Do we need a European "National Market System"? Competition, arbitrage, and suboptimal executions[*]

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Abstract

The introduction of the European Markets in Financial Instruments Directive (MiFID) ended the quasi-monopoly of national exchanges in equity trading across Europe and many new trading platforms emerged. European trading venues are neither formally linked by technology nor does regulation enforce price-priority across platforms. This raises the question of market integration of fragmented markets. We find that quotes for UK blue-chip stocks are closely linked across trading venues and that a high fraction of trades is executed at best available prices. Our results suggest that competition forces competing but disconnected platforms to quote prices as if they were formally linked.

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1 Introduction

Automation of exchanges and new regulation significantly altered the trading landscape during the last decade, facilitating new trading venues to enter the market for exchange business. One consequence of competition between trading venues is that liquidity, i.e. the ability to trade shares, is fragmented across different trading venues, creating search costs for investors. In the U.S., different trading venues are linked by the National Market System (NMS) so that investors can see the best available price. In Europe, there is no such link. Since it is in the investors interest to trade at best prices, it is an open question whether competition ensures an integrated market in the absence of a formal linkage. This paper addresses this question.

MiFID came into effect in all 27-member states of the European Union on November 1, 2007. It allows three types of platforms to compete for equity order flow: regulated markets, e.g. the London Stock Exchange and Euronext Paris, multilateral trading facilities (MTF), e.g. Chi-X and BATS, and investment firms acting as a systematic internalizer, e.g. Knight Capital Europe and Goldman Sachs International.[1] Today, the majority of trades is executed on regulated markets and MTFs with a steadily increasing MTF market share. MTFs are comparable to electronic communication networks (ECNs) in the U.S. Currently, Chi-X is the largest MTF in Europe accounting for roughly 27.0% of daily trading volume in UK blue-chip stocks and about 17.0% in continental European equity trading.[2]

In Europe, intermediaries (e.g. investment firms, brokers) that execute orders on behalf of their clients have to set out a best execution policy. This policy has to be reviewed at least once per year.[3] Best execution is multi-dimensional on factors such as price, trading costs, speed, size, probability of execution, or probability of settlement. To enhance pre-

[1]See http://mifiddatabase.esma.europa.eu/ for a complete list.

[2]As of April 12, 2011, see http://www.ft.com/intl/trading-room/.

[3]In some cases these rules are very simple. Deutsche Bank, for example, outlines that it executes clients' orders in German stocks on Xetra, the electronic order book of Deutsche Boerse, assuming that the largest platform in terms of trading volume also guarantees best prices.

trade transparency, MiFID requires regulated markets and MTFs to publish best bid and ask prices along with the number of shares quoted at these prices on a continuous basis. Post-trade requirements include the time of execution, the execution price, and the associated trading volume.

Competition between traditional exchanges and alternative trading venues resulted in the fragmentation of order flow and liquidity. Investors may not always receive the best available price as price-time priority is not enforced across markets. Less integrated markets may be detrimental to price discovery and may increase costs of trading such as access fees or search costs. Proponents of MiFID argue that intermarket competition put downward pressure on explicit transaction costs, for instance, exchange fees and brokerage commissions, and provided trading venues with incentives to innovate on their services (European Commission 2010). Increasing use of technology may mitigate some of the potentially negative side effects of market fragmentation. For instance, algorithmic traders may link platforms by consolidating order flow.

Comparing European equity trading regulation under MiFID and its U.S. counterpart, Regulation NMS (RegNMS)[4], reveals substantial differences. Most importantly, there is a lack of trade-through protection and consolidated trade and quote information in Europe. RegNMS requires trading venues to establish, maintain, and enforce procedures to prevent trade-throughs (Rule 611), i.e. orders that are executed at worse prices than the best available price across trading venues. For this purpose trading venues are electronically linked via the Intermarket Trading System (ITS) and private linkages.[5] In the U.S., comprehensive consolidated market information is available from the exchange industry. The data compromise the National Best Bid and Offer (NBBO) for a stock, the corre-

[4]RegNMS is a further adaption of the Securities Exchange Act of 1934. The Securities and Exchange Commission (SEC) adapted RegNMS on June 9, 2005. The rules had different effective dates starting in August, 2005.

[5]Rule 611, RegNMS (Order Protection Rule) only protects quotes that are immediately accessible for automatic execution. It does not protect manual quotes entered on 'slow' trading venues, i.e. a trading floor, and only takes outstanding limit order at the top of the book into account. Rule 610, RegNMS (Access Rule) guarantees fair access to quotations and limits fees that a trading venue may impose for execution against a protected quotation.

sponding volume, and the trading venue. European regulation does not establish a single data consolidator.[6]

There is an ongoing debate among practitioners and academics about the impact of differences in MiFID and RegNMS on market quality. MiFID allowed the market entry of new platforms but it does not impose a formal linkage between trading venues. O'Hara and Ye (2011) argue that "it is hard to see how a single virtual market can emerge" in Europe without consolidated trade and quote information and trade-through protections. Stoll (2001), however, points out that a formal linkage may impede innovation and cause high infrastructure costs. This paper studies the question whether competition for order flow forces competing but disconnected platforms to quote prices that are closely integrated.

We study FTSE 100 constituents traded on the London Stock Exchange (LSE) and the three largest MTFs, Chi-X, BATS, and Turquoise. Our analysis is based on two observation periods: April/May 2009 and April/May 2010. We begin by examining spread and quote competition measures. While the LSE posts on average the smallest quoted spreads and is most often at the best available price in the consolidated order book over the observation period in 2009, Chi-X is more liquid in 2010. We use the number of locks and crosses to evaluate the coordination of quotes across trading venues. Quotes are locked if the European Best Bid (EBB) equals the European Best Offer (EBO) and crossed if the best bid exceeds the best posted ask (EBB>EBO). In April/May 2009, we find that markets are locked (crossed) for 24.5 minutes (16.0 minutes) of a trading day. Over our observation period in 2010, the average time of locks (crosses) decreases to 6.4 minutes (19.8 seconds), representing an 74.0% (97.6%) decline. Quotes of Turquoise are considerably more often locked and crossed than quotes of any other trading venue. We estimate potential revenues from arbitrage activities during crossed market periods. In 2009, we identify overall revenues of 614,217 GBP before transaction costs and 404,700 GBP in 2010, representing a 34,1% decline. However, it seems that not every arbitrage opportu-

[6] There are, however, commercial products available. For example, Thomson Reuters offers a consolidated data stream, see http://thomsonreuters.com/products_services/financial/financial_products/equities_derivatives/.

nity is exploitable after transaction costs.

Trade-through rates are a common statistic to evaluate price priority violations. The fraction of trade-throughs as a percentage of the total number of trades per day and per stock ranges from 5.2% to 8.7% across trading venues over the 2009 observation period and from 4.7% to 6.9% over 2010. Taking the available depth at the EBBO into account, investors strictly excuting at the best available price can realize potential savings of 2,095 GBP per day and per stock in April/May 2009 and 1,569 GBP in April/May 2010. We find that the likelihood of trade-throughs increases in the demand of speedy executions measured by the level of inside quoted spreads. It appears that investors trade off liquidity and search costs. Overall, our results suggest that disconnected trading venues behave as if they were formally linked, assuring a high level of market integration in FTSE 100 constituents.

The remainder of this paper is structured as follows. Section 2 discusses related literature. Section 3 provides details to competing markets in the UK. Section 4 describes our data and Section 5 presents descriptive statistics. Section 6 examines the quote process. Section 7 analyzes trade executions across trading venues. Section 8 summarizes and concludes.

2 Related Work

There is an increasing body of literature that analyzes the effects of MiFID on market quality. Hengelbrock and Theissen (2009) use an event study approach to examine the market entry of Turquoise in 14 European countries. Results on liquidity are ambiguous, there is only some evidence that quoted spreads on traditional exchanges decline after the entry of Turquoise. On average, quoted and effective spreads tend to be higher on Turquoise. Riordan, Storkenmaier, and Wagener (2010) analyze competition between the LSE and MTFs in FTSE 100 constituents over an observation period in April/May 2009. Their data show that the LSE leads in liquidity provision and trade based price discovery whereas Chi-X leads in quote based price discovery. BATS and Turquoise contribute little to price formation.

Degryse, de Jong, and van Kervel (2011) shed light on the effects of liquidity fragmentation under MiFID for Dutch stocks from 2006 to 2009. They show that depth in the consolidated order book across trading venues increases with the level of fragmentation. This effect is mainly driven by depth close to the midpoint. On the regulated home market, Euronext Amsterdam, depth close to the midpoint reduces by about 10.0%. Their result suggests that investors who trade large quantities and only have access to Euronext Amsterdam may be worse off under MiFID. Foucault and Menkveld (2008) study the market entry of EuroSETS on the Dutch stock market prior to the introduction of MiFID in May 2004. Their findings support the view that trade-throughs discourage liquidity supply.

There are a number of papers studying competition between traditional exchanges and ECNs in the U.S. Over the last decade, ECNs captured a significant fraction of trading volume, especially in Nasdaq-listed stocks. Findings support the view that competition between ECNs and Nasdaq market makers has significantly reduced quoted and effective spreads (Barclay, Christie, Harris, Kandel, and Schultz (1999), Weston (2000), and Fink, Fink, and Weston (2006)). Trades on ECNs seem to be more informative and contribute to price discovery (Huang (2002) and Barclay, Hendershott, and McCormick (2003)). Goldstein, Shkilko, Van Ness, and Van Ness (2008) show that ECNs are at the best bid/ask for a similar fraction of time compared to Nasdaq market makers. However, quote quality varies across ECNs and market maker quotes seem to be generally more stable, i.e. less volatile. Shkilko, Van Ness, and Van Ness (2008) document locked and crossed markets for about 10.6% of the trading day for Nasdaq and 4.1% for NYSE-listed stocks over a sample period in 2003. They argue that locks and crosses arise naturally in fragmented markets, for example, due to simultaneously submitted quotes or stale limit orders.

Methodologically, our study is related to Battalio, Hatch, and Jennings (2004) who analyze quote and execution quality of multiple listed U.S. equity options. In late 2002, the SEC imposed a formal linkage and more stringent quoting and disclosure rules on U.S. option markets. Their study looks at two periods prior to the new rules, June 2000 and January 2002, where the second period was under the threat of the SEC's formal linkage plan. They find that locked and crossed market quotes and the number of trade-throughs decrease over time. The average time an option is locked (crossed) per trading day decreases from 15.5 minutes (93.6 seconds) in June 2000 to 8.8 minutes (14.4 seconds) in January 2002. The trade-through rate falls from 11.1% to 3.7% between the first and second observation period. Their results lead them to conclude that competition between trading venues, improved technology, and the threat of increased regulation can integrate platforms without a formal linkage.

One force that may integrate fragmented platforms are algorithmic or high-frequency traders. To date, algorithmic traders generate more than half of the trading volume in blue-chip stocks, submitting smaller orders at a higher frequency than human traders. Trading speed became an important component of market quality (Garvey and Wu 2010). Hasbrouck and Saar (2009) argue that high-frequency trading strategies, coordination in fragmented markets, and hidden liquidity promote new high-speed order submission strategies. There is evidence that algorithmic trading has a positive impact on liquidity (Hendershott, Jones, and Menkveld 2011), order book depth (Hasbrouck and Saar 2011), and quote based price discovery (Hendershott and Riordan 2009). Menkveld (2011) uses proprietary data to analyze multi-market trading of one high-frequency trader on Chi-X and Euronext (Amsterdam). It appears that the high-frequency trader acts as a market maker on both platforms enforcing market integration.

3 Details on the UK Stock Market

This section offers details on trading of FTSE 100 constituents[7] on the regulated market, the LSE, and MTFs. We limit our discussion to the LSE, Chi-X, BATS, and Turquoise as these four markets account for approximately 95% of non-OTC trading volume during our observation periods.

Market entry of MTFs. Chi-X, the largest MTF, started trading in German and Dutch blue-chip stocks about six month ahead of MiFID on March 30, 2007. The full list of FTSE 100 constituents became available on Chi-X in August 2007. Its market share in UK stocks increased from 8.8% in March 2008 to 14.9% while celebrating its second anniversary in March 2009 and reached 27.6% in the second quarter of 2010.[8] On BATS, all FTSE 100 constituents were available for trading at the beginning of November 2008. BATS is operated by BATS Europe, a subsidiary of the U.S. based company BATS Global Markets. In February 2011, BATS agreed to combine with Chi-X Europe.[9] Previously, Chi-X Europe was owned by Instinet, a subsidiary of Nomura Holdings, and a number a major investment banks and broker houses. While BATS reports a FTSE 100 market share of about 9.0% in the first quarter of 2010, the market share of Turquoise reaches 5.0%. Turquoise completed the roll-out of the entire universe of FTSE 100 constituents by the end of August 2008. In February 2010, the LSE completed the acquisition of Turquoise. The existing shareholders, international investment banks, still own 40.0% of the new company. The ownership structure of MTFs is an important detail. Investment firms may predominately submit orders to trading venues of which they are shareholder.

Trading mechanism. While regulated markets and MTFs compete primarily on technology and trading costs, the LSE, Chi-X, BATS, and Turquoise provide the same basic market model. They all operate an electronic, fully integrated limit order book which

[7]FTSE 100 constituents are the largest companies listed on the LSE representing a broad cross-section of industries.

[8]http://www.chi-x.com/chi-x-press-releases/chi-x-europe-q2-2010-trading-stats-draft-v0-3.pdf.

[9]http://www.batstrading.co.uk/resources/press_releases/BATS_Chi-X_SPA_FINAL.pdf.

combines both visible and hidden liquidity.[10] The LSE trades FTSE 100 constituents on the Stock Exchange Trading System (SETS). In addition, broker dealers may provide liquidity via the Stock Exchange Automated Quotation System (SEAQ). Continuous trading starts at 8:00 a.m. GMT on all four trading venues and lasts until 4:30 p.m. GMT.

Iceberg orders that only display a portion of their total volume are available on all four trading venues. Fully hidden limit orders are not visible to any investor and have to meet the Large-In-Scale considerations of MiFID.[11] The LSE introduced fully hidden orders on December 14, 2009. Displayed orders have priority over non-displayed fractions of iceberg orders and fully hidden orders with the same price ('price-visibility-time priority'). Chi-X, BATS, and Turquoise also offer pegged orders. The execution price for this type of order is determined based on a reference price, e.g. the European Best Bid and Offer (EBBO). Executions on the three MTFs are subject to a price check. Possible orders are not executed if the execution price is in a certain range above or below the EBBO.

Trading Speed. MTFs offer potential benefits to speed-sensitive investors such as algorithmic or high-frequency traders. A delay in the time it takes to process a trade can result in missed trading opportunities, misplaced liquidity, and higher risk exposure. Technically, MTFs offer on average eight to ten times higher trading speed than the LSE during the observation periods. For example, for May 2010, BATS reports an average order latency of 200 microseconds.[12]

Fee schemes. Algorithmic and high-frequency traders are very sensitive to explicit trading costs. During the first observation period in 2009, the LSE, Chi-X, BATS, and Turquoise feature a maker/taker pricing scheme. At the LSE an investor is charged between 0.45 bps and 0.75 bps of the order volume for an active order that hits an outstanding limit order in the order book. Executed passive orders receive a rebate of up

[10]See Biais, Hillion, and Spatt (1995) for a description of a generic limit order book design.

[11]MiFID requires all regulated markets and MTFs to be pre-trade transparent. An exception are orders that are large in scale compared with normal market size (Article 22(2) of Directive 2004/39/EC). Normal market size is provided by the European Securities and Markets Authority (ESMA) and reviewed on a yearly basis, see http://mifiddatabase.esma.europa.eu/.

[12]See http://www.batstrading.co.uk/resources/participant_resources/BATSEuro_Latency.pdf.

to 0.40 bps. Trading fees depend on the order volume that an investor generated during the previous month. Chi-X and BATS charge an active order with 0.28 bps and rebate a passive order with 0.20 bps. Investors pay 0.28 bps for an active order on Turquoise and receive a rebate of 0.20 to 0.24 bps for an executed passive order depending on their trading volume during the previous month. The LSE switched back to a traditional fee schedule on September 1, 2009. Investors are charged between 0.20 bps and 0.45 bps for both aggressive and passive orders. On May 4, 2010, the LSE introduced two additional rates for high-volume traders that run in parallel with the LSE's existing price schedule. The first new rate waives trading fees of executed passive orders for firms providing a large amount of liquidity. The second new rate charges 0.29 bps for aggressive orders. Investors have to apply to be included in the new rate groups and have to meet specific criteria, e.g. a high prior trading volume. On BATS investors who remove liquidity are charged 0.28 bps while participants who add liquidity are rebated 0.18 bps over the second observation period in 2010. Maker/taker fees on Chi-X and Turquoise are the same as in the first observation period, April/May 2009.

4 Data

Our empirical analyses are based on the following two observation periods: April 20 to May 29, 2009 and April 19 to May 28, 2010. The first observation period is determined by the availability of a stable market structure. There are no market microstructure, fee, or trading system changes on the LSE, Chi-X, BATS, and Turquoise. We choose the second time period in April/May 2010 to study effects of competition on quote and execution quality over time. Moreover, this choice reduces seasonal effects that can distort results. Markets are closed on UK Bank holidays, May 4 and May 25, 2009 as well as May 3, 2010. We further exclude May 1, 2009 due to a considerably smaller trading volume.[13] The final sample covers 27 trading days in 2009 and 29 trading days in 2010.

[13] Most European countries celebrate May Day and the markets are closed.

We retrieve trade and quote data from the Thomson Reuters DataScope Tick History archive through SIRCA for each trading venue, the LSE, Chi-X, BATS, and Turquoise.[14] FTSE 100 constituents are identified using Thomson Reuters Instrument Codes (RIC), a unique instrument identifier. Specifically, we obtain trade prices, volumes, best bid and ask including associated volumes, and order book information up to three levels behind best prices for both observation periods. Specific data qualifiers are further used to delete cross-reported trades on the LSE. Trades and quotes are reported in British pence and they are time-stamped to the millisecond. We apply the following selection criteria on both the trade and quote data and the FTSE 100 constituents finally included into the data set:

Tick data level: (1): To avoid biases associated with the market opening and closing procedures and to accommodate lagged variables, analyses are restricted to continuous trading, meaning that the first and last fifteen minutes of a trading day are excluded. The data spans the period between 8:15 a.m. and 4:15 p.m. GMT. (2): A single market order that trades against more than one limit order produces multiple data entries in the raw data. Thus, we combine all buys (sells) on one trading venue that are recorded for the same millisecond per stock. (3): Prior to the introduction of hidden orders on the LSE in December 2009, trades on the LSE are either executed at the best bid and ask or at multiple prices in the order book. In cases where the raw data records executions inside the spread, we thus assume technical irregularities and eliminate the trade from the data. Such trades account for only 0.9% of all LSE trades and for 1.4% of LSE trading volume over April/May 2009.

Firm level: We apply the following three filters on FTSE 100 constituents in both sample periods. (1): We require all stocks to have more than ten trades per trading day on the LSE, Chi-X, BATS, and Turquoise throughout the observation period. (2): Stocks with missing trade and quote data are excluded.[15] (3): We eliminate firms with corporate

[14]We thank SIRCA for providing access to the Thomson Reuters DataScope Tick History archive, http://www.sirca.org.au/.

[15]BATS trade and quote data is missing on SIRCA for stocks affected by this filter.

actions during the observation period.[16]

These filters result in 74 stocks for the observation period in April/May 2009 and we obtain 98 stocks for April/May 2010. To analyze differences over time, we restrict our sample to 70 firms which are traded in both observation periods.[17] In the 2009 observation period, HSBC HOLDINGS is traded most with an average daily trading volume of 290,973 million GBP. The company with the lowest daily trading volume is STANDARD LIFE with 9,349 million GBP. For the 2010 observation period, the most/least traded firm is BP (477,807 million GBP) and INMARSAT (9,104 million GBP), respectively.

To analyze the level of market integration, it is necessary to merge single order books of each trading venue into one consolidated order book per stock. Based on RICs and timestamps, we compute the European Best Bid (EBB), the highest bid across the LSE, Chi-X, BATS, and Turquoise, and the lowest ask price, the European Best Offer (EBO). Thomson Reuters also delivers a consolidated FTSE 100 data feed including the best bid and ask published on all order book driven trading venues. However, the data do not reveal the trading venues that quote the best available prices. To properly assess trading venue differences, we therefore compute our own consolidated order book.[18]

5 Descriptive Statistics

Figure 1 illustrates the average daily market share of the LSE, Chi-X, BATS, and Turquoise for the observation periods in 2009 and 2010. Over the 2009 observation period the LSE attracts on average roughly 70.2% of daily trading volume. As expected, we find a signifi-

[16] Corporate actions are obtained through Thomson Reuters.

[17] Both eliminated and final sample firms are available in an Internet appendix, see http://dl.dropbox.com/u/26069412/InternetAppendix.pdf.

[18] As a robustness check, we compare our consolidated order book including the LSE, Chi-X, BATS, and Turquoise with the Thomson Reuters consolidated European data feed using the *xbo*-RIC (see http://thomsonreuters.com/products_services/financial/financial_products/a-z/regulatory_compliance_mifid/ for a brief discussion of the data characteristics). First, we compute prevailing midpoint differences on a tick-by-tick basis between both data streams. Then, daily average values per stock are obtained. The data show a small average midpoint difference of 0.001 pence (0.001 pence) between both data streams for the 2009 (2010) observation period. In light of an average tick size of 0.508 pence (0.559 pence) over the observation period April/May 2009 (2010), our robustness check is evidence for the high quality of our consolidated order book.

cantly smaller LSE market share of 51.8% in 2010. Chi-X, the largest MTF, attracts about 20.3% of daily trading volume over the 2009 observation period and 30.8% in April/May 2010. BATS more than triples its market share between both observation periods to 11.6% in 2010. The market share of Turquoise reaches 6.0% of daily trading volume over both observation periods. The descriptive statistics show that fragmentation in FTSE 100 constituents increases over time.

Table 1 reports trading activity and liquidity measures for both observation periods computed per day and per stock. In line with expectations, the data show a significantly higher daily trading volume for all trading venues over the 2010 observation period than in 2009.[19] Interestingly, the average trade size increases across all trading venues. In both sample periods average trade sizes on the LSE are statistically and economically significantly larger than on any MTF.

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Insert Figure 1 here

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Quoted spreads are calculated for each price and volume update in the order book whereas quoted spreads at trades and effective spreads are computed trade-by-trade. We adapt the Bessembinder and Kaufman (1997) spread calculation in combination with the Bessembinder (2003) adjustment of the standard Lee and Ready (1991) algorithm to estimate the trade direction. All liquidity measures are winsorized at 1.0% and 99.0% to account for potential extreme values through technical data recording errors. We present computational details in the appendix of this paper.

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Insert Table 1 here

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Over April/May 2009, the average daily quoted spread ranges from 6.266 bps for the

[19] According to the European Equity Market Report of the Federation of European Securities Exchanges (FESE), average daily trading volume on the LSE, Chi-X, BATS, and Turquoise increases by about 54.0% between the first half of 2009 and 2010, see http://www.fese.eu/.

LSE to 14.003 bps for Turquoise. All trading venues exhibit smaller quoted spreads at trades than during periods without trades. This is evidence that investors actively monitor multiple order books and trade when it is relatively inexpensive to do so. Effective spreads are not considerably different from quoted spreads at trades indicating that most trades are executed at the best bid or ask. Our results also suggest that a considerable number of trades is executed against hidden orders on Turquoise as the average effective spread is considerably smaller than the quoted spread at trades.[20] The observation period in 2009 shows that order book depth is significantly larger on the LSE and Chi-X than on BATS and Turquoise. However, we likely underestimate the depth at best prices due to iceberg orders and hidden liquidity.

In 2010, the average daily number of trades is 3,105 per stock on the LSE and 2,874 on Chi-X. However, the average trading volume is still considerably higher on the LSE. The average LSE trade size is roughly 3,500 GBP larger than on Chi-X. This result is consistent with Goldstein, Shkilko, Van Ness, and Van Ness (2008) who find smaller trade sizes on ECNs compared to Nasdaq montage. Quoted spreads on the LSE decrease between the 2009 observation period and 2010 by 0.893 bps, on Chi-X by 2.020 bps, on BATS by 2.514 bps, and on Turquoise by 5.996 bps. Economically, the differences in liquidity between the LSE, Chi-X, and BATS in FTSE 100 constituents are on average negligible in April/May 2010. For very large orders, trading on the LSE may still be cheaper as the quoted volume is significantly larger than on any MTF. The descriptive statistics provide first evidence of strong competition for liquidity supply and additionally a market whose overall liquidity increases.

6 Quote Quality

In this section we focus on quote quality. Quotes are determined by traders who submit limit orders. It is possible that traders systematically ignore competing quotes on other

[20] We find that on average about 3.0% (11.0%) of all trades on Turquoise are executed inside the individual order book's spread over the 2009 (2010) observation period.

platforms, so that arbitrage opportunities arise. Section 6.1 describes how long each market is at the inside spread in the sense that it quotes the highest bid (EBB) and the lowest ask across trading venues (EBO). Section 6.2 investigates the prevalence of locked (EBB=EBO) and crossed markets (EBB>EBO). Section 6.3 provides details on determinants of non-positive spread initiations and terminations per platform.

6.1 Quote Competition

Transaction costs compromise of explicit and implicit trading costs. Explicit costs include, for instance, transaction fees and taxes, implicit costs are associated with costs for immediacy, market risk, and market impact. Assuming equal explicit costs and sufficient market depth across trading venues, investors can realize best execution selling (buying) in the market with the highest bid (lowest ask). As a consequence, the attractiveness of a trading venue to liquidity takers may be characterized by the platform's participation rate in the inside spread. We provide four measures of quote competitiveness (Goldstein, Shkilko, Van Ness, and Van Ness 2008): (1): presence at the EBBO (inside bid and/or ask) (2): presence at the EBB and EBO (3): alone at the EBBO (inside bid and/or ask) (4): alone at the EBB and EBO. Table 2 reports results on each measure as a percentage of the total trading day (Panel A) and as percentage of daily executed trades (Panel B) per stock during our observation periods. Over the observation period in 2009, the LSE quotes either the EBB or EBO or both during 85.0% of the trading day, Chi-X in 76.9%, BATS in 60.6%, and Turquoise in 52.9%. The participation rate of BATS and Turquoise is statistically and economically significantly lower than that of the LSE and Chi-X. The contribution of all trading venues to quote competition falls significantly when analyzing presence at both sides of the inside spread. Our measure ranges between 73.5% for the LSE and 30.1% for Turquoise. The LSE quotes the EBBO alone for 12.0% of the trading day. The patterns are confirmed by the fraction of trade executions on the different trading venues (Table 2, Panel B). There is a high number of trades when one trading venue posts the EBBO alone. This suggests that investors actively monitor multiple markets seeking best execution.

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Over the observation period in 2010, Chi-X is the most active quoting venue for FTSE 100 constituents (Table 2, Panel B). The LSE is at the EBBO only in 78.2% of the trading day compared to 87.2% for Chi-X. Quote contribution is lower on BATS and Turquoise. The LSE still provides competitive quotes, however, Chi-X and also BATS significantly increase their quote quality between 2009 and 2010.

Figure 2 provides insights into the fraction of the trading day that a trading venue is not at the EBBO (ticks away>0). In this case, we see for both observation periods that all trading venues provide quotes close to the EBBO. In April/May 2009, prevalence at the EBBO, one tick away, or two ticks away averages about 94.0% of time and 96.0% in April/May 2010. In line with our results on quoted spreads, we find that Turquoise is a significantly higher fraction of time further away from the EBBO than any other market. Overall, our results are in line with Goldstein, Shkilko, Van Ness, and Van Ness (2008) who find similar results for quote competition between Nasdaq's Super Montage and three ECNs, Archipelago, Island, and Instinet. Their findings show that the largest trading venue, Nasdaq's Super Montage, contributes more to the inside spread than the three ECNs.

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Insert Figure 2 here

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We further analyze time priority of best quotes (Table 2, Panel C). A quote is considered to have time priority either if it is at the best bid or ask alone or if it is at the best bid or ask and additionally has been submitted earlier than quotes at the same price (Goldstein, Shkilko, Van Ness, and Van Ness 2008). We average time priority of the bid and ask side of the order book per day and per stock. Time priority varies between 29.9% for Chi-X, 9.7% for BATS, and 15.0% for Turquoise over the observation period in 2009. LSE quotes have time priority in 44.5% in 2009 and in 38.8% in 2010. However, Chi-X increases time priority of its quotes by 7.8% between the two observation periods. In comparison to the LSE and Chi-X, time priority of BATS and Turquoise is smaller indicating more frequent quote changes. Flickering quotes may reduce transparency, discourage liquidity provision, and complicate best execution.

6.2 Locked and Crossed Markets

We follow Battalio, Hatch, and Jennings (2004) and identify locks and crosses in the consolidated order book. A stock is considered locked if the best bid equals the best ask on another trading venue (EBB=EBO, inside spread is zero) and it is crossed if the highest bid across trading venues is greater than the lowest ask across trading venues (EBB>EBO, inside spread is negative). Battalio, Hatch, and Jennings (2004) argue that “locked and crossed quotes locked and crossed quotes represent foregone trading opportunities” and are not in the investor’s best interest, assuming that investors want to trade instead of quoting. Under RegNMS, the SEC requires trading venues to establish, maintain, and enforce rules which prevent traders to lock or cross protected quotations (Rule 610), assuming that non-positive spreads are inconsistent with fair and orderly markets. MiFID does not address this concern.

Table 3 reports locks and crosses as percentage of quotes, as percentage of the trading day, and as percentage of trades. By construction, the percentage of positive inside spreads, locks, and crosses sum to 100.0%. In April/May 2009, the consolidated order book across trading venues has a non-positive spread in 8.5% (5.1% + 3.4%) of the trading day compared to 1.4% (1.3% + 0.1%) in 2010. On average, the percentage of quotes forming locked (crossed) quotes decreases from 11.1% (3.9%) to 5.5% (0.7%). Further the average duration of a lock (cross) decreases from 2.51 sec (10.83 sec) to 0.86 sec (0.41

sec). This represents a 65.8% (96.2%) reduction. The findings support the view that competition for order flow may force trading venues to quote closely linked prices.

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Insert Table 3 here

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Crossed quotes provide potential arbitrage opportunities and thus, are particularly interesting. Assuming that one trading venue quotes a higher bid than the lowest ask across the other platforms (EBB>EBO), an arbitrageur may buy shares and immediately sell them to realize a profit. To explore arbitrage activity, we look at the duration of crosses along with trading activity when a stock is crossed. We establish seven duration of cross categories: 1 to 9 milliseconds, 10 to 19 milliseconds, 20 to 49 milliseconds, 50 to 99 milliseconds, 100 to 999 milliseconds, 1,000 to 4,999 milliseconds, and equal or larger 5 seconds. Table 4 reports the number of crosses, the percentage of crosses with at least one trade, the tick size, and the value of a cross per category on a daily stock basis. Overall, differences in the number of crosses do not differ significantly between both observation periods. However, we find a strong tendency towards a shorter average duration of crosses. For example, the average number of daily crosses that lasts more than 5 seconds decreases from roughly 10 over the 2009 observation period to less than 1 in 2010. The average tick size and the value of a cross reveals that most crosses are only initiated by a difference of one tick between the EBB and the EBO. We also see a significant increase in trading activity for all duration categories. There is even at least one trade for crosses that last less than 10 milliseconds in almost 80.0% of time.[21]

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Insert Table 4 here

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[21] Table 1 shows an significant increase in daily number of trades between the observation period in 2009 and 2010. As a consequence, trades during crosses become more likely by construction. However, we argue that arbitrageurs actively take advantage of price differences. For example, BATS reports an average order latency of 200 microseconds in May 2010 (See http://www.batstrading.co.uk/resources/participant_resources/BATSEuro_Latency.pdf).

Our data allow us to estimate revenues from apparent arbitrage opportunities. We obtain the number of outstanding shares a trader can arbitrage for each cross and use the value of a cross to calculate associated revenues. Supposing that a high-frequency trader is able to submit a pair of orders to arbitrage crossed quotes within 1 millisecond, such a trader can earn on average 325 GBP per day and per stock in 2009 and 199 GBP in 2010, representing a 38,7% decline. Altogether, total potential revenues are 614,217 GBP for 70 FTSE 100 constituents during 27 trading days in April/May 2009 and 404,700 GBP during 29 trading days in April/May 2010. Transaction costs may be one reason why these arbitrage opportunities exist. The data show an average arbitrable depth of 5,093 GBP during a cross in 2009 and 5,956 GBP in 2010. Minimum transaction costs are 0.28 bps of trading volume for active orders (see Section 3). Transaction costs average 1,103 GBP in 2009 and 1,477 GBP in 2010 per day and per stock for a pair of orders and thus are considerably larger than potential arbitrage revenues. We therefore conclude that not all arbitrage opportunities are economically exploitable.

6.3 Determinants of Locked and Crossed Markets

This section examines initiations and terminations of locks and crosses for each trading venue separately. While we analyze the aggregated market in previous sections, we now seek to identify differences in initiations and terminations of locks and crosses between platforms. We further test several factors that potentially affect investors decisions to submit locking or crossing quotes in a multivariate regression framework.

Table 5 provides descriptive statistics on active, passive, and simultaneous locks and crosses for the LSE, Chi-X, BATS, and Turquoise per day and per stock. According to Shkilko, Van Ness, and Van Ness (2008), active initiations of locks (crosses) are characterized by an outstanding quote which is actively locked (crossed) and which stands in the order book for a minimum duration before being locked (crossed), here 250 milliseconds[22]. Active terminations of locks and crosses are defined accordingly. A simultaneous

[22]We also perform our analysis with a time limit of 1 second and find the expected significant increase

lock (cross) happens if an investor submits a limit order that locks (crosses) a quote which was posted less than 250 milliseconds before. Passive locks occur when a trading venue comes out of a cross. Assuming a crossed market, an investor may send an order to a trading venue which potentially locks a quote. Then, if the cross is resolved, the passive quote becomes active and locks the stock. By construction, the percentages of active, simultaneous, and passive locks sum to 100.0%. We average bid and ask-initiated and terminated locks and crosses and report our main statistics of interest, active locks and crosses, for each trading venue separately.

In April/May 2009, we find that active locks (crosses) represent on average 78.1% (85.1%) of all initiated locks (crosses), simultaneous locks (crosses) 14.8% (14.9%), and passive locks 7.0% (Table 5, Panel A). Traders on Chi-X and the LSE enter significantly more locking quotes than traders on the other two MTFs, 36.0% and 31.2% of all actively posted locks. 44.5% of all crosses are actively initiated by the LSE, 32.7% by Chi-X, 5.0% by BATS, and 3.0% by Turquoise. Quotes of all four trading venues are quite often locked, the percentage varies between 22.9% for the LSE and 15.8% for Chi-X. BATS and Turquoise are most affected by active crosses with a fraction of 28.7% and 40.3% during the 2009 observation period. The LSE and Chi-X appear to terminate locks and crosses most actively.

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Insert Table 5 here

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Our analyses show a significantly higher percentage of simultaneously submitted quotes during the observation period in 2010 compared to 2009, indicating a higher trading speed (Table 5, Panel B). As a consequence, we see for almost every category of active cross and lock initiations and terminations a significant drop between both observation periods.

in simultaneous locks and crosses. Because of faster trading compared to Shkilko, Van Ness, and Van Ness (2008), we reduce the time limit for simultaneous initiations and terminations to 250 milliseconds. However, similar patterns of active lock and cross initiations and terminations between trading venues and over time are found for the 1 second case and are not reported for brevity.

Chi-X and the LSE still submit the highest fraction of active locks and crosses and BATS and Turquoise are still most often actively crossed. Compared to the observation period in 2009, a similar pattern is found for locked quotes, unlocks, and uncrosses in 2010. This may provide evidence that investors use each trading venue for similar trading strategies during both observation periods.

However, we have to take into account the number of quote updates that each trading venue posts. As a percentage of the total number of submitted EBBO quotes, Chi-X provides a daily average fraction of 36.2% and 42.0% over the observation periods in 2009 and 2010, respectively. The LSE also enters a considerable number of quotes that form the inside spread, 32.0% and 26.4%. The average daily fraction of BATS remains relatively stable at roughly 24.0% and well ahead of Turqouise with less than 8.0%. Comparable to Shkilko, Van Ness, and Van Ness (2008), we further examine active locked and crossed market initiations and terminations as percentages of EBBO updates (Table 5, Panel A & B). We do not find significant differences for lock and cross initiations across trading venues ranging from 0.03% to 0.70% of all posted quotes per market over the observation period in 2009. All corresponding statistics are significantly smaller over the 2010 observation period. Our results do not provide evidence that one trading venue causes a substantially higher fraction of locks and crosses relative to its number of EBBO updates. A different pattern can be seen for inside quotes being locked and crossed. Turquoise quotes are significantly more often locked and crossed over both observation periods. However, Turquoise also shows the highest number of unlocks and uncrosses. Riordan, Storkenmaier, and Wagener (2010) analyze the contribution of the LSE, Chi-X, BATS, and Turquoise to price formation in FTSE 100 constituents in April/May 2009. It appears that Turquoise contributes significantly less to quote based price discovery than the three other trading venues. Taken together, evidence suggests that Turquoise is more often locked and crossed as a result of stale quotes.

There are several reasons why locks and crosses can arise. Investors may avoid to trade against an outdated quote or against a limit order with a small associated volume.

To directly test these arguments, we estimate bivariate logistical regressions for each of the observation periods. We run separate regressions for bid-initiated (ask-initiated) locks and crosses.[23] The general model is defined as follows:

$$\ln\left[\frac{\pi_j}{\pi_{Quote}}\right] = \beta_1 \ \mathit{InsideSpreadLag} + \beta_2 \ \mathit{TimeLSE} + \beta_3 \ \mathit{TimeChiX} + \beta_4 \ \mathit{TimeBATS} + \beta_5 \ \mathit{TimeTQ} + \beta_6 \ \mathit{vol1} + \beta_7 \ \mathit{rv1} \tag{1}$$

where the dependent variable equals one for bid-initiated (ask-initiated) non-positive inside spreads with $j \in \{Lock, Cross\}$ and is zero otherwise. π is the modeled response probability, *InsideSpreadLag* the inside quoted spread before a lock or cross is initiated, and *TimeLSE*, *TimeChiX*, *TimeBATS* and *TimeTQ* represent the outstanding quote time on each of the four trading venues in seconds. The variables *vol1* and *rv1* are control variables representing lagged one minute trading volume in British Pounds/10^6 and lagged one minute realized volatility in basis points preceding a price change.[24] We further include firm dummy variables and intraday dummy variables for each half-hour of the trading day.

Times of high trading activity may be an indication that traders disagree on public information or have differential private information. A resulting demand for speedy executions can increase the probability of locks and crosses. According to Shkilko, Van Ness, and Van Ness (2008), we expect locks and crosses to become more likely when inside spreads are narrow. In line with our expectations, we obtain significantly negative coefficients on *InsideSpreadLag* for all regression models (Table 6).

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Insert Table 6 here

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[23] We exclude quote updates that do not change the EBB (EBO) from the regressions.

[24] Given the average duration of positive inside spreads (about 48 sec over the 2009 observation period and 73 sec in 2010, see Table 3), lagged one minute variables seem to be a reasonable choice. However, we rerun all regressions with lagged three minute control variables. The results do not change and are therefore not reported.

In their study of locks and crosses in Nasdaq and NYSE-listed stocks, Shkilko, Van Ness, and Van Ness (2008) find a positive coefficient on outstanding quote time, indicating that some exchanges are often tardy with quote updates. Over the observation period in 2009, our data only indicates that the outstanding quote time increases the likelihood of a lock on the LSE. BATS and Turquoise show a significant positive coefficient on *TimeBATS* and *TimeTQ* over the 2010 observation period. However, the effect seems to be small. Lagged volatility and trading volume may also indicate a period of high liquidity and varying trading interests. Although, we would expect locks and crosses to become more likely with an increasing value of *rv1* and *vol1*, we only find significant positive coefficients for the more recent observation period in 2010.

MiFID's main objective is to create greater competition across Europe and to contribute to more integrated financial markets. Our evidence on quote competition suggests that inside quotes change frequently. We find that cross and lock initiations and terminations are not caused by one specific trading venue. Due to interrelated effects of intermarket competition, such as lower explicit trading fees, faster exchange infrastructure (Riordan and Storkenmaier 2010), an increasing use of co-location services (Garvey and Wu 2010), and more sophisticated high-frequency trading strategies (Menkveld 2011), traders may be able to quickly resolve arbitrage opportunities. Regression results suggest that locks and crosses are more likely in fast-moving market periods and are correlated with investors' demand for speedy executions.

7 Trade-Throughs

In the fragmented UK trading environment, investors sometimes execute worse than the best available price, e.g. the best available price is traded-through. Trade-throughs represent a violation of price priority and "are indicative of economically inefficient trades because investors seemingly should receive better prices" (Battalio, Hatch, and Jennings 2004). Section 7.1 examines the question whether investors do execute at the best available price and Section 7.2 analyzes determinants of trade-throughs in a multivariate regression framework.

7.1 Trade-Through Statistics

Table 7 reports trade-through rates as percentages of the daily number of trades (Panel A) and as percentage of daily trading volume (Panel B) per stock over both observation periods.[25] We further differentiate between five trade sizes categories measured by shares traded: 0-499 shares, 500-1,999 shares, 2,000-4,999 shares, 5,000-9,999 shares, and trades with 10,000 shares or more.[26] Our data show a decrease in the percentage of trade-throughs for the LSE and Chi-X and the expected negative sign for the other two MTFs between the observation periods in 2009 and 2010. The fraction varies across trading venues between 5.2% and 8.7% for the 2009 observation period and between 4.7% and 6.9% for 2010.[27] Overall, Turquoise attracts over both periods the lowest number of trade-throughs. The fraction of trade-throughs does not differ considerably between the LSE, Chi-X, and BATS. An increasing trade-through rate in trade-sizes provide some evidence that investors trade off best prices and available depth. Large orders may execute against multiple limit orders at different levels in the order book. Findings suggest that investors rather optimize the average volume-weighted trade price than executing simply at the best price. We also see that in volume terms trade-throughs are much more prevalent (Table 7, Panel B).

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Insert Table 7 here

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Figure 3 depicts the fraction of trades for different order execution levels. We see

[25] Orders may execute against hidden orders in the order book that are not visible to any investor. To allow a clean analysis of trade-through determinants, we do not include those types of trades.

[26] We base our classification on SEC trade size categories (see RegNMS, Rule 600).

[27] In their May 2010 report, Equiduct Trading provides an average trade-through rate of 8.6% for FTSE 100 constituents traded on the LSE, Chi-X, BATS, and Turquoise that is similar to the fraction we find in our data, see http://www.equiduct.com/.

that a high fraction of trade-throughs is executed one or two ticks away from the EBBO during both observation periods. Our data allow us to estimate potential savings of avoiding trade-throughs. It appears that there is not always sufficient depth available at the EBBO to execute the entire order strictly at the best price. 56.8% of trade-throughs could have been entirely executed at a better price on another platform in April/May 2009 and 58.5% in April/May 2010. Executing the available volume of an order at the EBBO, investors would have been able to save on average 1,451 GBP per day and stock on the LSE, 474 GBP on Chi-X, 84 GBP on BATS, and 87 GBP on Turquoise in 2009. In 2010, the corresponding statistics are 761 GBP for the LSE, 530 GBP for Chi-X, 210 GBP for BATS, and 68 GBP for Turquoise. The increase in potential savings on Chi-X and BATS between both observation periods is driven by a higher absolute number of trade-throughs. Altogether, we obtain potential savings of roughly 4,0 million GBP for our sample of 70 FTSE 100 constituents during 27 trading days in April/May 2009 and 3,2 million GBP during 29 trading days in April/May 2010.[28]

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Insert Figure 3 here

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Overall, we find a dramatically smaller trade-through rate than Foucault and Menkveld (2008) who study competition on the Dutch stock market after the market entry of EuroSETS in May 2004. They find an average trade-through rate of over 73.0%. Since 2004, computer algorithms advanced and smart order routing (SOR) systems that split large orders seeking best execution for investors became more sophisticated. Our smaller trade-through ratio may provide some evidence that on the one hand trading venues post more aligned quotes and that on the other hand liquidity takers make more use of SOR systems.

[28]If we assume sufficient depth at the EBBO for each order size, we obtain total potential savings of roughly 15,4 million GBP in 2009 and 14,2 million GBP in 2010.

7.2 Determinants of Trade-Throughs

To better understand the factors that lead to a trade-through, we estimate bivariate logistical regressions on trade-throughs for each of the two observation periods. The dependent variable takes the value one for a trade-through and is zero otherwise. The general model is defined as follows:

$$\ln\left[\frac{\pi_{TradeThrough}}{\pi_{Trade}}\right] = \beta_1\ \mathit{InsideSpread} + \beta_2\ \mathit{AvgDepth1} + \beta_3\ \mathit{ShareVolume} + \beta_4\ \mathit{vol1} + \beta_5\ \mathit{rv1} \tag{2}$$

where π is the modeled response probability, *InsideSpread* the inside spread in basis points at trade time, and *AvgDepth1* is the average quoted volume of the consolidated order book. *ShareVolume* is the number of shares traded divided by 1,000. The variables *vol1* and *rv1* are control variables and defined as in Equation (1).[29] We further include firm dummy variables and intraday dummy variables for each half-hour during the trading day. Table 8 provides the regression estimates for all trading venues combined and each trading venue separately over both observation periods.

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Insert Table 8 here

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In line with our results on locks and crosses, we expect trades-throughs to become more likely with smaller inside spreads. Narrow spreads may be a sign of high trading activity and the demand for speedy executions (Shkilko, Van Ness, and Van Ness 2008). Moreover, when spreads are narrow the benefits to search for better terms of trade are likely to fall. The results confirm our expectations. The coefficients on *InsideSpread* are negative and highly significant for all regressions, except for Turquoise over the 2010 observation period. The average quoted depth across trading venues can be an additional explanatory variable for investors' order routing decisions. The coefficients on *AvgDepth1*

[29]Changing the lag length to three minutes does not affect the results.

are significantly negative indicating that trade-throughs become less likely with an increasing average depth at best prices in the consolidated order book. Our results are confirmed when we replace *AvgDepth1* with average depth up to three ticks behind best prices. This may be evidence that depth as a decision factor becomes less important for investors along with a high level of consolidated depth. Investors are rather concerned to trade at the best available price across trading venues. Our findings are mirrored in the results on *ShareVolume*, which has a positive coefficient in all regressions and confirms our descriptive statistics (Table 7). The probability of a trade-through increases in trade size. Increasing lagged trading volume (*vol1*) and lagged volatility (*rv1*) have a significantly positive effect on trade-throughs across all trading venues. In times of high market activity, liquidity in the order books should be high. Investors may want to trade promptly and trade off searching costs, liquidity, and speed of execution. In summary the regression models indicate that investors actively base their decision to trade-through the best available price on market conditions.

Best execution under MiFID relies on multiple factors. MiFID explicitly allows financial service providers to include multiple factors such as price, trading costs, speed, probability of execution, or probability of settlement in their best execution policy. Under RegNMS, fragmented trading venues are virtually linked and price priority is enforced across platforms. Prior to the linkage of U.S. equity option markets, Battalio, Hatch, and Jennings (2004) find an average trade-through rate of 11.1% in June 2000 and 3.7% in January 2002. Compared to their second observation period, our data reveal on average a higher trade-through rate for FTSE 100 constituents. However, evidence suggests that investors base their trading decisions on best prices and other variables such as available depth.

8 Conclusion

The Markets in Financial Instruments Directive (MiFID) is a major part of the European Union's plan to promote competition among trading venues. Since its introduction in November 2007, established exchanges are challenged by alternative trading venues, so-called multilateral trading facilities (MTF) that gained significant market shares in nearly all European equity markets. In contrast to U.S. equity market's Regulation NMS (Reg-NMS), MiFID neither imposes a formal linkage between trading venues nor establishes a single data consolidator for pre- and post-trade information. Further, intermediaries, such as investment firms or brokers, acting on behalf of their clients have to ensure best execution and trading venues are required to publish quote and trade information. In this paper, we study whether competition for order flow of disconnected platforms forces a single virtual market to emerge.

We use order book data of FTSE 100 constituents traded on the LSE and the three MTFs, Chi-X, BATS, and Turquoise. The analysis is based on two observation periods in April/May 2009 and April/May 2010. Between both observation periods, the LSE market share in FTSE 100 constituents decreases from 70.2% to 51.8%. While the LSE posts on average the smallest quoted spread over the first observation period, Chi-X is the most liquid platform in April/May 2010. To examine market coordination, we analyze arbitrage opportunities and suboptimal executions. Quotes are locked if the best bid across trading venues equals the best ask (EBB=EBO) and crossed if the best bid exceeds the best posted ask (EBB>EBO). Neither situation seems consistent with an economically efficient market: Locked quotes suggest that traders who could trade on a consolidated market do not. Crossed quotes are arbitrage opportunities in the simple form as they violate the law of one price. Markets are locked (crossed) in 24.5 minutes (16.0 minutes) of a trading day during the 2009 observation period. For April/May 2010, we find locks (crosses) in 6.4 minutes (19.8 seconds) per trading day. This represents a 83.5% decline in non-positive spreads. In addition, we estimate that potential arbitrage revenues before transaction costs fall by 38,7% between both observation periods per day and per stock. It appears that competition for order flow forces disconnected trading venues to quote closely aligned prices.

Best execution under MiFID is multi-dimensional on factors such as price, trading costs, speed, size, probability of execution, or other factors. This is in contrast to U.S. regulation which enforces price priority across trading venues. We examine trade-throughs, e.g. trades that are executed worse than the best available price across platforms. Our data shows that the average trade-through rate decreases from 7.7% over our first observation period to 6.0% in April/May 2010. We interpret this result as evidence for an increasing use of smart order routing systems. Regressions show that trade-throughs become more likely in times of narrow inside spreads suggesting that investors trade off liquidity and search costs during fast-moving market periods.

Regulatory authorities, practitioners, and academics are concerned that MiFID results in a fragmented European trading landscape, but leaves it to the market to solve integration. Our research provides some evidence that competition forces may be able to integrate disconnected platforms and that infrastructure costs of a formal linkage may be avoided.

Computational Details

In this section we provide details on the computation of our liquidity measures. The most common measure is the quoted spread. The wider the quoted spread, the less liquid is an instrument. However, this variable only captures liquidity for relatively small order sizes. Quoted spreads are calculated as a proxy of trading costs for each trading venue on an individual order book level. Let $a_{i,t}$ be the ask price for an instrument i at time t and $b_{i,t}$ the respective bid price. $m_{i,t}$ denotes the mid quote, then the relative quoted half spread ($qspread_{i,t}$) in basis points is calculated as follows:

$$qspread_{i,t} = (a_{i,t} - b_{i,t})/(m_{i,t} \times 2) \times 10,000$$

This measure is based on a quote-to-quote process that is characterized by every price or volume update and each trade during the trading day. Then, quoted spreads are aggregated per day and per stock for each trading venue. To avoid some of the noise of tick-by-tick data, all liquidity measures are winsorized at the 1.0% level and the 99.0% level. Another liquidity measure, quoted spread at trades ($qspread\_trade_{i,t}$), captures liquidity represented through the best bid and ask at the time of execution.

The effective spread is the spread that is actually paid when an incoming market order trades against a limit order. We use the standard Lee and Ready (1991) algorithm to estimate trade direction as proposed by Bessembinder (2003). Using the variables from above and let $p_{i,t}$ be the execution price, then the effective half spread ($espread_{i,t}$) is defined as:

$$espread_{i,t} = D_{i,t} \times ((p_{i,t} - m_{i,t})/m_{i,t}) \times 10,000$$

where $D_{i,t}$ denotes the trade direction with -1 for market sell and $+1$ for market buy orders. Effective spreads also capture institutional features of trading venues like hidden liquidity or market depth. For example, iceberg-orders that only display a fraction of total trading volume and fully hidden limit orders are available on the LSE, Chi-X, BATS, and Turquoise. Effective spreads are usually equal to or larger than the second liquidity measure, quoted spreads at trades. However, they might be smaller if trading venues feature hidden liquidity and there is a reasonable number of trades executed inside the spread.

Finally, depth data is used to the compute the quoted volume at different order book levels in individual order books of each trading venue. Let $B_{i,t}$ be the corresponding volume at the bid and $A_{i,t}$ at the ask, then the quoted half depth ($depth_{x,i,t}$) in British Pounds is computed as follows:

$$depth_{x,i,t} = \sum_{x=1}^{X} (B_{x,i,t} + A_{x,i,t})/(2 \times 100)$$

where $X = \{1, 3\}$ characterizes the order book level. $depth_{1,i,t}$ is the average half quoted volume at the best bid and ask and $depth_{3,i,t}$ incorporates the quoted volume up to three ticks behind best prices.

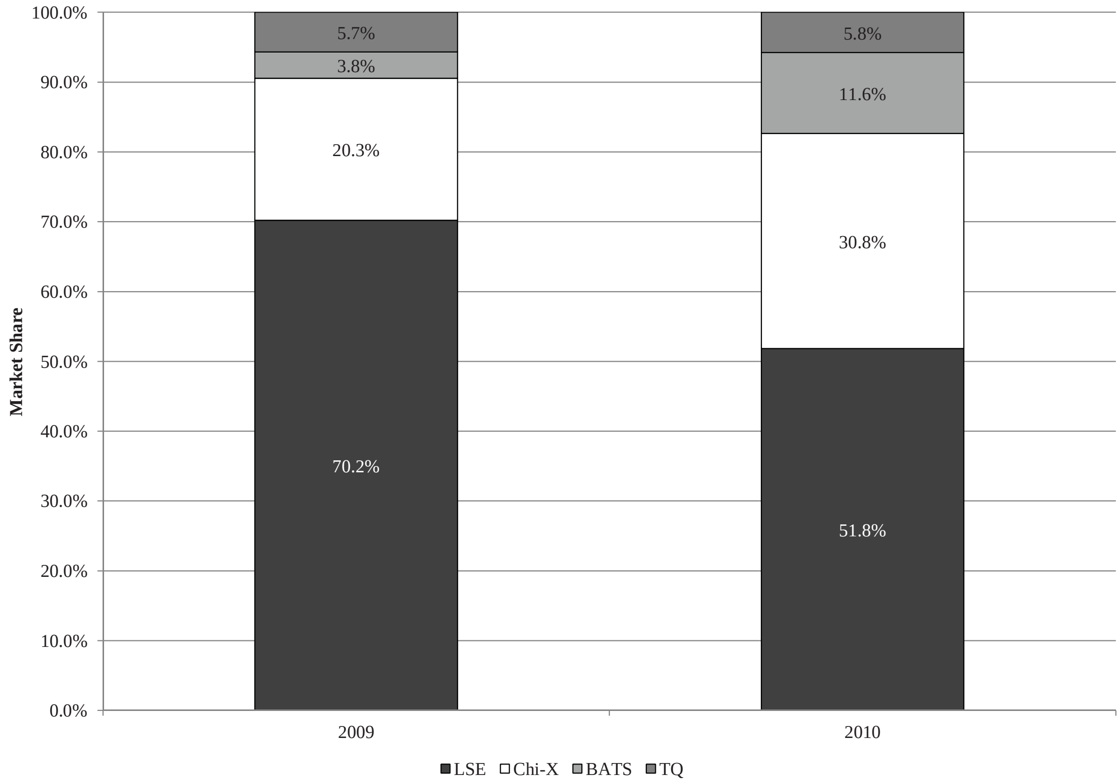


Figure 1

Market Shares of the LSE, Chi-X, BATS, and Turquoise

The figure depicts market shares for FTSE 100 constituents traded on the LSE, Chi-X, BATS, and Turquoise. Our sample consists of 70 stock pairs traded during both observation periods April 20 to May 29, 2009 and April 19 to May 28, 2010. Market shares are based on trading volume in British Pounds per day and per stock.

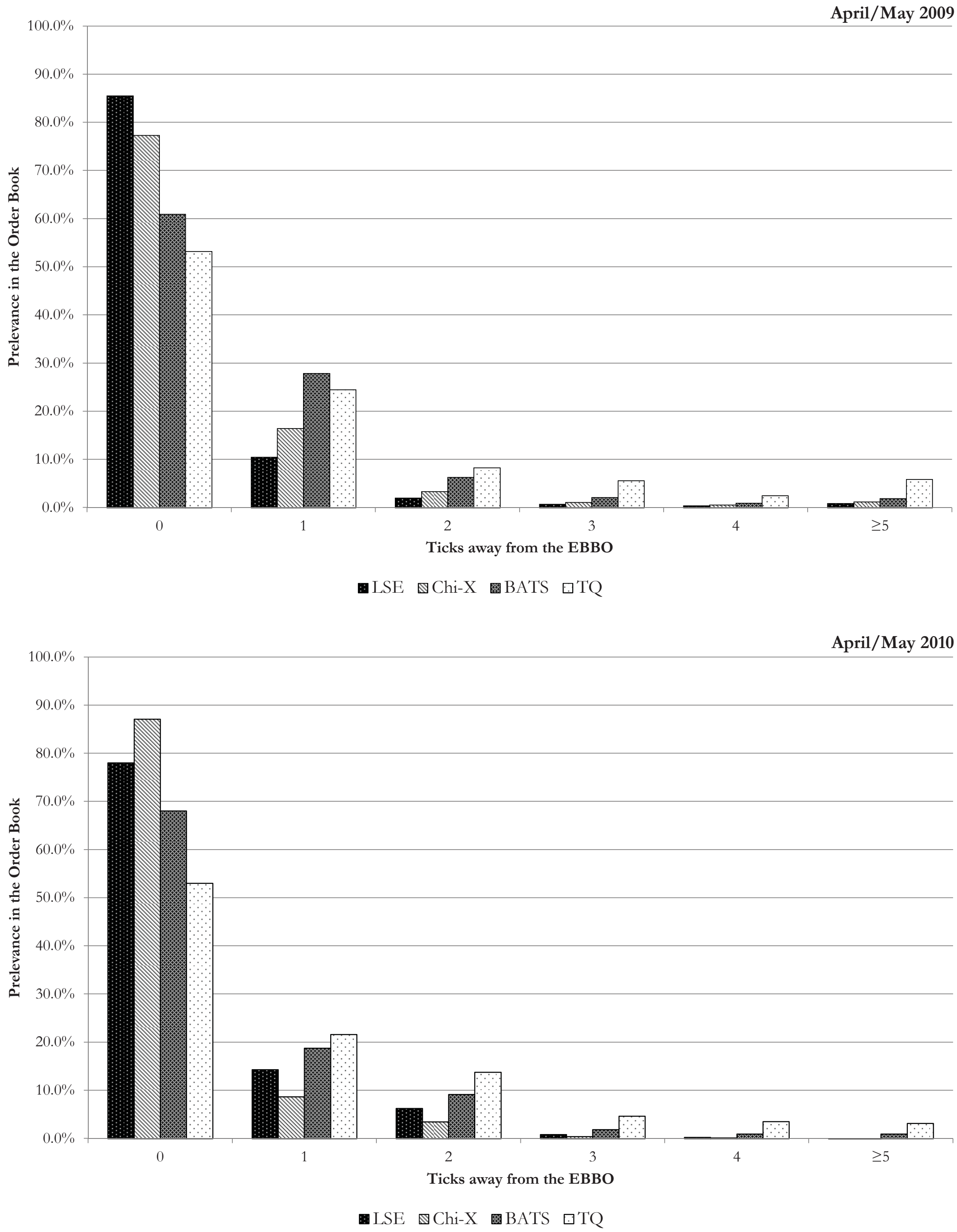
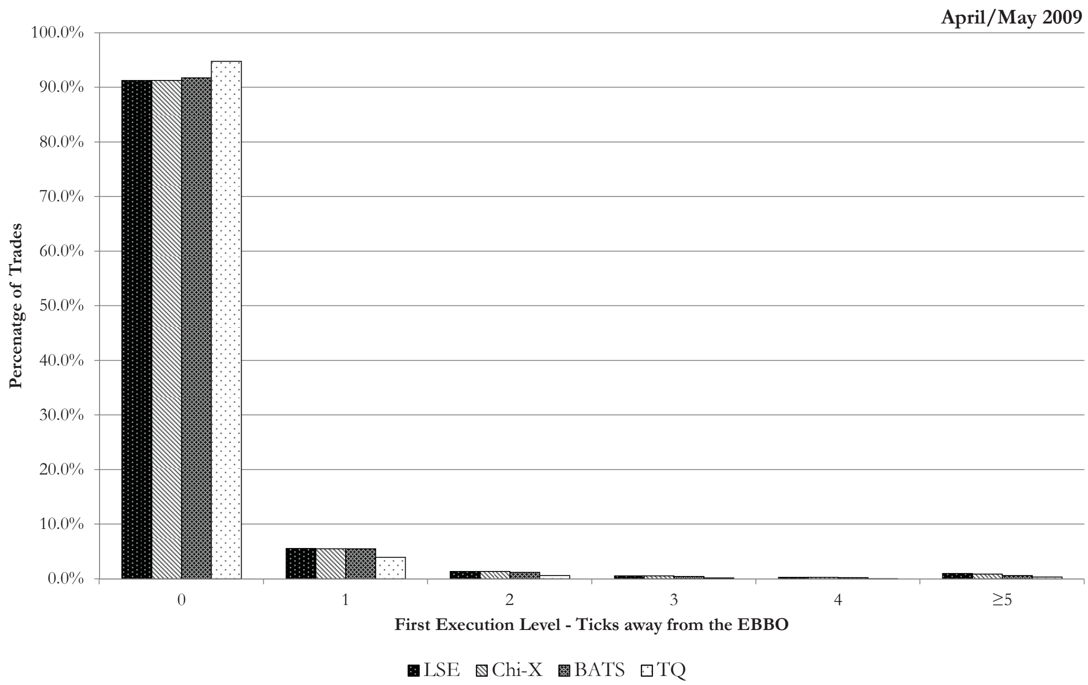


Figure 2

Quotations According to the EBBO

The figures depict the fraction of a trading day a trading venue spends at the EBBO (ticks away=0) and at different levels away from the EBBO per day and per stock. Results for the observation period April/May 2009 are presented in the upper figure and for April/May 2010 in the lower figure.



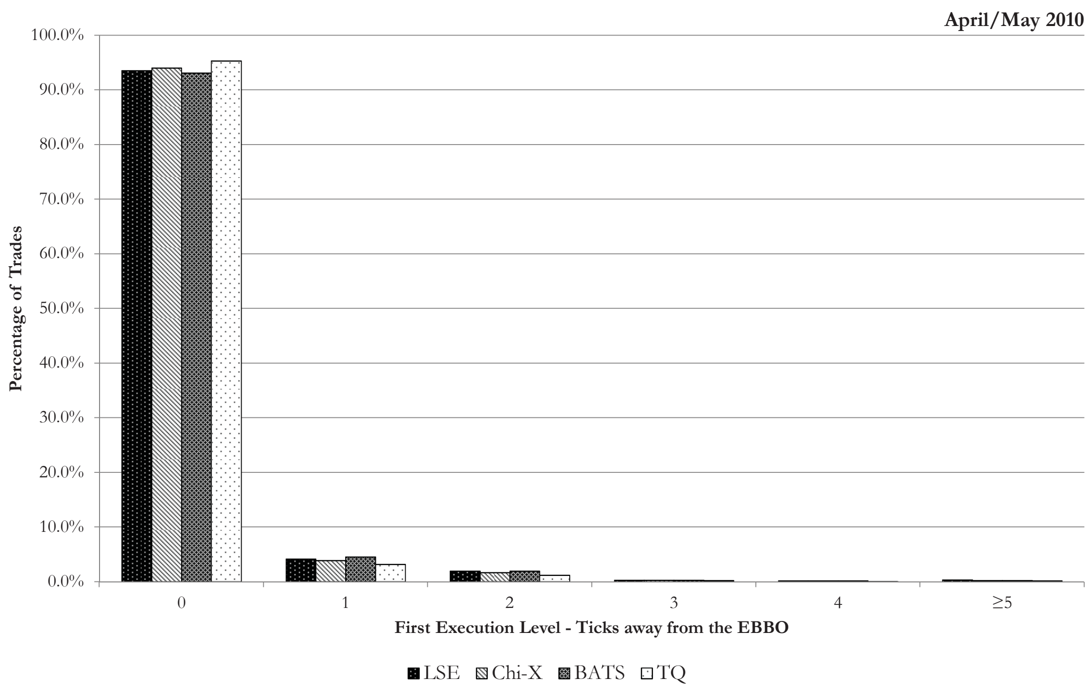


Figure 3

Order Execution Levels According to the EBBO

The figures depict the fraction of trades as a percentage of the total number of trades for different order execution levels according to the EBBO per day and per stock. Trades executed at the best available price are zero ticks away from the EBBO. Results for the observation period April/May 2009 are presented in the upper figure and for April/May 2010 in the lower figure.

Table 1

Descriptive Statistics: Trading Intensity and Liquidity Measures

We collect trade and quote data of FTSE 100 constituents over two observation periods: April 20 and May 29, 2009 and April 19 and May 28, 2010. The table presents daily trading intensity and liquidity measures per instrument for 70 stock pairs that are traded in both periods. Volume gives the trading volume in thousand British Pounds, Trade Count the corresponding number of executed trades, and Trade Size the average traded volume of an execution in British Pounds. All spread measures are reported in basis points. Quoted Spread is calculated on a tick-by-tick basis per stock and Quoted Spread Trade and Effective Spread are reported trade-by-trade. Depth1 is half the quoted volume at the best bid and ask in British Pounds and Depth3 incorporates the quoted volume 3 ticks behind best prices. Standard deviations are reported in parentheses below the daily means. Mean differences between the two observation periods are tested for statistical significance using Thompson (2011) clustered standard errors with 'a' denoting statistical significance at the 1% level and 'b' at the 5% level.

	April/May 2009				April/May 2010			
	LSE	Chi-X	BATS	TQ	LSE	Chi-X	BATS	TQ
Volume (1,000 GBP)	36,754	11,282	2,136	3,232	43,981[b]	28,301[a]	9,250[a]	4,082[a]
	(45,893)	(14,031)	(2,902)	(4,572)	(62,799)	(41,325)	(11,459)	(4,755)
Trade Count	2,949	1,460	352	493	3,105	2,874[a]	1,318[a]	606[a]
	(2,139)	(1,098)	(307)	(488)	(3,192)	(3,141)	(1,264)	(532)
Trade Size (GBP)	9,982	6,044	4,723	5,306	11,624[a]	8,118[a]	6,048[a]	5,867[a]
	(4,883)	(3,223)	(2,519)	(2,328)	(4,953)	(3,690)	(2,899)	(2,488)
Quoted Spread	6.266	6.632	8.075	14.003	5.373[a]	4.612[a]	5.561[a]	8.037[a]
	(2.336)	(2.651)	(6.455)	(16.128)	(1.873)	(1.745)	(2.346)	(3.739)
Quoted Spread Trade	4.714	5.019	5.852	8.852	3.644[a]	3.459[a]	3.975[a]	5.131[a]
	(1.727)	(1.899)	(2.439)	(8.726)	(1.290)	(1.278)	(1.570)	(2.197)
Effective Spread	4.792	5.115	6.067	8.711	3.662[a]	3.430[a]	3.998[a]	4.570[a]
	(1.757)	(1.933)	(2.518)	(8.721)	(1.289)	(1.239)	(1.556)	(1.900)
Depth1 (GBP)	36,334	30,342	21,623	8,917	43,696[b]	35,540	23,988	13,377[a]
	(29,335)	(33,416)	(23,191)	(5,738)	(28,845)	(30,450)	(21,648)	(9,161)
Depth3 (GPB)	129,579	141,376	83,333	28,445	231,022[a]	174,592	108,224[b]	48,911[a]
	(111,706)	(160,010)	(91,600)	(28,060)	(185,854)	(145,087)	(95,801)	(43,028)

Table 2

Quote-Based Competition: Trading Venue Participation in the EBBO

We consolidate single order books of the LSE, Chi-X, BATS, and Turquoise to one integrated European order book per stock to the millisecond over the two observation periods. A trading venue is at the European Best Bid and/or Offer (EBBO), if it quotes the highest bid and/or the lowest ask. If it participates alone in the EBBO, it provides the best price alone across the four trading venues. For both categories the table further presents statistics, if a trading venue forms the entire EBBO. A trading venue has time priority, if it is alone at the EBBO or posted the best price earlier than all other trading venues. Standard deviations are reported in parentheses below the daily means. Mean differences between the two observation periods are tested for statistical significance using Thompson (2011) clustered standard errors with 'a' denoting statistical significance at the 1% level and 'b' at the 5% level.

	April/May 2009				April/May 2010			
	LSE	Chi-X	BATS	TQ	LSE	Chi-X	BATS	TQ
Panel A: Time-weighted averages, % of trading day								
At EBBO	85.00%	76.85%	60.59%	52.87%	78.16%[a]	87.24%[a]	68.20%[a]	53.14%
(bid and/or ask)	(12.14%)	(11.16%)	(15.78%)	(17.80%)	(12.05%)	(5.51%)	(17.16%)	(21.70%)
At both inside	73.49%	59.47%	36.96%	30.10%	62.66%[a]	75.82%[a]	48.54%[a]	32.55%
(bid and ask)	(16.97%)	(15.57%)	(17.42%)	(17.86%)	(18.06%)	(9.60%)	(22.03%)	(24.17%)
Alone at EBBO	11.98%	1.97%	2.08%	4.05%	6.99%[a]	5.03%[a]	1.49%[a]	1.65%[a]
(bid and/or ask)	(5.60%)	(2.36%)	(2.59%)	(5.23%)	(3.79%)	(4.06%)	(0.86%)	(1.04%)
Alone at both inside	1.30%	0.26%	0.04%	0.09%	0.37%[a]	1.33%[a]	0.04%	0.03%[a]
(bid and ask)	(1.91%)	(1.45%)	(0.15%)	(0.26%)	(0.61%)	(2.25%)	(0.09%)	(0.08%)
Panel B: Trade-weighted averages, % of trades								
At EBBO	76.82%	55.18%	44.15%	41.00%	66.96%[a]	60.71%[a]	50.98%[a]	41.36%
(bid or ask)	(8.54%)	(9.47%)	(12.33%)	(12.97%)	(7.19%)	(6.44%)	(12.34%)	(14.34%)
At both inside	57.48%	40.58%	24.76%	19.28%	48.04%[a]	50.34%[a]	34.10%[a]	21.14%
(bid and ask)	(12.90%)	(11.70%)	(13.23%)	(12.46%)	(13.38%)	(8.51%)	(15.87%)	(16.38%)
Alone at EBBO	22.87%	5.88%	3.76%	5.72%	16.82%[a]	11.11%[a]	5.33%[a]	4.83%
(bid or ask)	(7.01%)	(3.03%)	(2.22%)	(5.19%)	(5.49%)	(4.86%)	(1.83%)	(1.67%)
Alone at both inside	1.28%	0.22%	0.04%	0.05%	0.58%[a]	1.08%[a]	0.09%	0.02%
(bid and ask)	(1.97%)	(0.95%)	(0.07%)	(0.14%)	(0.87%)	(1.60%)	(0.10%)	(0.04%)
Panel C: Time priority, % of trading day								
Time priority	44.48%	29.91%	9.68%	15.04%	38.78%[a]	37.70%[a]	12.17%[a]	11.05%[a]
	(7.88%)	(7.32%)	(4.03%)	(7.38%)	(6.60%)	(6.91%)	(3.84%)	(4.14%)

Table 3

Crossed and Locked Market Statistics

The table presents means and standard deviations in parentheses for different market regimes per day and per stock for both observation periods. A positive inside spread characterizes a 'normal' market regime with a positive inside spread (EBB<EBO). A stock is locked if the best posted bid across all trading venues equals the best ask (EBB=EBO). If markets are crossed, a trading venue's inside bid is greater than another markets ask (EBB>EBO). Mean differences between the two observation periods are tested for statistical significance using Thompson (2011) clustered standard errors with with 'a' denoting statistical significance at the 1% level and 'b' at the 5% level.

	April/May 2009			April/May 2010		
	Positive	Locked	Crossed	Positive	Locked	Crossed
% of quotes	84.99%	11.12%	3.89%	93.80%^{a}	5.50%^{a}	0.65%^{a}
	(9.22%)	(4.23%)	(6.96%)	(2.75%)	(2.57%)	(0.60%)
% of trading day	91.53%	5.11%	3.35%	98.60%^{a}	1.33%^{a}	0.08%^{a}
	(10.92%)	(3.40%)	(6.57%)	(1.07%)	(0.94%)	(0.11%)
% of trades	74.57%	20.11%	5.30%	84.78%^{a}	13.69%^{a}	1.52%^{a}
	(9.34%)	(5.02%)	(7.28%)	(3.57%)	(3.54%)	(1.32%)
Time of trading day, min	439.35	24.49	15.99	473.23^{a}	6.36^{a}	0.33^{a}
	(52.42)	(16.33)	(31.53)	(5.13)	(4.49)	(0.54)
Average duration, sec	48.00	2.51	10.83	72.59^{a}	0.86^{a}	0.41^{a}
	(31.86)	(3.22)	(24.94)	(61.23)	(1.25)	(6.13)

Table 4

Detailed Analysis of Crossed Market Quotes

The table presents statistics for crossed market regimes per day and per stock over both observation periods. A stock is crossed, if a trading venue's inside bid is greater than another markets ask (EBB>EBO). The average number of crosses, the percentage of crosses with one or more trades reported during the cross, the average tick size, the average difference of the best bid and ask in pence, and potential arbitrage revenues in GBP are presented for different duration of crosses per day and per stock. Standard deviations are reported in parentheses below the daily means. Mean differences between the two observation periods are tested for statistical significance using Thompson (2011) clustered standard errors with 'a' denoting statistical significance at the 1% level and 'b' at the 5% level.

	April/May 2009					April/May 2010				
Duration of cross, ms	No. of crosses	With trades	Tick size	Value of cross	Arbitrage	No. of crosses	With trades	Tick size	Value of cross	Arbitrage
0	15.17					28.68^{b}				
	(20.33)					(71.27)				
1 to 9	12.17	63.90%	0.504	0.539	41.10	38.49^{a}	79.63%^{a}	0.538	0.536	75.38^{a}
	(17.37)	(25.92%)	(0.342)	(0.425)	(65.00)	(97.55)	(18.80%)	(0.641)	(0.646)	(147.28)
10 to 19	11.01	73.15%	0.506	0.546	44.12	16.87	87.52%^{a}	0.517	0.521	39.63
	(14.44)	(23.90%)	(0.344)	(0.399)	(68.98)	(39.00)	(16.92%)	(0.601)	(0.647)	(70.17)
20 to 49	17.51	77.20%	0.507	0.559	75.66	17.53	90.84%^{a}	0.504	0.523	43.25^{a}
	(22.10)	(19.39%)	(0.340)	(0.464)	(123.67)	(37.93)	(14.82%)	(0.553)	(0.585)	(71.34)
50 to 99	7.99	78.79%	0.504	0.569	42.01	5.44^{b}	89.65%^{a}	0.420^{b}	0.449^{a}	16.25^{a}
	(9.92)	(24.87%)	(0.341)	(0.457)	(73.69)	(14.24)	(20.86%)	(0.496)	(0.546)	(29.98)
100 to 999	9.62	75.37%	0.503	0.542	30.07	7.25	82.74%^{a}	0.408^{a}	0.428^{a}	15.27^{a}
	(11.60)	(23.86%)	(0.342)	(0.404)	(39.29)	(19.52)	(25.89%)	(0.439)	(0.484)	(31.27)
1,000 to 4,999	6.01	77.40%	0.502	0.575	22.64	1.64^{a}	85.09%^{a}	0.349^{a}	0.399^{a}	4.56^{a}
	(8.27)	(26.06%)	(0.341)	(0.472)	(31.24)	(3.94)	(27.08%)	(0.456)	(0.596)	(7.69)
$\geq$ 5,000	10.31	88.26%	0.503	0.939	69.38	0.33^{a}	87.23%	0.356^{a}	0.494^{a}	5.01^{a}
	(17.26)	(19.79%)	(0.339)	(2.005)	(113.13)	(0.83)	(30.47%)	(0.512)	(0.749)	(14.61)
Total	89.79	76.30%	0.506	0.587	322.54	116.24	86.10%^{a}	0.553	0.562	208.99^{a}
	(97.23)	(23.40%)	(0.340)	(0.429)	(417.79)	(279.09)	(22.12%)	(0.650)	(0.669)	(403.01)

Table 5

Initiations and Terminations of Locks and Crosses

The table presents statistics on locks and crosses for both observation periods on a daily per instrument basis. A trading venue locks another, if it posts a bid (ask) which equals the outstanding ask (bid) on another venue (locking), trading venues on the passive side of such an initiation are locked. A trading venue crosses another, if it quotes an ask that is greater than the highest bid across all trading venues (crossing). Trading venues with the highest bid are locked. Terminations are unlocking and uncrossing, respectively. Active (simultaneous) initiations and terminations are characterized by an outstanding inside quote on the other side that is posted at least (less than) 250 milliseconds before the lock or cross happens. Passive locks happen, if a trading venue comes out of a cross. First, the table shows shares for actively, passively, and simultaneously initiated locks and crosses. Active initiations and terminations are also reported for each trading venue separately. Fractions of lock- and cross-initiating quotes in the total number of inside quotes are given in the second part of each panel. Mean differences between the two observation periods are tested for statistical significance using Thompson (2011) clustered standard errors with 'a' denoting statistical significance at the 1% level and 'b' at the 5% level.

	% of inside quotes	Locking	Locked	Unlocking	Crossing	Crossed	Uncrossing
Panel A: April/May 2009							
% of locked and crossed market initiations and terminations							
Active		78.13%	80.03%	62.35%	85.09%	84.81%	57.80%
		(9.00%)	(8.84%)	(10.84%)	(12.28%)	(12.29%)	(19.26%)
LSE	32.00%	31.17%	22.91%	22.06%	44.48%	6.71%	25.79%
	(8.27%)	(8.28%)	(6.76%)	(7.09%)	(16.97%)	(7.25%)	(12.95%)
Chi-X	36.17%	36.01%	15.84%	20.22%	32.69%	9.14%	13.99%
	(5.14%)	(8.94%)	(4.57%)	(6.67%)	(14.17%)	(7.74%)	(9.23%)
BATS	24.05%	9.32%	19.27%	14.29%	4.98%	28.70%	8.56%
	(5.98%)	(5.75%)	(5.48%)	(6.22%)	(5.72%)	(16.99%)	(7.57%)
TQ	7.79%	1.63%	22.01%	5.79%	2.94%	40.26%	9.47%
	(4.81%)	(1.26%)	(7.14%)	(2.86%)	(6.50%)	(21.92%)	(9.76%)
Passive		7.03%	5.76%				
		(6.09%)	(5.30%)				
Simultaneous		14.84%	14.21%	37.65%	14.91%	15.19%	42.20%
		(5.90%)	(5.99%)	(10.84%)	(12.28%)	(12.29%)	(19.26%)
Locked and crossed market initiations and terminations as % of inside quotes per venue							
LSE		0.64%	0.74%	0.46%	0.11%	0.03%	0.07%
		(0.24%)	(0.39%)	(0.24%)	(0.12%)	(0.05%)	(0.09%)
Chi-X		0.68%	0.44%	0.39%	0.09%	0.02%	0.04%
		(0.35%)	(0.24%)	(0.26%)	(0.13%)	(0.02%)	(0.06%)

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	% of inside quotes	Locking	Locked	Unlocking	Crossing	Crossed	Uncrossing
BATS		0.26%	0.89%	0.42%	0.03%	0.14%	0.06%
		(0.26%)	(0.68%)	(0.34%)	(0.05%)	(0.34%)	(0.12%)
TQ		0.17%	5.02%	0.81%	0.03%	1.85%	0.38%
		(0.21%)	(7.08%)	(1.01%)	(0.09%)	(5.09%)	(1.01%)
Panel B: April/May 2010							
% of locked and crossed market initiations and terminations							
Active		72.02%[a]	73.75%[a]	50.05%[a]	71.60%[a]	71.88%[a]	42.73%[a]
		(11.26%)	(11.16%)	(8.78%)	(17.78%)	(17.92%)	(18.58%)
LSE	26.40%[a]	24.47%[a]	17.87%[a]	17.14%[a]	31.37%[a]	6.59%	20.20%[a]
	(6.59%)	(8.11%)	(5.10%)	(5.52%)	(19.75%)	(6.31%)	(15.37%)
Chi-X	41.98%[a]	35.79%	14.46%[a]	18.09%[a]	31.02%	9.45%	13.94%
	(7.27%)	(8.30%)	(4.11%)	(5.79%)	(17.51%)	(10.99%)	(11.36%)
BATS	24.23%[a]	9.48%	19.73%	9.72%[a]	7.81%[a]	22.48%[a]	5.97%[a]
	(6.46%)	(4.84%)	(5.61%)	(4.50%)	(9.49%)	(16.61%)	(8.10%)
TQ	7.39%[a]	2.27%[a]	21.69%	5.10%[a]	1.41%[b]	33.37%[a]	2.62%[a]
	(3.80%)	(1.69%)	(6.07%)	(2.64%)	(3.97%)	(17.31%)	(4.58%)
Passive		4.38%[a]	3.65%[a]				
		(3.35%)	(2.93%)				
Simultaneous		23.60%[a]	22.60%[a]	49.95%[a]	28.40%[a]	28.12%[a]	57.27%[a]
		(8.70%)	(8.91%)	(8.78%)	(17.78%)	(17.92%)	(18.58%)
Locked and crossed market initiations and terminations as % of inside quotes per venue							
LSE		0.35%[a]	0.42%[a]	0.25%[a]	0.04%[a]	0.02%	0.03%
		(0.17%)	(0.27%)	(0.14%)	(0.04%)	(0.03%)	(0.03%)
Chi-X		0.32%[a]	0.19%[a]	0.16%[a]	0.02%[a]	0.01%	0.01%
		(0.15%)	(0.09%)	(0.10%)	(0.03%)	(0.01%)	(0.01%)
BATS		0.15%[a]	0.48%[a]	0.15%[a]	0.01%	0.04%[a]	0.01%
		(0.10%)	(0.25%)	(0.10%)	(0.02%)	(0.05%)	(0.02%)
TQ		0.12%[a]	2.00%[a]	0.32%[a]	0.01%	0.28%[a]	0.02%[a]
		(0.10%)	(1.17%)	(0.26%)	(0.02%)	(0.39%)	(0.04%)

Table 6

Logistic Regressions: Determinants of Lock and Cross Initiations

We run bivariate logistical regressions on locks and crosses for both observation periods separately. The dependent variable equals one for bid-initiated (ask-initiated) non-positive inside spread initiations and is zero otherwise. The last inside spread in basis points is *InsideSpreadLag* and *TimeLSE*, *TimeChiX*, *TimeBATS*, and *TimeTQ* represent the outstanding quote time in seconds on each of the four trading venues before a quote change. *vol1* and *rv1* are control variables representing the lagged trading volume in British Pounds/10^6 and the realized volatility in basis points over the one minute interval proceeding the quote change. Chi-Square statistics are reported in parentheses below the regression estimates. 'a' denotes significance at the 1% level and 'b' at the 5% level. We do not report firm dummy variables and intraday dummy variables for each half hour.

	April/May 2009				April/May 2010			
	Locking		Crossing		Locking		Crossing	
	Bid-Initiated	Ask-Initiated	Bid-Initiated	Ask-Initiated	Bid-Initiated	Ask-Initiated	Bid-Initiated	Ask-Initiated
InsideSpreadLag	-0.0516[a]	-0.0554[a]	-0.1110[a]	-0.1140[a]	-0.2142[a]	-0.2200[a]	-0.4107[a]	-0.4107[a]
	(31,297)	(38,486)	(46,870)	(50,804)	(76,390)	(81,669)	(71,569)	(71,762)
TimeLSE	0.0018[a]	0.0018[a]	-0.0081[a]	-0.0113[a]	-0.0006[a]	-0.0003[a]	-0.0140[a]	-0.0161[a]
	(3,787)	(3,427)	(575)	(974)	(228)	(43)	(917)	(1,266)
TimeChiX	-0.0028[a]	-0.0037[a]	-0.0295[a]	-0.0361[a]	-0.0047[a]	-0.0054[a]	-0.0453[a]	-0.0540[a]
	(1,922)	(3,120)	(2,600)	(3,254)	(3,145)	(3,806)	(1,678)	(1,910)
TimeBATS	-0.0008[a]	-0.0007[a]	-0.0022[a]	-0.0026[a]	0.0004[a]	0.0003[a]	0.0013[a]	0.0003[b]
	(1,305)	(1,003)	(1,996)	(1,439)	(92)	(46)	(82)	(4)
TimeTQ	-0.0004[a]	-0.0006[a]	-0.0012[a]	-0.0015[a]	0.0010[a]	0.0009[a]	0.0010[a]	0.0014[a]
	(653)	(1,298)	(1,016)	(1,332)	(1,031)	(786)	(139)	(295)
vol1	-0.2773[a]	-0.2255[a]	-2.8594[a]	-4.2109[a]	0.0176[a]	0.0207[a]	0.0477[a]	0.0440[a]
	(341)	(219)	(502)	(669)	(31)	(49)	(72)	(49)
rv1	-1.3447[a]	-1.1901[a]	-3.6891[a]	-3.5326[a]	0.0491[a]	0.0533[a]	0.2527[a]	0.2745[a]
	(9,972)	(8,474)	(9,113)	(8,626)	(9)	(10)	(119)	(153)
# Obs.	19,544,959	21,144,046	19,544,959	21,144,046	39,787,992	40,574,964	39,787,992	40,574,964
Somer's D	0.235	0.258	0.160	0.160	0.405	0.414	0.639	0.639
c statistic	0.617	0.629	0.580	0.580	0.702	0.707	0.820	0.820

Table 7

Trade-Through Statistics

The table presents trade-through rates as a percentage of daily number of trades (Panel A) and as a percentage of daily trading volume (Panel B) per stock. Trade-throughs occur when a trade is executed worse than the inside bid (ask). Results are given based on shares traded according to SEC trade size categories. Standard deviations are reported below the daily means. Mean differences between the two observation periods are tested for statistical significance using Thompson (2011) clustered standard errors with 'a' denoting statistical significance at the 1% level and 'b' at the 5% level.

	April/May 2009				April/May 2010			
	LSE	Chi-X	BATS	TQ	LSE	Chi-X	BATS	TQ
Panel A: Trade-weighted averages, % of daily number of trades								
≤499	7.04%	7.55%	7.08%	4.69%	4.80%^{a}	4.51%^{a}	5.39%^{b}	3.63%^{a}
	(6.95%)	(6.89%)	(7.78%)	(5.24%)	(3.32%)	(2.97%)	(3.37%)	(2.81%)
500 to 1,999	8.89%	9.33%	8.98%	5.49%	6.49%^{a}	6.72%^{a}	8.48%	5.59%
	(7.36%)	(7.44%)	(8.80%)	(5.64%)	(4.06%)	(4.14%)	(5.76%)	(5.01%)
2,000 to 4,999	10.87%	11.68%	10.35%	5.55%	8.77%^{b}	9.23%^{a}	10.39%	7.21%^{b}
	(9.18%)	(11.38%)	(15.54%)	(11.28%)	(5.67%)	(7.21%)	(10.28%)	(12.44%)
5,000 to 9,999	12.91%	13.78%	10.80%	5.30%	11.89%	12.78%	13.38%^{b}	8.49%^{a}
	(13.11%)	(18.04%)	(18.90%)	(12.47%)	(11.01%)	(15.15%)	(18.49%)	(18.43%)
≥10,000	21.14%	14.61%	12.11%	5.68%	18.20%^{b}	15.71%	14.46%	11.88%^{a}
	(23.96%)	(23.51%)	(21.64%)	(14.29%)	(19.24%)	(22.46%)	(23.06%)	(24.06%)
Total	8.71%	8.68%	8.20%	5.22%	6.51%^{a}	6.00%^{a}	6.93%	4.69%
	(7.04%)	(6.69%)	(7.10%)	(4.58%)	(3.79%)	(3.31%)	(3.94%)	(3.24%)
Panel B: Trade-weighted averages, % of daily trading volume								
≤499	7.33%	7.87%	7.62%	5.08%	5.12%^{a}	4.99%^{a}	6.28%	4.19%
	(7.20%)	(7.11%)	(8.21%)	(6.01%)	(3.56%)	(3.43%)	(4.25%)	(5.77%)
500 to 1,999	9.12%	9.59%	9.08%	5.38%	6.73%^{a}	6.94%^{a}	8.80%	5.75%
	(7.44%)	(7.63%)	(8.91%)	(5.48%)	(4.14%)	(4.30%)	(5.95%)	(5.45%)
2,000 to 4,999	11.03%	11.88%	10.54%	5.56%	8.99%^{b}	9.45%^{a}	10.53%	7.37%^{b}
	(9.32%)	(11.46%)	(15.74%)	(11.36%)	(5.83%)	(7.31%)	(10.41%)	(12.70%)
5,000 to 9,999	13.01%	14.01%	10.88%	5.32%	12.14%	12.95%	13.50%^{b}	8.53%^{a}
	(13.25%)	(18.37%)	(19.04%)	(12.58%)	(11.40%)	(15.34%)	(18.63%)	(18.55%)
≥10,000	26.07%	14.95%	12.43%	5.70%	22.86%^{b}	15.82%	14.76%	12.10%^{a}
	(27.07%)	(23.72%)	(21.86%)	(14.39%)	(24.05%)	(22.44%)	(23.38%)	(25.15%)
Total	12.08%	10.36%	9.55%	5.50%	10.26%^{b}	7.97%^{a}	9.12%	5.96%
	(8.32%)	(6.87%)	(7.42%)	(4.98%)	(6.55%)	(3.98%)	(5.14%)	(4.90%)

Table 8

Logistic Regressions: Determinants of Trade-Throughs

We run bivariate logistical regressions on trade-throughs for both observation periods separately. The dependent variable equals one for a trade ignoring the best available price across trading venues and is zero otherwise. *InsideSpread* is the inside spread at time of execution. *AvgDepth1* is the average depth at best best prices in the consolidated order book in British Pounds/10^6. *ShareVolume* is the number of shares traded. *vol1* and *rv1* are control variables representing the lagged trading volume in British Pounds/10^6 and the realized volatility in basis points over the one minute interval preceding a trade. Chi-Square statistics are reported in parentheses below the regression estimates. 'a' denotes significance at the 1% level. We do not report firm dummy variables and intraday dummy variables for each half hour.

	April/May 2009					April/May 2010				
	All	LSE	Chi-X	BATS	TQ	All	LSE	Chi-X	BATS	TQ
InsideSpread	-0.171^a	-0.152^a	-0.206^a	-0.230^a	-0.157^a	-0.259^a	-0.105^a	-0.461^a	-0.367^a	0.011^a
	(222,857)	(113,803)	(82,125)	(19,480)	(9,357)	(169,374)	(11,370)	(155,659)	(60,483)	(18)
AvgDepth1	-3.862^a	-4.303^a	-3.113^a	-2.491^a	-3.484^a	-4.111^a	-4.906^a	-3.208^a	-2.578^a	-10.750^a
	(2,040)	(1,465)	(357)	(53)	(141)	(3,108)	(1,846)	(617)	(225)	(1,193)
ShareVolume	0.011^a	0.009^a	0.024^a	0.030^a	0.005^a	0.009^a	0.006^a	0.021^a	0.025^a	0.025^a
	(6,319)	(4,269)	(3,224)	(656)	(8)	(5,589)	(2,448)	(4,361)	(1,782)	(546)
vol1	0.216^a	0.164^a	0.277^a	0.279^a	0.275^a	0.070^a	0.048^a	0.081^a	0.085^a	0.108^a
	(8,235)	(2,569)	(3,992)	(974)	(1,255)	(8,688)	(1,856)	(3,867)	(2,121)	(1,007)
rv1	0.245^a	0.242^a	0.225^a	0.178^a	0.360^a	1.158^a	1.091^a	1.294^a	1.179^a	0.531^a
	(501)	(288)	(119)	(14)	(74)	(4,474)	(1,924)	(1,682)	(681)	(62)
# Obs.	9,193,651	5,090,696	2,624,776	625,402	852,777	14,879,290	5,882,072	5,416,966	2,510,581	1,069,671
Somer's D	0.517	0.500	0.581	0.546	0.411	0.357	0.296	0.460	0.436	0.301
c statistic	0.759	0.750	0.790	0.773	0.706	0.678	0.648	0.730	0.718	0.651

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