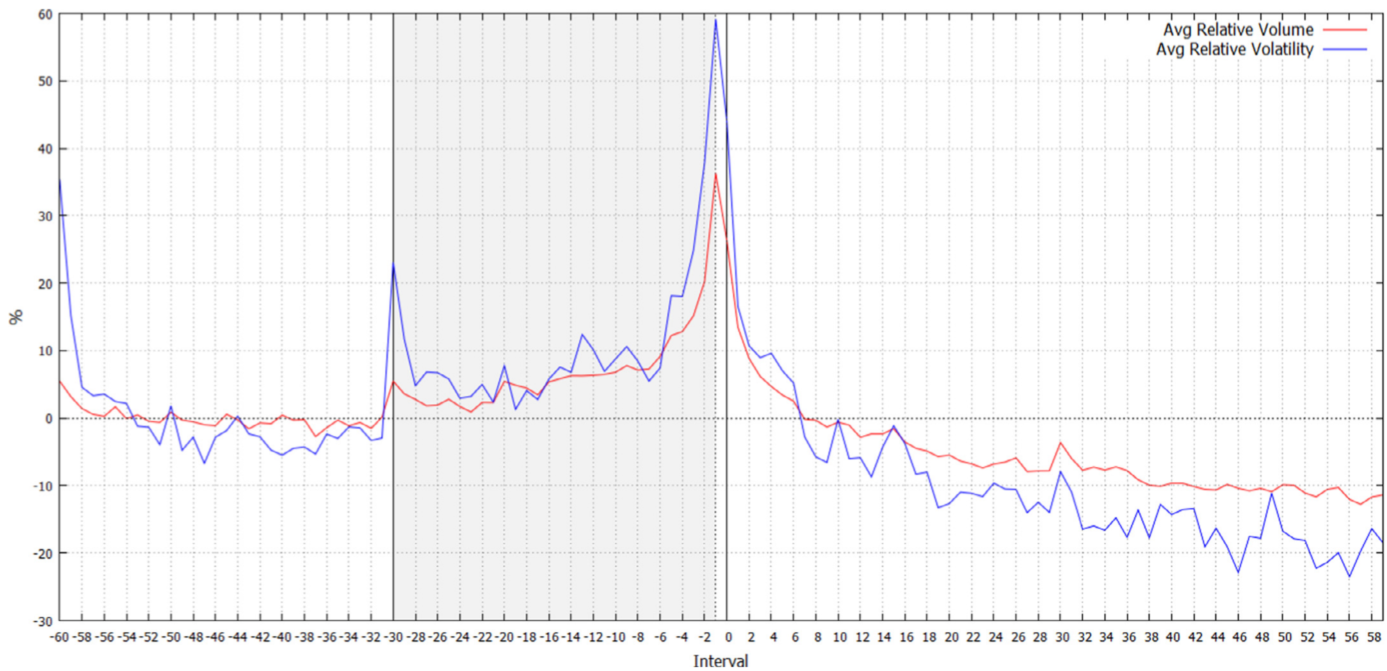

Fig. 2. Average trading activity in ICE Brent crude futures.
Notes: This figure shows the average relative volume and volatility. All measures are reported in percentage terms (%). The shaded area indicates the event window from fixing start (t_{-30}) to fixing end (t_{-1}) [16:00:00, 16:29:59]. The vertical black line marks the interval following the Platts Dated Brent assessment end: t_0 [16:30:00, 16:30:59].

or decrease relative to the estimation window. The log transformation normalizes the data, mitigates the skewness effect caused by the zero bound on volume, and improves the robustness of the subsequent t-tests (Caminschi and Heaney, 2014).

To measure Brent futures price volatility for each interval t of the window of investigation, we compute the standard deviation of 1-second returns within each 1-minute interval t on trading day d, and follow the same rationale as described in Eqs. (1) and (2).[17]

Results for the relative trading volume and volatility are reported in Fig. 2 and Table 1. For parsimony, we only report the sub-window [t_{-35} = 15:55, t_{+5} = 16:35] of the full 120 min window under investigation in Table 1. This sub-window covers 5 min before the fixing start and 5 min after the assessment end; the approach does not result in any loss of information.

Relative volume, as well as relative volatility, show enhanced values during the Platts Dated Brent price assessment. For $\overline{VM_t}$ in Panel A of Table 1 and Fig. 2, the increase in trading intensity coincides with the start of the Platts Window (t_{-30} = 16:00) and falls sharply thereafter (t_{+1} = 16:31). Average relative trade volume for ICE Brent Crude futures inflates by approximately 5.5% at the fixing start and rises to 36.3% above pre-benchmark assessment levels, with the highest trading volume recorded immediately prior to the end of the Dated Brent price assessment by Platts (t_{-1} = 16:29). Following the completion of the fixing, $\overline{VM_t}$ gradually reverts to pre-event levels. The increase in relative trading volume is statistically significant at the 1% level and persists for 30 min. Panel B of Table 1 and Fig. 2 report volatility behavior in ICE Brent Crude futures contracts. Relative volatility increases significantly by 23.1% immediately after the fixing start, and remains several percentage points above estimation window levels for the next 15 min (from t_{-28} = 16:02 to t_{-14} = 16:16). Volatility rises significantly again and peaks at 59.2% above estimation levels just before the Dated Brent Window end at 16:30. The last five minutes of the benchmark assessment are characterized by a particularly volatile futures market. As we observe in relation to volume, volatility declines at the fixing end and remains depressed during the post-event window (see Fig. 2). Overall, the results for the intervals during the 30-minute Platts Window from 16:00 (t_{-30}) to 16:29 (t_{-1}) are, for the most part, significantly different from zero for both measures. Trading activity peaks immediately before the Platts Window end, and is succeeded by a general decline thereafter.

Collectively, these findings strongly support our expectation that the financial oil market is sensitive to the Platts Dated Brent benchmark assessment, highlighting the benchmark process as an essential spot crude oil information event. The trading activity results imply that an unusually high number of traders arrive at the market after the fixing start and prior to the fixing end, as demonstrated by the high volume, and the Brent futures market is uncommonly 'alert and nervous' during the event window, as documented by the volatility levels. In the following sections, we further examine this view by conducting an analysis of the evolution of informed trading around the benchmark period.

4.2. Returns analysis around the dated Brent benchmark assessment

In order to evaluate our expectations regarding informed directional trading, we compute the *simple* and *directional returns* available to both 'uninformed' and 'informed' participants, respectively. The directional returns are a measure of hypothetical gains available to a trader who has an informational advantage over the general market. It is plausible that the informational advantage is derived from physical oil market intelligence, enabling, for example, futures speculation based on an ex ante approximation of the direction of the Dated Brent benchmark assessment, or

[17] We also compute the Garman and Klass (1980) volatility estimator, specified as follows:

$$V_{t,d} = \sqrt{\frac{1}{2}\left(\ln\left(\frac{H_{t,d}}{L_{t,d}}\right)\right)^2 - (2\ln(2)-1)\left(\ln\left(\frac{C_{t,d}}{O_{t,d}}\right)\right)^2}$$

where $H_{t,d}$, $L_{t,d}$, $O_{t,d}$, $C_{t,d}$ refer to high, low, open and close prices for the interval t on day d respectively. The results obtained with this approach are qualitatively similar to those reported for the 1-minute standard deviation estimates. Moreover, we calculate the average relative trade size using the same approach. For parsimony, the results, which are consistent with other trading activity measures, and a short discussion are presented in Appendix 2 to this paper.

Table 1
Trading activity in ICE Brent Crude futures.

		Panel A Avg relative volume			Panel B Avg relative volatility		
t_i	*Time*	*VM*	*Sign*	*t-value*	*V*	*Sign*	*t-value*
−35	15:55	−0.28		−0.52	−3.00	*	−1.68
−34	15:56	−1.11	**	−2.17	−1.28		−0.52
−33	15:57	−0.62		−1.15	−1.43		−0.7
−32	15:58	−1.49	***	−2.83	−3.29		−1.49
−31	15:59	0.19		0.32	−2.93		−1.44
−30	16:00	5.49	***	8.55	23.13	***	6.21
−29	16:01	3.60	***	5.64	11.70	***	3.93
−28	16:02	2.78	***	4.79	4.81	*	1.81
−27	16:03	1.85	***	2.9	6.83	**	2.18
−26	16:04	1.95	***	3.04	6.73	**	2.52
−25	16:05	2.82	***	4.43	5.81	**	2.22
−24	16:06	1.74	***	2.75	2.96		1.07
−23	16:07	0.92		1.44	3.23		1.1
−22	16:08	2.35	***	3.99	5.00	*	1.65
−21	16:09	2.33	***	3.5	2.39		0.82
−20	16:10	5.45	***	7.99	7.78	***	2.62
−19	16:11	4.88	***	7.71	1.31		0.54
−18	16:12	4.47	***	7.25	4.07		1.37
−17	16:13	3.46	***	5.36	2.77		1.02
−16	16:14	5.36	***	8.05	5.78	**	2.04
−15	16:15	5.85	***	9	7.57	**	2.49
−14	16:16	6.29	***	10.49	6.79	**	2.08
−13	16:17	6.28	***	10.16	12.40	***	3.44
−12	16:18	6.35	***	10.17	10.12	***	2.95
−11	16:19	6.49	***	10.04	6.94	**	2.14
−10	16:20	6.81	***	10.7	8.79	***	2.86
−9	16:21	7.80	***	12.75	10.61	***	3.36
−8	16:22	7.12	***	10.69	8.46	***	2.83
−7	16:23	7.28	***	11.52	5.49	**	2.14
−6	16:24	9.15	***	15.94	7.43	***	3.77
−5	16:25	12.24	***	20.51	18.14	***	4.33
4	16:26	12.84	***	20.37	18.04	***	6.76
3	16:27	15.17	***	28.14	24.86	***	8.45
−2	16:28	20.27	***	36.95	37.91	***	11.57
−1	16:29	36.29	***	63.55	59.18	***	18.98
0	16:30	26.33	***	46.44	44.08	***	16.46
1	16:31	13.46	***	22.82	16.55	***	5.93
2	16:32	8.85	***	14.11	10.72	***	3.61
3	16:33	6.18	***	10.34	8.96	***	3.06
4	16:34	4.69	***	8.46	9.62	**	2.47
5	16:35	3.42	***	5.77	7.02	*	1.84

Notes: This table reports the results of the average relative trading activity measures. Panels A and B present the results for the average relative volume and the average relative volatility respectively. Both measures are reported in percentage terms (%). The *t*-value is the statistic of a one sample *t*-test of the mean being equal to zero. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. Sample period is 09.01.2012–31.03.2016. Timestamps represent interval start times. The two single horizontal black lines represent the Platts Dated Brent fixing start and fixing end. The interval following the Platts Dated Brent assessment end is t_0 [16:30:00, 16:30:59] London local time.

spot-futures arbitrage incorporating information as the fixing progresses.

4.2.1. Simple returns

Simple returns are those available to a random long only investor, measured using the closing price $C_{t,d}$, for each 1 min interval t on trading day d. We standardize the returns across our sample periods as follows:

$$SR_{t,d} = \ln\left(\frac{C_{t,d}}{C_{t-1,d}}\right) \tag{3}$$

$$\overline{SR_t} = \frac{1}{D}\sum_{d\in D} SR_{t,d} \tag{4}$$

$$CSR_t = \sum_{t=-60}^{t} \overline{SR_t} - \sum_{t=-60}^{-31} \overline{SR_t} \tag{5}$$

$\overline{SR_t}$ describes the returns for interval t averaged across all trading days D; CSR_t measures cumulative simple returns in excess of an offsetting factor (see Eq. (5)) such that $CSR_{-31} = 0$ (Caminschi and Heaney, 2014), making it easier to determine the evolution of cumulative returns during the benchmark assessment process [t_{-30} = 16:00, t_{-1} = 16:29].

4.2.2. Directional returns

In order to measure returns attributable to an informed trader who trades in the direction of the benchmark assessment outcome in advance of its release, we compute directional returns. We follow Ederington and Lee (1995) and Caminschi and Heaney (2014) and sign simple returns using a spot fixing direction parameter. The direction factor takes the value of +1 (−1) if the published Platts Dated Brent price (t_0) on day d is higher (lower) than the price of the BFO crude oil spot on d immediately prior to the start of the Platts Window (t_{-31}), assuming that the informed trader takes a long (short) position (see Fig. 1). Based on this, our sample contains 527 positive, 521 negative, and 8 flat assessment days. Directional returns are hypothetical, and measured for each 1-minute interval t as follows:

$$FIXDIR_{t,d} = \begin{cases} +1, & DB_{0,d} > CS_{-31,d} \\ -1, & DB_{0,d} < CS_{-31,d} \\ 0, & DB_{0,d} = CS_{-31,d} \end{cases} \tag{6}$$

$$DR_{t,d} = FIXDIR_{t,d} \times SR_{t,d} \tag{7}$$

$$\overline{DR_t} = \frac{1}{D}\sum_{d\in D} DR_{t,d} \tag{8}$$

$$CDR_t = \sum_{t=-60}^{t} \overline{DR_t} - \sum_{t=-60}^{-31} \overline{DR_t} \tag{9}$$

where DB and CS in Eq. (6) are the prices of Dated Brent and the BFO crude spot approximation in interval t on trading day d, respectively. The cumulative directional returns (CDR_t) represent the attainable gain through directional trading during the event window.[18]

In order to address the inherent relationship between directional trading based on spot market information and the futures market price movement,[19] we apply additional tests that isolate the spurious correlation between the futures returns and the direction parameter, consistent with Ederington and Lee (1995, EL).[20] This is achieved by assigning $FIXDIR_{t,d} = 1$ if $(R_{-31,0} - R_t) > 0$, $FIXDIR_{t,d} = -1$ if $(R_{-31,0} - R_t) < 0$, and $FIXDIR_{t,d} = 0$ if $(R_{-31,0} - R_t) = 0$ for intervals within the event window, where $R_{-31,0}$ is defined as $\log(DB_{0,d} / CS_{-31,d})$ and R_t is the $\log(CS_t / CS_{t-1})$. Hence, the directional parameter for interval t within the window is based on the sign of the spot return over the other 29 min of the Platts assessment.[21] For intervals [t_{-60} = 15:30, t_{-31} = 15:59] and [t_0 = 16:30,

[18] We remove the 8 flat fixing days from our analysis since the zero returns would attenuate the averaged outcome on positive and negative fixing days. There is no material difference in results.

[19] The correlation coefficient of close-to-close Brent futures returns and the close-to-close Platts Dated Brent returns based on prices at 16.30 London time amounts to 0.97. However, the coefficient of the correlation determined based on the sign of (1) the difference between futures prices at 16.30 and 16.00, and (2) the difference between the Platts Dated Brent benchmark at 16.30 and the BFO crude spot price at 16.00 is considerably lower, at 0.53.

[20] We thank an anonymous reviewer for suggesting this approach.

[21] Under the standard directional measure, we test whether the futures return of interval t within the 30-minute window is correlated with the overall 30-minute spot direction. Given the close co-movement between the spot and futures market, it may appear that the return in interval t is correlated with the spot direction; however, it is actually only correlated with the overall 30-minute futures return. Hence, in order to avoid this correlation with itself (since the interval return is part

Table 2
Return Measures by Batches for ICE Brent Crude Futures.

10 mins				Panel A Avg simple returns			Panel B Avg directional returns			Panel C Avg EL30 returns		
From (t_i)	*To* (t_i)	*From (Time)*	*To (Time)*	*SR*	*Sign*	*t-value*	*DR*	*Sign*	*t-value*	*EL30R*	*Sign*	*t-value*
−60	*−51*	*15:30*	*15:39*	−0.60		−0.57	1.02		0.96	1.02		0.96
−50	*−41*	*15:40*	*15:49*	−0.70		−1.00	−0.60		−0.83	−0.60		−0.83
−40	*−31*	*15:50*	*15:59*	−0.10		−0.16	0.64		0.83	0.64		0.83
−30	*−21*	*16:00*	*16:09*	−3.70	***	-4.55	6.60	***	8.14	1.97	**	2.10
−20	*−11*	*16:10*	*16:19*	−1.50	**	−2.11	6.37	***	9.20	1.93	**	2.30
−10	*−1*	*16:20*	*16:29*	−1.70	**	−1.98	10.60	***	12.97	4.11	***	4.16
0	*9*	*16:30*	*16:39*	2.47	***	3.23	0.10		0.12	0.10		0.12
10	*19*	*16:40*	*16:49*	−0.02		−0.03	1.12		1.61	1.12		1.61
20	*29*	*16:50*	*16:59*	0.77		1.10	−0.30		−0.39	−0.30		−0.39
30	*39*	*17:00*	*17:09*	0.20		0.33	0.71		1.19	0.71		1.19
40	*49*	*17:10*	*17:19*	0.89		1.40	1.59	**	2.50	1.59	**	2.50
50	*59*	*17:20*	*17:29*	1.08	*	1.90	−0.10		−0.23	−0.10		−0.23

Notes: This table reports the results of the average return measures in 10-minute batches. Panels A, B and C present the results for the average simple returns, the average directional returns and the EL-corrected 30-minute directional returns respectively. All return measures are reported in bps (1 bps = 0.01%). The t-value is the statistic of a one sample t-test of the mean being equal to zero. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. Sample period is 09.01.2012–31.03.2016. 'From' and 'To' timestamps represent interval start times. The two single horizontal black lines represent the Platts Dated Brent fixing start and fixing end. The interval following the Platts Dated Brent assessment end is t_0 [16:30:00, 16:30:59] London local time.

t_{+59} = 17:29] outside of the Platts Window, the direction parameter is determined as specified in Eq. (6). The EL approach can be considered as a conservative robustness test of the directional return measure.[22]

Fig. 3 reports the directional ICE Brent Crude futures returns around the Platts benchmark assessment using the two directional parameters. In Table 2, we report the ICE Brent Crude futures returns in 10 min pooled batches across the full window of investigation.[23] The returns associated with both are referred to as *DR* and *EL30R* respectively.

The cumulative simple returns plot for Brent futures in Panel A of Table 2 illustrates the responsiveness of the futures market to the daily benchmark assessment. This is supported by significantly negative $\overline{SR_t}$ values during the 30 min Platts Window in Panel A of Fig. 3. In Panel B of Table 2 we report the directional returns attributable to a physical market-informed futures trader. An immediate and significant directional return is observed with the start of the fixing (t_{-30}), a pattern which carries forward throughout the assessment process — all 10 minute intervals exhibit significance at the 1% level. Further, the $\overline{DR_t}$ of intervals during the final phase of the benchmark assessment are particularly pronounced, measuring on average 10.6 bps from 16:20 to 16:29. Following the benchmark assessment end (t_0) the pattern in directional returns is reversed and falls to zero. The returns for the other 10 min batches outside the 30 min assessment window are smaller in magnitude, mostly insignificant, and depict no discernible pattern.

The cumulative directional returns in Panel A of Fig. 3 represent the hypothetical gains attainable through directional trading in Brent futures during the Platts Window. There is an important run-up in *CDR* instantly after the fixing start and prior to the fixing end. As demonstrated in Panel A of Fig. 3, the clear and continuous trend in directional futures returns during the event window suggests that the trading activity, such as spot market-informed futures speculation or informed spot-futures arbitrage, leads to an adjustment of almost 24 bps on average. The trend of the Brent futures price in the 'right' direction prior to the daily Platts Window end amounts to 16.5 bps during positive assessments, and 30.8 bps during negative assessments. The steepening of the *CDR* curve from t_{-7} onwards underlines the importance of the final minutes of the Platts Window. This pattern is followed by a reversal on negative days, possibly due to overshooting in the market. However, on positive days a slight and continuous upward trend is observed.

Panel C of Table 2 reports the returns based on the EL-corrected 30 min directional sign (*EL30R*), designed to avoid the expected spurious correlation between the return in interval t and the spot direction on day d during the Platts Window. Under this conservative measure the direction of interval t is based on the sign of the spot return over the other 29 min. While our *EL30R* results are smaller in magnitude, the estimates remain statistically significant during all three 10-minute batches, culminating in an average return of 8 bps (Panel C of Table 2). Consistent with earlier results, Panel B of Fig. 3 shows that negative Platts assessment days experience stronger cumulative directional returns, while the movement is less pronounced on positive assessment days.[24]

Overall, both directional return measures yield consistent results, albeit at different magnitudes, implying that there is an idiosyncratic information component in the spot market, enabling a directional pattern to emerge in the futures market during the Platts Dated Brent assessment. The findings suggest that, theoretically, a futures trader with spot market information could make an average profit of between 8 bps and 24 bps during the 30 min assessment window.

4.3. Trade order imbalance around the dated Brent benchmark assessment

In order to further substantiate the view that informed trading is driving directional trading in the Brent futures market, we next examine the evolution of trade order imbalance around the assessment window. Order imbalance is a well-established measure in the literature for identifying patterns of informed trading (e.g. Bernile et al., 2016). We apply the Lee and Ready (1991) trade classification algorithm to identify Brent futures trades as either

of the 30-minute return), we compute the direction for each interval t within the window using the sign of the spot return of the other 29 minutes.

[22] Given that the last five minutes of the Dated Brent assessment are considered crucial (as described in sub-section 2.1 and identified by the evolution of the volume and volatility in Figure 2), we implement a conservative third directional return measure. In this case the FIXDIR is determined by the sign of the differential between the Dated Brent price and the BFO spot price five minutes before the assessment end. The unreported results are smaller in magnitude but consistent with those reported in Table 2.

[23] For parsimony we do not report the minute-by-minute results; however, the results are available on request.

[24] Since the EL direction parameter equals the standard fixing direction for intervals outside the event window, the *DR* and *EL30R* during the pre-event and post-event windows are identical in Panels B and C.

Fig. 3. Cumulative returns for ICE Brent crude futures.
Notes: Panels A and B show the cumulative directional return measures using the standard directional fixing parameter and the EL-corrected 30 min directional parameter respectively. The split into positive (+ve) and negative (-ve) assessment days is determined for each panel based on $FIXDIR_{t,d}$ described in Eq. (6). All return measures are reported in bps (1 bps = 0.01%). The shaded area indicates the event window from fixing start (t_{-30}) to fixing end (t_{-1}) [16:00:00, 16:29:59]. The vertical black line marks the interval following the Platts Dated Brent assessment end: t_0 [16:30:00, 16:30:59].

buyer- or seller-initiated. Trades above the prevailing midpoint are classified as buys, and those below the prevailing midpoint are deemed to be sells.[25] We measure order imbalance as follows:

$$DOIB\#_{t,d} = \frac{(\#B_{t,d} - \#S_{t,d}) \times FIXDIR_{t,d}}{\#B_{t,d} + \#S_{t,d}} \quad (10)$$

[25] In case the trade was executed exactly at the midpoint, we determine the direction based on the first preceding transaction which was executed at a different price, a practice also called 'tick test' (Lee and Ready, 1991). Holden and Jacobsen (2014) report that the Lee and Ready (1991) trade classification algorithm is reasonably accurate (88%) in today's context of fast markets.

$$\overline{DOIB\#_t} = \frac{1}{D}\sum_{d\in D} DOIB\#_{t,d} \quad (11)$$

where $\#B_{t,d}$ is the aggregated number of buyer-initiated transactions in interval t, and $\#S_{t,d}$ the aggregated number of seller-initiated transactions in interval t (Chordia et al., 2008). We sign the Brent futures order imbalance for each interval t by the fixing direction of that trading day d (Eq. (10)) to facilitate the identification of directional trading. We apply an additional specification of the direction parameter, as described in

Table 3
Order imbalance measures by batches for ICE Brent Crude futures.

10 mins				Panel A Avg DOIB (#)			Panel B Avg EL30 DOIB (#)		
From (t_i)	*To* (t_i)	*From (Time)*	*To (Time)*	*DOIB#*	*Sign*	*t-value*	*EL30#*	*Sign*	*t-value*
−60	−51	15:30	15:39	0.49		1.03	0.49		1.03
−50	−41	15:40	15:49	−0.96	**	−2.01	−0.96	**	−2.01
−40	−31	15:50	15:59	−0.32		−0.66	−0.32		−0.66
−30	−21	16:00	16:09	1.79	***	4.07	0.88	**	1.99
−20	−11	16:10	16:19	2.43	***	5.05	1.53	***	3.11
−10	−1	16:20	16:29	1.94	***	5.07	0.91	**	2.42
0	9	16:30	16:39	−1.62	***	−3.78	−1.62	***	−3.78
10	19	16:40	16:49	−0.91	*	−1.68	−0.91	*	−1.68
20	29	16:50	16:59	−1.10	**	−1.99	−1.10	**	−1.99
30	39	17:00	17:09	−1.07	*	-1.82	−−1.07	*	−1.82
40	49	17:10	17:19	−0.16		−0.28	−0.16		−0.28
50	59	17:20	17:29	−0.64		−1.13	−0.64		−1.13

Notes: This table reports the results of the average directional order imbalance (*DOIB*) measures in 10-minute batches. Panels A and B present the results for the average order imbalance by number of trades (#) using the different specifications of the directional parameter as described in sub-Section 4.2. All *OIB* measures are expressed in percentage terms (%). The t-value is the statistic of a one sample t-test of the mean being equal to zero. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. Sample period is 09.01.2012–31.03.2016. 'From' and 'To' timestamps represent interval start times. The two single horizontal black lines represent the Platts Dated Brent fixing start and fixing end. The interval following the Platts Dated Brent assessment end is t_0 [16:30:00, 16:30:59] London local time.

sub-Section 4.2 (i.e. the EL-corrected direction parameter over the full 30 min window). The *DOIB* measures adopt positive values if market participants trade in the 'right' direction, and negative values otherwise. If there is no evidence of consistent directional trading in the Brent futures contract, a random pattern should be observed. $\overline{DOIB\#_t}$ and $\overline{EL30\#_t}$ describe the values for interval t averaged across all trading days D. The results for the directional order imbalance by number of trades (#) are presented in Table 3. [26] We report the order imbalance results in 10 min batches.

Overall, the results largely mirror our earlier directional return findings. The $\overline{DOIB\#_t}$ values in Panel A are typically statistically insignificant for intervals preceding the event window, but show continuous and significant positive non-zero values during the Platts Window. The pattern is reversed following the completion of the assessment window. With mean values of 2.43% between 16:10 and 16:19, trades in the 'right' direction outweigh trades in the 'wrong' direction by several percentage points at their peak. In addition, and again in support of earlier findings, $\overline{DOIB\#_t}$ yields values of −1.62% (1% level of statistical significance) immediately after the Dated Brent fixing end from 16:30 to 16:39. These values indicate a transaction pattern in the opposite direction of the fixing and is possibly driven by the reversal of positions of some participant groups following the end of the benchmark assessment. This could also be the consequence of the crowding out of informed traders by noise/uninformed traders, as the former abandon their positions upon their earning of abnormal returns at the assessment end.

Order imbalance results using the conservative EL-corrected direction sign are presented in Panel B of Table 3. The *EL30#* estimates show positive and highly significant order imbalance values, consistent with Panel A's estimates, although marginally lower in magnitude. The estimates for 16:00 – 16:09, 16:10 – 16:19 and 16:20 – 16:29 are 0.88, 1.53 and 0.91 respectively. Following the assessment end (16:30 to 17:29), we obtain significantly negative values, indicating an overbalance of trades in the opposite direction of the price movement during the Platts Window. The absence of a similar trading behavior outside of the event window supports our directional trading proposition that informed activity in the Brent futures market from 16:00 to 16:30 leads to an adjustment of the futures price in the direction of the benchmark outcome.

[26] The results for the order imbalance measure by dollar value ($) are identical.

4.4. The arrival rate of informed traders

To substantiate the suggestion that the observed pattern is driven by informed trading, we estimate the probability of an informed trade (*PIN*) model (see Easley et al., 1996a; Easley et al., 1996b; Easley et al., 1997; Easley et al., 2002). The *PIN* model assumes that the trading process involving informed and liquidity traders and market makers iterates over multiple trading intervals. Four parameters determine this trade process: α, the probability that an information event occurs; δ, the probability of the former being a bad news event; μ, the arrival rate of informed traders; and ε, the arrival rate of uninformed traders. Assuming a Poisson-like distribution of trades, the model allows us to estimate each of the parameters of the Brent futures trading process by maximizing the following likelihood function:

$$\begin{aligned} L((B,S)|\theta) = {} & (1-\alpha)e^{-\varepsilon T}\frac{(\varepsilon T)^B}{B!}e^{-\varepsilon T}\frac{(\varepsilon T)^S}{S!} \\ & +\alpha\delta e^{-\varepsilon T}\frac{(\varepsilon T)^B}{B!}e^{-(\mu+\varepsilon)T}\frac{[(\mu+\varepsilon)T]^S}{S!} \\ & +\alpha(1-\delta)e^{-(\mu+\varepsilon)T}\frac{[(\mu+\varepsilon)T]^B}{B!}e^{-\varepsilon T}\frac{(\varepsilon T)^S}{S!} \end{aligned} \tag{12}$$

PIN is computed as:

$$PIN = \frac{\alpha\mu}{\alpha\mu + 2\varepsilon} \tag{13}$$

where B and S are the total number of buys and sells in interval t respectively. As in sub-Section 4.3, we use the Lee and Ready (1991) algorithm to identify trade initiation. Brent futures are characterized by high liquidity, and we therefore use minute-by-minute buys and sells as input in our model, and subsequently estimate the *PIN* of 10 min batches on a daily basis (following Easley et al., (1996b) as in Eq. (13)). In a final step, we average the 10 min batch results across all trading days D to obtain our final parameter estimates.

During the event window, a surge in the arrival rate of informed traders is observed, as shown in Panel A of Table 4. The arrival rate of informed traders (μ) rises from 161.61 at the start of the event window [16:00, 16:09], to 162.56 [16:10, 16:19] and

Table 4
Probability of information-based trading by batches for ICE Brent Crude futures.

10 mins From (t_i)	To (t_i)	From (Time)	To (Time)	Panel A Arrival of informed traders μ	Panel B Arrival of uninformed traders ε	Panel C Probability of information event α	Panel D Probability of low signal δ	Panel E Probability of informed trade *PIN*
−60	−51	15:30	15:39	178.27	108.09	35.62	49.30	23.16
−50	−41	15:40	15:49	149.45	91.37	36.86	50.47	23.28
−40	−31	15:50	15:59	145.31	87.27	37.16	51.59	23.01
−30	−21	16:00	16:09	161.61	99.71	37.50	51.76	22.85
−20	−11	16:10	16:19	162.56	100.41	38.18	52.53	23.24
−10	−1	16:20	16:29	287.43	154.81	31.19	52.18	21.75
0	9	16:30	16:39	221.04	114.79	30.92	49.47	22.54
10	19	16:40	16:49	137.53	73.38	37.81	49.05	25.40
20	29	16:50	16:59	120.68	61.70	38.20	49.79	26.40
30	39	17:00	17:09	121.03	60.86	36.79	51.73	25.81
40	49	17:10	17:19	111.04	52.79	37.37	51.02	26.53
50	59	17:20	17:29	104.19	50.26	37.49	50.30	26.59

Notes: This table reports the results of the average estimates of the parameter vector of the structural model in 10 min batches. The parameters μ, ε, α and δ refer to the arrival rate of informed traders, the arrival rate of uninformed traders, the probability of an information event occurring, and the probability of a low signal occurring respectively, per 10-minute batch and averaged across trading days *D*. *PIN* is computed daily by batch as in Eq. (13), and then averaged across trading days *D*. The probability measures α, δ and *PIN* are expressed in percentage terms (%). Minute-by-minute buys and sells serve as input to the structural model. Sample period is 09.01.2012–31.03.2016. 'From' and 'To' timestamps represent interval start times. The two single horizontal black lines represent the Platts Dated Brent fixing start and fixing end. The interval following the Platts Dated Brent assessment end is t_0 [16:30:00, 16:30:59] London local time.

reaches a peak of 287.43 immediately prior to the Platts Window end [16:20, 16:29]. During the last 5 min of the benchmark fixing, the valuation of Forward BFOE is taking place (see Institutional Details in sub-Section 2.1), and is arguably the most important phase of the Dated Brent assessment. This supports the conclusions earlier drawn with respect to the directional return and order imbalance estimates, and thus our postulation on directional trading is also sustained. It now appears to be a reasonable conclusion that informed traders drive at least part of the price run-up in the direction of the Dated Brent fixing price. Nonetheless, the arrival rate of uninformed traders (ε) also increases from 99.71 at the start of the event window [16:00, 16:09], to 100.41 [16:10, 16:19], and peaks at 154.81 ahead of the benchmark assessment end [16:20, 16:29]. These findings align with the results of heightened futures volume during the Platts fixing, as a lot of participants with varying interests and degrees of sophistication are coming to the market during a period of very high liquidity. Informed speculators rely on liquidity, and thus noise traders, to make profitable trades, and a well-functioning futures market is therefore characterized by the presence of both informed and uninformed traders (cf. Silber, 1981; Brunnermeier and Pedersen, 2009). The enhanced ε (154.81), combined with the reduced probability that an information event occurs (α) ahead of the assessment end (see α of 31.19% [16:20, 16:29]) has the consequence that the largely increased μ (287.43) does not translate into a higher level of *PIN* (21.75%). Hence, with a diverse mix of uninformed and informed traders in the market, the probability of a market maker being adversely selected remains roughly equal. Overall, the probability of information-based trading remains at a constant level throughout the estimation and event window (see *PIN* in Table 4). Informed traders can, potentially, profit from the high volumes and use the correspondingly high level of uninformed traders to camouflage their informed trading activity (e.g., Kyle, 1985; Collin-Dufresne and Fos, 2016). It is important to note that the sustained presence of uninformed traders in the market, even in the face of a potential increase in adverse selection risk, is critical for the price discovery process (see Glosten and Milgrom, 1985; Kyle, 1985).

4.5. Predictive co-movement analysis

Opportunities to capitalize on oil market information should be greater on days with pronounced benchmark price innovations, measured by the magnitude of the differential between the Platts Dated Brent price and the pre-assessment spot price. If there is any predictive value in market movements, one should observe futures trading (for arbitrage purposes or speculation) in the direction of the fix as the benchmark assessment evolves. In Table 5, consistent with Caminschi and Heaney (2014), we report the alignment between $FIXDIR_{t,d}$ and the futures price change between interval t and the pre-assessment futures price (t_{-31}). We measure $FUTDIR_{t,d} = sign(F_{t,d} - F_{-31,d})$, over the 30 intervals making up the Platts Window. If $FIXDIR_{t,d} = FUTDIR_{t,d}$ alignment is established; the converse is true in the case of deviations. We condition on *small* or *large* assessment days, depending on whether the Dated Brent assessment magnitude on day *d* is below or above the median assessment magnitude over the full sample period. Subsequently, we examine whether the alignment rates of futures returns with the fixing directions are uniformly distributed for small and large Dated Brent assessments. If there is no value in the initial market movements, alignment for small and large innovation days should be equally likely.

The sub-samples consist of 528 large innovation days and 528 small innovation days. The baseline case considers the interval immediately preceding the Dated Brent assessment start (t_{-31}). Specifically, when the prediction of the fixing direction is based on returns in the futures market from 15:59 to 16:00, we find poor alignment. Futures returns only correctly identify the assessment direction 45.64% of the time. While proportions are different between large and small innovation days, chances remain poorer than a coin toss (42.80% vs. 48.48%, respectively). Immediately after the Dated Brent assessment start (interval t_{-30}), the first minute return in the futures market aligns with the spot fixing direction 51.89% of the time. Futures price movements are 56.44% accurate on large innovation days, and significantly different from small innovation days (47.35%). This pattern remains consistent throughout the Platts Window.

On small fixing days, futures returns have an above average probability of being aligned with the fixing direction only 5 minutes (t_{-26}) after the assessment start. On large innovation days, however, that probability already amounts to approximately 61%. Halfway through the assessment window, the probability rises to 74% (t_{-15}) and reaches 80% five minutes before the assessment end. On small fixing days, the probability that futures returns are correctly aligned with the fixing direction stays close to 50% for the

Table 5
Co-movement of futures returns and the fixing direction.

t_i	*To*	Magn	Deviate	Align	Prop	χ2	t_i	*To*	Magn	Deviate	Align	Prop	χ2
−31	*15:59*	Small	302	226	42.80%	3.44*	*−15*	*16:15*	Small	239	289	54.73%	43.87***
		Large	272	256	48.48%				Large	136	392	74.24%	
−30	*16:00*	Small	278	250	47.35%	8.74***	*−14*	*16:16*	Small	230	298	56.44%	32.14***
		Large	230	298	56.44%				Large	142	386	73.11%	
−29	*16:01*	Small	274	254	48.11%	4.38**	*−13*	*16:17*	Small	234	294	55.68%	39.96***
		Large	240	288	54.55%				Large	136	392	74.24%	
−28	*16:02*	Small	279	249	47.16%	10.26***	*−12*	*16:18*	Small	240	288	54.55%	52.32***
		Large	227	301	57.01%				Large	128	400	75.76%	
−27	*16:03*	Small	264	264	50.00%	8.8***	*−11*	*16:19*	Small	226	302	57.20%	41.71***
		Large	216	312	59.09%				Large	127	401	75.95%	
−26	*16:04*	Small	256	272	51.52%	8.86***	*−10*	*16:20*	Small	220	308	58.33%	39.73***
		Large	208	320	60.61%				Large	124	404	76.52%	
−25	*16:05*	Small	260	268	50.76%	15.81***	*−9*	*16:21*	Small	218	310	58.71%	40.88***
		Large	196	332	62.88%				Large	121	407	77.08%	
−24	*16:06*	Small	257	271	51.33%	13.44***	*−8*	*16:22*	Small	210	318	60.23%	32.39***
		Large	198	330	62.50%				Large	124	404	76.52%	
−23	*16:07*	Small	257	271	51.33%	13.44***	*−7*	*16:23*	Small	203	325	61.55%	34***
		Large	198	330	62.50%				Large	116	412	78.03%	
−22	*16:08*	Small	256	272	51.52%	14.89***	*−6*	*16:24*	Small	204	324	61.36%	35.58***
		Large	194	334	63.26%				Large	115	413	78.22%	
−21	*16:09*	Small	248	280	53.03%	13.59***	*−5*	*16:25*	Small	188	340	64.39%	32.54***
		Large	189	339	64.20%				Large	105	423	80.11%	
−20	*16:10*	Small	242	286	54.17%	17.25***	*−4*	*16:26*	Small	179	349	66.10%	32.11***
		Large	176	352	66.67%				Large	98	430	81.44%	
−19	*16:11*	Small	237	291	55.11%	24.58***	*−3*	*16:27*	Small	180	348	65.91%	39.32***
		Large	159	369	69.89%				Large	91	437	82.77%	
−18	*16:12*	Small	236	292	55.30%	31.69***	*−2*	*16:28*	Small	175	353	66.86%	40.31***
		Large	148	380	71.97%				Large	86	442	83.71%	
−17	*16:13*	Small	228	300	56.82%	29.28***	*−1*	*16:29*	Small	183	345	65.34%	48.02***
		Large	144	384	72.73%				Large	85	443	83.90%	
−16	*16:14*	Small	235	293	55.49%	37.32***	*0*	*16:30*	Small	173	355	67.23%	43.88***
		Large	140	388	73.48%				Large	81	447	84.66%	

Notes: This table reports the results of the alignment of the futures return with the Dated Brent assessment direction. t_i represents interval cut-offs. 'To' timestamps represent interval start times. Magnitude is assessed as abs(log($DB_{0,d}$ / $CS_{-31,d}$)). *Large* (*Small*) days are days with a Dated Brent assessment magnitude above or equal to (below) the median assessment magnitude. $FIXDIR_{t,d}$ = sign($DB_{0,d}$ - $CS_{-31,d}$) as described in Eq. (6). $FUTDIR_{t,d}$ = sign($F_{t,d}$ − $F_{-31,d}$), where $F_{t,d}$ is the Brent futures price at the end of cut-off interval *t*, and $F_{-31,d}$ is the Brent futures price immediately preceding the start of the assessment window. For the special baseline case of interval t_{-31}, $FUTDIR_{-31,d}$ = sign($F_{-31,d}$ − $F_{-32,d}$). *Align* (*Deviate*) is the count of days where $FIXDIR_{t,d} = FUTDIR_{t,d}$ ($FIXDIR_{t,d} \neq FUTDIR_{t,d}$) for the cut-off interval in question. All proportions are calculated as the ratio of *Align* / (*Deviate* + *Align*), and are expressed in percentage terms (%). χ2 reports the chi-squared test statistic of the contingency table formed by *Large, Small, Align*, and *Deviate*. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. Sample period is 09.01.2012–31.03.2016. The interval preceding the Platts Dated Brent assessment start is t_{-31} [15:59:00, 15:59:59] London local time. The interval following the Platts Dated Brent assessment end is t_0 [16:30:00, 16:30:59] London local time.

majority of the assessment, remains below 60% until 16:21 (t_{-9}), and does not surpass 67% until the assessment end. Overall, the rate of increase in the probability of alignment is considerably slower on small fixing days.

The difference in likelihood of correct alignment between small and large days is significant at the 1% level for every interval. The fact that large innovation days achieve alignment faster may also imply less noise in the assessment process, and supports the presence of directional trading in the Brent futures market by informed participants.

4.6. Multivariate regression analysis

In this section, we test the robustness of our findings around the Dated Brent price assessment by Platts within a multivariate framework. We estimate the following regression models using the minute-by-minute interval data sample:

$$\begin{aligned} DV_{t,d} = \alpha &+ \beta_1 EVENT_{t,d} + \beta_2 POST_{t,d} + \beta_3 r_{VIX_{t,d}} \\ &+ \beta_4 r_{SP500_{t,d}} + \beta_5 r_{USDEUR_{t,d}} + \beta_6 r_{GOLD_{t,d}} \\ &+ \beta_7 r_{SPOT_{t,d}} + \beta_8 r_{MINING_{t,d}} \\ &+ \beta_9 r_{OILGAS_{t,d}} + \beta_{10} ENERGY_{t,d} + \beta_{11} ECON_{t,d} + \beta_{12} EXP_{t,d} \\ &+ \beta_{13} SUR_{t,d} + \beta_{14} SENT_{t,d} + \beta_{15} CONTANGO_{t,d} + \varepsilon_{t,d} \end{aligned} \tag{14}$$

where the dependent variable (*DV*) corresponds to our directional return or order imbalance measure. *EVENT* is a dummy variable equaling 1 during the Dated Brent benchmark assessment and 0 otherwise; it captures whether or not the directional trading effect during the event window persists after controlling for other possible drivers. *POST* equals 1 during the post-event window and 0 otherwise. The directional log return on the S&P 500 volatility index (*VIX*), the S&P 500 stock index (*SP500*), the *USDEUR* spot exchange rate, and spot *Gold,* are included following interrelations with the oil market evidenced in previous literature (e.g., Fan and Xu, 2011). *SPOT* is the directional log return of the arithmetic average of Thomson Reuters oil spot and swap prices. The directional log returns on the FTSE 350 mining sector (*MINING*) and the oil and gas sector (*OILGAS*) are included to control for price movements of related commodity firms. *ENERGY* and *ECON* equal 1 on days with an important energy market or economic information release, respectively, and 0 otherwise.[27] *EXP* equals 1 on ICE Brent Crude futures expiry days, and 0 otherwise. The *SUR* indicator captures differences in the futures market on days with surprise Dated

[27] The calendar is received from Bloomberg for all G8 countries and includes monetary, trade, labor, services, industrial, housing, purchasing and governmental events and publications for the *ECON* dummy. The *ENERGY* dummy includes events such as the publication of the US Energy Information Administration (EIA) Weekly Petroleum Status Report or the EIA Natural Gas Storage Change. Filters are applied to the releases in order to capture those of very high market relevance only. Recently, the intraday event study by Gu and Kurov (2016) provides evidence of early-informed trading in natural gas futures ahead of the release of the EIA Weekly Natural Gas Storage Report.

Table 6
Regression of returns and order imbalance on control variables.

Variable	Panel A Directional returns Coeff	Sign	t-value	Panel B Directional order imbalance (#) Coeff	Sign	t-value
Intercept	−3.31E-06		−0.44	6.39E-03	**	2.26
EVENT	6.67E-05	***	9.96	1.38E-02	***	5.50
POST	2.94E-04		0.35	−3.76E-02		−0.12
VIX	3.33E-03	**	2.07	−5.36E-01		−0.88
SP500	3.46E-01	***	20.79	6.80E+01	***	10.87
USDEUR	−7.56E-02	***	−4.94	−5.32E+01	***	−9.29
GOLD	1.49E-01	***	16.58	3.20E+01	***	9.50
SPOT	−7.88E-03		−0.54	4.41E+00		0.81
MINING	8.28E-02	***	11.68	6.30E+00	**	2.37
OILGAS	5.44E-01	***	57.42	3.88E+01	***	10.92
ENERGY	7.60E-06		1.07	2.50E-03		0.94
ECON	−1.91E-06		−0.28	−4.65E-03	*	−1.82
EXP	−1.22E-05		−0.69	5.44E-03		0.82
SUR	4.80E-05	***	5.78	5.53E-03	*	1.77
SENT	−3.15E-05	***	−4.68	−1.52E-02	***	−6.02
CONTANGO	2.55E-05	***	3.71	1.08E-03		0.42

Notes: This table reports the results of a simple OLS regression of the dependent variables (*DR, DOIB#*) on several control variables over the total window of investigation. Panels A and B present the regression results for *DR* and *DOIB#* respectively. The independent variables account for different effects: *EVENT* adopts the value 1 during the Dated Brent benchmark assessment window and 0 otherwise; *POST* adopts the value 1 during the post-event window and 0 otherwise; *VIX, SP500, USDEUR* and *GOLD* are the directional log returns on the S&P 500 volatility index, the S&P 500 stock index, the spot exchange rate between the USD and the EUR and spot gold respectively. *SPOT* is the directional log return on the arithmetic average of Thomson Reuters oil spot and swap prices and serves as model for light crude spot oil. *MINING* and *OILGAS* are the directional log returns on the FTSE 350 mining sector and oil and gas sector respectively. *ENERGY* and *ECON* adopt the value 1 on days with an important energy market or economic information release and 0 otherwise. *EXP* adopts the value 1 on ICE Brent Crude futures expiry days and 0 otherwise. *SUR* adopts the value 1 for surprise Dated Brent fixings, defined as being in the top 9th or bottom 1st decile, and 0 otherwise. *SENT* is an indicator adopting the value 1 for days with a positive spot fixing direction and 0 for days with a negative spot fixing direction. *CONTANGO* adopts the value 1 or 0 on days where the Brent futures market is in contango or backwardation, based on the respective Bloomberg metric, controlling for the trend in oil prices. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. Sample period is 09.01.2012–31.03.2016.

Brent price announcements, equaling 1 accordingly, and zero otherwise. A surprise announcement is defined as a daily difference belonging to the top 9th or bottom 1st decile of all differentials between the published Dated Brent price and the pre-assessment spot price. The sentiment indicator (*SENT*) is 1 on days with a positive fixing direction, and zero on days with a negative fixing direction. *CONTANGO* is a dummy variable that takes the value 1 on days where the structure of the Brent futures contract is in contango and 0 on days where it is in backwardation; this variable is included to control for the trend in oil prices. The sample contains 527 positive fixing days, 521 negative fixing days, and 8 flat days.

Table 6 reports the multiple regression estimates. There are several estimates of interest in light of earlier findings in this paper. Firstly, the *EVENT* dummy is significantly different from zero, and positive relative to the estimation window at the 1% level, even after controlling for numerous possible confounding effects. This abnormal return pattern suggests that trading behavior during the unfolding of the Platts Dated Brent benchmark assessment is indeed driven by directional trading activity. The *POST* dummy is insignificant in both panels, suggesting that trading activity is not different to the pre-event window following the assessment end.

We find that a positive relationship exists between our directional Brent futures returns and order imbalances and the S&P 500 stock index and spot gold returns. Moreover, a negative relationship is observed between the *USDEUR* exchange rate and Brent futures. These findings are broadly consistent with the existing literature on the interdependencies between oil, equities, gold and the dollar (e.g., Zhang et al., 2008; Narayan et al., 2010; Fan and Xu, 2011). Furthermore, we find that positive interrelations exist between our dependent variables and the mining and oil and gas sector returns. Stock market volatility, as captured by *VIX*, positively influences directional returns, whereas no connection can be established for the order imbalance measure. The *SPOT* variable, modelling spot oil price movements, does not influence our directional Brent futures returns or order imbalances.[28]

The *ENERGY* and *ECON* dummy variables are insignificant in Panel A, demonstrating that the various energy and economic announcements do not impact the Brent futures directional returns over the window of investigation. However, in Panel B, the coefficient for economic announcement days is negative and statistically significant (10% level). In addition, contract rollover on expiry days of ICE Brent Crude futures has no statistically significant effect on either *DR* or *DOIB*. The regression results indicate that the directional returns and order imbalances are stronger on surprise Dated Brent announcement days (captured by the *SUR* variable). The negative and highly statistically significant *SENT* coefficient suggests that the directional futures returns on days with a positive Dated Brent fixing direction behave differently to days with a negative fixing direction (refer to Appendix 3 for a more detailed discussion). Finally, structure, as proxied by *CONTANGO*, plays a role, as directional returns are significantly more marked on days where the oil market is in contango.

4.7. Early assessments

As with many important information releases, identification issues persist in the presence of confounding events. The typical assessment of the Platts Dated Brent coincides with the daily close of UK equity markets trading at 16:30 London time. However, on one day in the year this is not the case: *Holy Thursday*. On this day, two conditions are fulfilled that permit the disentangling of the effects of the equity market close on trading behaviour in the oil derivatives market: 1) the benchmark assessment is conducted early and ends at 12:30 London time, and 2) UK equity and Brent futures trading continues as usual. We identify seven relevant days,[29] repeat our analysis, and compare them to our full sample results to address the identification concerns. Fig. 4 compares the volume and volatility for Holy Thursday each year from 2010 to 2016, providing evidence that there is an increase in volume and volatility during the half hour ahead of 12:30 with no comparable intensification in trading activity at 16:30.

At the same time, for normal assessment days, there is no discernible pattern in volume and volatility around 12:30. Moreover, market opening or closing times of other major trading hubs cannot explain the 12:30 spike on Holy Thursdays. Hence, when the Platts assessment deviates from its usual time schedule, we observe a shift in the trading activity of the Brent futures market that coincides with the alternate assessment times. The pattern in

[28] We attempt to control for other specific spot oil products such as the Dated Brent to Frontline Brent Futures contract, EFP contracts, or North Sea spot grade differentials. However, our efforts are constrained by various factors such as the unavailability of data, data restrictions, or the illiquidity of products.

[29] We are grateful to Platts for providing data on these dates for an extended period and thank an anonymous reviewer for pointing us in this direction. The Platts Holiday Schedule available online allows us to confirm that the early assessment on Holy Thursday started in 2010. The inclusion of 2 out-of-sample days increases the sample size.

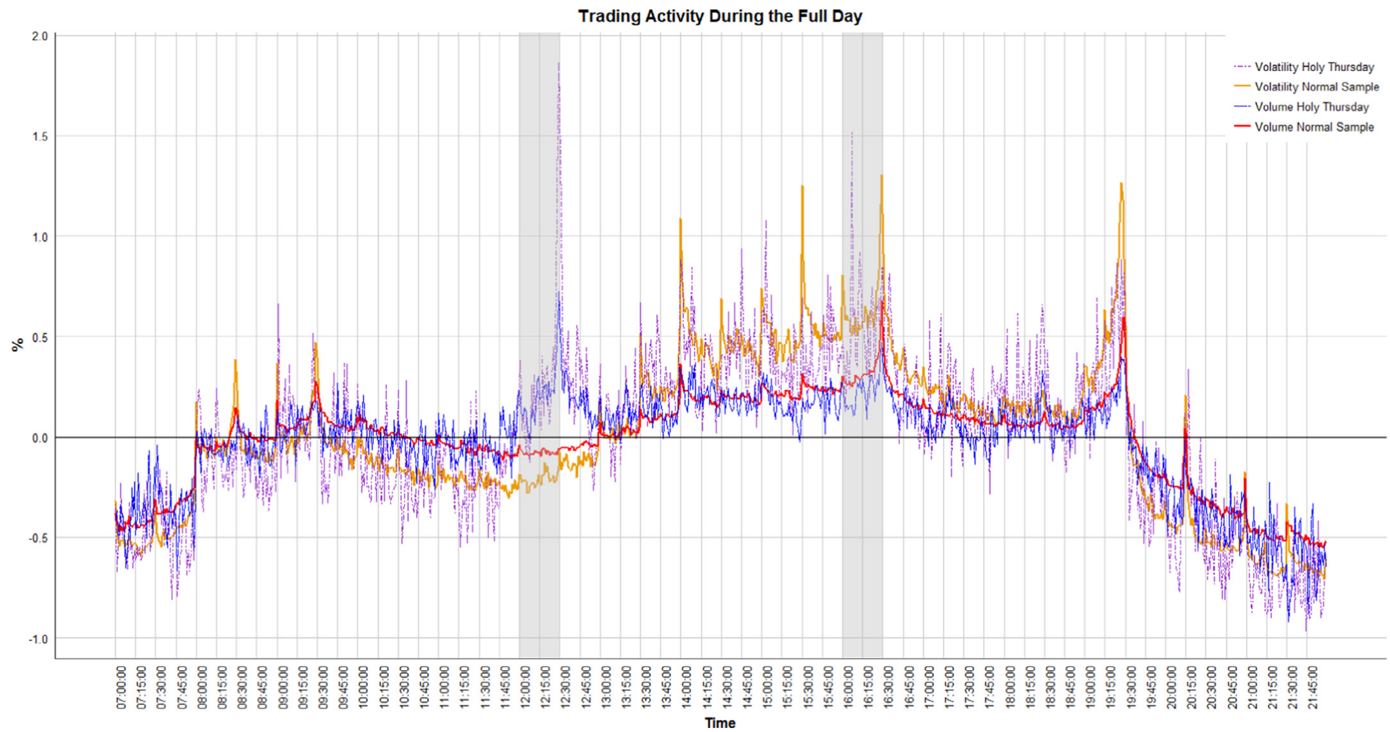

Fig. 4. Full day trading activity on normal and 'Early Assessment' days.
Notes: This figure shows the development of volume and volatility on days with a 16:30 Dated Brent assessment (referred to as 'normal sample' days) and on days with a 12:30 Dated Brent assessment (referred to as 'Holy Thursdays'). Volume is computed as the log volume during interval *t* on trading day *d*, averaged across trading days *D*. Volatility is computed as the standard deviation of 1 s returns within each 1 min interval *t* on trading day *d*, averaged across trading days *D*. The time series are demeaned and reported as percentage (%) increase/decrease relative to the daily mean. The shaded area marks the period from 12:00 to 12:30 and 16:00 to 16:30 respectively. The normal sample consists of 1056 days, while the 'Holy Thursday' sample comprises 7 days from 2010 to 2016. The latter includes 2 out-of-sample days, to increase the sample size and smooth the series without changing the results.

directional returns is also consistent with the results, albeit not statistically significant.

Fig. 4 identifies additional increases in volume and volatility at other times of the day. Unsurprisingly, they also correspond to meaningful events, for example the start of the Open Outcry for WTI futures at 08:00 CT (14:00 London time), the US market openings (14:30 London time corresponding to 09:30 in New York), and the daily settlement of Brent futures at 19:30 London time. Morning US economic announcements align with the early afternoon in London. Predictably, the EIA Weekly Petroleum Status Report, with a release time corresponding to 15:30 London time, also causes major volatility in the oil futures market.

5. Conclusion

This paper is the first to document the observed behavior of Brent futures prices and the trading pattern around the Dated Brent benchmark assessment operated by the PRA, Platts. This study comes at a time when the regulatory status of commodity benchmarks has shifted back into focus with the upcoming *EU Benchmarks Regulation*.

We report significantly enhanced ICE Brent Crude futures market activity and sensitivity during the benchmark assessment from 16:00 to 16:30, as measured by trading volume and price volatility. Futures market activity is particularly pronounced between 16:25 and 16:30, an interval of strategic importance in the Platts assessment. The futures price experiences a marked run-up commencing with the start of the Dated Brent price assessment period, and is quickly followed by a price reversal after the benchmark price assessment end. We find evidence consistent with informed directional trading contributing to the price adjustment of the Brent futures in alignment with the Dated Brent benchmark outcome during the unfolding of its assessment. Nevertheless, the Platts Window also attracts many uninformed participants during this period of heightened futures market activity, suggesting that they do not withdraw from the market when faced with high informed trading activity. The continued presence of uninformed participants is critical to the transfer of price-relevant information to the Brent futures market, and is deserving of further research in the future. Over the full 30 min assessment window, spot market-informed futures traders can realize returns amounting to 24 bps on average, with 8 bps being our most conservative estimate. Directional trading may be driven by futures speculation or spot-futures arbitrage, the informational advantage for which is plausibly gained in the physical crude oil market. The results are robust to a range of controls aimed at addressing correlation between the developing benchmark assessment and futures price movements on the one hand, and capturing the effects of confounding events on the other. Overall, the results present a consistent view that the physical oil assessment by Platts is of material importance to the paper oil market.

Two caveats apply to the interpretation of our results. Firstly, the documented pattern may be magnified by market dynamics, such as participants herding on common signals (e.g. futures market order flow). Secondly, some of the interrelatedness between the spot and futures market could be explained by an established cointegration relationship, which we are unable to completely factor into our analysis due to the unavailability of intraday North Sea crude spot data. These limitations notwithstanding, the extensive nature of our analysis suggests that the Dated Brent assessment plays a pivotal role in the price discovery of Brent futures. This study therefore emphasizes the influence of physical commodity benchmarks on exchange-traded financial products.

Appendix

Appendix 1. Platts and its Dated Brent benchmark

Platts, a division of S&P Global, is a leading information service provider for commodity markets specialising in price references and benchmarks for, amongst others, the energy market. One of its flagship benchmarks is the Dated Brent. Dated Brent is a benchmark price for physical North Sea crude oil. *Dated* thereby refers to a physical cargo of North Sea Brent-Forties-Oseberg-Ekofisk (BFOE) crude oil that has been assigned a loading date for shipping (has become wet) no less than 10 days forward.

The assessment of Dated Brent started in 1980. In July 2002, Platts launched a process called Market on Close (MOC)[30] to assess the daily price of Dated Brent, and due to declining production of Brent added two grades to its assessment: Forties and Oseberg. The loading date range of cargoes that are considered in the assessment was also widened to 10–21 days forward. In June 2007, Ekofisk was added to the basket. On 6 January 2012, Platts widened the dated range again to 10–25 days forward. Finally, in 2015, the date range was extended to 10–30 days forward.

A central element of the MOC is the 30 min time frame from 16:00 to 16:30 London local time called the *Window*. Platts operates an online data-entry and communications system called *eWindow* (Platts Editorial Window), which is an OTC real-time open order book revealing transaction data and bids and offers communicated to Platts by the market participants. The *eWindow* tool facilitates price discovery in the physical oil market, as it is compatible with the *WebICE* trading platform of the Intercontinental Exchange (ICE), designed to combine state of the art trading technology with the functionalities required for trading in the OTC market.

Platts determines the Dated Brent price based on a combination of data received for three OTC variables: (i) physical North Sea cargoes; (ii) short-term swaps between Dated Brent and Forward Brent (i.e. Contracts for Difference, CFD); and (iii) outright Forward Brent (also called cash BFOE). In order to become a so-called *market maker* in the Platts Window, a participant must indicate his interest to trade to Platts ahead of certain cut-off period by submitting a new bid/offer. After the cut-off period, no new bids/offers are accepted and only existing quotes can be amended. However, so-called *market takers* can hit the bid or lift the offer of a market maker at any time. The window itself can thereby be divided into three phases. The cut-off time for new bids/offers for physical North Sea cargoes is 16:10:00, 16:15:00 for CFDs and 16:25:00 for cash BFOE, and thereafter only existing quotes can be amended.[31] Physical North Sea bids/offers can be changed until 16:25:00. Quotes for CFD bids/offers can also be amended until 16:25:00. Finally, bids/offers for cash BFOE can be changed until the close at 16:30:00. Price changes need to be incremental (under normal market conditions up to 5 cts/bbl) and prices must stand firm long enough to be acted upon by a counterparty, in order to ensure orderly price discovery. After 16:30:00 all bids/offers that have not been acted upon during the Platts Window expire.[32] Platts' editorial team takes all the data collected during the 30-minute period and calculates the Dated Brent Strip based on the quoting and trading activity of the aforementioned variables. A price is then established for each of the four North Sea oil grades (Brent, Forties, Oseberg, Ekofisk), with the most competitive grade setting the daily Dated Brent price. The Dated Brent reflects the spot market value of the most competitive BFOE grade at 16:30 London time.

A key requirement for participating in the Dated Brent assessment is to follow Platts' rules and guidelines, designed to ensure the transparency, integrity and reliability of the benchmark. Platts pays particular attention to the repeatability of transactions, such that traders do not engage in non-repeatable transactions to bias the market's perception of the true value. Moreover, prices need to evolve sequentially and incrementally, and Platts does not consider quotes that are the result of price gapping.

It is important to note that the window is merely a part of the whole MOC price setting process, and Platts monitors the physical market throughout the trading day as well. The MOC methodology has the advantage of promoting liquidity, in a rather illiquid market, as it leads to a natural concentration of activity in a short period at the end of the day (Barret, 2012a). Typically, the window therefore experiences the highest participant activity. Although the OTC physical oil market is effectively open 24 hours, the price at 16:30 London time reflects the most useful price for the day at the 'close' of the physical market.

The minimum trade size for physical BFOE is a partial cargo of 100,000 barrels, and a full cargo corresponds to 600,000 barrels. The minimum shipment size acts as barrier-to-entry to the physical oil market such that, typically, during the Platts Window only a handful of participants contribute to the price assessment at any given time, and of those even fewer account for roughly half of the total trading activity (Fattouh, 2011; Barret, 2012a). The participating companies are mostly major oil multinationals or large commodity traders, but also include financial institutions. Companies wishing to participate in the Platts Dated Brent assessment need to pass Platts' vetting and due diligence process which consists, amongst others, of checks on the credibility, creditworthiness, ownership structure, logistical ability, trade performance history, and market acceptance by counterparties of the applicant.[33]

Appendix 2. Relative trade size evolution around the Dated Brent benchmark assessment

Trade size in interval t is defined as the division of trading volume by the number of trades. For the computation of the average relative trade size ($\overline{TS}_t$) we follow the same rationale as described in Eqs. (1) and (2). Fig. A1 shows that the relative trade size $\overline{TS}_t$ gradually increases during the 30 min Platts Window up to a maximum of nearly 40% above the reference level, and reverts to its previous levels after the end of the price fixing. The reversion in trade size, however, is moderate with regard to volume and volatility measures. The larger trade sizes suggest a degree of urgency in trade completion consistent with trading behavior associated with short-lived information.

[30] The MOC process has the advantage of reflecting market conditions more precisely at the end of the day than an averaging approach and takes structure (contango/backwardation) into account.

[31] Source: http://www.rusneftekhim.com/docs/crude_oil.pdf

[32] Information received during the ***Platts Oil Methodology Explained*** session at the *Platts London Oil & Energy Forum*.

[33] Information in this appendix was received at the ***Platts Oil Methodology Explained*** session hosted by Platts in London. For more information and references on the MOC price assessment methodology see: http://www.rusneftekhim.com/docs/crude_oil.pdf, http://www.platts.com/products/ewindow and https://www.platts.com/IM.Platts.Content/aboutplatts/mediacenter/PDF/intromocoil.pdf.

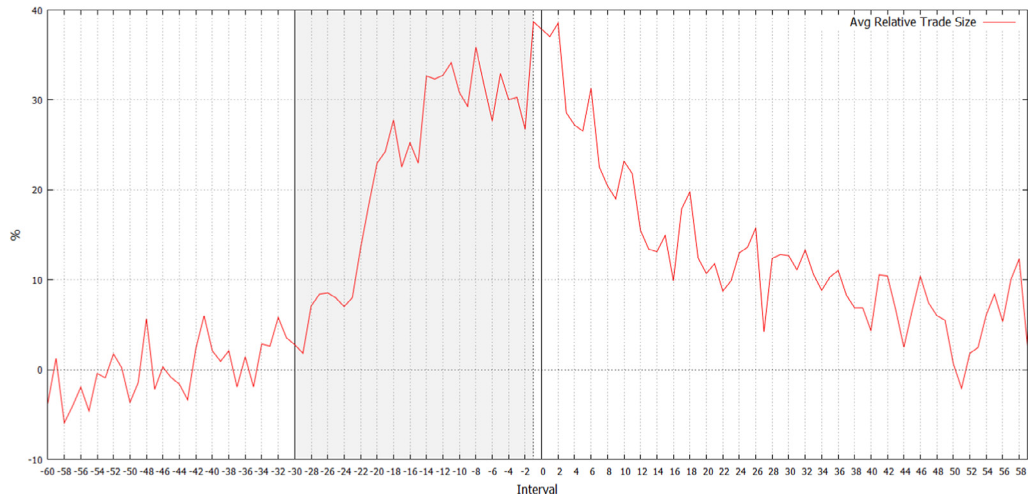

Fig. A1. Average relative trade size.
Notes: Figure A1 shows the average relative trade size. The measure is reported in percentage terms (%). The shaded area indicates the event window from fixing start (t_{-30}) to fixing end (t_{-1}) [16:00:00, 16:29:59]. The vertical black line marks the interval following the Platts Dated Brent assessment end: t_0 [16:30:00, 16:30:59].

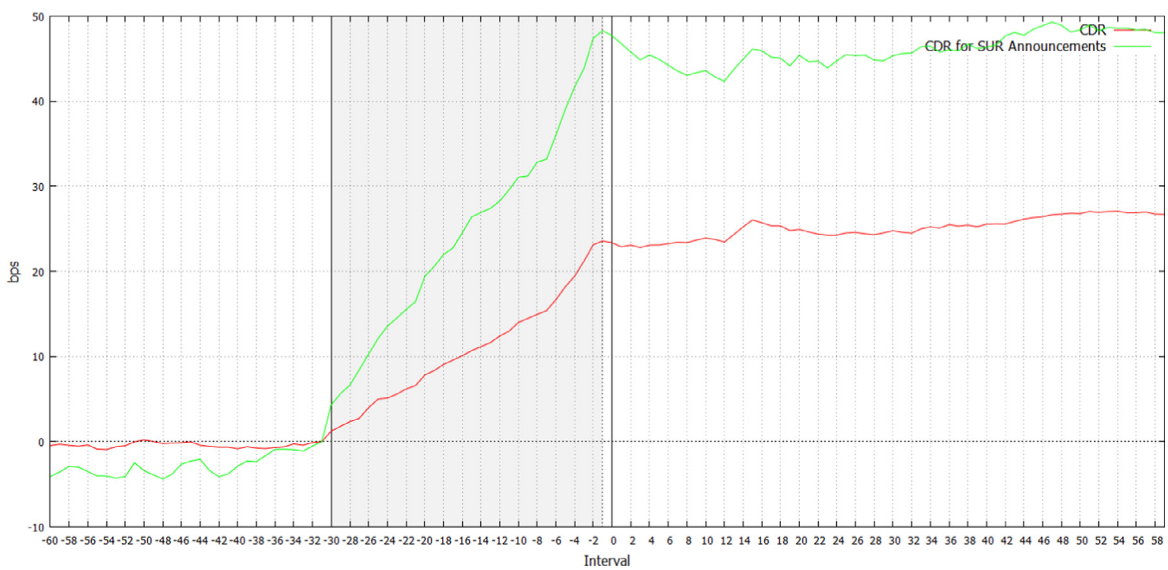

Fig. A2. Cumulative directional returns for surprise announcements.

Appendix 3. Surprise announcements and sentiment differences

The *SUR* dummy in Panel A of Table 6 implies that *DR* is, on average, higher on days with a surprise announcement (1% significance level). Theoretically, the profit potential of directional traders is greater on days with surprise announcements. Fig. A2 shows that surprise Dated Brent price announcements more than double the average daily potential gain to an average of nearly 48 bps over the 30 min assessment window, compared to an average of roughly 24 bps for all sample days. This is also consistent with the insights gained from the co-movement analysis in Section 4.5. Furthermore, the interval-by-interval *DOIB$* during the benchmark assessment are, on average, several percentage points higher on surprise announcement days (see Fig. A3). Directional traders are even more likely to trade in the direction of the ongoing benchmark fixing on surprise announcement days; that is, the imbalance between fixing direction-aligned transactions and transactions in the opposite direction is more pronounced.[34]

The negative and highly statistically significant *SENT* dummy variable coefficient in Panel A of Table 6 suggests that, over the full window of investigation [15:30, 17:29], the directional futures returns on days with a positive Dated Brent fixing direction do behave differently compared with days with a negative fixing direction. Similarly, the negative and statistically significant *SENT* coefficient in Panel B of Table 6 implies that interval-by-interval order imbalance during the benchmark assessment is more pronounced on negative fixing days. This is consistent with the general acceptance of a stronger market reaction to negative news. The cumulative directional returns in Panel A of Fig. 3 of the main paper show that the profit potential on negative sentiment days is approximately 31 bps, and only 17 bps on positive sentiment days.

[34] Statistical tests support the results illustrated in this figure. For parsimony, the statistical tables are not presented, but are available on request.

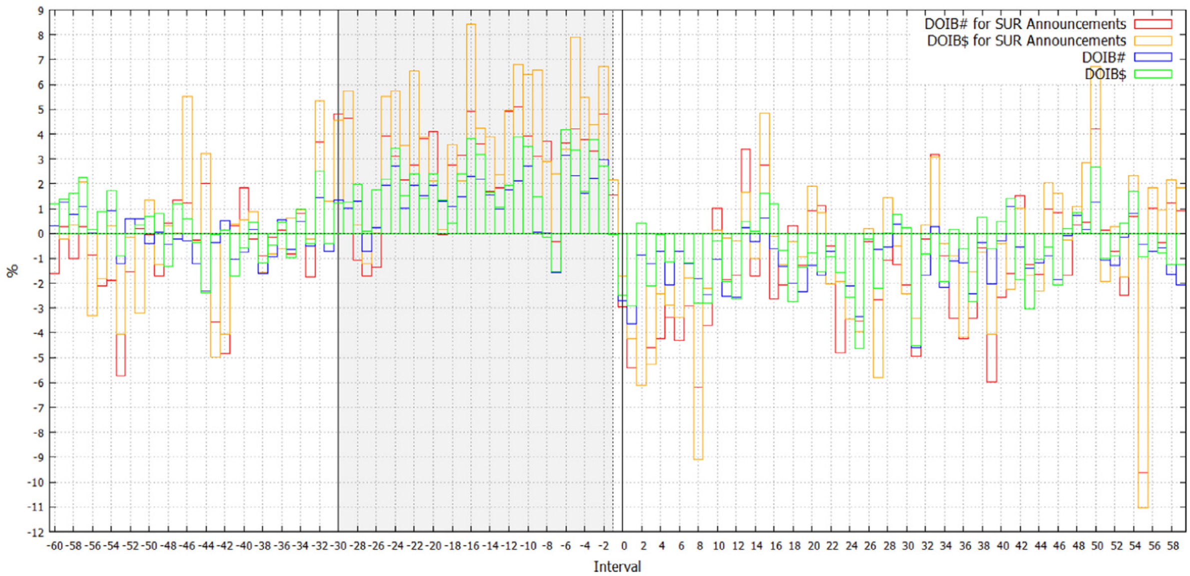

Fig. A3. *DOIB#* and *DOIB$* for surprise announcements.
Notes: Figure A2 shows cumulative directional returns for days with surprise Dated Brent announcements (SUR = 1 vs. SUR = 0) versus all announcement days. Figure A3 shows cumulative directional order imbalance by number of trades (DOIB#) and dollar value (DOIB$) for days with surprise Dated Brent announcements (SUR = 1 vs. SUR = 0) versus all announcement days. All return measures are reported in bps (1 bps = 0.01%). All order imbalance measures are reported in percentage terms (%). The shaded area indicates the event window from fixing start (t_{-30}) to fixing end (t_{-1}) [16:00:00, 16:29:59]. The vertical black line marks the interval following the Platts Dated Brent assessment end: t_0 [16:30:00, 16:30:59].

Furthermore, in the post-event window, negative fixing days are characterized by a more pronounced price reversal of several bps, whereas positive fixing days experience a drift ex-post of the announcement.

References

Abrantes-Metz, R.M., Kraten, M., Metz, A.D., Seow, G.S., 2012. Libor manipulation? J. Bank. Finance 36, 136–150.
Aspris, A., Foley, S., Gratton, F., O'Neill, P., 2015. Towards a new fix: assessing the new FIX regimes for metals trading. Working Paper, University of Sydney.
Barret, C., 2012a. Brent prices: impact of PRA methodology on price formation. Oxford Energy Comment. The Oxford Institute for Energy Studies.
Barret, C., 2012b. Oil. In: Price Benchmarks in International Trade - Brent Prices: Physical or Future Prices?, 87. Oxford Energy Forum, pp. 8–11.
Bernile, G., Hu, J., Tang, Y., 2016. Can information be locked-up? informed trading ahead of macro-news announcements. J. Financ. Econ. 121, 496–520.
Brunnermeier, M.K., Pedersen, L.H., 2009. Market liquidity and funding liquidity. Rev. Financ. Stud. 22, 2201–2238.
Caminschi, A., Heaney, R., 2014. Fixing a leaky fixing: short-term market reactions to the London pm gold price fixing. J. Fut. Markets 34, 1003–1039.
Chordia, T., Roll, R., Subrahmanyam, A., 2008. Liquidity and market efficiency. J. Financ. Econ. 87, 249–268.
Collin-Dufresne, P., Fos, V., 2016. Insider trading, stochastic liquidity and equilibrium prices. Econometrica 84, 1441–1475.
Cooper, A., 2017. Mercuria Warns of Undue Impact of Derivatives on Dated Brent Oil Price. Thomson Reuters Corp, Reuters.
Davis, M., 2012. In: Oil Price Benchmarks in International Trade - Benchmark Pricing: a Co-dependent Matrix, 87. Oxford Energy Forum, pp. 14–17.
Duffie, D., Dworczak, P., Zhu, H., 2016. Benchmarks in search markets. J. Finance forthcoming.
Duffie, D., Stein, J.C., 2015. Reforming LIBOR and other financial market benchmarks. J. Econ. Perspect. 29, 191–212.
Dunn, S., Holloway, J., 2012. The Pricing of Crude Oil. RBA Bulletin, Reserve Bank of Australia.
Easley, D., Hvidkjaer, S., O'Hara, M., 2002. Is information risk a determinant of asset returns? J. Finance 57, 2185–2221.
Easley, D., Kiefer, N., Ohara, M., 1996a. Cream-skimming or profit-sharing? the curious role of purchased order flow. J. Finance 51, 811–833.
Easley, D., Kiefer, N.M., O'Hara, M., 1997. The information content of the trading process. J. Empir. Finance 4, 159–186.
Easley, D., Kiefer, N.M., O'Hara, M., Paperman, J.B., 1996b. Liquidity, information, and infrequently traded stocks. J. Finance 51, 1405–1436.
Ederington, L.H., Lee, J.H., 1995. The short-run dynamics of the price adjustment to new information. J. Financ. Quant. Anal. 30, 117–134.
Evans, M.D.D., 2016. Forex trading and the WMR fix. Working Paper, Georgetown University.
Fan, Y., Xu, J.-H., 2011. What has driven oil prices since 2000? a structural change perspective. Energy Econ. 33, 1082–1094.
Fattouh, B., 2011. An anatomy of the crude oil pricing system. Working Paper, The Oxford Institute for Energy Studies.
FCA, 2015. Our powers. Financial Conduct Authority, FCA.
Fouquau, J., Spieser, P.K., 2015. Statistical evidence about LIBOR manipulation: a "Sherlock Holmes" investigation. J. Bank. Finance 50, 632–643.
Frino, A., Lepone, A., Mollica, V., Zhang, S., 2016. Are hedgers informed? an examination of the price impact of large trades in illiquid agricultural futures markets. J. Fut. Markets 36, 612–622.
Frino, A., McKenzie, M.D., 2002. The pricing of stock index futures spreads at contract expiration. J. Fut. Markets 22, 451–469.
Garman, M.B., Klass, M.J., 1980. On the estimation of security price volatilities from historical data. J. Bus. 53, 67–78.
Glosten, L.R., Milgrom, P.R., 1985. Bid, ask and ransaction prices in a specialist market with heterogeneously informed traders. J. Financ. Econ. 14, 71–100.
Hasbrouck, J., 1995. One security, many markets: determining the contributions to price discovery. J. Finance 50, 1175–1199.
Holden, C.W., Jacobsen, S., 2014. Liquidity measurement problems in fast, competitive markets: expensive and cheap solutions. J. Finance 69, 1747–1785.
Hurst, L., Blas, J., 2017. Shell Shakes Up Oil Trading World With Brash Buying Sprees. Bloomberg Inc, Bloomberg.
Inci, A.C., Seyhun, H.N., 2015. Degree of integration between brent oil spot and futures markets: intraday evidence. Bus. Manage. Rev. 6, 59.
Kemp, J., 2013. U.S. Cracks Apart London's Commodity Market Omerta. Thomson Reuters Corp, Reuters.
Kyle, A.S., 1985. Continuous auctions and insider trading. Econometrica 53, 1315–1335.
Lee, C.M.C., Ready, M.J., 1991. Inferring trade direction from intraday data. J. Finance 46, 733–746.
Mackey, P., Lawler, A., 2013. EU Oil Price Probe Puts Platts in Spotlight. Thomson Reuters Corp, Reuters.
Makan, A., 2013. Oil Markets: The Danger of Distortion. The Financial Times Ltd, FT.
Makan, A., Blas, J., Spiegel, P., 2013. European Commission Raids Oil Groups Over Price Benchmarks. The Financial Times Ltd, FT.
Mathur, A., 2013. Reassessing the Brent benchmark for crude oil. Econ. Polit. Week. 48, 14–16.
Monticini, A., Thornton, D.L., 2013. The effect of underreporting on LIBOR Rates. J. Macroecon. 37, 345–348.
Moore, M.J., Payne, R., 2011. On the sources of private information in FX markets. J. Bank. Finance 35, 1250–1262.
Narayan, P.K., Narayan, S., Zheng, X., 2010. Gold and oil futures markets: are markets efficient? Appl. Energy 87, 3299–3303.
Perkins, J., Mortby, P., 2015. Evolving financial benchmarks: the impact on legacy contracts. J. Securities Oper. Custody 7, 296–304.
Silber, W.L., 1981. Innovation, competition, and new contract design in futures markets. J. Fut. Markets 1, 123–155.
Swinand, G.P., O'Mahoney, A., 2014. Detecting abnormalities in the brent crude

oil commodities and derivatives pricing complex. Working Paper, London Economics.
Tetlock, P.C., 2010. Does public financial news resolve asymmetric information? Rev. Financ. Stud. 23, 3520–3557.
Tuson, A., 2014. Benchmark manipulation – price of oil in the spotlight. Berwin Leighton Paisner LLP, BLP.
Van Voris, B., Nguyen, L., Olson, B., Martinuzzi, E., 2013. Brent Crude Traders Claim Proof BFOE Boys Rigged Market. Bloomberg Inc, Bloomberg.
Vega, C., 2006. Stock price reaction to public and private information. J. Financ. Econ. 82, 103–133.
Zhang, Y.-J., Fan, Y., Tsai, H.-T., Wei, Y.-M., 2008. Spillover effect of US dollar exchange rate on oil prices. J. Pol. Model. 30, 973–991.