Benchmark Regulation and Market Quality

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Authors

Matteo Aquilina, Gbenga Ibikunle, Vito Mollica, and Tom Steffen.

Matteo Aquilina and Tom Steffen work in the Economics Department of the Financial Conduct Authority. Gbenga Ibikunle is an Associate Professor at the University of Edinburgh and Vito Mollica is an Assistant Professor at Macquarie University.

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Summary

Benchmarks are fundamental elements of financial markets' infrastructure. In this paper, we analyse the effects of the change from the panel-based benchmark assessment under the ISDAFIX regime to the market-based assessment under the ICE Swap Rate regime and the simultaneous start of regulatory supervision by the FCA. We find that the transition in March 2015 has a neutral to positive effect on the representativeness of the benchmark. Studying proprietary order book data of electronically-traded USD interest rate swaps, we also find that liquidity in the underlying market improves following the benchmark regime change. Our results are robust to a multitude of controls and show that the enhancement in liquidity for swaps with a regulated benchmark assessment is over and above the improvement in those swaps without assessment. As such, the effects of the regulation, as measured in this study, are positive. Overall direct savings measured in this study are in the region of $4m–$7m, but they only account for one tenor and a single trading platform. The overall benefits are likely to be substantially larger.

1 Overview

Introduction

In this paper, we examine the implications of the benchmark regime change (BRC) in the interest rate swap (IRS) market on underlying market conditions. Specifically, we focus on the transition on 31 March 2015 from the unregulated panel-based ISDAFIX benchmark to the regulated market-based ICE Swap Rate.

The swap market is particularly important and its size is estimated at $289 trillion in notional amounts outstanding. Swaps are practically and economically relevant, and used as hedging instruments for interest rate risk. It is therefore vital to guarantee the integrity of the benchmark and ascertain the implications of regulatory change on the marketplace.

In recent years, several major banks have been fined for misconduct and manipulation[1] related to LIBOR (London Interbank Offered Rate), the WM/Reuters FX benchmark, the LBMA Gold Price and the ISDAFIX rate damaging market confidence and integrity. A robust, objective and representative benchmark is crucial for the effective functioning of financial markets – an important objective of the Financial Conduct Authority (FCA). It is also in the FCA's interest that fundamental innovations to market infrastructure, such as the BRC, have no negative unintended consequences on the functioning of the market. This paper examines the transition to the ICE Swap Rate in light of this objective.

On the basis of available academic literature, we hypothesise that the benchmark regime change could improve pricing efficiency and liquidity in the underlying IRS market through two channels: 1) increased price transparency, on-platform participation and dealer competition, and 2) enhanced benchmark integrity enforced by regulatory oversight.

Focusing on USD swaps, we find that the BRC has a neutral to positive effect on the representativeness of the benchmark rate as measured by the differential between the execution of a standard market size (SMS) trade at the benchmark rate and the approximate execution price of the same trade size on-platform. In addition, our results provide evidence that market quality in terms of liquidity improves following the BRC, as measured via quoted spreads, depth and execution costs. Spreads have narrowed and the order book has become deeper. Even though quoted depth at the best bid and offer has thinned, the overall 10-level order book depth has slightly increased and the book has consolidated, enabling cheaper executions of SMS orders.

We also endogenously determine the structural breaks in the time series of the employed liquidity measures using statistical techniques and find that the improvement is for a large part driven by higher venue participation. However, difference-in-difference panel regressions show that the increase in liquidity is more pronounced for benchmark grade swaps, i.e. swaps for which a regulated benchmark rate is assessed daily, than for non-benchmark grade swaps. The findings show that the BRC has a positive effect on the liquidity of benchmark grade swaps over and above the improvement induced by higher venue participation. Hence, confidence in the benchmark integrity and regulatory oversight beneficially impact underlying market conditions.

[1] The FCA issued fines amounting to a total of over £2 billion: https://www.fca.org.uk/markets/benchmarks/enforcement. It should be noted that the FCA did not issue fines regarding the ISDAFIX benchmark. In the US, the Commodity Futures Trading Commission (CFTC) recently issued and settled multiple charges for attempted manipulation of the ISDAFIX rate.
See for example: http://www.cftc.gov/PressRoom/PressReleases/pr7505-16, http://www.cftc.gov/PressRoom/PressReleases/pr7527-17, http://www.cftc.gov/PressRoom/PressReleases/pr7371-16.

Our results are robust after controlling for a multitude of confounding effects such as volatility and macroeconomic events and alternative regression specifications.

Key Findings

The key findings of our study can be divided into three categories:

1. Implications of the benchmark regime change on the representativeness of the ISDAFIX benchmark and the ICE Swap Rate:
    - The move from a panel-based assessment methodology under the ISDAFIX regime to an electronic market-based methodology under the ICE Swap Rate regime has a neutral to positive effect on the representativeness of the benchmark rate.
    - Under the new regime, the approximate execution price of a SMS trade is on average closer to the benchmark rate of the day.
2. Implications of the benchmark regime change on the quality of the underlying market:
    - Following the introduction of the new benchmark regime market liquidity measurably improves, as evidenced by narrower spreads, a deeper order book, and cheaper execution costs.
    - Statistical techniques confirm that breaks in the long-term time series of the liquidity measures occur imminently before the introduction of the ICE Swap Rate regime and regulatory supervision by the FCA.
    - Difference-in-difference panel regressions show that the increase in liquidity is more pronounced for benchmark grade swaps suggesting that confidence in the benchmark integrity and regulatory oversight have a beneficial impact on underlying market conditions.
3. Microstructure of the electronic interest rate swap market:
    - Over 99% of the messages on the platform are implied quotes generated through the interaction of prices between the different tenors on the swap curve.
    - The remaining outright messages, which account for less than 1%, are direct price submissions in a specific contract.
    - The quote-to-trade ratio is very large, with the average daily number of messages in the 10-year (10Y) USD interest rate swap contract amounting to 30 million on average, while the number of trades averages 21 per day.
    - With an average volume of 54 million per 10Y USD swap transaction, the average trade size by far exceeds that of traditional equity markets.

The remainder of this paper is organised as follows: the next section presents the literature and provides an overview of the existing policy measures, section three describes the institutional background and introduces the data and study design, section four details the results and section five concludes.

2 The Role of Benchmarks

Benchmarks are critical to the efficient functioning of financial markets. They are used to price financial products, serve as reference rates for fund managers, and increase price transparency for investors.

Imperfections such as information asymmetries, market power and externalities may prevent markets from working well.[2] Economic arguments for benchmark regulation are based on a broad range of potential issues such as inadequate competition including network effects, pricing power, barriers to entry and switching costs, or market abuse and misconduct including benchmark manipulation. The concern of benchmark manipulation has been highlighted most prominently by the LIBOR scandal. Deficient assessment methodologies and conflicts of interests can lead to market abuse by benchmark submitters. When the benchmark process is subject to manipulation, the assessed benchmark rates are inaccurate and do not reflect true market fundamentals. This can result in the loss of confidence in established benchmarks and a decline in the integrity of financial markets.

In 2013, the International Organization of Securities Commissions (IOSCO) published the *Principles for Financial Benchmarks* outlining voluntary guidelines to enhance the quality of benchmarks. Being a critical element of market infrastructure, the FCA started regulating LIBOR in April 2013. In an additional effort to address shortcomings in the Fixed Income, Currencies and Commodities (FICC) markets, the Bank of England (BoE), in collaboration with the FCA and Her Majesty's Treasury (HMT), undertook the *Fair and Effective Markets Review* (FEMR) setting out recommendations to increase, among others, the standards of benchmarks. Regulatory oversight was expanded in April 2015 to include seven other benchmarks, specified by HMT: Sterling Overnight Index Average (SONIA), Repurchase Overnight Index Average (RONIA), WM/Reuters 4pm London Closing Spot Rate, ICE Swap Rate, LBMA Gold Price, LBMA Silver Price and ICE Brent Index. The FCA's June 2015 consultation paper *Fair, Reasonable and Non-Discriminatory Access to Regulated Benchmarks* (FRAND) aimed to restrict market power of administrators and to ensure accessibility by all users. Since July 2016, under the *Market Abuse Regulation* (MAR), manipulation of regulated benchmarks is a civil offence. The EU Benchmark Regulation is more comprehensive and will affect a much larger number of benchmarks and will apply from January 2018, underlining the timeliness of our study.

Academic literature on financial benchmarks and their interactions with the underlying market is scarce and, to our best knowledge, there are only a few theoretical and empirical benchmark studies. Existing research focuses on the robustness of price-setting processes and behaviour in related products, trading patterns that are incompatible with competitive trading, and optimal benchmark design.[3]

The academic interest in benchmarks started with LIBOR, and then evolved to include precious metals, oil and foreign exchange benchmarks. Abrantes-Metz et al. (2012) study the market dynamics around the benchmark for short-term interest rates and, although they do not report conclusive evidence of manipulation, they find patterns suggestive of anticompetitive behaviour in the 1-month LIBOR rate. Monticini and Thornton (2013) analyse the conjecture that some panel participants understated their LIBOR submissions and present evidence that this behaviour likely

[2] Iscenko et al. (2016). Economics for Effective Regulation (FCA Occasional Paper No. 13) (pp. 1–61). Financial Conduct Authority. Retrieved from https://www.fca.org.uk/publication/occasional-papers/occassional-paper-13.pdf

[3] A related strand of literature analyses changes to transparency and competition, often induced by changes to market infrastructure and regulation (see for example Benos, Payne, & Vasios, 2016; Bessembinder, Maxwell, & Venkataraman, 2013, 2006; Boehmer, Saar, & Yu, 2005; Edwards, Harris, & Piwowar, 2007; Goldstein, Hotchkiss, & Sirri, 2007; Harris & Piwowar, 2006; Trebbi & Xiao, 2016).

led to a reduction in the reported rate. Fouquau and Spieser (2015) apply a novel technique allowing them to detect possible cartels. The companies singled out by their identification methodology correspond to the manipulating banks that have been fined by regulators for their role in the 2012 LIBOR scandal.

Focusing on the precious metal market, Caminschi and Heaney (2014) examine the intraday behaviour of financial instruments around the London PM Gold price fixing and deduce that information is leaking from the physical benchmark price assessment into the gold derivatives market ahead of the official price publication. Aspris et al. (2015) conclude that the transition from the traditional manual fixing auction for gold, silver, platinum and palladium to the more transparent electronic-based auction led to a measurable improvement in market quality of the related financial derivatives. While their study is similar in nature to ours, we believe that the evolution of the ISDAFIX benchmark to the ICE Swap Rate is more suitable for an event study of this type, since the benchmark assessment methodology was overhauled by moving from panel submissions to a market-based assessment.

Analysing Brent futures trading behaviour around the assessment of the less known but highly influential Dated Brent spot oil benchmark, Frino et al. (2017) report evidence of directional trading ahead of the assessment end that is most likely driven by physical market information. Finally the theoretical paper by Osler (2016) and the theoretical and empirical study by Evans (2016) focus on foreign exchange and the WM/Reuters London 4pm FX fix. While the former models dealer behaviour around benchmark price assessments and derives trading patterns that suggest collusion among participating dealers, the latter finds currency price movements that align with collusive activities rather than trading in a competitive market environment.

The issues raised in the academic literature are a source of concern for market participants and regulators alike. Hence, this research stream led to a set of papers focusing on the reform of financial benchmarks (see for example Duffie et al., 2016; Perkins & Mortby, 2015) and their value for financial markets. Most importantly, Duffie et al. (2016) model the microstructure as well as the economic and welfare implications of benchmarks in opaque over-the-counter (OTC) financial markets. The authors demonstrate that the introduction of a benchmark can enhance welfare as it improves the information available to traders and reduces their search costs, leading to increased price transparency.[4] For this reason, a benchmark encourages dealers to compete more aggressively for the best price, prompts more efficient dealer–trader matching and increases the volume of beneficial transactions. The raised inter-dealer competition improves market liquidity and reduces transaction costs. The authors show that a benchmark thereby stimulates greater entry by traders while at the same time “the most efficient dealers can use a benchmark as a ‘price transparency weapon’ that drives inefficient competitors out of the market” (Duffie et al., 2016, p. 3).

Duffie et al. (2016) place their paper in an opaque OTC market with no central limit order book (CLOB) having little to no pre-trade price transparency. Our setting is slightly different. Although the IRS market had historically been a purely OTC market, nowadays several regulated trading venues offer pre-trade transparency. Nevertheless, the market is still considered opaque due to the fragmentation across numerous trading platforms, interweaving trading methods (e.g. voice trading and electronic trading) and the split of the market between large dealers and buy-side clients. Hence, only sophisticated market participants have a holistic view of the market and the market is still dominated by large dealer banks. In addition, the setting of Duffie et al. (2016) describes the development from a market without a benchmark to a market with a benchmark. In our case, a benchmark already existed before, but it was substantially reformed and regulated during our sample period.

While the setting of our study is somewhat distinct from the environment chosen for the theoretical model, we believe that several commonalities can be found. Importantly, the transition to a benchmark that benefits from higher levels of robustness and integrity may produce similar

[4] The vast literature on search costs, such as pecuniary and time costs, includes papers such as Duffie et al. (2005), Duffie (2012), Zhu (2012), Duffie and Zhu (2016), Flood (1999).

benefits to those described in the aforementioned theoretical paper. Under the old benchmark regime, the assessment was opaque, subjective and confined to a limited number of submitters. Moreover, regulatory scrutiny on benchmark submitters causes reluctance to participate in a confined panel price setting process, as seen for example by the fall in the number of submitters from 15 in 2012 to 8 in 2014 under the ISDAFIX regime, potentially deteriorating the representativeness of the rate. The fact that former panel banks asked for clarification from the new administrator whether they would still be classified as submitters under the new market-based ICE Swap Rate regime further underlines the sensitivity of having a panel assessment.[5]

Hence, the transition to a new transparent, objective and regulated benchmark regime may have several advantages. First, a more robust assessment methodology should signal higher benchmark integrity. In addition, the market-based approach benefits from the advantage that no labelling of panel banks as submitters is necessary, alleviating perceived regulatory pressures, and for this reason possibly incentivises greater dealer participation. Second, the revelation of a benchmark price, which is based on a larger number of participants, is likely to be more representative of market fundamentals. Third, the increased price transparency incites higher dealer competition on the quoted prices. Finally, a more representative and competitively priced benchmark allows traders to make better-informed decisions leading to more efficient market entry and trading.[6] Hence, it is not unreasonable to control whether or not the benchmark reform led to an on-platform improvement in pricing efficiency and liquidity.

In line with the FCA's objectives, a more transparent and competitively priced benchmark should increase the confidence in the assessed rate and reduce asymmetric information and adverse selection, thus leading to a higher level of market integrity. Based on the above theoretical predictions, we hypothesise that there are two channels through which the methodological changes and regulatory oversight could lead to improved market liquidity: 1) increased price transparency, on-platform participation and dealer competition and 2) enhanced benchmark integrity enforced by regulatory oversight. This study is the first to investigate the evolution of a benchmark from a submission-based assessment to a market-based assessment. In line with the FCA's objective of making markets work well, we aim to establish whether or not this change had a measurable effect on the underlying market and determine the desirability of potential implications (positive or negative) from a regulatory perspective.

[5] See https://web.archive.org/web/20140706105057/http://www2.isda.org/attachment/NjQ1OA==/ISDAFIX%20USD%20Rates%2016%20April%202014.pdf, https://web.archive.org/web/20121130195444/http://www2.isda.org/attachment/NTAwMw==/ISDAFIX%20USD%20Rates%20November%202012%20Final.pdf and https://www.theice.com/publicdocs/ISDAFixOversightCommitteeMinutes20150202.pdf.

[6] This is subject to the limitation of being able to participate on one of the four platforms contributing quotes to the benchmark assessment. We acknowledge that these platforms are mostly inter-dealer brokers and therefore the large majority of participants are major dealer banks, but recently several buy-side firms gained access to the trading venues too.

3 Background, Data and Method

Market Characteristics and Institutional Details

The Interest Rate Swap Market

Historically, fixed-for-floating IRS (henceforth simply referred to as swaps) were traded mostly OTC. With the implementation of the Markets in Financial Instruments Directive (MIFID) in Europe and the Dodd-Frank Wall Street Reform and Consumer Protection Act (the so-called Dodd-Frank Act) in the US, mandatory trading on regulated venues was introduced for certain traditional OTC derivatives markets to promote competition and to enhance transparency.

With a notional amount outstanding of $384 trillion at the end of 2015, interest rate derivatives represent 78% of the global OTC derivatives market. The stake of IRS amounts to $289 trillion, among which USD contracts are the most popular with a notional amount outstanding of $139 trillion.[7] Given its prominence, we focus on the USD segment of the swap market. The data contributed to the ICE Swap Rate assessment for USD IRS is sourced from the swap execution facility (SEF) order books of the contributing electronic trading venues.[8] It is therefore sensible to provide some background information about the Dodd-Frank regulation.

The reforms implemented by the Dodd-Frank Act targeted pre- and post-trade transparency, as well as centralised clearing of eligible derivatives contracts. One major element to achieve enhanced transparency was the introduction of mandatory trading of eligible swap contracts on SEFs, a type of multilateral electronic trading venue, assigning them large parts of trading, reporting, clearing and settlement responsibilities allowing for easier regulation and supervision. The regulation further stipulates the real-time reporting of transactions to swap data repositories (SDRs) to enable public dissemination.

The US Commodity Futures Trading Commission (CFTC) defines SEFs as electronic trading platforms that post and execute bid and offers of multiple participants. Under the mandatory trade execution requirement, swaps made available to trade (MAT)[9] are mandated to be executed on SEFs from February 2014 onwards.[10] A list of the USD IRS maturities captured by the MAT mandate can be found in Table 1. The on-platform trading mandate applies to contracts involving at least one US entity.[11] All transactions must be processed on SEFs, mandatorily cleared via derivatives clearing organisations and reported to SDRs. Recent statistics estimate that two thirds of fixed-for-floating IRS trading nowadays takes place on-SEF.[12]

The minimum trading functionality rule defines that registered SEFs must operate limit order books (LOB) with standard functionalities for all listed swaps. However, the minimum execution method states that the platforms can also offer a request for quote (RFQ) or voice-based system

[7] See statistics of the Bank of International Settlement (http://stats.bis.org/statx/srs/table/d5.1) for more details.

[8] The four electronic trading venues are Trad-X (Tradition), BGC Trader (BGC Partners), i-Swap (ICAP) and tpSWAPDEAL (Tullett Prebon), which are authorised multilateral trading facilities (MTFs) in the UK and also operate SEFs under US legislation. For the EUR and GBP benchmark assessments the data is sourced from the MTF order books. For the USD benchmark assessment data is sourced from the respective SEF order books.

[9] MAT is a procedure used to determine if a swap that is required to be cleared is subject to the trade execution requirement and must be traded on SEF using one of the minimum execution methods. As such, a SEF establishes if a swap is made available to trade based on predefined criteria such as availability of buyers and sellers, and trading frequency and volume, and submits the determination to the CFTC for approval. Once certified by the CFTC the MAT swap needs to be traded per trade execution requirement on all SEFs.

[10] Multilateral electronic trading venues for swaps already existed before this date. After the effective date of the mandate, SEFs must register with the CFTC and operate under its regulatory oversight.

[11] A detailed definition can be found here: http://www.cftc.gov/idc/groups/public/@newsroom/documents/file/crossborder_factsheet_final.pdf

[12] See Benos et al. (2016), Annex 3I and https://www.clarusft.com/what-is-left-off-sef/

functionality in conjunction with the LOB. The SEFs therefore often run a hybrid model pairing electronic and voice broking.[13]

Table 1: Fixed-for-Floating Interest Rate Swaps

	Currency	*Maturity*
Made Available to Trade (MAT)	USD	1Y, 2Y, 3Y, 4Y, 5Y, 6Y, 7Y, 10Y, 12Y, 15Y, 20Y, 30Y
ICE Swap Rate assessment	USD	1Y, 2Y, 3Y, 4Y, 5Y, 6Y, 7Y, 8Y, 9Y, 10Y, 15Y, 20Y, 30Y

Notes: This table shows the tenors (maturity expressed in years [Y]), which are captured by the MAT mandate, and those for which the ICE Benchmark Administration (IBA) is assessing the ICE Swap Rate benchmark. The USD MAT swaps relevant for our study have a 3-month LIBOR interest rate basis, a semi-annual payment frequency and a day count convention of 30/360, aligning with the characteristics of swaps feeding into the assessment by IBA. The MAT mandate for USD tenors was implemented in February 2014. Under the ICE Swap Rate regime, no benchmark rate is assessed for the 12Y USD tenor, which is relevant for later parts of this study. See http://www.cftc.gov/idc/groups/public/@otherif/documents/file/swapsmadeavailablechart.pdf and https://www.theice.com/iba/ice-swap-rate for more information.

In the US, numerous firms operate SEFs that offer standardised electronic trading of formerly mostly OTC-traded derivatives.[14] Dealers continuously stream firm quotes on the LOB and interact with counterparties via voice broking. Generally speaking, SEFs are split into inter-dealer brokers (IDB) such as Tradition and BGC Partners, and dealer-to-client platforms such as operated by Bloomberg and Tradeweb, even though under the Commodity Exchange Act of Dodd-Frank SEFs need to provide impartial access to all eligible participants[15] in a transparent and non-discriminatory manner. This split, often referred to as bifurcation, is a feature of the swap market allowing dealers to interact with each other on one platform and to serve their clients on another platform. Industry estimates indicate that for IRS, the market share split between the dealer-to-dealer and dealer-to-client segments is 40% and 60% respectively, although these numbers fluctuate depending on tenor and currency. Moreover, intelligence gathered in discussions with both industry participants and FCA supervisory departments suggests that most recently some buy-side firms participate on traditional IDB platforms.

The Interest Rate Swap Benchmark

The economic significance of the IRS market and its high degree of interconnectedness with the fixed income and money market amplify the importance of swaps to the global financial markets. Hence, the need for a reference price in the form of a standardised benchmark rate to value and settle contracts was recognised early on.

The ICE Swap Rate, formerly the ISDAFIX rate, is of crucial importance to these markets as it is used in the valuation of, for example, early-terminated IRS, cash-settled swaptions, exchange-traded swaps and swapnote futures, constant maturity swaps, spreadlocks, floating rate bonds, debt issuances, interest rate indexes and portfolios, and many others, or is used for instance by pension funds to hedge interest rate risk or in the US Federal Reserve's statistical release.[16]

[13] SEFs often operate a hybrid model offering an order book functionality and RFQ functionality. Alternatively, the hybrid model includes a voice broking service in conjunction with the limit order book facility. RFQs must be simultaneously disseminated to multiple dealers. The SEF then needs to provide the requester with any quotes received from the dealers plus the firm best bid and offer available on the LOB.

[14] A full list of registered SEFs can be found here: https://sirt.cftc.gov/SIRT/SIRT.aspx?Topic=SwapExecutionFacilities

[15] Broadly speaking, an eligible contract participant is a sophisticated market participant that has a regulated status or sufficient amounts of assets and is authorised to engage in complex financial transactions. Further information can be found here: http://www.cftc.gov/idc/groups/public/@lrlettergeneral/documents/letter/12-17.pdf and http://dodd-frank.com/cftc-addresses-definition-of-eligible-contract-participant/

[16] See http://www.cftc.gov/PressRoom/PressReleases/pr7505-16, https://web.archive.org/web/20140706105057/http://www2.isda.org/asset-classes/interest-rates-derivatives/isdafix, https://www.theice.com/iba/ice-swap-rate

Historical Submission-Based ISDAFIX

The International Swaps and Derivatives Association (ISDA) established the leading benchmark for fixed rates on swaps in 1998 in collaboration with Reuters (now Thomson Reuters) and Intercapital Brokers (now ICAP).[17] The benchmark rates were assessed based on submissions by a panel of 16 banks representing the mid-market rate at which they were willing to trade a SMS swap. The SMS differs across tenors and is $50m for the 10-year (10Y) USD contract, which is the most liquid and actively traded tenor in our sample. The benchmark submitters were asked to submit a live mid-market rate derived from their own bid/offer spread in the current market environment, and not where they see the mid-market rate away from their own quotes (i.e. not where other dealers were willing to trade). For USD swaps, the panel submission polling window ranged from 11:00:00 to 11:15:00 ET and the ISDAFIX rates were published at 11:30:00 ET.[18] Please refer to Panel B and C of Figure 1 for a comparison of the old and new assessment proceeding. To establish the daily benchmark rates, a trimmed mean of the submitted rates was computed, depending on the number of bank participants.

While the number of submitting banks in 2012, for example for USD rates, was 15, it substantially decreased over time until only 8 submitters were left in 2014.[19] A stark reduction in the number of participants is a threat to the viability and integrity of the benchmark. The reasons cited for this decline are numerous, ranging from increased regulatory, compliance and operational costs, and highlighted the need for an alternative robust, objective and representative benchmark regime.

Reformed Market-Based ICE Swap Rate

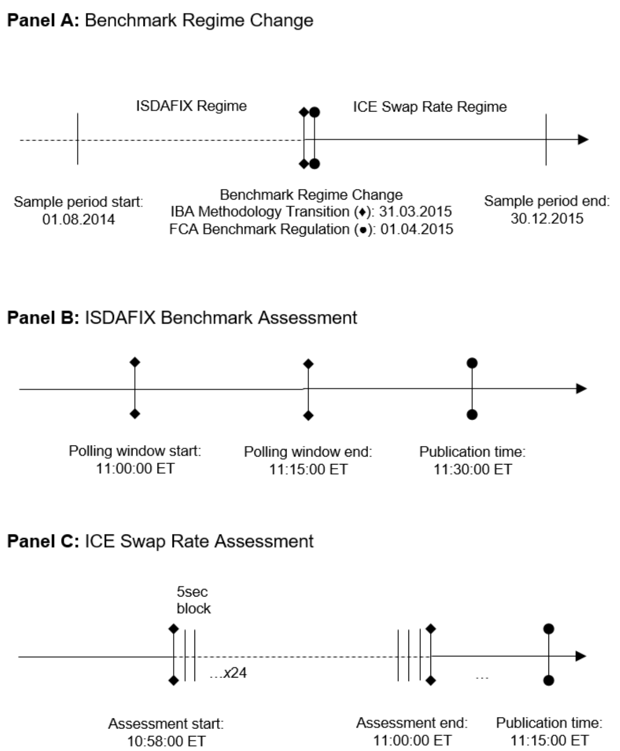
On 1 August 2014, ICE Benchmark Administration (IBA) took over full responsibility from ISDA for all major currency assessments, but kept the old submission-based methodology until 30 March 2015 (inclusive). The change of benchmark administrators was part of a wider attempt to enhance the integrity and robustness of benchmarks after investigations by regulators around the world into claims of misconduct and manipulation of benchmarks.

[17] ICAP was responsible for the USD ISDAFIX rate, while Thomson Reuters was in charge of assessing all non-USD ISDAFIX rates. For a short period, from 27 January 2014 until 1 August 2014, Thomson Reuters served as the submission collection agent for all currencies.

[18] See https://web.archive.org/web/20140706105057/http://www2.isda.org/attachment/NjQ1OA==/ISDAFIX%20USD%20Rates%2016%20April%202014.pdf

[19] See https://web.archive.org/web/20140706105057/http://www2.isda.org/attachment/NjQ1OA==/ISDAFIX%20USD%20Rates%2016%20April%202014.pdf and https://web.archive.org/web/20121130195444/http://www2.isda.org/attachment/NTAwMw==/ISDAFIX%20USD%20Rates%20November%202012%20Final.pdf

Figure 1: Timeline of Events



Notes: Panel A shows the timeline of events of the benchmark regime change. Our sample period starts on the 1 August 2014 and ends on 30 December 2015. On 31 March 2015 (diamond) ICE Benchmark Administration successfully transitioned to the new assessment methodology. The FCA regulatory regime for the ICE Swap Rate started on 1 April 2015 (circle). Panel B shows the polling and publication times under the old ISDAFIX regime. Panel C shows the assessment and publication times under the new ICE Swap Rate regime.

On 31 March 2015, IBA completed the transition from the submission-based assessment system to an automated and market-based methodology, and assessed the benchmark rates for the first time relying on *tradable* quotes from regulated electronic trading venues. The benchmark was renamed ICE Swap Rate, taking effect 1 April 2015.[20] The methodological change went hand-in-hand with the introduction of regulatory supervision by the FCA, starting 1 April 2015. A timeline of events is illustrated in Panel A of Figure 1.

Currently, IBA sources prices for the assessment of the ICE Swap Rate from four IDB platforms: Trad-X (Tradition), BGC Trader (BGC Partners), i-Swap (ICAP) and tpSWAPDEAL (Tullett Prebon).[21] For the period of our investigation, Tradition is the market leader in the IDB segment, accounting for a market share of over 50%, followed by ICAP, BGC and Tullett, although this number fluctuates depending on the currency and swap tenor.[22]

The ICE Swap Rate is the principal global benchmark setting the fixed leg price for IRS at a certain time of the day and is assessed for EUR, GBP and USD and tenors ranging from 1 to 30 years. The ICE Swap Rate represents the mid-price for the execution of a SMS[23] trade, based on the best available prices across trading venues at that specific point in time for the chosen currency and tenor. By means of example, the data collection window for the morning run of USD rates ranges from 10:58:00 to 11:00:00 ET, with the rates published at 11:15:00 ET (see Panel C of Figure 1).

The two-minute data collection window is divided into 24 blocks of 5 seconds and a random snapshot is taken from the order book of each trading venue during each of the blocks. At each snapshot time, the benchmark administrator creates a synthetic order book from the snapshots collected from all venues by ranking the quotes by price. The order book is then used to calculate the volume-weighted bid, offer and average mid-price to execute a SMS order. This process is repeated for each snapshot time and, after discarding illiquid and outlier snapshots, the remaining snapshots are quality-weighted to calculate the ICE Swap Rate.[24]

[20] See http://ir.theice.com/press/press-releases/all-categories/2015/04-01-2015 for the official press release.

[21] In 2015, BGC Partners and GFI Group merged. Until 21 August 2015, GFI Group operated a major MTF, which also provided tradable quotes to IBA for the ICE Swap Rate assessment.

[22] This intelligence was gathered mostly during discussions for this study, but can also be retrieved from industry sources (e.g. http://www.traditionsef.com/markets/irs/) or the SEFView service of Clarus Financial Technology (https://sefview.clarusft.com/).

[23] The SMS differs by currency and tenor as set out by IBA in their methodology document: https://www.theice.com/publicdocs/ICE_Swap_Rate_Full_Calculation_Methodology.pdf

[24] The quality weight is determined based on the tightness of the spread between the volume-weighted bid and volume-weighted offer. The full methodology can be found here: https://www.theice.com/publicdocs/ICE_Swap_Rate_Full_Calculation_Methodology.pdf

Data Sample

For the USD ICE Swap Rate assessments, IBA collects data from three of the four trading venues (namely BGC, ICAP and Tradition). Intelligence that we gathered suggests that, for the assessment of USD rates in the period relevant for our analysis, around 50% to 75% (depending on the swap tenor) of tradable quotes contributing to the ICE Swap Rate assessment originate from the Trad-X LOB.

We obtained message-by-message IRS data from Tradition (UK) Ltd. Since we focus on USD swaps, the data is sourced from the Trad-X SEF order book for LCH cleared swaps.[25] The data records all usual order book variables and covers all USD tenors, ranging from 1 to 50 years. The time period is 1 August 2014 to 30 December 2015, a total of 331 trading days (after data cleaning).[26]

In our data, the 10Y USD swap is on average the most liquid tenor with respect to quote submissions and transactions, and therefore the focus of our analysis.[27] The interest rate basis for the floating leg is the 3-month LIBOR rate and the day count convention is semi-annual 30/360.

Messages consist of three action types – new order submissions, changes, and cancellations – and are timestamped in GMT to the nearest millisecond (ms). Given the USD emphasis, we convert all our time references to local New York Eastern Time (ET) adjusting for Eastern Daylight Time (EDT) in the summer and Eastern Standard Time (EST) in the winter. Each message is labelled with a unique order identifier, allowing us to follow its life cycle evolution. Every order ID occurs at a minimum two times and up to *n* times, starting with the submission, including potential order changes, up to the final order cancellation. An order change message can amend the price and/or the volume. A message cancellation is recorded following an active cancellation or after a transaction has been concluded. Both outright and implied orders[28] are recorded, and as tradable quotes they both contribute to the ICE Swap Rate assessment. All messages are indexed by a sequence number, enabling us to correctly trace the unfolding of events. We also receive reports of electronically executed transactions. On the Trad-X platform approximately 25% of transactions are executed electronically, while 75% of transactions are concluded via the voice functionality.

We use the raw message files received from Tradition to reconstruct the aggregated 10-level full order book at the end of each second, *t*. The order book follows price-time priority. The minimum tick size for USD swaps on the Trad-X platform is 1/8 of a bps. We study the order book data during the normal trading hours of the major US exchanges from 9:30am to 4pm ET.

Methodology

The market-based assessment of the ICE Swap Rate by IBA using tradable quotes from limit order books of regulated electronic trading venues was conducted for the first time on 31 March 2015. On 1 April 2015, the FCA started regulating the ICE Swap Rate. We refer to the period before the change to the benchmark assessment methodology and regulation as pre-BRC and the period after this date as post-BRC. We employ an event study methodology, where 31 March 2015 is the event day, t_0, which is exogenously determined due to the changes to the benchmark

[25] Tradition runs a hybrid model offering voice instruction in conjunction with the LOB. We receive the electronic LOB data for our study. In addition, it is worth noting that Tradition operates two separate order books: one for LCH and one for CME cleared interest rate products. The LCH order book is the more active of the two by a large margin.

[26] We exclude holidays following the IBA Holiday Calendar (https://www.theice.com/iba/holiday-calendars). Moreover, we exclude days where no benchmark rate was assessed, where an early close of US (or UK) exchanges took place, and where trading took only place for less than 50% of the normal trading hours.

[27] USD rates are assessed twice daily for 13 different tenors, at 11am and 3pm ET respectively. Additionally, the USD spreads are assessed at 11am ET.

[28] The Trad-X platform includes an implied engine, which produces implied orders along the swap curve. An implied order is generated synthetically from orders in individual tenors and spread contracts available in the market and used to compute a tradable implied price. Implied orders substantially enhance market liquidity in both the individual contracts and the respective spread contracts. See the glossary in Annex 1 for more detailed definitions.

regime. The ISDAFIX regime encompasses [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. The ICE Swap Rate regime extends [d_0 = 31 March 2015, d_{170} = 30 December 2015]. Statistical tests are used to compare one period to the other. We also employ statistical tests to endogenously determine the break dates in our data.

In our analysis, we focus on two related but separate aspects: the effects on the quality of the benchmark itself and the effects on the quality of the underlying swap market.

Benchmark Quality

To measure changes to the quality of the benchmark, we use the Benchmark-to-Market Differential (*BMD*). The ISDAFIX ahead of 31 March 2015 represented the rate at which dealer banks were willing to buy and sell a swap of a SMS ($50m for 10Y USD IRS) each day before the end of the polling period. The new ICE Swap Rate assessment methodology also calculates the benchmark rate by continuously simulating the filling of an SMS order during a two-minute time window. Hence the benchmark rate should be indicative of market conditions and thus a representative price for the execution of a SMS trade around 11am, both under the ISDAFIX regime as well as under the ICE Swap Rate Regime.

Hence we define the *BMD* simply as:

$$BMD_{t,d} = \left|R_d - F_{t,d}\right| \tag{1}$$

where R_d is the assessed benchmark rate on day d and $F_{t,d}$ is the estimated average of the buy and sell price for a SMS order at time t, on day d, and computed as the average of F_t^A and F_t^B.

F_t^A (F_t^B) is the hypothetical execution price for a SMS buy (sell) order at time t assuming that an aggressive buyer (seller) crosses the spread and consumes liquidity on the ask (bid) side of the order book. A small differential would be interpreted as a benchmark rate that is indicative of market fundamentals. We average the $BMD_{t,d}$ over different windows (1 min, 10 mins, 30 mins etc.) around the 11am assessment in order to provide a comprehensive picture of the representativeness of the rate.

Market Quality

For our analysis of market quality, we rely on standard liquidity measures such as spreads and depth that are established in the market microstructure literature. For a more detailed description of the measures, see McInish and Wood (1992), Lee et al. (1993), and Hegde and McDermott (2003). The measures we use are described below.

$$QS_t = (A_t - B_t) \tag{2}$$

Quoted spread (*QS*) is the difference between the offer/ask price (A_t) and the bid price (B_t) available in the market at time t.

$$RQS_t = \frac{(A_t - B_t)}{M_t} \tag{3}$$

Relative quoted spread (*RQS*), also called percentage quoted spread, equals the dollar quoted spread divided by the market mid-price (M_t), defined as the average between the best bid and offer price at time t.

$$FS_t = (F_t^A - M_t) + (M_t - F_t^B) \tag{4}$$

Due to the infrequent occurrence of transactions in this market, the hypothetical fill spread (*FS*) measure aims to approximate the effective spread.[29] Normally the effective spread is computed as $2 \times DIR_t(P_t - M_t)$ where DIR_t is a direction parameter accounting for buyer-initiated transaction and seller-initiated transactions and P_t is the transaction price. Naturally, a trader could execute a buy or a sell transaction. Since we simulate the fill of both a buy (F_t^A) and a sell (F_t^B) SMS order at any point in time, we do not need DIR_t. Similarly, the comparison to the mid-price in Equation 4 cancels out. So the hypothetical fill spread can be written as:

$$FS_t = (F_t^A - F_t^B) \tag{5}$$

We are left with our FS_t in Equation 5 as the difference between F_t^A and F_t^B, i.e. the roundtrip costs for completing a buy transaction and a sell transaction approximating the liquidity on both sides of the order book at time *t*.

$$QD_t = (V_t^A + V_t^B) \tag{6}$$

$$QD10_t = \sum_{l=1}^{10} (V_{l,t}^A + V_{l,t}^B) \tag{7}$$

Quoted depth (*QD*) and 10-level quoted depth (*QD10*) are defined as the sum of the offer volume (V_t^A) and the bid volume (V_t^B) at time *t* at the best level and the best 10 levels (*l* = 1,…,10) of the order book respectively.

We time-weight all our measures as follows:

$$TWLM_t = \frac{1}{T}\sum_{i=1}^{N} LM_t(t_{i+1} - t_i) \tag{8}$$

LM_t represents one of the above described liquidity measures. *t* is the timestamp of the *i* = 1,…,*N* intraday quote update on day *d*. *T* is the length of the trading day.

[29] We also report the actual effective spread as computed from the few direct 10Y USD IRS transactions per day available to us. The findings are reported alongside the fill spread results in the next section.

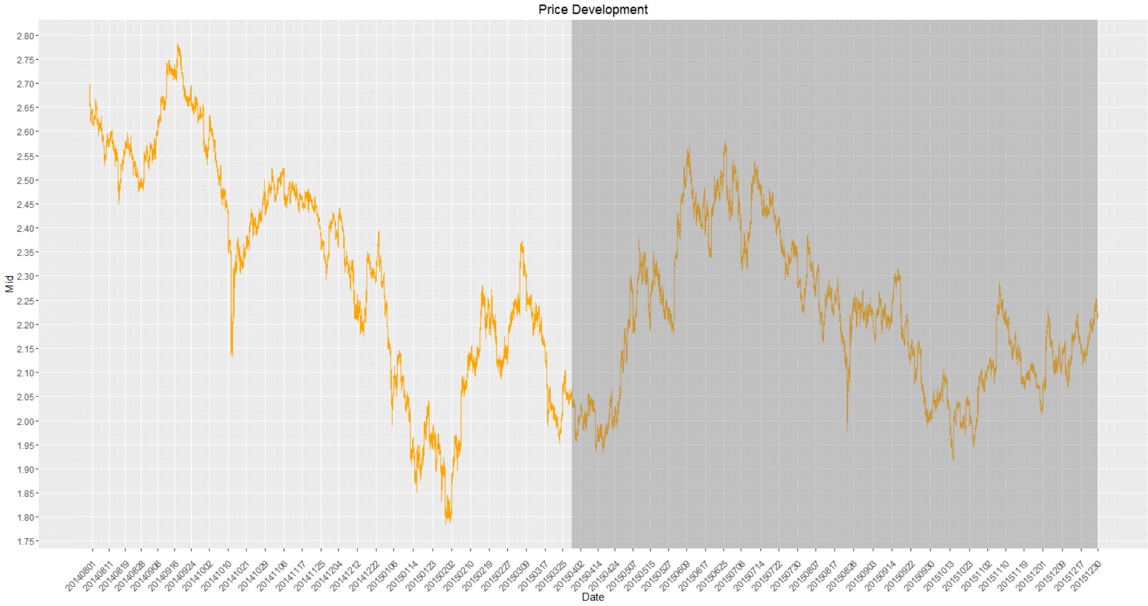
4 Results

Electronic Trading of Interest Rate Swaps

Before discussing the effects of the regulation and change in methodology, we begin with a brief description of the data at our disposal.

The midpoint price (where the price of a swap is a percentage rate – we use the terms interchangeably) in the 10Y USD IRS is depicted in Figure 2. The shaded area represents the period after the regime change. Overall the pre-BRC period includes 160 trading days and the post-BRC covers 171 trading days. The average quoted mid-price for a 10Y USD swap before 31 March 2015 is 2.33 and the average best bid and offer (BBO) quote size amounts to 50.66 million. After 31 March 2015 (inclusive), the average mid-price is 2.21 and the BBO quote size is $45.18 million respectively. The period of investigation was characterised by significant price volatility due to several macroeconomic and political events. The average daily price volatility (measured by the standard deviation of the mid-price) during the pre- and post-period amounts to 0.24 and 0.15 respectively, and is thereby slightly lower after the event date. We will consider this in our analysis. Although the size of the submitted BBO quotes is smaller, there is also less variability in their size ($40.52 million versus $37.14 million).

Figure 2: 10Y USD Swap Price Development



Notes: This figure shows the mid-price development of the 10Y USD IRS over the full sample period from 1 August 2014 to 30 December 2015. The shaded area marks the period of the new benchmark regime from 31 March 2015 to 30 December 2015.

Descriptive statistics of quotes and transactions can be found in Table 2 and Table 3. For the 10Y swap contract, a total average of 30.27 million messages is recorded every day. The messages are split between implied and outright orders. Due to the nature of the IRS market, characterised by interweaving swap curve and strategy dynamics[30], and the development of potent pricing engines by electronic trading venues, implied orders play an increasingly important role in the

[30] We refer to swap curve dynamics as the interaction between different swap tenors, for example via curve spreads and butterflies. We label as strategies the interaction between the bond and swap market, for example via swap spreads. See the glossary in Annex 1 for more details.

continuous pricing of products and substantially increase market liquidity. It should be stressed that both outright and implied orders are firm and executable.

Table 2: Summary Statistics – Messages

Price and quotes						
	n_D	μ_{MID}	σ_{MID}	$\mu_{QUOTE\ SIZE}$	$\sigma_{QUOTE\ SIZE}$	
Full sample	331	2.27	0.21	47.80 m	38.89 m	
Pre-BRC	160	2.33	0.24	50.66 m	40.52 m	
Post-BRC	171	2.21	0.15	45.18 m	37.14 m	
Messages						
	$\bar{n}_{TOTAL}$	$\bar{n}_{NEW}$	$\bar{n}_{CANCEL}$	$\bar{n}_{CHANGE}$	$\bar{n}_{OUTRIGHT}$	$\bar{n}_{IMPLIED}$
Full sample	30.27 m	15.14 m	15.14 m	1.90	103.10 k	30.17 m
Pre-BRC	25.89 m	12.94 m	12.94 m	2.17	90.79 k	25.80 m
Post-BRC	34.37 m	17.19 m	17.19 m	1.71	114.63 k	34.26 m
%-Diff	33%	33%	33%	-21%	26%	33%

Notes: This table reports simple descriptive statistics on electronic trading of the 10Y USD IRS on the Trad-X SEF. n_D reports a count of the number of trading days. μ and σ report the arithmetic mean and standard deviation of the mid-price and quote size for orders at the best bid and offer respectively. $\bar{n}$ reports the average daily count of the total number of messages, new quote submissions, cancellations, changes, outright messages and implied messages respectively. *k* and *m* refer to thousands and millions respectively. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. *%-Diff* reports the simple percentage difference between the two periods.

For the 10Y USD swap contract, on average, a total of 103,000 messages are related to outright orders, while the remaining 30.17 million messages are related to implied orders, accounting for more than 99% of total message flow. Of these 30 million messages, half accounts for new order submissions, while the other half corresponds to their respective cancellations.[31] There are only very few order changes (an average of two change messages daily; see Table 2). A cancel and replace message is faster and is effectively the same as a change message.

Our data includes only electronically executed transactions. The ratio of electronic to voice executions on this specific platform is approximately 25%. In discussions with market participants, the platform was described as the 'shop window', attracting traders' attention. The traders then often use the voice functionality of the platform to conclude transactions. Nevertheless, the electronic and voice systems of the trading venues are closely interlinked. As such, price innovations in one execution method are likely reflected in the other method too. Given the large number of messages, trading on regulated SEFs is characterised by a very high quote-to-trade ratio. Transactions can either be directly executed in the individual swap legs, such as the 10Y IRS, or produced via a 'packaged' trade. Packaged transactions, such as swap spreads, curve spreads or butterflies, technically correspond to simultaneous individual transactions in the respective swap legs and are the most frequent (see the glossary in Annex 1 for detailed definitions). For example, a transaction in the 10Y versus 12Y curve spread leads to individual executions in the 10Y leg and 12Y leg. During the full sample period there were only 165 direct 10Y USD swap trades, averaging less than one transaction per day.[32] The average daily total number of transactions in the 10Y USD swap leg contract on this platform is 21, while a total number of 6,835 transactions have been executed over the same period. This is still a low number compared to, for instance, equity markets. However, the average trade volume of $54 million is considerable, leading to a non-negligible total average daily executed volume of $1.14 billion. Overall, between August 2014 and December 2015 a total volume of $370 billion in 10Y

[31] Given the functioning of the raw message files, each message is labelled by a unique order identifier, allowing us to follow its life cycle evolution. Every order ID occurs at a minimum two times and up to *n* times, starting with the submission, including potential order changes, up to the final order cancellation. A message cancellation is recorded following an active cancellation or after a transaction has been concluded. Hence, each recorded message has an associated cancellation.

[32] We do not report summary statistics of direct 10Y USD IRS transactions in this study. The average transaction volume for direct 10Y IRS transactions amounts to $43 million, accumulating to a total overall executed volume of $7.1 billion.

USD swaps was traded electronically on Trad-X alone.[33] For the rest of this paper, we will consider all transactions in the 10Y IRS, direct executions as well as executions in the individual 10Y leg, as an element a of packaged trade.

Table 3: Summary Statistics – Transactions

			n_{TRANS}	VOL_{TRANS}
Sum			*total*	*total*
	Full sample		6.84 k	370.19 b
		Pre-BRC	3.19 k	172.94 b
		Post-BRC	3.65 k	197.25 b
		%-Diff	14%	14%
Average			*daily*	*per trade*
	Full sample		21.10	54.16 m
		Pre-BRC	20.29	54.23 m
		Post-BRC	21.80	54.10 m
		%-Diff	7%	0%
Median			*daily*	*per trade*
	Full sample		20.00	50.00 m
		Pre-BRC	19.00	50.00 m
		Post-BRC	21.00	50.00 m
		%-Diff	11%	0%

Notes: This table reports descriptive statistics on transactions that were electronically executed on the Trad-X platform. n_{TRANS} reports the number of transactions. VOL_{TRANS} reports the transaction volume. *k*, *m*, and *b* refer to thousands, millions, and billions respectively. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. *%-Diff* reports the simple percentage difference between the two periods.

The total number of messages as well as the number of outright messages have gradually increased over time; given that the large majority of messages are implied, the evolution of total and implied messages is identical (see also Annex 3A). Pre-BRC, an average total of 25.89 million messages was recorded on the Trad-X platform for 10Y swaps, compared to 34.37 million messages in the post-BRC period (a rise of 33%). New order submissions and cancellations went up proportionally. Outright order submissions increased by 26% from 91,000 to 115,000. With regard to transactions, the average daily number of 10Y USD IRS transactions has grown by 7% from 20 to 22, while average volume per transaction has remained stable (negligible change from $54.23 million to $54.10 million). The post-BRC period saw an increase in transactions by 14% to 3,650 compared to 3,190 for the pre-BRC period. The total volume traded likewise expanded from $173 billion pre-BRC to $197 billion post-BRC, a gain of 14%.

In summary, the vast majority of messages recorded are implied orders, most of which are cancelled during the trading day without being traded upon. Electronic trades are infrequent but considerable in terms of volume. Nevertheless, the firm nature of quotes ensures their reliability by holding participants accountable for submitted prices. The price discovery process of the market can therefore be compared to the 'tâtonnement' process described in Biais et al. (1995, 1999), where the efficient price is discovered in a gradual learning process of submitting additional buy and sell orders. The order flow in itself is informative.

Effects on Benchmark Quality

One element of this study is to analyse whether or not the new benchmark regime shifted the benchmark rate closer to market fundamentals. We test the hypothesis that the BRC did not lead

[33] For the total period of investigation from 1 August 2014 to 30 December 2015 and executions (direct and packaged) in all tenors, a total overall volume of $4.7 trillion was traded electronically on Trad-X.

to an improvement in the representativeness of the rate. On this account, our dataset allows us to compare the benchmark rates under the ISDAFIX regime as well as under the IBA regime to market prices available on regulated trading venues.

The benchmark-to-market differential (*BMD*) aims to measure the absolute gap for trading a SMS order at the benchmark rate (R_d) versus the estimated average of the buy and sell price of a SMS trade ($F_{t,d}$) in the market around the time of the 11am benchmark assessment (as detailed in Section 3). The *pre* and *post* values in Table 4 report the average daily *BMD* during the ISDAFIX and the ICE Swap Rate regime respectively.[34] The pre-BRC and post-BRC regimes differ both in terms of methodologies (panel-based versus market-based) and in terms of assessment lengths (15 minutes versus 2 minutes). For reasons of comparability and robustness, we compare the average *BMD* measure pre- and post-BRC for multiple windows of different length centred on the 11am benchmark assessment.

By means of example, for the 11am window in Table 4 we calculate the *BMD* at each point in time *t* for the 1-minute window from [11:00:00; 11:00:59] and then average across days within the pre- and post-period. The result indicates that for this particularly short window, an on-platform execution of a SMS order would have, on average, been executed closer to the benchmark rate under the old regime (0.11 bps versus 0.15 bps differential). This difference, given the additional evidence presented in the table that we discuss below, is likely driven by the differing assessment methodologies. Under the ISDAFIX regime, panel banks submitted point estimates on the basis of which the administrator calculated the benchmark rate. Submissions opened and concentrated at 11am[35] and thus by construction, the difference between the assessed rate and the market price at that point in time is small. The ICE Swap Rate, however, is essentially a 2-minute average of the market price from 10:58:00 to 11:00:00, introducing stronger sensitivity to price movements, and therefore by construction a larger differential to the market price at 11am (see also Figure A12 and A13 in Annex 3D).

Table 4: Benchmark-to-Market Differential

Window	*Time*	*Pre-BRC*	*Post-BRC*	*t-Stat*	*%-Diff*
1 min	*[11:00:00; 11:00:59]*	0.11	0.15	3.65***	37.19%
4 mins	*[10:58:00; 11:01:59]*	0.14	0.13	-1.55	-9.68%
10 mins	*[10:55:00; 11:04:59]*	0.22	0.19	-2.24**	-12.01%
20 mins	*[10:50:00; 11:09:59]*	0.29	0.27	-1.5	-7.72%
30 mins	*[10:45:00; 11:14:59]*	0.35	0.34	-0.56	-2.87%
60 mins	*[10:30:00; 11:29:59]*	0.48	0.46	-0.67	-3.41%
10 mins before	*[10:48:00; 10:57:59]*	0.35	0.30	-2.15**	-14.71%
10 mins after	*[11:00:00; 11:09:59]*	0.30	0.31	0.55	4.02%
Assessment end	*[11:15] & [11:00]*	0.48	0.15	-9.83***	-68.07%
Publication	*[11:30] & [11:15]*	0.66	0.52	-2.72***	-21.79%

Notes: This table reports the benchmark-to-market differential $BMD_{t,d} = |R_d - F_{t,d}|$ where R_d is the assessed benchmark rate on day *d* and $F_{t,d}$ is the hypothetical on-platform average execution price for a SMS order at time *t,* on day *d*. We average the $BMD_{t,d}$ over different windows around the 11am assessment in order to provide a comprehensive picture of the representativeness of the rate. For the *Assessment End* window, we compute the differential using hypothetical execution prices during the full minute after the respective assessment end times of the old [11:15:00; 11:15:59] and new [11:00:00; 11:00:59] regimes. For the *Publication* window, we compute the differential using execution prices during the full minute after the respective publication times of the old [11:30:00; 11:30:59] and new [11:15:00; 11:15:59] regimes. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%). The t-value is the statistic of a two-sample t-test of $\mu_1 - \mu_2 = 0$. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. *%-Diff* reports the simple percentage difference between the two periods.

[34] We use hypothetical execution prices because of the lack of enough direct swap trades per day in the 10Y USD IRS. As reported in the descriptive statistics section, over the full period only 165 direct 10Y USD IRS were executed electronically. We still compute the *BMD* based on the few executed transactions and find a qualitatively similar result.

[35] Annex 3D shows that under the ISDAFIX regime the benchmark rate is much more indicative of the market price at the start of the polling window (11:00:00) rather than at the end of the polling window (11:15:00).

Hence, we argue that a comparison of the benchmark rate to the estimated average execution price for different time windows centred on 11am is most meaningful. By extending the window length over which we compute the *BMD* measure, we find that post-BRC the benchmark rate is indicative of market prices for a longer period of time. For the 4 mins, 10 mins, 20 mins, 30 mins and 60 mins comparisons, the *BMD* is 3% to 12% lower under the new regime compared to the old regime. This finding is only statistically significant for the 10-minute window centred on 11am, although generally speaking we do see a pattern of a smaller benchmark differential under the ICE Swap Rate regime. Nevertheless, based on the 10-minute window, we can reject the hypothesis that the BRC did not affect the representatives of the benchmark rate at the 5% significance level. Moreover, the benchmark-to-market differential at the respective assessment ends and publication times of the ISDAFIX and ICE Swap Rate regimes is significantly smaller (subject to the above-mentioned limitations) under the new benchmark regime (a reduction of 68% and 22% respectively); results which are statistically significant at the 1%-level.

We want to highlight the findings of the 10-minute window immediately preceding the start of the benchmark assessments. The benchmark rate should be indicative of where the dealers see the market price at the time of the assessment and the quote submissions ahead of the assessment start should thus be indicative of the upcoming benchmark rate. With a mean value of 0.35 bps versus 0.30 bps, the average daily *BMD* during the 10-minute window from [10:48:00; 10:58:00] is 15% smaller during the post-BRC period compared to the pre-BRC period. This development is statistically significant at the 5% level. The benchmark-to-market differentials during the 10 minutes after 11am for the old and new regime are not significantly different from each other. This may suggest that price discovery of the benchmark rate takes place in the market place ahead of 11am.

Overall, the results presented in Table 4 show that the new regime did not lead to a deterioration of the representativeness of the benchmark rate; if anything, the transition to the ICE Swap Rate improved the representativeness of the benchmark. We also note that under the old regime the rate was already closely reflecting on-platform market conditions. It is possible that the ISDAFIX benchmark submissions were already very closely geared towards electronic markets, particularly since the Dodd-Frank mandate shifted trading in eligible IRS contracts to regulated platforms starting February 2014 (predating our sample period).[36] It was therefore sensible to move the assessment process to regulated electronic venues altogether. Moreover, the pre-BRC period covered by our sample saw the number of ISDAFIX submitters decrease to 8 (from an initial 15), most likely due to regulatory scrutiny. The remaining submitters had an incentive to adjust their benchmark submissions to closely reflect on-SEF swap prices.

Implications for the Swap Market Quality

We now move to discussing the observed effects on the quality of the swap market. The economic rationale for testing whether or not a more robust benchmark assessment can have an impact on pricing efficiency and liquidity of underlying products is elaborated in Duffie et al. (2016). We determine two channels through which the BRC could impact market quality: 1) increased price transparency, on-platform participation and dealer competition due to a market-based benchmark assessment; 2) enhanced benchmark integrity and market confidence due to the added regulatory oversight.

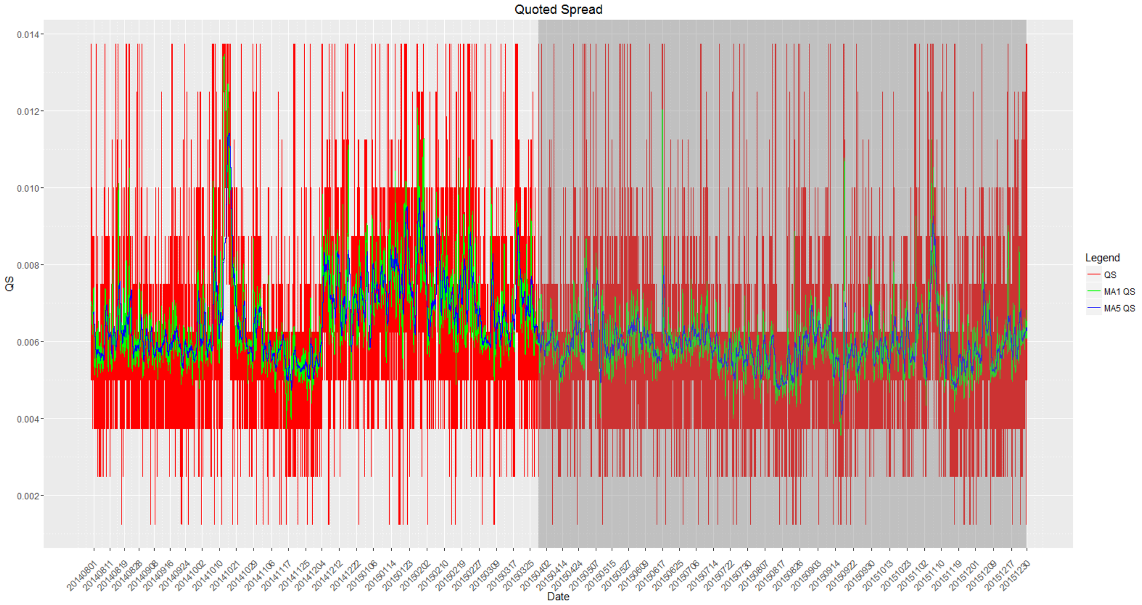
Quoted Liquidity

Previous work has found that greater transparency through better market infrastructure, changes in regulation or enhanced reporting often leads to an improvement in market liquidity (see for example Benos, Payne, & Vasios, 2016; Trebbi & Xiao, 2016). In our analysis, we follow standard microstructure literature and assess market liquidity using the absolute quoted spread (dollar spread) as well as the relative quoted spread (percentage spread). We also develop a novel

[36] However, the results presented in Annex 3K also show that the price discovery process is more efficient under the new regime.

measure of spread (which we label 'fill spread' and which is defined in the methodology section) for markets characterised by a LOB but very few transactions.[37] The quoted dollar spread is defined as the difference between the best bid and offer price. The relative quoted spread is determined as the ratio of the quoted spread and the quoted mid-price. The relative spread is sensitive to the movement of the market price, which in our case is volatile and on average lower during the post-BRC period (see Table 2); hence this measure serves as a robustness test, since a lower price should lead to a larger relative spread. Given that the fill spread approximates the execution costs of a roundtrip SMS trade, our view is that this is the best measure of liquidity to assess. All spread and depth measures are time-weighted.

Figure 3: Quoted Spread – 10Y USD Interest Rate Swaps



Notes: This figure depitcs the simple quoted spread (red) for the 10Y USD IRS on the Trad-X platform (not time-weighted for illustration purposes) on a second-by-second basis for the trading hours from 9:30am to 4pm ET over the full sample period from 1 August 2014 to 30 December 2015. The shaded area marks the period of the new benchmark regime from 31 March 2015 to 30 December 2015. The green line plots the 1-hour moving average. The blue line plots the 5-hour moving average. Values are expressed in absolute dollar terms.

Figure 3 illustrates the quoted spread (red) on a second-by-second basis over the full sample period (1 August 2014 to 30 December 2015). On average, quoted spreads hover around 0.64 bps. The spikes in spreads mostly coincide with unusual market events (e.g. US treasury flash crash on 15 October 2014, CHF-EUR unpegging on 15 January 2015) or macroeconomic announcements (e.g. a European Central Bank (ECB) announcement on 4 December 2014). As can be seen by the 1-hour moving average (green) and 5-hour moving average (blue), quoted spreads increase in early December 2014 and remain large for several months. Quoted spreads then narrow around the end of March 2015 and remain at lower levels for the rest of the year.

In Table 5, we report the long-term comparison of the liquidity measures by splitting the sample period before and after the event date. We report three spread measures and two market depth measures. Quoted spreads and relative quoted spreads are both significantly lower in the post-BRC period. The average daily time-weighted quoted spread (*TWQS*) decreases from 0.7 bps to 0.6 bps, a reduction of 14%. Similarly, the average daily time-weighted relative quoted spread (*TWRQS*), which accounts for fluctuations in the price, narrows from 0.31 bps to 0.27 bps, a drop of 11%. The improvement in time-weighted average spread measures is significant at the 1% level. Variations in the width of the spread measures reduce after the BRC, with the average daily

[37] As reported in the descriptive statistics section, only 165 direct swap trades were executed in the 10Y USD IRS. Further complicating the matter is the fact that of the total 6,835 10Y USD IRS trades, for example, swap spread transactions (i.e. trading the differential between the bond yield and swap rate) are priced against the bond yield. Hence, the transaction price determined for the 10Y USD swap usually falls within the BBO spread of the order book, not allowing us to calculate effective spread measures for individual swap leg transactions of packaged trades. We nevertheless compute the volume-weighted effective spread (*VWES*) for the few electronically executed direct swap transactions. The mean value for the *VWES* for the pre-BRC period amounts to 0.3 bps and 0.27 bps for the post-BRC period. This corresponds to a reduction of 10.65%, in line with our results in Table 5.

standard deviation contracting by 34% to 37%. Our results also hold if we use daily median values instead of mean values, to account for potential skewness of the data.

Table 5: Quoted Liquidity under the ISDAFIX and ICE Swap Rate Regime

	Spreads			Depth	
	TWQS	*TWRQS*	*TWFS*	*TWQD*	*TWQD10*
Mean					
Pre	0.70	0.31	0.78	100.81 m	3.39 b
Post	0.60	0.27	0.70	90.56 m	3.52 b
t-Stat	-6.76***	-4.21***	-5.65***	-4.54***	1.5
%-Diff	-14.34%	-10.96%	-11.24%	-10.17%	3.94%
Median					
Pre	0.67	0.29	0.74	89.20 m	3.52 b
Post	0.60	0.27	0.68	79.27 m	3.65 b
t-Stat	-6.03***	-3.15***	-5.89***	-4.35***	1.41
%-Diff	-10.82%	-7.27%	-8.42%	-11.13%	3.90%
Std Dev					
Pre	0.17	0.08	0.16	51.72 m	0.79 b
Post	0.11	0.05	0.10	47.03 m	0.72 b
t-Stat	-3.58***	-3.23***	-3.17***	-3.46***	-2.39**
%-Diff	-36.71%	-34.35%	-33.52%	-9.08%	-9.63%

Notes: This table reports the long-term comparison of liquidity variables before and after the change in benchmark regime. Time-weighted quoted spread (*TWQS*) reports the spread in absolute dollar terms. Time-weighted relative quoted spread (*TWRQS*) reports the ratio of the quoted spread to the mid-price and is also referred to as %-spread. The time-weighted fill spread (*TWFS*) reports the difference between the hypothetical execution prices of a SMS trade on both sides of the book as per the methodology section. Time-weighted quoted depth (*TWQD*) is the sum of the depth at the best bid and offer price. 10-level time-weighted quoted depth (*TWQD10*) is the sum of the depth at the bid and offer side of the 10-levels of the order book. All liquidity measures are computed as daily averages (medians) and then averaged across the period of interest. The median captures the weighted median (by number of occurrence) of the liquidity measures. Standard deviation reports the average daily standard deviation of the liquidity measures. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All spread measures are expressed in bps (1 bps = 0.01%). *m* and *b* refer to millions and billions respectively. The t-value is the statistic of a two-sample t-test of $\mu_1 - \mu_2 = 0$. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. *%-Diff* reports the simple percentage difference between the two periods.

We complement the spread analysis by studying market depth, both at the best bid and offer level as well as at the bid and offer of the full first 10 levels of the order book. Columns 4 and 5 of Table 5 report the results for the time-weighted quoted depth measures. On the one hand, average daily quoted depth is lower during the post-BRC period ($100 million versus $90 million), a deterioration of 10% at the 1% significance level. On the other hand, 10-level quoted depth increases somewhat from an average daily value of $3.39 billion pre-BRC to $3.52 billion post-BRC. However, this 4% increase in *TWQD10* is not statistically significant. Again, the results are consistent when using median values.[38]

In short, spreads narrow and the order book at the first 10 levels appears to be marginally deeper, but depth at the best level is thinner. Traders however are interested in the costs of trading. Consequently, in the third column of Table 5, we report the results for the time-weighted fill spread (*TWFS*). Average (median) daily fill spreads on the Trad-X platform in the post-BRC period narrow from 0.78 (0.74) bps to 0.7 (0.68) bps, a decrease of 11% (8%) at the 1% significance level. This result shows that it is cheaper to trade electronically under the ICE Swap Rate regime. In addition, although not reported in this table, the total number of times that a SMS order can't be executed (on a second-by-second basis) on the Trad-X platform on either side of the book due to missing liquidity decreases from 885 in the pre-BRC period to 326 in the post-BRC period, corresponding to a drop of 63%.

[38] We report an alternative measure of order book depth in Annex 3J. We simulate the continuous fill of a large transaction (several multiples of the 10Y tenor SMS) to corroborate our results. We find a highly significant improvement in execution costs for large and very large transactions too.

Naturally, it is difficult to assign the improvement in liquidity to the BRC, especially by exogenously identifying the potential break date. Changes to the microstructure of the underlying market could have occurred before or after the event date, leading to an improvement in quoted liquidity. We therefore use the event study methodology as employed in Hegde and McDermott (2003) to tackle this problem. We calculate our average liquidity measures over different time intervals surrounding the event date of 31 March 2015 and compute a ratio by comparing them to the long-term average of the estimation window [d_{-160} = 1 August 2014, d_{-30} = 13 February 2015] extending up to 30 trading days before the regime change, a period that is unaffected by the BRC. If the ratio for the liquidity measure for some interval in Table 6 is bigger (smaller) than unity, the interval average is greater (smaller) than the estimation window average. Given the similarity of findings for the three spread measures in Table 5, we only report the *TWQS* here.

Table 6: Short-Term Liquidity Reaction to the Benchmark Regime Change

	TWQS		*TWQD*		*TWQD10*	
Interval	*Mean (Median)*	*t-Stat*	*Mean (Median)*	*t-Stat*	*Mean (Median)*	*t-Stat*
[0; 0]	0.87	-	1.03	-	1.27	-
	(0.94)	-	(0.92)	-	(1.29)	-
[-1; +1]	0.87	-37.68***	0.95	-1.22	1.05	0.29
	(0.94)	-	(0.94)	-3.38*	(1.07)	0.42*
[-2; +2]	0.88	-10.62***	0.98	-0.35	1.13	1.21
	(0.94)	-	(0.96)	-0.77*	(1.13)	1.25*
[-3; +3]	0.90	-3.48**	1.00	0.05	1.16	1.75
	(0.97)	-1.15	(1.01)	0.3*	(1.15)	1.76*
[-4; +4]	0.92	-3.09**	0.99	-0.13	1.12	1.5
	(0.96)	-1.77	(1.01)	0.13*	(1.10)	1.19*
[-5; +5]	0.92	-3.36***	1.01	0.18	1.12	1.71
	(0.96)	-2.38**	(1.02)	0.43*	(1.11)	1.43*
[-10; +10]	0.97	-0.53	1.03	0.74	1.09	1.56
	(0.98)	-0.66	(1.06)	1.67*	(1.07)	1.11*
[-20; +20]	0.96	-1.55	1.06	2.17**	1.09	2.5**
	(0.98)	-1.12	(1.09)	3.12***	(1.08)	2.15**
[-30; +30]	0.98	-0.64	1.04	1.82*	1.05	1.84*
	(0.98)	-1.04	(1.06)	2.31**	(1.05)	1.51*
[-30; -1]	1.08	1.43	1.09	2.9***	0.99	-0.23
	(1.03)	1.19	(1.12)	3.36***	(0.97)	-0.72*
[+1; +30]	0.89	-5.45***	0.99	-0.39	1.11	2.98***
	(0.94)	-3.04***	(1.01)	0.16*	(1.12)	3.28***

Notes: This table reports the short-term reaction of liquidity variables around the benchmark regime change. *Interval* represents the time period, in number of days $d \in D$ before and after the event date [d_0 = 31 March 2015], over which the liquidity measures are averaged. Time-weighted quoted spread (*TWQS*) reports the spread in absolute dollar terms. Time-weighted quoted depth (*TWQD*) is the sum of the depth at the best bid and offer price. 10-level time-weighted quoted depth (*TWQD10*) is the sum of the depth at the bid and offer side of the 10-levels of the order book. All liquidity measures are computed as daily averages (medians) and then averaged across the intervals of interest. The ratios are computed relative to a reference value, which is the average of the same liquidity measure over the estimation window [d_{-160} = 1 August 2014, d_{-30} = 13 February 2015]. All values are ratios. The t-value is the statistic of a one-sample t-test of $\mu = 1$. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. "-" is reported when the significance could not be assessed due to the small sample size of the interval.

The ratio using the average (median) time-weighted quoted spread for the interval [0;0] covering only the event date of 31 March 2015 is with 0.87 (0.94) considerably below its long-term average. For the first five intervals ([-1; +1], [-2; +2], [-3; +3], [-4; +4], [-5; +5]) centred on the event date, the average daily *TWQS* ratio indicates that spreads are significantly lower (5% level to 1% level) compared to their long-term average. During the 11-day interval [-5; +5] centred on the event date, average as well as median spreads are significantly lower with a value of 0.92 and 0.96 at the 1% and 5% significance level respectively. The results also hold for longer time periods, although at a non-significant level. The findings for the intervals [-30; -1] and [+1; +30] demonstrate that the narrowing of spreads is driven by a significant decrease in the post-BRC period rather than the pre-BRC period as determined by the ratio of 0.89 at the 1%-significance level versus 1.08 respectively.

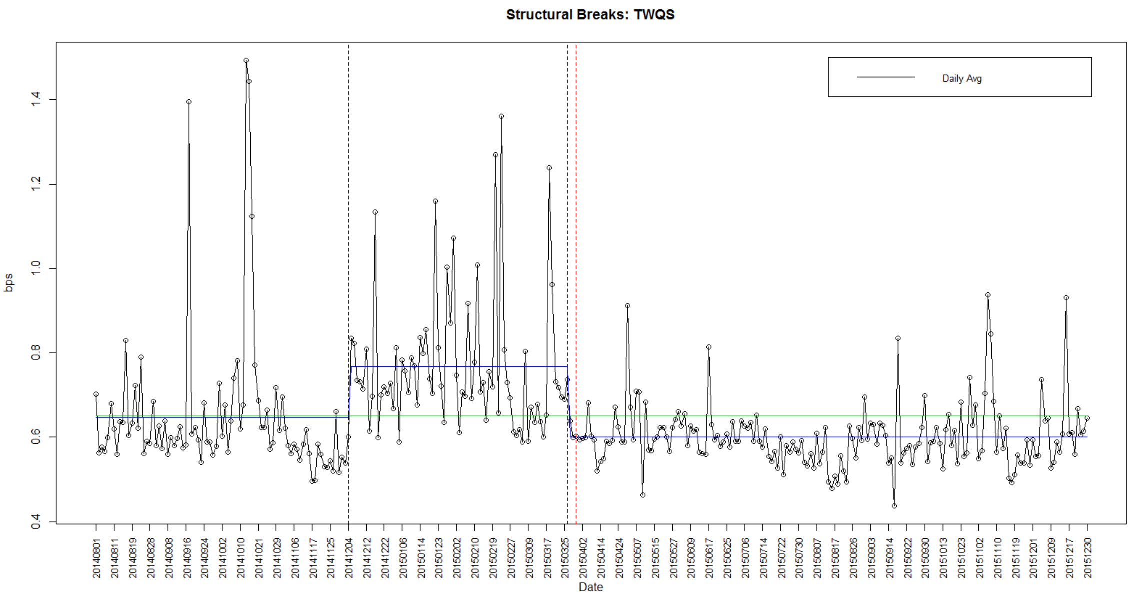
Since the earlier long-term results were less clear cut, the event study findings on order book depth are of particular interest. The average time-weighted quoted depth at the best level is above its long-term average on the event date [0, 0] itself (1.03), although its median is below unity and further drops significantly below the estimation window reference value for the intervals [-1; +1] and [-2; +2]. The interval [-30; -1] shows that *TWQD* is above its long-term average (1.09) at the 1% significance level ahead of the BRC. During the 30 days [+1, +30] after the BRC quoted depth is not significantly different from the reference value of the estimation window. In terms of average 10-level quoted depth, the book is much deeper on the event date [0; 0] with a value of 1.27. The [-30; -1] interval shows that the 30 days before the regime change are characterised by a slightly thinner order book (median ratio of 0.97 at the 10% significance level), whereas the [+1; +30] period shows a deeper order book (highly significant average ratio of 1.11 and median ratio of 1.12). The event study confirms our early findings suggesting that the BRC affected market liquidity, and has done so positively.

Structural Breaks

So far we relied on an exogenous determination of the event date to assess the implications of the BRC on liquidity. Namely we calculated our measures before and after the changes introduced to the methodology and the regulation of the benchmark. In this subsection, we statistically determine structural breaks in the liquidity measures endogenously. We follow the approach by Bai and Perron (BP, 1998, 2003) described in Annex 2.

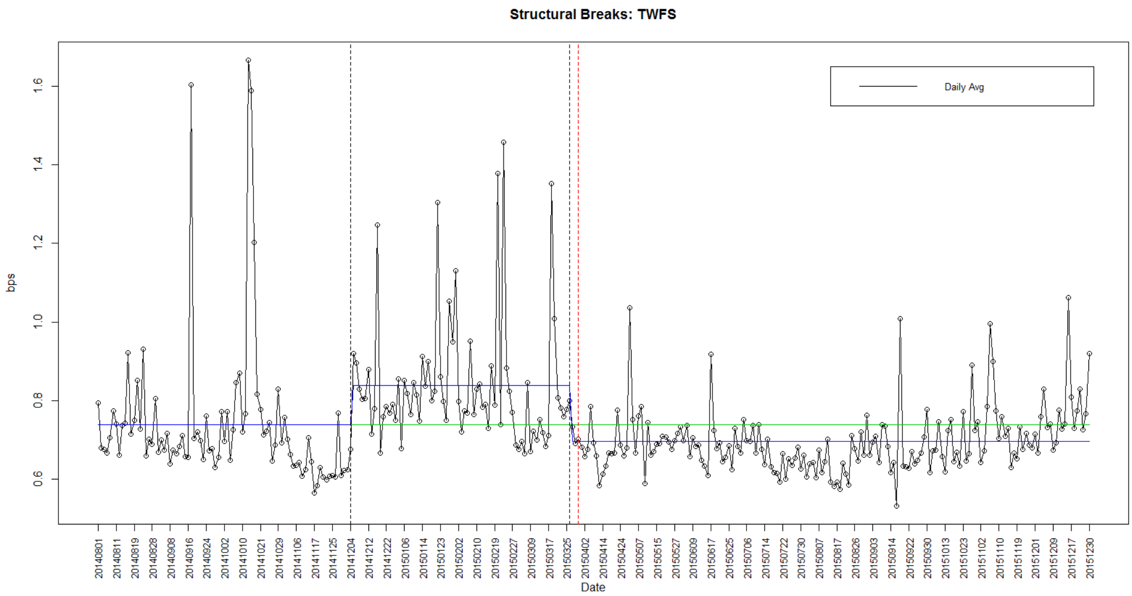
Figures 4 to 7 depict the determined structural changes in the time series of four different liquidity measures.

Figure 4: Time-Weighted Quoted Spread



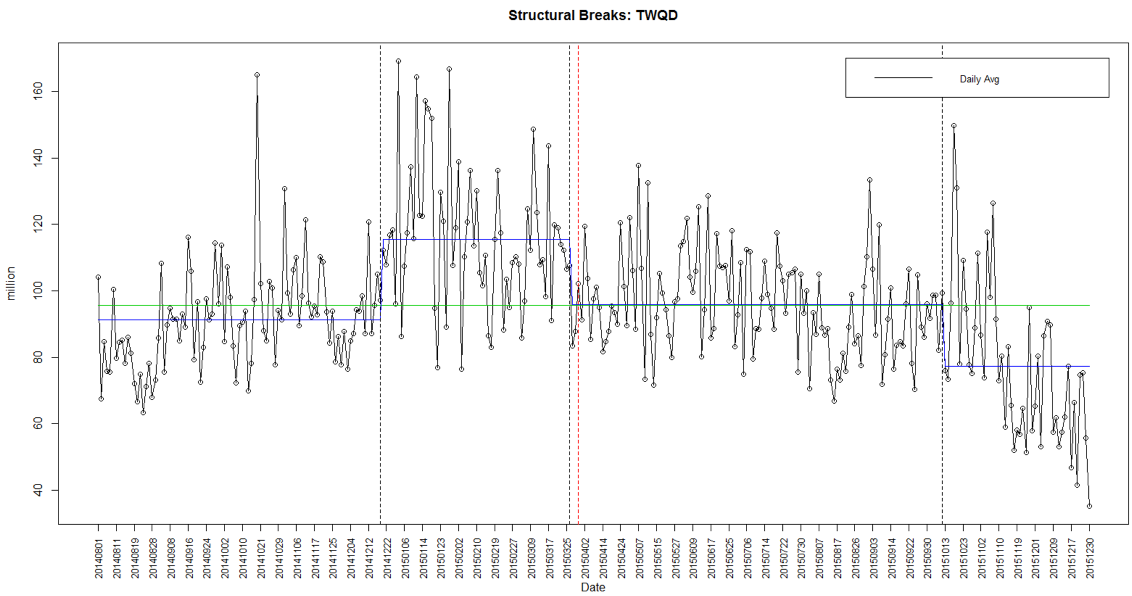
Notes: This figure shows the development of the daily average time-weighted quoted spread for the 10Y USD IRS over the sample period. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%).

Figure 5: Time-Weighted Fill Spread



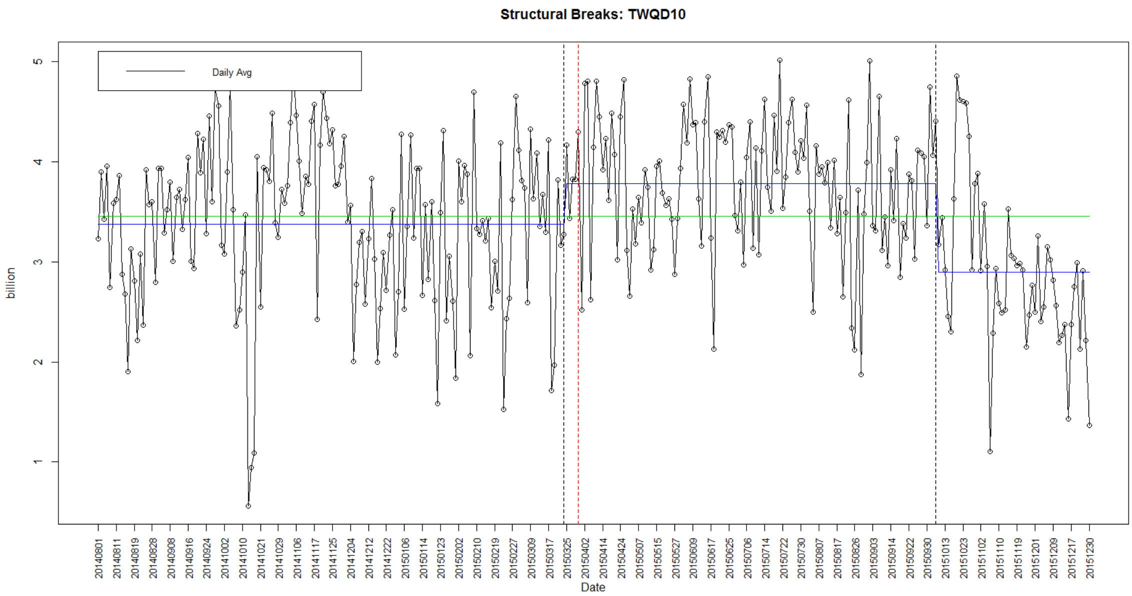
Notes: This figure shows the development of the daily average time-weighted fill spread for the 10Y USD IRS over the sample period. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%).

Figure 6: Time-Weighted Quoted Depth



Notes: This figure shows the development of the daily average time-weighted quoted depth for the 10Y USD IRS over the sample period. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015].

Figure 7: Time-Weighted 10-level Quoted Depth

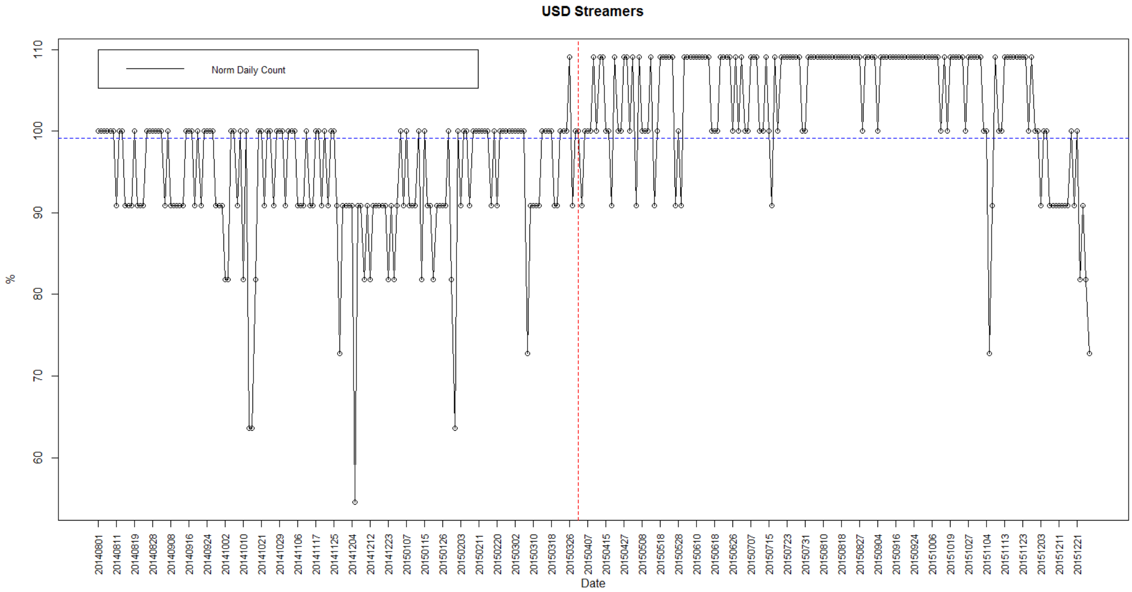


Notes: This figure shows the development of the daily average time-weighted 10-level quoted depth for the 10Y USD IRS over the sample period. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015].

The *TWQS*, *TWFS* and the *TWQD10* experience two breaks each, while the *TWQD* shows three breaks. The common pattern that can be established is that for each of the four liquidity measures, one break occurs very shortly before the introduction of the BRC. For both spread measures, the multiple structural break models indicate an upward first break in the data on 4 December 2014. We attribute this change to one of the following two possible drivers: 1) ECB president Mario Draghi announcing a potential quantitative easing intervention; 2) a drop in the number of USD streamers on the trading venue. On 5 December 2014, the number of dealers on the platform falls by roughly 45% (see Figure 8), which could also be the cause for the observed widening of spreads. The number of dealers recovers to its previous level on the next day and stays relatively stable thereafter. However, participation over the following days is volatile possibly explaining the wider spreads throughout December to March. The downward second break occurs on 26 March 2015, three trading days before the BRC.[39] Given the proximity to the event date (31 March 2015) and no occurrence of a major macroeconomic event around the break day (to the best of our best knowledge), we attribute this change in the long-term pattern, at least in part, to the upcoming change in benchmark regime. Duffie et al. (2016) suggest that improved price transparency generated by a benchmark encourages entry by traders and stimulates dealer competition on prices, which at the same time may lead to inefficient dealers exiting the market. In addition, we argue that a robust and regulated market-based benchmark reduces information asymmetry and signals integrity, encouraging greater market participation while also inciting price competition between dealers. The fact that on 26 March 2015, the Trad-X platform experiences a 10% increase in the number of participants supports our hypothesis. Figure 8 illustrates that the number of platform participants remains above its long-term average during the large majority of the post-BRC period.

[39] The same test also identifies a downward structural break for the benchmark differential on 25 March 2015. Moreover, given the extreme movements in quoted spreads on days with high uncertainty and volatility, such as macroeconomic news announcements, we reran our multiple structural breaks model using a trimmed time series in order to exclude extreme days. The break dates remain identical: 4 December 2014 and 26 March 2015. See Annex 3C for more details.

Figure 8: USD Participants



Notes: This figure shows the development of the daily count of USD streamers on the Trad-X platform over the sample period. The numbers are normalised and presented in percentage terms (%). The blue dotted line depicts the long-term average of the time series. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015].

The breaks determined for the two depth measures are somewhat different. The quoted depth time series shows three breaks: 18 December 2014, 26 March 2015 and 7 October 2015. The first and third breaks are different to the breaks established for the spread measures, but importantly the second downward break immediately precedes the BRC and suggests a slight reduction in depth at the best order book level, which is consistent with earlier findings. For the 10-level depth time series, the BP multiple structural break model identifies two breaks: 24 March 2015 and 7 October 2015. The October break is identical to before, but this time the March break occurs five trading days before the BRC. In general, the fact that all liquidity measures identify a break in the long-term time series just before the ISDAFIX regime was replaced by the ICE Swap Rate regime supports our earlier findings. It is likely that we observe a joint effect of more efficient entry by market participants, higher price transparency and intensified dealer competition.

Regulation as a Driver?

So far we have provided evidence that the quality of the swap market improved after the FCA started regulating the relevant benchmark, but we cannot infer that the regulation caused the changes. In this section, we address this shortcoming and attempt to determine causality to the extent possible. We do this by employing a difference-in-difference (DiD) approach. The panel regression models are of the following form:

$$DV_{i,d} = \alpha + \beta_1 Event_d + \beta_2 Treatment_i + \beta_3 Event_d \times Treatment_i + \gamma' X_d + \mu_i + \varepsilon_{i,d} \qquad (9)$$

where *i* denotes tenors and *d* denotes days. The dependent variable *DV* corresponds to one of the two liquidity measures: *TWQS* and *TWFS*.[40] *Event* is a dummy taking the value 0 for the pre-BRC period [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015] and 1 for the post-BRC period [d_0 = 31 March 2015, d_{170} = 30 December 2015]. *Treatment* is a dummy taking the value 1 for tenors that

[40] We only report the results for the spread measures in the main body of the study. The *TWFS* results account for the combined effect on spreads and order book depth and report the net effect. The *TWQD* and *TWQD10* specifications of the DiD panel regressions can be found in Annex 3F.

are part of the treated group and 0 otherwise. Our treated group is made up of tenors for which a benchmark is assessed. These tenors are therefore covered by the regulatory regime. For the results reported here, the tenor chosen for the treatment group is the 10Y USD IRS, and the tenor chosen for the control group is the 12Y USD IRS. No benchmark rate is being assessed for the 12Y tenor (see also Table 1) while at the same time it is the most actively quoted and traded non-benchmark MAT tenor in our data.[41] In Annex 3F we also report the results of running the DiD regressions using multiple tenors where the 5Y and 10Y form the treatment group and the 11Y and 12Y the control group – again chosen based on their liquidity profile.[42] X_d is a vector of control variables including swap and debt market volatility, venue participation, quoting and trading behaviour, macroeconomic developments and others. β_1 captures any common effects that impact all swap tenors following the BRC. β_2 absorbs any pre-existing differences in characteristics between the treatment and control group. The coefficient of interest is β_3 which captures the interaction of *Event* and *Treatment* and thus estimates any incremental effects of the BRC. Hence, β_3 reflects the change in liquidity for tenors that are part of the benchmark regime compared to the change in liquidity for tenors that are not. The model is estimated using tenor fixed effects.

Table 7: Difference-in-Difference Panel Regression for Spread Measures

	TWQS				*TWFS*			
	(1)		*(2)*		*(1)*		*(2)*	
	Coeff	*t-Stat*	*Coeff*	*t-Stat*	*Coeff*	*t-Stat*	*Coeff*	*t-Stat*
Constant	6.78E-03	32.82***	2.03E-02	9.03***	7.35E-03	45.83***	2.35E-02	11.3***
Event	-6.35E-04	-2.85***	-1.34E-04	-0.76	-2.00E-04	-1.1	3.45E-04	2.11**
Treatment	2.40E-04	4.24***	2.37E-04	4.15***	4.89E-04	4.66***	4.91E-04	4.64***
Interaction	-3.71E-04	-4***	-3.57E-04	-3.94***	-6.80E-04	-5.65***	-6.83E-04	-5.62***
SRVIX			1.10E-02	1.26			7.07E-03	0.82
TYVIX			-1.45E-03	-0.92			-2.68E-04	-0.19
MESS_10Y			4.60E-04	2.38**			5.25E-04	2.59***
MESS_12Y:10Y			-1.25E-04	-0.53			-2.56E-04	-1.31
TRANS_10Y			-6.14E-08	-0.01			8.80E-06	0.11
TRANS_12Y:10Y			-2.47E-05	-0.42			-1.45E-05	-0.27
PARTICIPANTS			-2.61E-03	-2.74***			-3.91E-03	-3.72***
MACRO			4.21E-03	8.78***			2.90E-03	6.26***
O:I_10Y			1.68E-03	5.2***			1.67E-03	5.39***
Adj R^2	8.57%		67.28%		6.37%		56.07%	
N	658		637		658		637	
Specification	FE		FE		FE		FE	

Notes: This table reports the results of the difference-in-difference (DiD) panel regression model specified in Equation 9 using time-weighted quoted spreads (*TWQS*) and time-weighted fill spreads (*TWFS*) as dependent variables. *(1)* presents the DiD model without controls while *(2)* presents the same specification with controls. *Event* is a dummy variable that takes the value 0 for the pre-BRC period [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015] and 1 for the post-BRC period [d_0 = 31 March 2015, d_{170} = 30 December 2015]. *Treatment* is a dummy that takes the value 1 for benchmark grade swaps (10Y) and 0 otherwise (12Y). *Interaction* is a dummy variable computed as *Event* * *Treatment*. *SRVIX* is the log return on the Interest Rate Swap Volatility Index. *TYVIX* is the log return on the 10-year US Treasury Note Volatility Index. *MESS_10Y* is the log daily count of the number of messages received by the platform operator for the 10Y IRS contract. *MESS_12Y:10Y* is the log ratio of messages for the 12Y contract relative to the 10Y contract. *TRANS_10Y* is the log daily number of transactions in the 10Y IRS contract. *TRANS_12Y:10Y* is the log ratio of the number of transactions in the 12Y contract relative to the 10Y contract. *PARTICIPANTS* represents the log number of USD streamers per trading day. *MACRO* is a dummy variable that takes the value 1 on days with macroeconomic announcements by the Federal Open Market Committee (FOMC) and the Governing Council of the ECB and 0 otherwise. *O:I_10Y* is the log ratio of outright to implied messages in the 10Y IRS contract. The models are estimated using tenor fixed effects. We use Driscoll and Kraay (1998) consistent standard errors. Robust t-statistics are shown in the *t-stat* columns. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. Sample period is 01.08.2014-30.12.2015.

Table 7 reports the estimation results. The DiD model is estimated without controls and with controls (the columns are labelled as [1] and [2] respectively). We show that there is little

[41] Due to spill over effects caused by the close interaction of the swap curve, the control group is not completely untreated. However, this means that our estimates are conservative. Moreover, differences in characteristics between the tenors are captured by the *Treatment* dummy variable, and we further control for differences in liquidity patterns over time via additional control variables.

[42] We choose to report these results in Annex 3F because the 11Y tenor is not an MAT swap. The time series and structural breaks of the 5Y, 11Y and 12Y liquidity measures can be found in Annex 3H.

difference in the coefficients of interest between the two specifications. Overall, our control variables help to significantly explain a proportion of the development of our liquidity measures with an adjusted R^2 of 67% and 56% respectively.

Firstly, with the BRC there is an improvement in *TWQS* for both groups of swap tenors, as indicated by the negative and highly significant *Event* coefficient. Importantly, however, the significant *Interaction* term shows that the enhancement in *TWQS* for the 10Y tenor is beyond the improvement in the 12Y tenor. The *TWFS* for the *Interaction* coefficient reports that the execution costs in the 10Y USD IRS have come down significantly more than the execution costs in the 12Y USD IRS following the change in benchmark assessment methodology and regulation by the FCA. The results are equally strong for the model specifications with multiple controls, among which we include the number of trading venue participants (*PARTICIPANTS*), suggesting that the liquidity improvement is over and above the positive impact of increased activity around the event date. The effects of the regulation are economically significant. The costs savings, as measured by the total effect of the BRC on electronically executed 10Y USD swaps on the Trad-X platform alone, amount to between $3.33 million and $9.92 million.[43] The marginal cost savings, computed on the basis of the incremental reduction in execution costs of the 10Y benchmark grade swap tenor over the 12Y non-benchmark grade tenor, range between $3.6 million to $6.7 million. Given that we only focus on one tenor and that the swaps can be traded on other venues too, the overall benefits are likely to be substantially larger.

We don't discuss the control variables in detail but it is worth noting that the number of USD streamers (*PARTICIPANTS*) has a strongly positive effect on our liquidity measures. An increase in the number of participants on the trading venue leads to a sharp and highly significant reduction in quoted spreads and fill spreads. This aligns with our earlier assertion of increased on-platform participation leading to a liquidity improvement, which is consistent with empirical microstructure findings (see for example Barclay & Hendershott, 2004). Importantly, even after controlling for a multitude of potentially confounding effects, our findings show a significant incremental improvement in on-platform execution costs for the benchmark grade swaps. Taken together, our results suggest that at least part of the liquidity improvement was driven by the regulatory change and methodological evolution of the benchmark.

[43] The total effect cost savings are computed following the rationale in Benos et al. (2016), which we adjust to our setting, as: $\sum_{i=1,3} \frac{\beta_i}{100 \times 2} \times Vol_{POST} \times Mat$, where β_i are the coefficients from Equation 9. We divide by 100 because swap prices are quoted as a percentage rate, and further divide by 2 to indicate the cost savings of a one-directional trade. Vol_{POST} is the sum of the electronic volume traded in the 10Y USD IRS contract following the BRC (197.25 b, Table 3), and *Mat* is the maturity of the contract (10 years). For the marginal effect cost savings, we only use the estimated coefficient of the interaction term (β_3). The cost savings represent the present value (assuming a zero risk-free rate) of the decreased future fixed-rate payments of a swap with a notional value amounting to Vol_{POST}.

5 Conclusion

Theoretical models suggest that benchmarks can increase social surplus and have positive welfare implications (see Duffie et al., 2016).

We find that the transition on 31 March 2015 from the unregulated panel-based ISDAFIX regime to the regulated market-based ICE Swap Rate regime led to a measurable improvement in market liquidity, translating into reduced execution costs for platform participants. The cost savings for electronic transactions in the 10Y USD interest rate swap from April 2015 to December 2015 on the Trad-X platform alone approximately amount to between $4 million and $7 million. A large part of the liquidity enhancement can be explained by an increment in the number of venue participants. Yet the effect is stronger for benchmark grade interest rate swap tenors – swap tenors for which a benchmark rate is assessed daily and which are presumably impacted more by the change in benchmark regime – compared to non-benchmark grade swap tenors. Hence, our results also suggest that the influence of the regulatory regime is beyond the effect of increased venue participation. We also find that the quality of the benchmark itself has likely improved, and certainly not deteriorated following the regulatory change.

There are two limitations to our study. First, we only analyse the order book data of the major inter-dealer platform contributing quotes to the ICE Swap Rate benchmark assessment. Developments in market quality on the remaining contributing venues, and dealer-to-client platforms, might look different from the observed reaction on Trad-X. Second, our study only captures electronic trading while a large part of the market takes place via voice broking. Future research should aim to consolidate electronic order book data with voice trading activity to further improve our understanding of the modern interest rate swap market.

We add to the existing literature in two ways. Firstly, the description of electronic swaps trading on multilateral venues furthers our knowledge of the microstructure of this historically opaque OTC market. Secondly, the event study of this paper enhances our understanding of the implications of market infrastructure regulation. We demonstrate that robust financial benchmarks can contribute to better financial markets.

Annex 1: Glossary

Definitions in this glossary are provided solely for the convenience of readers of this report. They are not presented as approved regulatory definitions or to be used for any other purpose.

Benchmark administrator – A person who has authorisation to carry on the regulated activity of administering a specified benchmark. (From FCA. (2017). *MAR 8.3 Requirements for benchmark administrators – FCA Handbook*. [online] Available at: https://www.handbook.fca.org.uk/handbook/MAR/8/3.html).

Benchmark submitter – A person carrying out the regulated activity of providing information in relation to a specified benchmark. (From FCA. (2017). *MAR 8.3 Requirements for benchmark administrators – FCA Handbook*. [online] Available at: https://www.handbook.fca.org.uk/handbook/MAR/8/3.html).

bps – One basis point equals 0.0001 or 0.01%. Interest rate swaps are quoted as a rate (in %).

Butterfly – A package involving the simultaneous trading of three different swap tenors on the swap curve. (From Barnes, C. (2017). *Mechanics and Definitions of Spread and Butterfly Swap Packages*. [online] Clarus Financial Technology. Available at: https://www.clarusft.com/mechanics-and-definitions-of-spread-and-butterfly-swap-packages/).

Specified benchmark – A benchmark as defined in section 22(1A)(b) of the Act and specified in Schedule 5 to the Regulated Activities Order pursuant to article 63R of the Regulated Activities Order. (From FCA. (2017). *MAR 8.3 Requirements for benchmark administrators – FCA Handbook*. [online] Available at: https://www.handbook.fca.org.uk/handbook/MAR/8/3.html).

CFTC – US Commodity Futures Trading Commission.

Curve spread/trade – A package involving the simultaneous trading of two different swap tenors on the swap curve. (From Clarus Financial Technology. (2017). *Curve Trade*. [online] Available at: https://www.clarusft.com/glossary/curve-trade/).

Dodd-Frank Act – Dodd-Frank Wall Street Reform and Consumer Protection Act.

IDB – Inter-dealer broker. Classification of a broker that traditionally organises trading of cash and derivatives between wholesale dealers. (From Skarecky, T. (2017). *IDB*. [online] Clarus Financial Technology. Available at: https://www.clarusft.com/glossary/idb/).

Implied order – An *Implied In* price is generated by the differential of two contracts. The differential of the known values (the legs) goes into generating the unknown value (the spread). When calculating *Implied Outs*, a leg price is generated by the spread price and one of the legs. The differential of the known values (the spread price and a leg price) goes into generating the unknown value (a leg price). One can also calculate implieds from implieds generating second generation, third generation etc. implied prices. (From Tradingtechnologies.com. (2017). *Calculating Implied Ins – Trading Technologies*. [online] Available at: https://www.tradingtechnologies.com/help/x-trader/trading-and-the-market-window/calculating-implied-ins/ and *Calculating Implied Outs – Trading Technologies*. [online] Available at: https://www.tradingtechnologies.com/help/x-trader/trading-and-the-market-window/calculating-implied-outs/).

IRS (also referred to as swap) – An Interest Rate Swap is an agreement between two counterparties in which one stream of future interest payments is exchanged for another based on a specified principal amount. Interest rate swaps usually involve the exchange of a fixed interest rate for a floating rate, or vice versa. (From Investopedia. (2017). *Interest Rate Swap*. [online] Available at: http://www.investopedia.com/terms/i/interestrateswap.asp).

Leg – A leg is one element of a swap structured to exchange fixed payments (the fixed leg) and floating payments (the floating leg). Alternatively, the individual swap tenors in a packaged trade are referred to as legs too.

MAT – Made Available to Trade. A designation for swaps such that they become a Required Transaction under the CFTC Trade Execution Requirement. Such swaps are mandatory to be executed on SEFs. (From Skarecky, T. (2017). *MAT*. [online] Clarus Financial Technology. Available at: https://www.clarusft.com/glossary/mat/).

MiFID/MiFIR – The Markets in Financial Instruments Directive is the framework of EU legislation for the organised trading of financial instruments, and MiFIR is the related regulation. MiFID was first implemented in 2007 and is being comprehensively revised (MiFID II), with the changes to take effect from January 2018. (From Aquilina, M., Foley, S., O'Neill, P., & Ruf, T. (2016). *Asymmetries in Dark Pool Reference Prices (FCA Occasional Paper No. 21)*. Financial Conduct Authority. Retrieved from https://www.fca.org.uk/publication/op16-21.pdf).

MTF – A Multilateral Trading Facility, operated by an investment firm or a market operator, that brings together multiple third-party buying and selling interests in financial instruments (in the system and in accordance with non-discretionary rules) in a way that results in a contract in accordance with the provisions of Title II of MiFID. (From Aquilina, M., Foley, S., O'Neill, P., & Ruf, T. (2016). *Asymmetries in Dark Pool Reference Prices (FCA Occasional Paper No. 21)*. Financial Conduct Authority. Retrieved from https://www.fca.org.uk/publication/op16-21.pdf).

OTC – Over-the-Counter. Often used to describe transactions that are not concluded via a traditional exchange.

Outright order – An outright order is a direct price submission in a specific contract, such as an individual swap contract or a packaged contract.

Packaged trade – A group of two or more transactions that are executed simultaneously, for a combined price. Common packages such as Spreads, Butterflies, and Curve Trades have been interpreted to be Required Transactions for SEF execution. (From Skarecky, T. (2017). *Package*. [online] Clarus Financial Technology. Available at: https://www.clarusft.com/glossary/package/).

RFQ – Request-for-Quote. A marketplace execution method whereby a participant requests prices for a particular instrument (e.g. OTC derivative) and this request is received and responded to by one or more participants. The CFTC requires SEFs to generate three responses to an RFQ. (From Skarecky, T. (2017). *RFQ*. [online] Clarus Financial Technology. Available at: https://www.clarusft.com/glossary/rfq/).

SDR – Swap Data Repository is a US trade repository for swap transactions. See Dodd-Frank Wall Street Reform and Consumer Protection Act for more information.

SEF – Swap Execution Facility. A CFTC designation for an exchange/venue for the trading of OTC derivatives. (From Skarecky, T. (2017). *SEF*. [online] Clarus Financial Technology. Available at: https://www.clarusft.com/glossary/sef/) See Dodd-Frank Wall Street Reform and Consumer Protection Act for more information.

Spread and Swap Spread – A general term referring to a packaged transaction/strategy whereby two trades or contracts are combined. For example, a 'Swap Spread' or 'Spread over Treasury' refers to the combination of a government bond with an interest rate swap. (From Skarecky, T. (2017). *Spread*. [online] Clarus Financial Technology. Available at: https://www.clarusft.com/glossary/spread/).

Annex 2: Methodology

The work by Bai and Perron (1998, 2003) provides an approach to estimating multiple unknown structural changes in a least-squares estimated model. We follow the empirical paper by Zeileis et al. (2003) to implement the Bai and Perron (1998, 2003) multiple structural change model.

We follow the notation of Zeileis et al. (2003). The model set-up is based on a standard linear regression of the form

$$y_i = x_i^T \beta_i + u_i \ (i = 1, \dots, n) \tag{A1}$$

where y_i and x_i correspond to the values of the dependent and explanatory variables respectively at time *i*. β_i is the regression coefficient, which can vary over time. The model tests the null hypothesis of the coefficient remaining constant over time versus the alternative of a change in the coefficient over time:

$$H_0: \beta_i = \beta_0 \ (i = 1, \dots, n) \tag{A2}$$

Breaks in the variance are allowed as long as they coincide with the breaks in the regression parameter although this is not the focus of the model, which is designed to identify beaks in the mean of y_i (Bai & Perron, 2003).

Assuming that there are *m* breakpoints in the time series where the mean of the coefficient is moving from one long-term level to another, the Equation A1 can be rewritten as

$$y_i = x_i^T \beta_i + u_i \left(i = i_{j-1} + 1, \dots, i_j, j = 1, \dots, m + 1\right) \tag{A3}$$

where *m* breakpoints imply *m+1* segments with a constant coefficient, and *j* is the segment index. The set of breakpoints, which are unknown and must be endogenously estimated, is denoted $J_{m,n} = \{i_1, \dots, i_m\}$, and also called an *m*-partition.

The dating procedure of the structural changes is as follows:

The least-squares estimates for an *m*-partition $i_1, \dots, i_m$ can be obtained where the minimal residual sum of squares is defined as

$$RSS(i_1, \dots, i_m) = \sum_{j=1}^{m+1} rss(i_{j-1} + 1, i_j) \tag{A4}$$

The aim of the dating procedure is to find the breakpoints $\hat{\imath}_1, \dots, \hat{\imath}_m$ that minimise the function in Equation A5 over all partitions $i_1, \dots, i_m$ using a dynamic programming algorithm suggested in Bai and Perron (2003) and implemented in Zeileis et al. (2003).

$$(\hat{\imath}_1, \dots, \hat{\imath}_m) = \underset{(i_1, \dots, i_m)}{\operatorname{argmin}} RSS(i_1, \dots, i_m) \tag{A5}$$

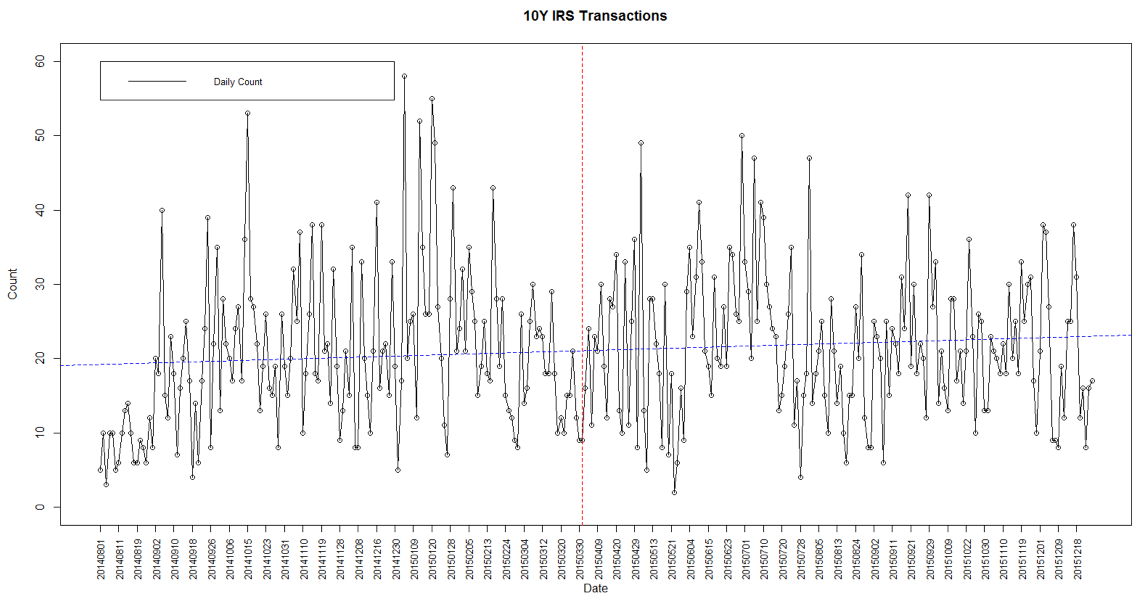
According to Bai and Perron (2003), the dynamic programming algorithm compares different combinations of *m*-partitions to achieve a minimum global residual sum of squares. The process sequentially examines the partition of *m+1* versus *m* breaks and compares which of the breaks partitions provide the overall minimal residual sum of squares compared with one additional segment.

In our case, we apply a pure structural change model, and we test whether the mean of the liquidity measure in question changes over the course of our sample period. We therefore fit a constant to the time series data of the dependent variable. We apply a trimming factor of 15% (as suggested by Bai & Perron, 2003) allowing for a maximum of five breaks. The trimming factor determines the minimum number of observations in each segment. Since our sample consists of 331 trading days, the trimming value implies that each segment is required to have at least 49 observations. As in Zeileis et al. (2003) we use a selection of tests such as the OLS-based CUSUM process, the F-statistic and the Bayesian Information Criterion (BIC) to determine the optimal number of breaks.

Annex 3: Additional Results

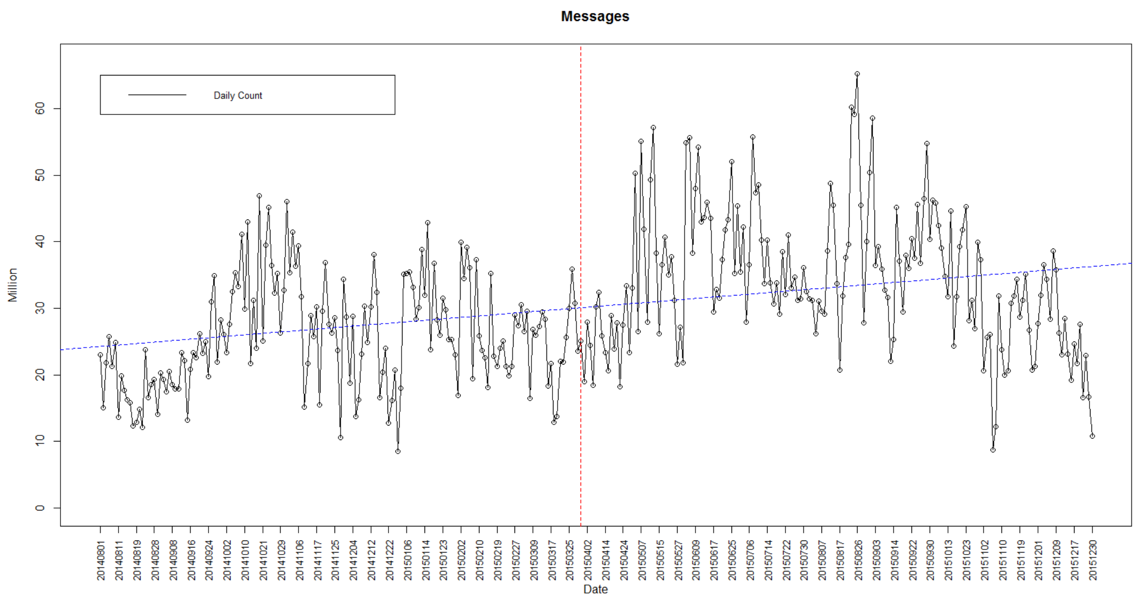
A: Evolution of Transactions and Messages Over Time

Figure A1: Number of Transactions



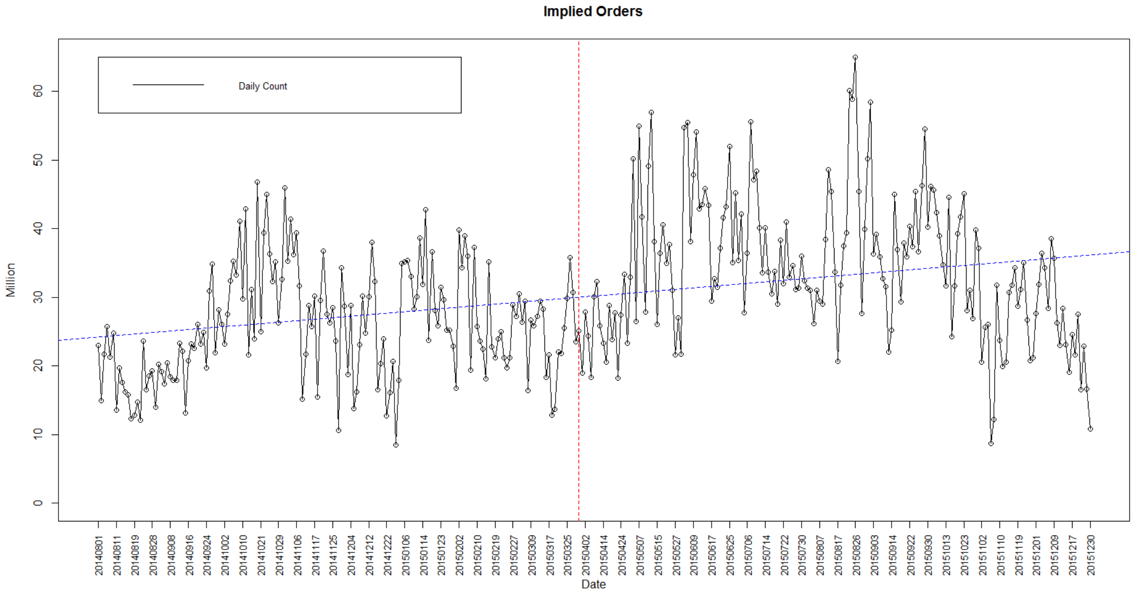
Notes: This figure shows the development of the daily count of the total number of electronically-executed transactions for the 10Y USD IRS over time. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015].

Figure A2: Total Number of Messages



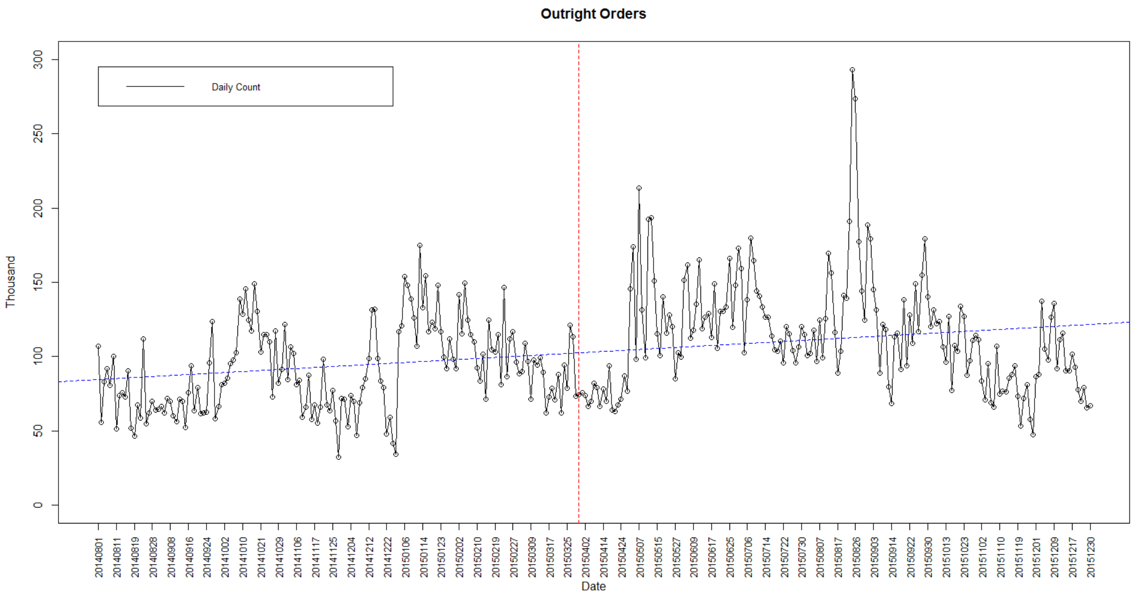
Notes: This figure shows the development of the daily count of the total number of messages for the 10Y USD IRS over time. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015].

Figure A3: Number of Implied Messages



Notes: This figure shows the development of the daily count of implied messages for the 10Y USD IRS over time. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015].

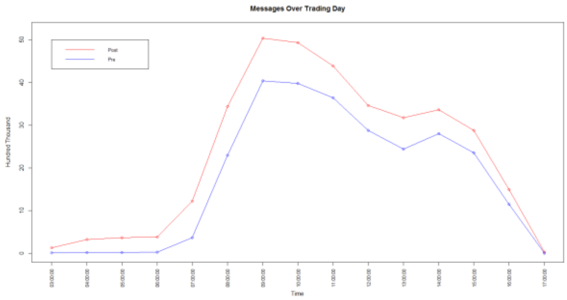
Figure A4: Number of Outright Messages



Notes: This figure shows the development of the daily count of outright messages for the 10Y USD IRS over time. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015].

B: Intraday Evolution of Transactions and Messages

Figure A5: Intraday Message Development

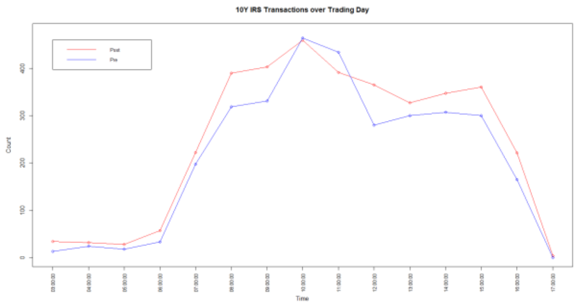


Notes: This figure shows the development of the average total number of messages for the 10Y USD IRS over the course of the trading day. Sample period for the blue line is the pre-BRC period of the ISDAFIX regime. Sample period for the red line is the post-BRC period of the ICE Swap Rate regime. Times depicted are interval start times and show the corresponding average value for the total interval. Timestamps are in ET.

In terms of message evolution over time, quoting activity for the 10Y swap is unsurprisingly most pronounced during normal US trading hours (9:30am to 4pm ET), although the Trad-X platform is available between 3am and 5pm ET.[44] Quote streaming peaks around 9am and remains elevated until 11am and then reduces gradually. As can be seen in Figure A5, more messages are received on average over the course of the trading day during the post-BRC period.

Figure A6 reports the development of 10Y IRS transactions over the trading day. We report the evolution of 10Y swap transactions engendered by all products (direct, spread-overs, curve trades and butterflies), since we deem this to be more informative, as they are all inextricably linked. Trading activity picks up between 8am and 9am and peaks during the hour (10am) ahead of the benchmark assessment and publication and remains elevated until mid-day. Again, the number of transactions in the post-BRC period is higher than in the pre-BRC period for most of the trading day. As reported in Annex 3A, the average daily number of 10Y IRS transactions gradually increases over time.

Figure A6: Intraday Transaction Development

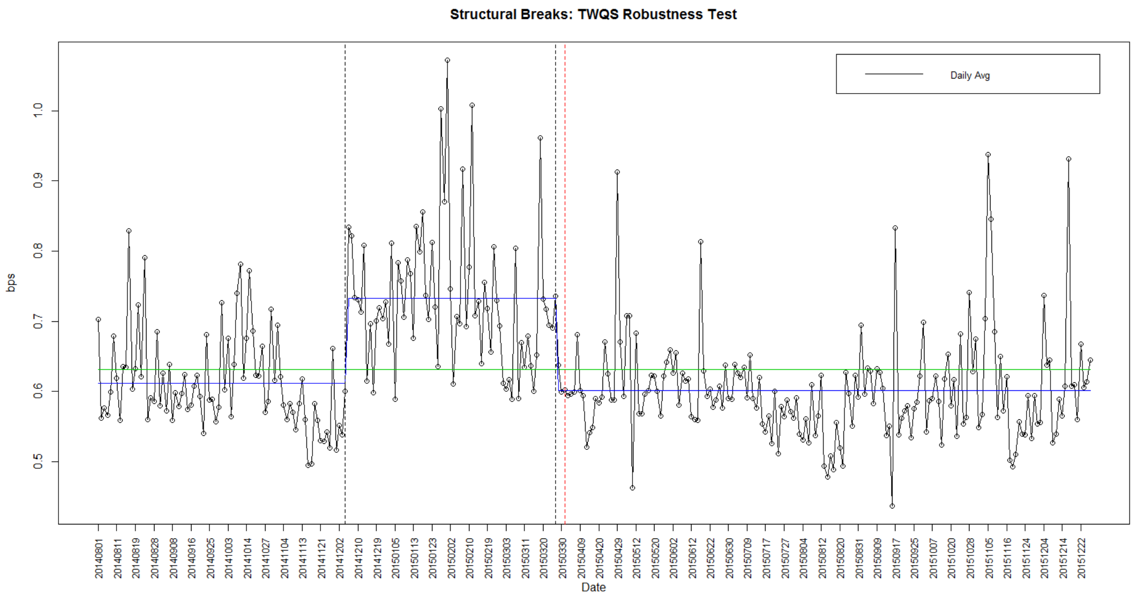


Notes: This figure shows the development of the average total number of 10Y USD IRS transactions over the course of the trading day. Sample period for the blue line is the pre-BRC period of the ISDAFIX regime. Sample period for the red line is the post-BRC period of the ICE Swap Rate regime. Times depicted are interval start times and show the corresponding average value for the total interval. Timestamps are in ET.

[44] See the Trad-X SEF rulebook here: http://www.traditionsef.com/assets/regulatory/Rulebook-Trad-X-Platform-Supplement-V-1.1.pdf

C: Structural Breaks Robustness Tests

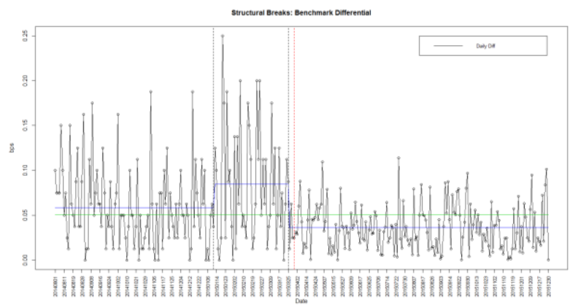
Figure A7: Time-Weighted Quoted Spread Robustness Test



Notes: This figure shows the development of the daily average time-weighted quoted spread for the 10Y USD IRS over the sample period. We use a trimmed time series in order to exclude extreme days such as macroeconomic outliers. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%).

Figure A8 illustrates the outcome of the BP multiple structural break test on the time series of the benchmark differential. The BP model establishes that a break occurs on 1 December 2014 and 25 March 2015. On 1 December 2014, the FCA published the Consultation Paper CP14/32 discussing bringing additional benchmarks into the regulatory and supervisory regime. The latter break arises four trading days before the effective date of the BRC. The benchmark differential dropped and settled at a significantly lower level from this date onwards. It should be noted that for the four days from 25 March to 31 March 2015, the benchmark rate was still relying on the panel-based assessment methodology. This finding suggests that a change in submission behaviour might have occurred slightly before the introduction of the market-based benchmark assessment. Panel banks potentially geared the submitted rates more strongly towards the quoted price on regulated trading venues.

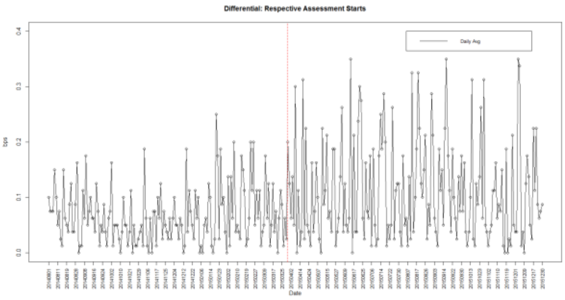
Figure A8: Benchmark Differential



Notes: This figure shows the development of the daily differential between the 10Y benchmark rate and the on-platform mid-price for the 10Y USD IRS using a two-tiered approach. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. For the former, the differential is calculated based on the benchmark rate and the point observation of the quoted mid-price at 11:00:00. For the post-BRC period, the differential is computed based on the benchmark rate and the average quoted mid-price during the 2-minute benchmark assessment. All values are expressed in bps (1 bps = 0.01%).

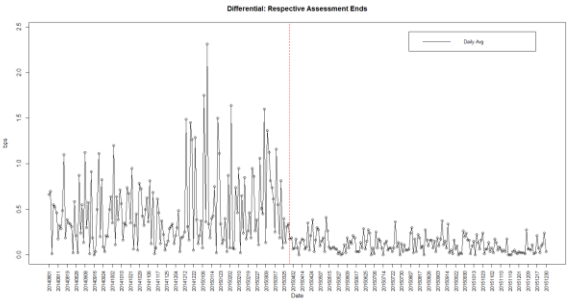
D: Benchmark Price versus Quoted Market Price

Figure A9: Assessment Start



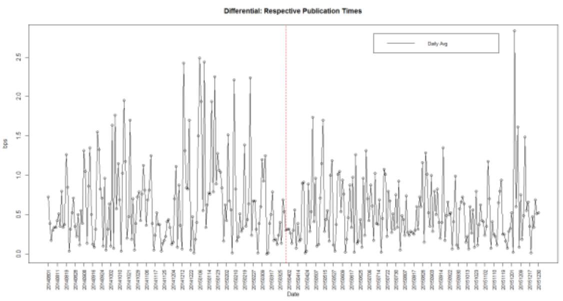
Notes: This figure shows the daily difference between the on-platform mid-price and the benchmark rate for the 10Y ICE Swap Rate at their respective assessment start times corresponding to 11:00:00 under the ISDAFIX regime and 10:58:00 under the ICE Swap Rate regime. Timestamps are in ET. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. Values are expressed in bps (1 bps = 0.01%).

Figure A10: Assessment End



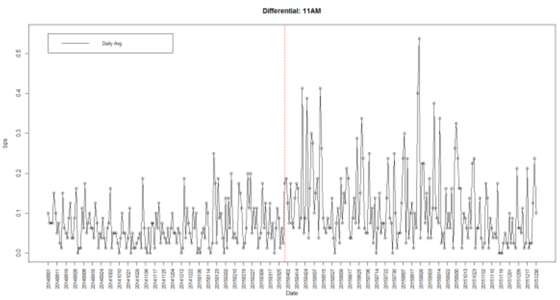
Notes: This figure shows the daily difference between the on-platform mid-price and the benchmark rate for the 10Y ICE Swap Rate at their respective assessment end times corresponding to 11:15:00 under the ISDAFIX regime and 11:00:00 under the ICE Swap Rate regime. Timestamps are in ET. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. Values are expressed in bps (1 bps = 0.01%).

Figure A11: Publication Time



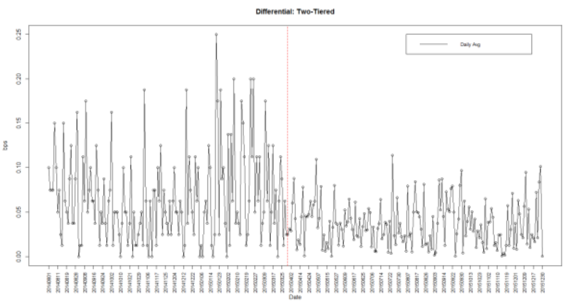
Notes: This figure shows the daily difference between the on-platform mid-price and the benchmark rate for the 10Y ICE Swap Rate at their respective publication times corresponding to 11:30:00 under the ISDAFIX regime and 11:15:00 under the ICE Swap Rate regime. Timestamps are in ET. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. Values are expressed in bps (1 bps = 0.01%).

Figure A12: 11am Point Observation



Notes: This figure shows the daily difference between the on-platform mid-price and the benchmark rate for the 10Y ICE Swap Rate at 11:00:00. Timestamps are in ET. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. Values are expressed in bps (1 bps = 0.01%).

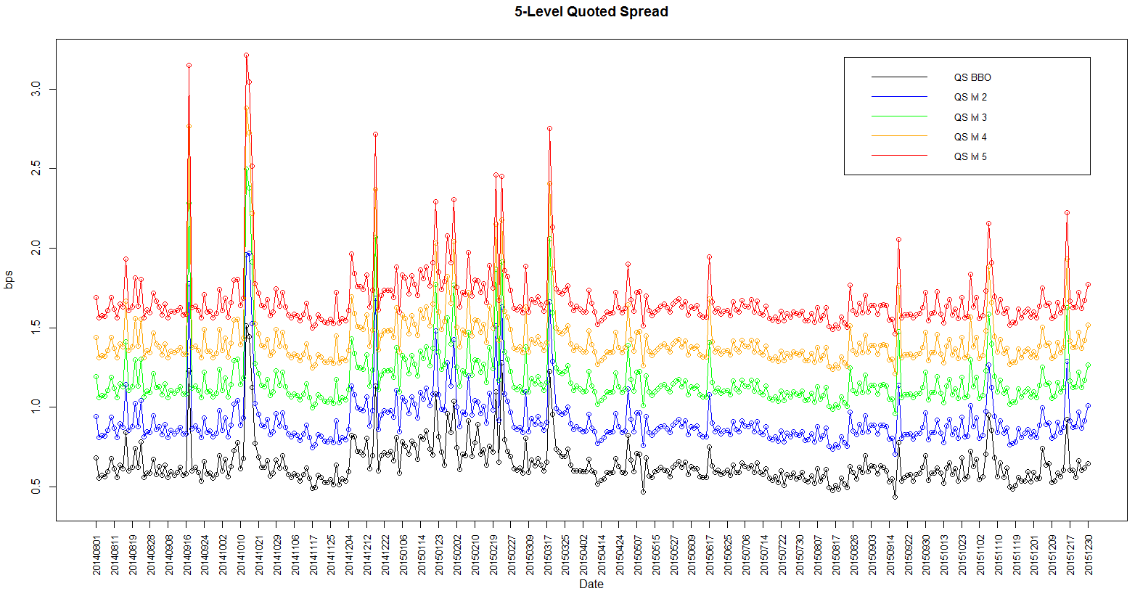
Figure A13: Two-Layered Comparison



Notes: This figure shows the development of the daily difference between the 10Y benchmark rate and the on-platform mid-price for the 10Y USD IRS using a two-tiered approach. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. For the former the differential is calculated based on the benchmark rate and the point observation of the quoted mid-price at 11:00:00. For the post-BRC period the differential is computed based on the benchmark rate and the average quoted mid-price during the 2-minute benchmark assessment. Values are expressed in bps (1 bps = 0.01%).

E: Order Book Consolidation

Figure A14: Five-Level Quoted Spreads



Notes: This figure depitcs the simple daily average quoted spread (not time-weighted for illustration purposes) for each of the five best levels of the order book for the 10Y USD IRS on the Trad-X platform over the full sample period from 1 August 2014 to 30 December 2015. All spread measures are expressed in bps (1 bps = 0.01%).

F: Difference-in-Difference Specifications

Table A1: Difference-in-Difference Panel Regression for Depth Measures

	TWQD				*TWQD10*			
	(1)		*(2)*		*(1)*		*(2)*	
	Coeff	*t-Stat*	*Coeff*	*t-Stat*	*Coeff*	*t-Stat*	*Coeff*	*t-Stat*
Constant	8.33E+07	51.08***	2.10E+07	0.48	1.38E+09	33.55***	-7.73E+09	-6.98***
Event	-5.71E+06	-2.37**	-1.05E+07	-3.45***	-1.46E+07	-0.2	-3.28E+08	-4.16***
Treatment	1.75E+07	9.16***	1.74E+07	8.98***	2.01E+09	38.97***	2.01E+09	38.43***
Interaction	-4.54E+06	-1.4	-3.71E+06	-1.18	1.48E+08	2.15**	1.54E+08	2.21**
SRVIX			9.81E+07	0.6			-1.20E+09	-0.5
TYVIX			-2.41E+07	-1.16			-6.62E+08	-1.27
MESS_10Y			6.44E+06	1.77*			2.44E+08	1.76*
MESS_12Y:10Y			6.75E+06	1.6			5.74E+08	3.99***
TRANS_10Y			2.50E+06	1.35			9.14E+06	0.23
TRANS_12Y:10Y			2.70E+06	2.49**			2.81E+07	0.87
PARTICIPANTS			2.71E+07	1.94*			1.38E+09	3.83***
MACRO			-1.63E+06	-0.27			-5.31E+08	-4.3***
O:I_10Y			1.91E+06	0.35			-1.09E+09	-5.65***
Adj R^2	18.49%		24.93%		71.89%		84.56%	
N	658		637		658		637	
Specification	FE		FE		FE		FE	

Notes: This table reports the results of the difference-in-difference (DiD) panel regression model specified in Equation 9 using time-weighted quoted depth (*TWQD*) and time-weighted 10-level quoted depth (*TWQD10*) as dependent variables. *Event* is a dummy variable that takes the value 0 for the pre-BRC period [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015] and 1 for the post-BRC period [d_0 = 31 March 2015, d_{170} = 30 December 2015]. *Treatment* is a dummy that takes the value 1 for benchmark grade swaps (10Y) and 0 otherwise (12Y). *Interaction* is a dummy variable computed as *Event * Treatment*. *SRVIX* is the log return on the Interest Rate Swap Volatility Index. *TYVIX* is the log return on the 10-year US Treasury Note Volatility Index. *MESS_10Y* is the log daily count of the number of messages received by the platform operator for the 10Y IRS contract. *MESS_12Y:10Y* is the log ratio of messages for the 12Y contract relative to the 10Y contract. *TRANS_10Y* is the log daily number of transaction in the 10Y IRS contract. *TRANS_12Y:10Y* is the log ratio of the number of transactions in the 12Y contract relative to the 10Y contract. *PARTICIPANTS* represents the log number of USD streamers by trading day. *MACRO* is a dummy variable that takes the value 1 on days with macroeconomic announcements by the Federal Open Market Committee (FOMC) and the Governing Council of the ECB and 0 otherwise. *O:I_10Y* is the log ratio of outright to implied messages in the 10Y IRS contract. The models are estimated using tenor fixed effects. We use Driscoll and Kraay (1998) consistent standard errors. Robust t-statistics are shown in the *t-stat* columns. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. Sample period is 01.08.2014 to 30.12.2015.

Table A2: Difference-in-Difference Panel Regression for Multiple Tenors

	TWQS		*TWFS*		*TWQD*		*TWQD10*	
	(3)		*(3)*		*(3)*		*(3)*	
	Coeff	*t-Stat*	*Coeff*	*t-Stat*	*Coeff*	*t-Stat*	*Coeff*	*t-Stat*
Constant	2.62E-02	7.69***	2.64E-02	9.94***	-4.97E+06	-0.09	-7.47E+09	-7.66***
Event	4.02E-04	1.42	1.12E-03	5.13***	-1.07E+07	-3.19***	-2.27E+08	-3.79***
Treatment	-1.80E-03	-9.4***	-9.32E-04	-9.44***	5.62E+07	19.33***	2.73E+09	38.69***
Interaction	-5.74E-04	-2.38**	-1.39E-03	-8.62***	9.65E+05	0.25	2.94E+08	3***
SRVIX	2.81E-02	1.59	1.46E-02	1.55	9.25E+07	0.57	6.12E+07	0.03
TYVIX	-1.59E-03	-0.75	-1.04E-03	-0.72	-2.47E+07	-1.08	-6.73E+08	-1.37
MESS_10Y	5.59E-04	2.05**	5.95E-04	2.18**	6.69E+06	1.5	2.05E+08	1.74*
MESS_12Y:10Y	-7.20E-04	-1.82*	-3.73E-04	-1.76*	6.91E+06	1.31	2.92E+08	2.68***
TRANS_10Y	-1.73E-04	-1.22	-1.10E-04	-0.99	-7.87E+05	-0.3	2.23E+07	0.54
TRANS_11Y	3.51E-04	1.76*	2.88E-04	1.37	6.30E+06	1.65	4.44E+06	0.07
TRANS_12Y:10Y	-9.84E-05	-1.29	-2.36E-05	-0.39	1.85E+06	1.31	2.59E+07	0.85
TRANS_11Y:5Y	-1.17E-04	-0.92	-1.51E-04	-1.44	-7.72E+05	-0.34	3.34E+07	0.88
PARTICIPANTS	-3.63E-03	-2.33**	-4.70E-03	-3.31***	3.38E+07	1.86*	1.36E+09	4.42***
MACRO	5.66E-03	6.43***	3.17E-03	5.51***	-7.50E+06	-1.11	-5.42E+08	-5.14***
O:I_10Y	2.23E-03	5.74***	1.69E-03	4.7***	-1.77E+06	-0.28	-9.89E+08	-6.22***
O:I_11Y	-3.69E-06	-0.03	2.45E-05	0.29	4.09E+05	0.16	7.01E+07	1.39
Adj R^2	41.31%		37.36%		35.18%		84.17%	
N	1276		1276		1276		1276	
Specification	FE		FE		FE		FE	

Notes: This table reports the results of the difference-in-difference (DiD) panel regression model specified in Equation 9 using time-weighted quoted spreads (*TWQS*), time-weighted fill spreads (*TWFS*), time-weighted quoted depth (*TWQD*) and time-weighted 10-level quoted depth (*TWQD10*) as dependent variables. *(1)* presents the DiD model without controls while *(2)* presents the same specification with controls. *Event* is a dummy variable that takes the value 0 for the pre-BRC period [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015] and 1 for the post-BRC period [d_0 = 31 March 2015, d_{170} = 30 December 2015]. *Treatment* is a dummy that takes the value 1 for benchmark grade swaps (5Y, 10Y) and 0 otherwise (11Y, 12Y). *Interaction* is a dummy variable computed as *Event* * *Treatment*. *SRVIX* is the log return on the Interest Rate Swap Volatility Index. *TYVIX* is the log return on the 10-year US Treasury Note Volatility Index. *MESS_10Y* is the log daily count of the number of messages received by the platform operator for the 10Y IRS contract. *MESS_12Y:10Y* is the log ratio of messages for the 12Y contract relative to the 10Y contract. *TRANS_10Y* and *TRANS_11Y* are the log daily counts of transactions in the 10Y and 11Y IRS contracts respectively. *TRANS_12Y:10Y* and *TRANS_11Y:5Y* are the log ratios of the number of transactions in the 12Y contract relative to the 10Y contract and the 11Y contract relative to the 5Y contract respectively. *PARTICIPANTS* represents the log number of USD streamers by trading day. *MACRO* is a dummy variable that takes the value 1 on days with macroeconomic announcements by the Federal Open Market Committee (FOMC) and the Governing Council of the ECB and 0 otherwise. *O:I_10Y* and *O:I_11Y* are the log ratios of outright to implied messages in the 10Y and 11Y IRS contracts respectively. The models are estimated using tenor fixed effects. We use Driscoll and Kraay (1998) consistent standard errors. Robust t-statistics are shown in the *t-stat* columns. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. Sample period is 01.08.2014 to 30.12.2015.

G: Correlation Tables

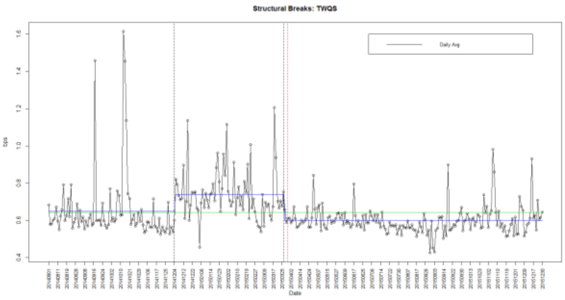
Table A3: Correlation Matrix

	Event	*SRVIX*	*TYVIX*	*PARTICI PANTS*	*MACRO*	*MESS_1 0Y*	*MESS_1 2Y:10Y*	*TRANS_ 10Y*	*TRANS_ 11Y*	*TRANS_ 12Y:10Y*	*TRANS_ 11Y:5Y*	*O:I_10Y*	*O:I_11Y*
Event	1.00	-0.11	-0.03	0.53	-0.16	0.40	0.06	0.06	-0.11	-0.10	-0.09	-0.11	-0.39
SRVIX	-0.11	1.00	0.46	-0.07	0.06	0.09	0.10	0.08	-0.03	0.01	-0.07	0.00	0.03
TYVIX	-0.03	0.46	1.00	0.02	-0.17	0.11	0.06	-0.05	-0.02	0.14	0.08	-0.11	0.05
PARTICI PANTS	0.53	-0.07	0.02	1.00	-0.28	0.52	0.08	0.02	-0.05	-0.03	0.01	-0.35	-0.12
MACRO	-0.16	0.06	-0.17	-0.28	1.00	-0.17	-0.02	0.08	0.04	-0.07	-0.11	0.40	0.09
MESS_1 0Y	0.40	0.09	0.11	0.52	-0.17	1.00	0.34	0.29	0.01	-0.15	-0.18	-0.41	-0.01
MESS_1 2Y:10Y	0.06	0.10	0.06	0.08	-0.02	0.34	1.00	0.20	0.00	0.00	-0.07	-0.13	0.44
TRANS_ 10Y	0.06	0.08	-0.05	0.02	0.08	0.29	0.20	1.00	0.13	-0.55	-0.63	-0.07	0.12
TRANS_ 11Y	-0.11	-0.03	-0.02	-0.05	0.04	0.01	0.00	0.13	1.00	0.21	0.36	-0.10	0.06
TRANS_ 12Y:10Y	-0.10	0.01	0.14	-0.03	-0.07	-0.15	0.00	-0.55	0.21	1.00	0.57	-0.02	-0.01
TRANS_ 11Y:5Y	-0.09	-0.07	0.08	0.01	-0.11	-0.18	-0.07	-0.63	0.36	0.57	1.00	-0.04	-0.02
O:I_10Y	-0.11	0.00	-0.11	-0.35	0.40	-0.41	-0.13	-0.07	-0.10	-0.02	-0.04	1.00	-0.09
O:I_11Y	-0.39	0.03	0.05	-0.12	0.09	-0.01	0.44	0.12	0.06	-0.01	-0.02	-0.09	1.00

Notes: This table reports the correlation matrix of the independent variables used in the DiD models above. *Event* is a dummy variable that takes the value 0 for the pre-BRC period [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015] and 1 for the post-BRC period [d_0 = 31 March 2015, d_{170} = 30 December 2015]. *SRVIX* is the log return on the Interest Rate Swap Volatility Index. *TYVIX* is the log return on the 10-year US Treasury Note Volatility Index. *MESS_10Y* is the log daily count of the number of messages received by the platform operator for the 10Y IRS contract. *MESS_12Y:10Y* is the log ratio of messages for the 12Y contract relative to the 10Y contract. *TRANS_10Y* and *TRANS_11Y* are the log daily counts of transactions in the 10Y and 11Y IRS contracts respectively. *TRANS_12Y:10Y* and *TRANS_11Y:5Y* are the log ratios of the number of transactions in the 12Y contract relative to the 10Y contract and the 11Y contract relative to the 5Y contract respectively. *PARTICIPANTS* represents the log number of USD streamers by trading day. *MACRO* is a dummy variable that takes the value 1 on days with macroeconomic announcements by the Federal Open Market Committee (FOMC) and the Governing Council of the ECB and 0 otherwise. *O:I_10Y* and *O:I_11Y* are the log ratios of outright to implied messages in the 10Y and 11Y IRS contracts respectively. We report Pearson correlation coefficients. Sample period is 01.08.2014 to 30.12.2015.

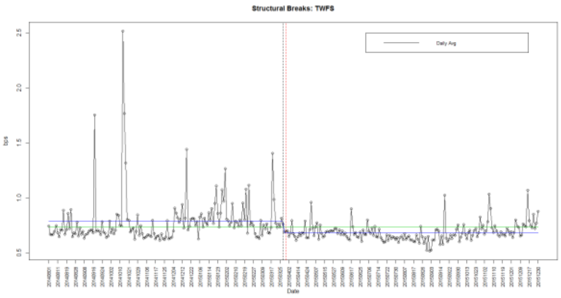
H: Evolution of Liquidity Measures for Other Tenors (5Y, 11Y, 12Y)

Figure A15: TWQS for 5Y IRS



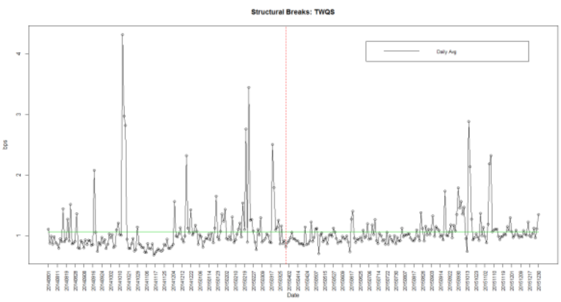
Notes: This figure shows the development of the daily average time-weighted quoted spread for the 5Y USD IRS over the sample period. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%).

Figure A16: TWFS for 5Y IRS



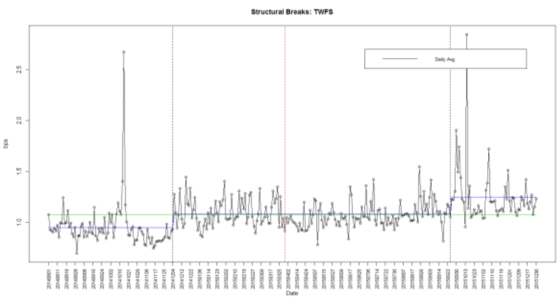
Notes: This figure shows the development of the daily average time-weighted fill spread for the 5Y USD IRS over the sample period. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%).

Figure A17: TWQS for 11Y IRS



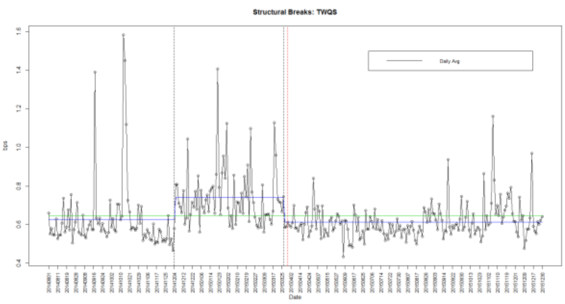
Notes: This figure shows the development of the daily average time-weighted quoted spread for the 11Y USD IRS over the sample period. The missing black dotted lines (usually marking the break dates as determined by the BP model) indicate that no structural breaks could be determined in the time series. The green line depicts the long-term average of the time series. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%).

Figure A18: TWFS for 11Y IRS



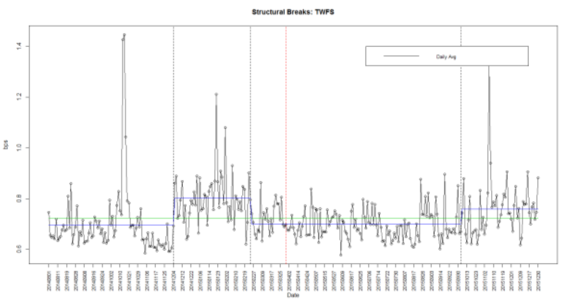
Notes: This figure shows the development of the daily average time-weighted fill spread for the 11Y USD IRS over the sample period. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%).

Figure A19: TWQS for 12Y IRS



Notes: This figure shows the development of the daily average time-weighted quoted spread for the 12Y USD IRS over the sample

Figure A20: TWFS for 12Y IRS



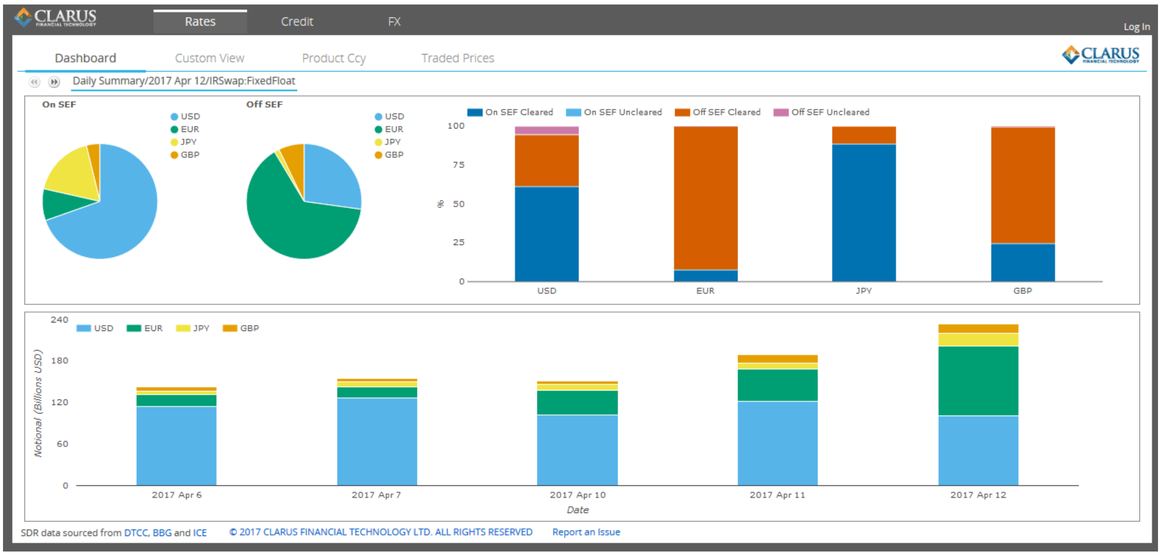
Notes: This figure shows the development of the daily average time-weighted fill spread for the 12Y USD IRS over the sample period.

period. The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%).

The black dotted lines mark the break dates as determined by the BP model. The green line depicts the long-term average of the time series, while the blue line shows the segment averages. The red dotted line marks the event date [d_0 = 31 March 2015]. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All values are expressed in bps (1 bps = 0.01%).

I: On-SEF versus Off-SEF Trading

Figure A21: Share of USD Fixed-for-Floating IRS Traded On-SEF



Notes: This figure shows the daily summary on the 12 April 2017 of the share of trading On-SEF as well as Off-SEF for interest rate swaps for multiple currencies, including USD swaps. The upper panel reports that On-SEF activity consists of 69.6% of USD IRS, 17.7% of JPY IRS, 8.9% of EUR IRS, and 3.8% of GBP IRS. Off-SEF activity consists of 64.2% of EUR IRS, 27.2% of USD IRS, 7.2% of GBP IRS, and 1.4% of JPY IRS. USD IRS are 61% On-SEF Cleared, 33.6% Off-SEF Cleared and 5.5% Off-SEF Uncleared. The lower panel reports that for the period 6 April 2017 to 12 April 2017, USD IRS activity accounted for a notional ranging from $100 billion to $127 billion. EUR, JPY and GBP accounted for a combined notional ranging between $25 billion to $50 billion on a normal day, and up to a maximum of $130 billion. From Clarus Financial Technology, (2017). SDRView Rates Dashboard Daily Summary/2017 Apr 12/IRSwap:FixedFloat. [image] Available at: http://sdrview.clarusft.com/ [Accessed 13 April 2017].

J: Execution Costs of Large Transactions

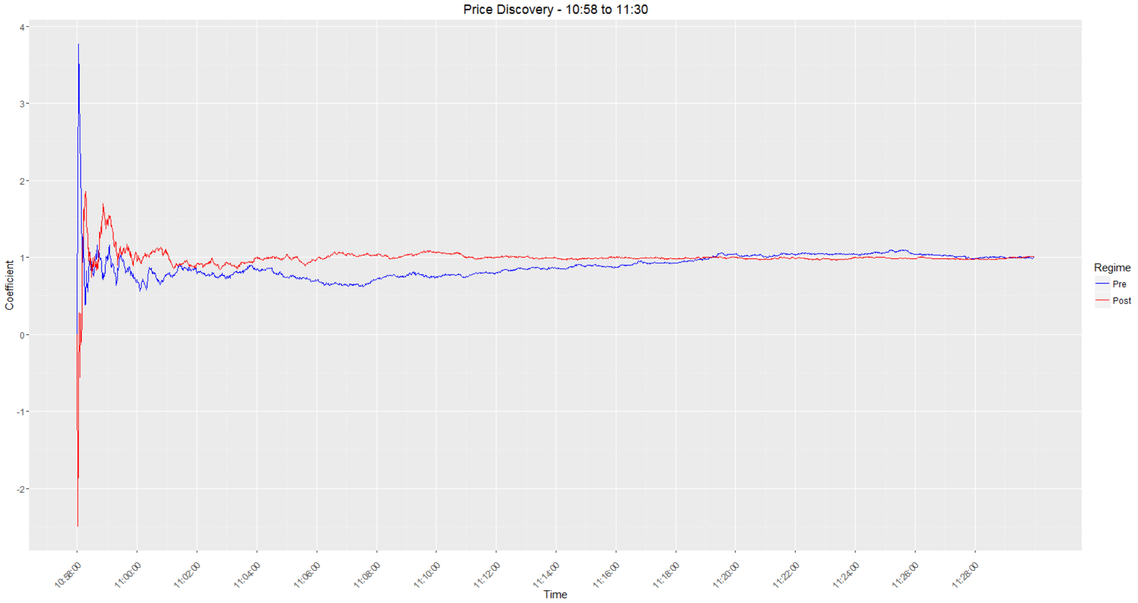
Table A4: Execution Costs under the ISDAFIX and ICE Swap Rate Regime

		Fill Spreads		
	TWFS2	*TWFS3*	*TWFS4*	*TWFS5*
Mean				
Pre	0.88	0.95	1.00	1.04
Post	0.78	0.85	0.91	0.95
t-Stat	-4.96***	-4.62***	-4.65***	-4.75***
%-Diff	-10.92%	-10.71%	-9.75%	-8.70%
Median				
Pre	0.82	0.89	0.95	1.00
Post	0.76	0.82	0.88	0.93
t-Stat	-5.21***	-4.82***	-4.5***	-4.3***
%-Diff	-7.97%	-7.96%	-7.80%	-7.60%
Std Dev				
Pre	0.18	0.20	0.20	0.20
Post	0.12	0.13	0.13	0.12
t-Stat	-2.88***	-2.75***	-3.02***	-3.32***
%-Diff	-33.45%	-32.95%	-34.91%	-36.53%

Notes: This table reports the long-term comparison of the time-weighted fill spread (*TWFS*) for large transactions in the 10Y tenor before and after the benchmark regime change. *TWFS* is computed simulating the execution of a large transaction of some multiple of the SMS. The multiple for *TWFS2*, *TWFS3*, *TWFS4*, and *TWFS5* is 2x, 3x, 4x, and 5x the SMS respectively. The liquidity measures are computed as daily averages (medians) and then averaged across the period of interest. The median captures the weighted median (by number of occurrence) of the liquidity measures. Standard deviation reports the average daily standard deviation of the liquidity measures. *Pre-BRC* refers to the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. *Post-BRC* refers to the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. All spread measures are expressed in bps (1 bps = 0.01%). The t-value is the statistic of a two-sample t-test of $\mu_1 - \mu_2 = 0$. *, ** and *** correspond to statistical significance at 10%, 5% and 1% levels respectively. *%-Diff* reports the simple percentage difference between the two periods.

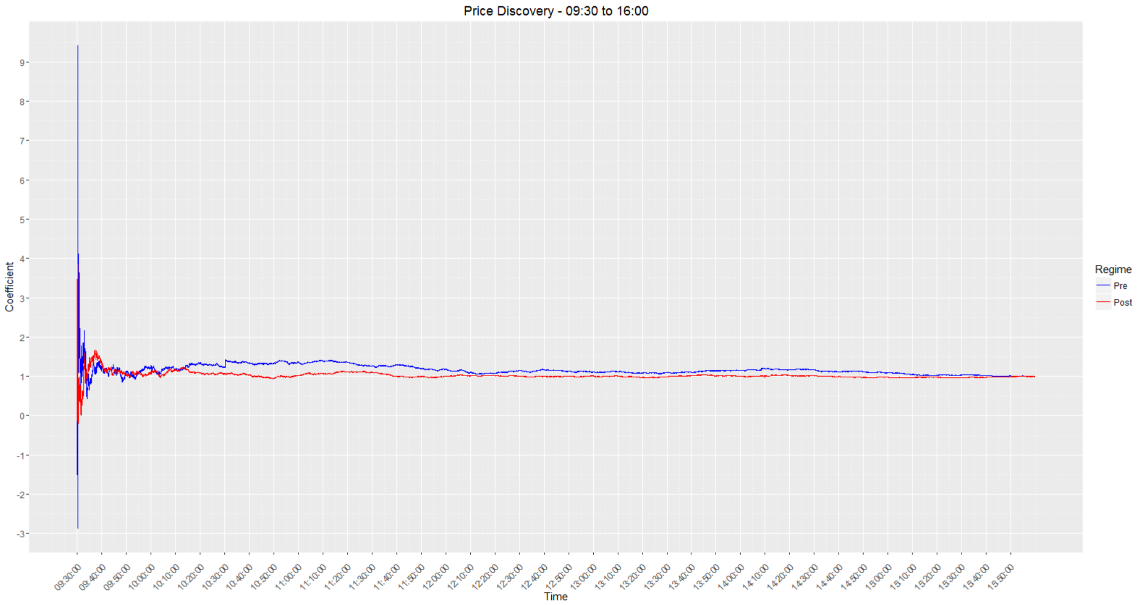
K: Price Discovery

Figure A22: Price Discovery Around the Benchmark Assessment



Notes: This figure shows the price efficiency of the 10Y USD IRS between 10:58:00 and 11:30:00. Timestamps are in ET. The blue line shows the price efficiency during the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. The red line shows the price efficiency during the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. Informational efficiency is computed based on an approach developed by Biais et al. (1995, 1999) and called 'unbiasedness regressions'. The coefficient of interest is β, which is determined by the regression $r_{oc} = \alpha + \beta r_{ot} + \varepsilon_{ot}$, where ret_{oc} is the open-to-close return for the time interval of interest and ret_{ot} is the return from the open of the period to the interval *t*. According to Biais et al. (1995, 1999), β measures the signal-to-noise ratio and a coefficient close to one suggests informationally efficient prices. A coefficient smaller than one is consistent with noisier prices. A coefficient bigger than one may be driven by stale prices.

Figure A23: Price Discovery During the Trading Day



Notes: This figure shows the price efficiency of the 10Y USD IRS between 09:30:00 and 16:00:00. Timestamps are in ET. The blue line shows the price efficiency during the ISDAFIX regime [d_{-160} = 1 August 2014, d_{-1} = 30 March 2015]. The red line shows the price efficiency during the ICE Swap Rate regime [d_0 = 31 March 2015, d_{170} = 30 December 2015]. Informational efficiency is computed based on an approach developed by Biais et al. (1995, 1999) and called 'unbiasedness regressions'. The coefficient of interest is β, which is determined by the regression $r_{oc} = \alpha + \beta r_{ot} + \varepsilon_{ot}$, where ret_{oc} is the open-to-close return for the time interval of interest and ret_{ot} is the return from the open of the period to the interval *t*. According to Biais et al. (1995, 1999), β measures the signal-to-noise ratio and a coefficient close to one suggests informationally efficient prices. A coefficient smaller than one is consistent with noisier prices. A coefficient bigger than one may be driven by stale prices.

Annex 4: Data Disclaimer

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Annex 5: References

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25 The North Colonnade Canary Wharf
London E14 5HS
Telephone: +44 (0)20 7066 1000
Website: www.fca.org.uk