Trading Fees and Intermarket Competition

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Abstract

Regulators, exchanges, and politicians are considering reining in maker-taker pricing, which is used as a competitive tool by trading venues to acquire order flow. Examining the 2013 reduction in trading fees operated by BATS on its European venues, we document significant effects on market quality and market share both on BATS and in competing venues. Interestingly, we identify cross-sectional differences which suggest that traders in large (small) capitalization stocks are more sensitive to changes in make (take) fees. Our results are consistent with the predictions derived from a model of two competing order books that employ trading fees.

JEL Classifications: G10, G12, G14, G18, G20, D40, D47
Keywords: Trading Fees, Access Fees, Maker-Taker Pricing, Intermarket Competition, Limit Order Book

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We thank Evangelos Benos, Bruno Biais, Luisella Bosetti, Jean Edward Colliard, Ryan Davies, Thierry Foucault, Michael Goldstein, Björn Hagströmer, Joel Hasbrouck, Frank Hatheway, Charles Jones, Andrea Lupi, Pamela Moulton, Maureen O'Hara, Gideon Saar, Duane Seppi, Satchit Sagade and Fabio Sist for useful discussions, comments and support. We also thank seminar participants at the European Summer Symposium in Financial Markets (ESSFM, Gerzensee 2016), the Bank of England, Cornell University, Babson College, University of Gothenburg, University of Saint Andrews, University of Glasgow, the Eighth Erasmus Liquidity Conference (2017), the European Finance Association (EFA 2017), and the Central Bank Conference in Market Microstructure (2017).

1 Introduction

In today's fragmented equity trading environment, venues use trading fees to compete for order flow. Most venues operate limit orders books, and rely on endogenous provision of liquidity. As a result, venues have an incentive to subsidize liquidity supply by offering a rebate (make fee) to traders submitting limit orders. However, venues have to generate revenues to cover their costs and therefore impose a higher positive fee (take fee) on market orders.[1] This type of pricing, called maker-taker pricing, is actively debated among academics, practitioners, market operators, and is currently under review by U.S. and European regulators. Maker-taker pricing is an important competitive tool for exchanges in today's fragmented markets, and may benefit investors to the extent that it contributes to narrower posted spreads. However, maker-taker pricing has recently been criticized for potentially exacerbating conflicts of interest between brokers and their customers, for contributing to market fragmentation and market complexity, and for undermining price transparency.[2]

This paper studies the effects of changes in trading fees in standard limit order books that have a price grid based on tick size, and that at the same time face competition from other trading venues. We base our empirical analysis on recent changes to maker-taker pricing implemented by BATS Europe (BATS) in its European markets.[3] We document significant changes in market shares and market quality following fee changes, both for the venues implementing the changes and for the competing venues, and significant cross-sectional differences in the response to fee changes. The latter results suggest that traders in large capitalization stocks are more sensitive to make fee changes whereas traders in small capitalization stocks are more sensitive to take fee changes. We also add to the theoretical literature by modeling two competing limit order books using trading fees.

Maker-taker pricing in the U.S. equity market was first adopted by the electronic trading platform Island ECN in the late 1990s in order to compete with exchanges. In response, other Alternative Trading Systems (ATSs) and exchanges also adopted maker-taker pricing. Starting from the mid-2000s, maker-taker pricing was the standard pricing model in the U.S. equity markets. Concerned about escalating access (take) fees, the U.S. Securities and Exchange Commission (SEC) imposed an access fee cap of 30 cents per 100 shares by adopting Rule 610 of Regulation NMS in 2005.[4] The 2007 MiFID I opened the European equity markets and

[1]According to the OICV-IOSCO (2013) report, there exists at least four types of fee structures: the symmetrical pricing model, with both the active and passive side of a trade paying the same fee; the asymmetrical pricing model, with both the active and the passive side of a trade paying a fee, but the fee paid is not the same; the maker-taker pricing model, with the provider of liquidity (maker) receiving a rebate and the taker of liquidity (taker) paying a fee; and the inverted maker-taker pricing model, with the provider of liquidity paying a fee and the taker of liquidity receiving the rebate.

[2]For extensive background and critical review on access fees, see the SEC Market Structure Advisory Committee's October 20, 2015, Memorandum "Maker-Taker Fees on Equities Exchanges."

[3]BATS Europe is a subsidiary of the U.S. exchange BATS.

[4]Securities Exchange Act Release No. 51808 (Jun. 9, 2005), 70 FR 37496, 3745 (Jun. 29, 2005) (File No.

allowed new trading platforms called Multilateral Trading Facilities (MTFs) to compete with exchanges by adopting maker-taker pricing.

In the ensuing decade, trading venues have frequently tweaked their maker-taker pricing models primarily to attract certain types of order flow. The liquidity rebates are particularly attractive to High Frequency Traders (HFTs) who have developed rebate harvesting strategies by acting as two-sided liquidity providers. Menkveld (2013) shows that the liquidity rebates can represent a significant fraction of a HFT trading firm's profits. As HFTs share of trading volume in both U.S. and European markets grew rapidly reaching close to 70% in the U.S. and 30% in Europe, the incentive to cater to this particular group of traders motivated even more aggressive competition for order flow using maker-taker pricing, often with added volume-based incentives.[5]

While maker-taker pricing has enabled new entrants to compete effectively with incumbent exchanges, potentially leading to narrower quoted spreads, the practice has been also criticized. Angel, Harris, and Spatt (2015) argue that maker-taker pricing obfuscates true spreads, that it distorts order routing decisions, and that it hurts both internalizing dealers and venues that do not use maker-taker pricing.[6] Harris (2015) further argues that rebates allow traders to circumvent the minimum price variation (tick size), thus by-passing Regulation NMS order protection rules. Angel et al. (2015) recommend that the SEC either requires that all brokers pass through access fees and liquidity rebates to their clients and clarify that best execution obligations apply to net prices instead of quoted prices, or prohibit maker-taker pricing altogether.

On the other hand, Malinova, Park, and Riordan (2018) see no reason to abolish maker-taker pricing as academic evidence suggest that HFTs and other traders pass through a significant fraction of the rebates to active traders.[7] Instead, they support initiatives to provide investors with better information about execution quality that includes maker-taker fees. Foucault (2012) shows that the make-take fee breakdown can affect the mix of market and limit orders and may even increase market participants' welfare. Consequently, he advocates that exchanges and regulators conduct pilot experiments to assess the effect of maker-taker fees on the composition of order flow (market vs. limit orders) before contemplating any changes to the current rules.

Not surprisingly, industry participants and exchanges and even members of Congress have also weighed in on the maker-taker pricing debate. The Intercontinental Exchange Group,

S7-10-04).

[5]Brogaard (2010) documents that HFTs represent 68% of Nasdaq trade volume, and Jarnecic and Snape (2010) document that HFTs represent 28% of total LSE volume.

[6]This concern has been validated using options market data, Battalio, Corwin, and Jennings (2015) who show that retail brokers appear to route orders to maximize order flow payments: selling market orders and sending limit orders to the venues paying large liquidity rebates, and that retail traders' limit order execution quality is negatively related to the level of the liquidity rebates.

[7]Hendershott and Riordan (2013) also show that HFT market makers pass through some of the rebates to active traders.

Inc. (ICE) and the Securities Industry Financial Markets Association (SIFMA) argue that the maker-taker pricing contributes to market complexity and that the SEC should reduce or eliminate maker-taker pricing and lower the cap on access fees from \$0.003 per share to \$0.0005 per share. BATS agrees that access fees should be lowered for the most liquid stocks, but argues that a tiered approach based on securities' characteristics should be applied for less liquid stocks. On March 3, 2015, Congressman Stephen F. Lynch introduced The Maker-Taker Conflict of Interest Reform Act of 2015 (H.R. 1216) which would require the SEC to carry out a pilot program to assess the impact of an alternative maker-taker pricing model.[8] On March 14, 2018, the SEC proposed a Transaction Fee Pilot for NMS stocks with the goal to "facilitate an informed, data-driven discussion about transaction fees and rebates and their impact on order routing behavior, execution quality and market quality in general" according to SEC Chairman Jay Clayton.[9] The proposed SEC Transaction Fee Pilot has not yet been implemented.

Equity markets are fragmented with several competing venues operating electronic limit order books with discrete prices, while the existing theoretical literature focuses either on a single venue with discrete prices (Foucault, Kadan, and Kandel, 2005), or on competing venues without price discreteness (Colliard and Foucault, 2012), or on the optimal fee structure (Chao, Yao, and Ye, 2017). To help us frame the empirical analysis, we develop a model of a dynamic limit order book with a discrete pricing grid that faces competition from another identical limit order book. Our model draws of Riccò, Rindi and Seppi (2018) which extends Chao et al. (2017) to include both different types of traders and three trading periods instead of two. It departs from Buti, Rindi, and Werner (2017) in that it has endogenous liquidity supply, trading fees and a competing limit order book.[10] We use the model to derive predictions on the effects of a change in fees on spread, depth and volume in a fragmented market. The new feature of our model is that it includes both frictions (tick size) and a competing venue. Our model complements both the Colliard and Foucault (2012) model in that it has a tick size, and the Foucault et al. (2005) model in that it includes a competing market. Moreover, unlike the Chao et al. (2017) model which focuses on the optimal fee structure, our focus is on the

[8]The Maker-Taker Conflict of Interest Reform Act of 2015 would require the SEC to identify a random sample of 50 of the 100 most heavily traded US stocks, and prohibit the payment of rebates market-wide for those stocks for six months.

[9]https://www.sec.gov/news/press-release/2018-43. The new rule is called Rule 610T of Regulation NMS (SEC Release No. 34-82873) and divides NMS stocks with a share price at or above \$2 per share into three test groups: Group 1 with a \$0.0015 fee cap for removing & providing displayed liquidity (no cap on rebates); Group 2 with a \$0.0005 cap for removing & providing displayed liquidity (no cap on rebates); and Group 3 with rebates and linked pricing prohibited for removing & providing displayed & undisplayed liquidity (Rule 610(c)'s cap continues to apply to fees for removing displayed liquidity); and a control group (Rule 610(c)'s cap continues to apply to fees for removing displayed liquidity).

[10]The first version of this paper included a model of a limit order book competing with a crossing network. We thank Charles Jones, Björn Hagströmer, and Satchit Sagade for suggesting to investigate the model with two competing limit order books.

effects of a change in fees on the quality of the limit order book.

Colliard and Foucault (2012) show that in a competitive market without tick size, traders perfectly neutralize a change in fees so that such a change has no effects on the spread net of fees (cum-fee spread). Foucault et al. (2005) instead show that in a single market limit order book, the make-take fee breakdown matters for spreads. With the support of our model we show how fee changes affect quoted spread, depth and volume in a market that has a tick size and at the same time faces competition from another trading venue.

In a fragmented market, a change in fees on one venue is likely to affect traders' order routing decisions, and hence result in a migration of orders between venues. Our model shows that in a primary market facing competition from another identical competing venue, an increase in the take fee reduces the attractiveness of the now more expensive primary market and induces orders to migrate away to the competing venue. The migration of orders has a detrimental effect on the quality of the primary market, measured by spread, depth and volume (market share). Similarly, an increase in the rebate on the primary market generates an inflow of orders from the competing trading platform which improves market quality in the primary venue.

We then use the model to construct hypotheses and frame our empirical analysis of the effects of changes in make-take fees implemented in January 2013 by BATS on its two lit venues – BXE and CXE. Specifically, CXE reduced its make fee while leaving its take fee constant and BXE eliminated the make fee entirely and cut its take fee in half. We study the effect of these fee changes on BXE and CXE market quality and market share relative to the London Stock Exchange (LSE) where the fees remained unchanged. BATS' venues faced competition not just from the LSE but also from other non-exchange venues such as Turquoise (TQ). Therefore, we also study changes in TQ's market quality and market share following the BATS' fee changes.

Our model predicts that a make fee reduction will have the opposite effect on market quality and market share to that of a take fee reduction. Therefore, the predicted effects on BXE market quality and market shares depend on whether traders are more sensitive to changes in make fees or in take fees. In particular, our model shows that the reduction in both the make fee and the take fee generates two opposite effects on traders' willingness to supply liquidity. The reduction of the rebate reduces the reward for supplying liquidity, whereas the reduction of the take fee increases the execution probability of limit orders. The rebate represents a more significant fraction of the spread for a liquid than for a less liquid stock. Hence, the rebate effect prevails for liquid stocks whereas the take fee effect prevails for less liquid stocks which generally have a wider spread.

Consistent with our theoretical predictions, we find that the effect of BXE's fee changes differs significantly in the cross-section. Specifically, the evidence is consistent with traders in large capitalization stocks being primarily focused on rebates whereas traders in small capitalization stocks being more focused on take fees. As a result, we find that the same fee changes are associated with a significant deterioration of market quality for large capitalization stocks while market quality and market shares significantly improve for small capitalization stocks.

In real markets, it is the relative fees that matter for traders' order selection and order routing decisions. Hence, even though CXE reduces its make fee, the new fee is still much more attractive relative to BXE which no longer offers rebates. Similarly, although CXE does not change its take fee, it is now competing against a fifty percent lower take fee on BXE. It follows that CXE's make fee and take fee both increase relative to BXE and our model again suggests that the consequences for market quality and market share depend on whether traders are more sensitive to changes in make fees or take fees. In addition, CXE's make fee falls relative to TQ's which gives limit order traders an incentive to route orders away from CXE to TQ resulting in lower CXE depth. Our empirical results suggest that the relative increase in the CXE take fee and/or the loss of limit orders to TQ are the most important driving forces. As a result, CXE market quality and market share deteriorate significantly following the BATS fee changes, and this is true both for large and small capitalization stocks.

Finally, TQ's make fee improves while its take fee deteriorates relative to BXE following BATS' fee changes and our model therefore suggests that the consequences for market quality and market share depend on the the sensitivity of traders to make fees compared to take fees. Moreover, as noted above, TQ may attract more limit orders from CXE. Our results again suggest that there are traders in large capitalization stocks who are more sensitive to the make fees while traders in small capitalization stocks are more sensitive to take fees. As a result, we find that TQ market quality and market shares improve for large capitalization stocks and deteriorate for small capitalization stocks following the BATS fee changes.

Our paper contributes to the empirical literature by taking intermarket competition into account when studying the effects of make-take fee changes empirically. We show that the simultaneous reduction in the make fee and take fee has a different effect for large capitalization stocks compared to small capitalization stocks. Our sample is drawn from a recent time period, which is important as market structure and the ecosystem of traders has changed significantly over time.[11]

The paper is organized as follows. In Section 2 we briefly review the existing literature and in Section 3 we present the theoretical model and discussion of our empirical predictions. We present our datasets and the methodology in Section 4. In Section 5 we discuss our empirical results,and in Section 6 we provide a series of robustness checks. Finally, in Section 7 we present our conclusions and the policy implications of our findings.

[11]We also study the introduction of fee schedules that depend on the value traded as in Malinova and Park (2015), but this analysis is relegated to Appendix 2.

2 Literature review

Theoretical models of make-take fees have primarily focused on whether the breakdown of the total fee charged by a venue into rebate and take fee matters for order flow composition, market quality, and welfare. Colliard and Foucault (2012) model a dealer market that competes with a limit order book with no frictions and a zero tick size to show that the breakdown does not affect the order flow composition, the trading rate, or welfare. Foucault et al. (2013) model of a limit order book with a positive tick size, populated by two distinct groups of traders – market makers and market takers – to show that the total fee breakdown matters. Brolley and Malinova (2017) model a dealer market with informed limit order traders to show that the breakdown of the total fee matters when investors pay a flat fee while liquidity providers incur take fees and receive rebates. Finally, Chao et al. (2017) model a 2-period limit order book with a tick size equal to the sum of the supports of all traders' personal evaluations to show that in equilibrium the optimal fee structure is either the maker-taker or -symmetrically- the taker-maker. They also conclude that a driving force behind the dispersion of fees across different trading platforms is the discrete tick size. More precisely, Chao et al. (2017) show that an exchange setting make and take fees simultaneously chooses the price of the execution service (make fee) and the quality of the execution service (take fee). This simultaneous choice creates an incentive for the owner - say - of two trading platforms like BATS Europe to engage in second-degree price discrimination and set different fee structures across the two trading platforms. While Chao et al. (2017) conclude that the owner of two trading venues may use fees to discriminate across different customers, they do not offer predictions for the effects of a change in fees on the market quality of the two competing venues.

To date, empirical work on make-take fees is relatively limited. Lutat (2010) studies the October 2008 introduction of a maker-taker pricing model on the Swiss exchange and find a decrease in depth but no significant effect on spreads. Malinova and Park (2015) study the 2005 switch by the Toronto Stock Exchange from a value-based to a volume based make-take fee schedule that was accompanied by an increase both in the rebate and the take fee, and they find that for the stocks that did not experience a change in total fee, quoted spread declined but cum-fee spreads (quoted spread plus twice the take fee) remained unaffected ostensibly supporting Colliard and Foucault (2012).[12] We instead find that a decrease in make and take fees is related to changes in both quoted and cum-fee spreads.[13] Skjeltorp, Sojli, and Tham (2018) using data from the Nasdaq OMX BX and exogenous changes in make-take fees and a technological shock to liquidity takers to show that cross-side liquidity externalities exist and

[12] An important caveat is that the Colliard and Foucault (2012) model is based on a protocol without a tick size, whereas the Toronto Stock Exchange (TSX) on which Malinova and Park (2015) base their empirical analysis is a standard limit order book with a tick size grid.

[13] Using Rule 605 data O'Donoghue (2015) finds that changes in the split of trading fees between liquidity suppliers and demanders affect order choice and thereby execution quality.

conclude that the reason is that an increase in market makers' monitoring benefits market takers as predicted by Foucault, Kadan, and Kandel (2013). The same experiment is studied by Black (2016) who documents that a simultaneous reduction in make and take fees results in lower market efficiency. Cardella, Hao and Kalcheva (2017) investigate 108 instances of fee changes for U.S. exchanges in 2008-2010 and find that an increase in take fees has a larger impact on trading activity than an increase in make fees. He, Jarnecic, and Liu (2015) study the entry of Chi-X in Europe, Australia, and Japan and find that Chi-X's market share is negatively related to total trading fees and latency, while positively related to liquidity relative to thelisting exchanges. Clapham et al (2017) study the Xetra Liquidity Provider Program at Deutsche Boerse which introduced liquidity rebates and find that the program results in higher liquidity, larger contribution to market-wide liquidity and a higher market share for the venue implementing the rebates, but that market-wide turnover and liquidity do not change. Anand et al (2018) study the 2012 introduction of maker-taker pricing in the NYSE Arca options market, and document that execution costs (including fees) for liquidity demanders decline and that the maker-taker pricing encourages market makers to improve quoted prices. Finally, Comerton-Forde, Gregoire, and Zhong (2018) and Lin, Swan, and Harris (2017) study the effects of the U.S. tick size pilot on venues with different maker-taker (and inverted) pricing models and document that an increase in the tick size results in redistribution of volume towards inverted fee venues.

3 Theoretical Background and Empirical Predictions

3.1 Model

We model two identical limit order books that we label primary market (Prim) and competing market (Comp) respectively. Each limit order book, be it Prim or Comp, has a grid of four prices, $P_i^j = \left\{S_2^j, S_1^j, B_1^j, B_2^j\right\}$, for $j = Prim, Comp$, two on the ask and two on the bid side of the book around the same asset value AV. Both trading platforms have a tick size equal to τ, so the ask prices are equal to $S_1^j = AV + \frac{1}{2}\tau$ and to $S_2^j = AV + \frac{3}{2}\tau$ respectively for the inside and outside quotes, and symmetrically the bid prices are equal to $B_1^j = AV - \frac{1}{2}\tau$ and to $B_2^j = AV - \frac{3}{2}\tau$. The trading game lasts three periods, $t_z = \{t_1, t_2, t_3\}$. Each risk-neutral trader is characterized by a private evaluation equal to $\gamma\, AV$, where γ is drawn from a normal distribution, $\gamma \sim N(\mu, \sigma^2)$, and lies within the interval $\gamma \in (\underline{\gamma}, \overline{\gamma})$, so that conditional on $\underline{\gamma} < \gamma < \overline{\gamma}$, γ has a truncated normal distribution where σ indicates the dispersion of traders' beliefs around the mean μ. Without loss of generality, we assume that $AV = \sigma = \mu = 1$ and that $\tau = 0.1$. Traders coming to the market with extreme values of γ are more eager to trade by taking liquidity, whereas traders arriving with γ values close to 1 are more patient and willing to supply liquidity. The larger the support, the higher is the probability that market participants have extreme evaluations. We will consider two scenarios, one with a large support, $\gamma \in (0.0, 2.0)$, in which the valuations of market participants are more dispersed relative to the asset value, and one with a smaller support, $\gamma \in (0.8, 1.2)$, in which the valuations of market participants are tighter around the asset value with less extreme valuations. Trade size is unitary.

When dealing with trading fees it is crucial to take into account the effects of competition across trading venues.[14] For this reason, we consider a market with two competing limit order books. In each period t_z, traders can choose to post a limit order ($LO^j_{t_z}(P^j_i)$) or a market order ($MO^j_{t_z}(P^{j,b}_i)$) either to the primary market or to the competing market.[15] The trader can alternatively choose not to trade (NT_{t_z}). However, because both the primary and the competing markets open empty, at t_1 traders will not be able to take liquidity via market orders. At t_2 traders can take or make liquidity via market or limit orders, and at t_3, which is the last period of the trading game, they will not choose limit orders as their execution probability is zero. Conditional on their personal valuation, γ, traders opt not to trade (NT_{t_z}) in any period t_z when the payoffs of the possible $LO_{t_z}(P^j_i)$ and $MO_{t_z}(P^{j,b}_i)$ are non-positive. Traders face trading fees. We label a fee imposed by the primary market (competing market) TF (tf) when it is a take fee, i.e., it affects market orders, and MF (mf) when it is a make fee, i.e., it affects limit orders. We assume that MF is a negative fee and therefore it is a rebate. For example, if the primary market opts for a maker-taker pricing structure, a market participant sending a market order to the primary market will have to pay a TF to the trading platform when it executes. Traders opting instead to post a limit order on the primary market will receive a rebate (MF) if the limit order is executed. So the make fee is a reward that traders receive when they supply liquidity to the limit order book, whereas the take fee is a charge traders have to pay when they take liquidity.

Both the primary and the competing market are governed by standard price and time priority rules. So if at time t_1 a trader posts, for example, a limit sell order to the primary market at the second level of the book, the next period a trader can undercut the resting limit order by posting a more aggressive limit sell order on the first level on either the primary or the competing limit order book. Furthermore, he can hit the limit order initially posted on the primary market with a market buy order, or he can post a limit buy order to the competing market at the second level of the book. He can finally decide not to trade. Table 1 reports the payoffs from the different orders that a trader can choose when arriving at the market at time t_z either in the primary or in the competing market. When choosing their order submission strategies, traders face a trade-off between non-execution costs and price opportunity costs. If they opt for a $MO^j_{t_z}(P^{j,b}_i)$, they get immediate execution at

[14] We thank Tito Bastianello for thorough discussions and suggestions on this aspect.

[15] We label the best ask and the best bid prices with the superscript "b".

the best ask price, $S_{t_z}^{j,b} = min\left\{S_{t_z,i}^{j}|l_{t_z,i}^{S^j} > 0\right\}$ if it is a buy order or at the best bid price, $B_{t_z}^{j,b} = max\left\{B_{t_z,i}^{j}|l_{t_z,i}^{B^j} > 0\right\}$, if it is a sell order, where $l_{t_z,i}^{S^j}$ ($l_{t_z,i}^{B^j}$) indicates the number of shares available at the i-th price level of the ask side (bid side) of the j-th market. If instead they choose a $LO_{t_z}^{j}(P_i^j)$, they face execution uncertainty but they will get a better price if the order executes. When the expected payoffs for an order routed either to the primary or to the competing limit order book are the same, we assume that the trader randomizes and routs the order with equal probability to both trading platforms.

[Insert Table 1 about here]

In equilibrium the trader will choose a $MO_{t_z}^{j}(P_i^{j,b})$ if the non-execution costs associated with the $LO_{t_z}^{j}(P_i^j)$ is higher than the price opportunity cost associated with the $MO_{t_z}^{j}(P_i^{j,b})$. Formally, at each period t_z, a trader will choose the order submission strategy ($ST_{t_z}^{*}$) that maximizes the expected payoff ($\pi_{t_z}^{e}$) conditional on his personal evaluation of the asset, $\gamma AV = \gamma$. The trader's expected payoff will be conditional on the state of the two limit order books, $lob_{t_z}^{j} = \left\{P_{t_z,i}^{j}, l_{t_z,i}^{P^j}\right\}$:

$$max_{ST_{t_z}^{*}} \pi_{t_z}^{e} \left\{MO_{t_z}^{j}(P_i^{j,b}),\, LO_{t_z}^{j}(P_i^{j}),\, NT_{t_z}(0) \mid \gamma,\, lob_{t_z}^{j}\right\} \qquad (1)$$

Following Colliard and Foucault (2012) as well as Chao et al. (2017), the model is solved by backward induction and conditional on the pricing grid and the support of trader evaluation, it has a closed form solution for each set of trading fees. We start from the end of the trading game (t_3) when traders rationally submit $MO_{t_3}^{j}(P_i^{j,b})$ but not $LO_{t_3}^{j}(P_i^{j})$, and solve the model for the equilibrium market buy and market sell orders. As the equilibrium probabilities of market buy and market sell orders at t_3 are the execution probabilities of $LO_{t_2}^{j}(P_i^{j})$ (to sell and to buy respectively) at t_2, the model can then be solved at t_2, and recursively at t_1.

All else equal, we solve the model under different sets of the make and the take fees in the primary market. This allows us to show how a change in trading fees in one market affects traders' strategies, and in turn the equilibrium order flows and the quality of the two markets. Limit orders in each period t and in each market j, $LO_{t_z}^{j}(P_i^{j})$, are computed as the weighted average of the probability of observing a limit order conditional on the different equilibrium states of the book, $lob_{t_z}^{j}$, where the weights are the probabilities of the different states of the book in period t_z : $E\left[Limit\,Orders_{t_z}^{j}|lob_{t_z}^{j}\right]$. $MO_{t_z}^{j}(P_i^{j,b})$ are computed in a similar way: $E\left[Market\,Orders_{t_z}^{j}|lob_{t_z}^{j}\right]$. We build measures of spread, depth at the best bid-offer and market share based on the equilibrium order submission strategies. In each period t_z and in each market j the spread, $Spread_{t_z}^{j}$, is computed as the weighted average of the probability of observing a particular inside spread conditional on the different equilibrium states of the book, $lob_{t_z}^j$, where -as before- the weights are the probabilities of the different states of the book in period $t_z: E\left[\left(S_i^{j,b} - B_i^{j,b}\right)|lob_{t_z}^j\right]$.[16] Depth at the best bid-offer, $BBODepth_{t_z}^j$ is computed in a similar way as the weighted average of the sum of the shares available at the best bid and ask prices: $E\left[\left(l_{t_z}^{S^{j,b}} + l_{t_z}^{B^{j,b}}\right)|lob_{t_z}^j\right]$. We then average $LO_{t_z}^j(P_i^{j,b})$, $Spread_{t_z}^j$ and $BBODepth_{t_z}^j$ over periods t_1 and t_2 to obtain LO^j, $Spread^j$ and $BBODepth^j$ respectively. Finally, we measure market share for the primary market, MS^{Prim}, as the average of market orders in the primary market over periods t_2 and t_3, divided by the sum of the average of market orders in the primary and in the competing market over the same periods: $\frac{(MO_{t_2}^{Prim}+MO_{t_3}^{Prim})/2}{(MO_{t_2}^{Prim}+MO_{t_3}^{Prim})/2+(MO_{t_2}^{Comp}+MO_{t_3}^{Comp})/2}$. We measure market share for the competing market in a similar way.

As we will discuss in Section 3.2, Table 2 shows the equilibrium values of order flows and market quality metrics for different sets of trading fees in the primary market, holding the fees in the competing market equal to zero, $mf = tf = 0.0$. Table 2 also reports results for both the case with a large support that we consider a less liquid market, and for the case with a small support that we consider a more liquid market. The set of trading fees used to build Table 2 aims to show the effects of an increase in the make fee and in the take fee separately, holding all the other fees constant. For this reason, we set the fees in the competing market equal to zero and only change one fee at the time in the primary market.

In Panel A we discuss the effects of a change in the make fee. However, with two identical limit order books, changing the make fee while keeping the take fee at zero would lead to an overall reduction rather than an increase in limit orders in the primary market.[17] The solution we adopt to avoid this unrealistic effect is to set the take fee in the primary market positive rather than equal to zero.[18] We could choose any positive TF provided that the MF is not smaller than the TF. Clearly, if we set the fees in the competing market such that they are realistically competitive, we could also choose a TF higher than the MF. We choose to pair the different values of the MF with TF=0.01 as this allows us to present results for a set of

[16] In our model liquidity supply is endogenous. When computing the spread, we assume that when the book is empty, at either the ask or the bid side, the maximum possible spread is five ticks.

[17] In period t_1 traders switch from limit orders posted at the outside quotes to limit orders posted at the inside quotes in response to the increased competition for the provision of liquidity generated by the increase in the rebate. Moreover, no traders choose to refrain from trade in period t_1 which means that at t_1 the probability to observe limit orders in the primary market is equal to 1. As a result, the book opens at t_2 with only two possible states on each side of the market. If the book opens with a limit order at the outside quote of the primary market, traders either take that liquidity or they undercut it by opting for a limit order at the inside quote. If instead the book opens with a limit order at the inside quote of the primary market, traders either take that liquidity or they post a limit order at the inside quotes but now in the competing market. In the latter case limit orders posted to the primary market decrease in period t_2. Traders do not get the rebate if their limit order in the competing venue executes, but they attract 50 % of all market orders because liquidity takers randomize between the two zero take fee markets at time t_3. The result is that the average (across periods and states of the book) limit orders posted to the primary market decreases.

[18] This way traders no longer randomize between the primary and the competing market in period t_3 and the overall effect of an increase in the rebate is an increase of liquidity supply in the primary market.

fees (MF=TF=0.01) that also appears in Figure 1 and which we discuss in the Appendix.

In Panel B we set the make fee equal to 0.05 in the primary market and change the take fee. This way, the primary market remains competitive even when we consider an increase in the take fee. If we hold all the other trading fees equal to zero and only consider a positive take fee in the primary market, the competing market would attract all the liquidity resulting in zero activity in the primary market. Clearly even this restriction could be relaxed if we added competitive fees in the competing market. Analogously, in Figure 1 we change the two fees symmetrically in the primary market and set the fees in the competing market equal to zero.

[Insert Table 2 and Figure 1 about here]

In Figure 1 the total fee, which is the sum of the MF and TF, is held constant at zero. In Panel C of Table 2 we build two experiments with a reduction in both the MF and the TF that lead to an increase in total fee, and in Figure 2 we show results from an example of a reduction in MF and TF that also leads to an increase in the total fee.

[Insert Figure 2 about here]

Appendix 1 shows how to solve the model for one set of trading fees, i.e., $MF = TF = 0.01$ and $mf = tf = 0.0$. It is then straightforward to obtain the results for the other chosen sets of fees.

3.2 Empirical Predictions

In this section we discuss the model's predictions, and in particular what we expect to happen to the liquidity of both the primary market and the competing market - measured by spread, depth at the best bid-offer (BBOdepth), and market share - when the primary market changes either the MF or the TF, or when the primary market changes both the MF and the TF. Table 2 shows the equilibrium order submission strategies and the metrics of market quality (column 1) that characterize both the primary and the competing market under two different regimes of fees. Panel A shows how order flows and market quality change following a change in the make fee (MF) while holding the take fee (TF) constant in the primary market, and Panel B shows the effects of a change in the take fee (TF) this time holding the make fee (MF) constant. Columns 7 and 13 report the percentage changes of the different metrics between the lowest and the highest fee. As our empirical analysis investigates the effects of a reduction in trading fees, we discuss a reduction rather than an increase in the trading fees.

Panel A shows that when the rebate (MF) decreases in the primary market, liquidity supply moves from the primary to the competing venue as limit orders migrate away from the primary to the competing market. Therefore liquidity, measured by spread and BBOdepth, deteriorates in the primary market and improves in the competing market. The effect of the order migration is also evident by looking at the market share which substantially increases in the competing market to the detriment of the primary market. Note that the effect of a decrease in rebate in the primary market is much stronger for liquid than for illiquid stocks as in liquid stocks the proportion of traders willing to supply liquidity is larger. These results lead to our first empirical prediction.

Prediction 1.

If a market decreases (increases) its make fee relative to a competing venue, orders migrate out of (into) the market, causing market quality to deteriorate (improve) and market share to decrease (increase).

We now consider a reduction in the take fee. When the primary market becomes cheaper than the competing venue, traders willing to supply liquidity anticipate that more market orders will hit their limit orders if they are posted in the cheaper venue and they migrate to the primary market where the execution probability is higher. Panel B shows that when the primary market becomes cheaper due to the reduction in the take fee, both limit and market orders migrate into the primary market. The migration of orders away from the competing market to the primary market generates an improvement of primary-market liquidity, measured by spread and BBOdepth, and a deterioration of liquidity in the competing market. The stronger effects for liquid stocks as opposed to illiquid stocks is still evident but somewhat muted as we are now dealing with a take fee which directly affects market orders rather than limit orders. This leads to our second empirical prediction.

Prediction 2.

If a market decreases (increases) its take fee relative to a competing venue, orders will flow into (out of) the market, causing market quality to improve (deteriorate) and market share to increase (decrease).

We now turn our attention to studying the effects of a decrease in both the make and the take fee (MF&TF). Figure 1 presents results for a symmetric change of the same make fee and take fee that result in the total fee being constant, and shows that the effects differ for liquid compared to illiquid stocks. Following a reduction of both the MF and the TF, traders face a trade-off when choosing whether to supply or to demand liquidity. The reduction of the rebate (MF) curtails the monetary incentive to offer liquidity thus directly decreasing traders' willingness to post limit orders. The reduction of the TF makes market orders cheaper thus increasing the execution probability of limit orders and consequently traders' incentive to choose limit orders. Hence the trade-off: if the rebate effect prevails, liquidity supply increases and market quality improves; if instead the TF effect prevails, liquidity supply decreases and market quality deteriorates. When the support of traders' personal evaluations is small and consequently the willingness of traders to supply liquidity is high (liquid stocks), the effects of the reduction in the rebate prevails and limit orders move away from the primary market to the competing venue causing a deterioration of both spread and BBOdepth in the primary market. At the same time, the reduction of the take fee makes the primary market cheaper and explains why market share increases in the primary market and decreases in the competing market. When instead the support of traders' evaluations is large and their willingness to take liquidity is stronger (illiquid stocks) the effects of the reduction in the take fee prevails and the increased execution probability of limit orders generates a migration of limit orders from the competing to the primary market. The migration of orders improves both spread and BBOdepth in the primary market and generates a deterioration of spread in the competing market. These results lead to our third empirical prediction.

Prediction 3.

If, all else equal, a competing market with the same take and make fees decreases (increases) the fees symmetrically, the effect on market quality and market share depends on the composition of traders that populates the markets. If rebate seeking traders are prevalent, the effects of the make fee decrease will prevail, market quality will deteriorate (improve) and market share will increase (decrease). If take fee sensitive traders are prevalent, the effects of the take fee decrease will prevail with the consequence that market quality will improve (deteriorate) and market share will increase (decrease).

Note that our results are consistent with the general view among market practitioners that HFTs are more sensitive to rebate changes for liquid stocks than for illiquid stocks as their relative gain from supplying liquidity (the spread) is substantially smaller for liquid stocks. Thus a further cut in revenues via a reduction in the rebate is a greater incentive to leave the market. Also note that when both the MF and the TF decrease in the primary market, independently of the liquidity of the book, the market share of the primary market increases; the reason being that when –all else equal– the market becomes cheaper, it attracts more market orders.[19]

Finally, we study the effects of an asymmetric change in the make (MF) and the take (TF) fees that leads to a change in the total fee. The results reported in Table 2, Panel A and Panel B, can be used to build experiments investigating what are the effects on market quality and market share when the MF and the TF change in different proportions – i.e. when the total fee changes. We can see that the effects on market quality and market share depend on the initial level of the fees, on the absolute variations of each fee and on the type of investors populating

[19] We can see the exact mechanism of the increase in market share if we consider one of the branches of the trading game discussed in the example reported in Tables A3, A2, A1 in Appendix 1 for the set of fees: MF=TF=0.01 and mf=tf=0.0. At t_1 a $LO_{t_1}(S_2^{Comp})$ is posted on the competing market; at t_2 investors undercut the existing limit order at the outside quote of the competing market by selling at the inside quote on the primary market, $LO_{t_2}(S_2^{Prim})$; and at t_3 investors hit the exiting liquidity at the inside quote of the primary market by sending a market order to buy, $MO_{t_3}(S_2^{Prim})$. It is precisely the probability to observe the latter that increases when both the MF and the TF decrease.

the markets. In Table 2, Panel C we report results for an asymmetric reduction in two sets of MF and TF. Experiment I shows the effects of an asymmetric reduction in fees that leads to an increase in the total fee by respectively 0.01 (case a) and 0.02 (case b); in this experiment we hold the change in the MF equal to -0.03 and achieve a different increase in the total fee respectively by reducing the TF by -0.02 (case I.a) and TF by -0.01 (case I.b). Experiment II shows the same increase in the total fee (0.01 and 0.02) as Experiment I for cases a and b respectively, but achieved by considering a greater change (in absolute value) of both the MF (-0.04 for both cases a and b) and the TF (-0.03 for case II.a and -0.02 for case II.b).

The results from the experiments reported in Panel C show that what matters when considering an asymmetric change in fees is not the change in the total fee but rather the initial level of the fees, their absolute variation and the type of investors that populate the market. Experiments I and II report results that lead to the same increase in total fees (i.e., I.a vs II.a, or I.b vs II.b) but have different effects on market quality. They show that a reduction in both fees lead, for example, to a deterioration of spread for liquid stocks, but in Experiment II the effects are stronger. Moving from case *a* to case *b* in both Experiments we hold the negative change in MF constant and consider a smaller reduction in the absolute value of the TF, thus resulting in a higher level of TF in case *b* than in case *a*. A higher TF has a dual effect on spread. On the one hand it directly reduces the incentive for traders to take liquidity thus preserving the spread, and on the other hand it indirectly reduces the execution probability of limit orders thus deteriorating both liquidity supply and spread. For liquid stocks the latter effect always prevails and the equilibrium spread increases. The reason why in Experiment I the effect on spread is stronger than in Experiment II, despite the exact same increase in total fee, is that in Experiment I the reduction of MF is smaller than in Experiment II (-0.03 as opposed to -0.04) and therefore in equilibrium the proportion of limit orders is higher thus enhancing the positive effect on spread that the increased TF may have via the reduction of their execution probability. A similar argument holds for the other metrics of market quality. These results lead to our final Prediction 4.

Prediction 4.

All else equal, if the make and the take fees vary asymmetrically so that the total fee changes, the effects on market quality and on market share depend both on the initial level of the fees, and on the absolute variation of each fee, and on the type of investors that populate the market. The same change in the total fee achieved via different changes in MF and TF may therefore lead to different effects on market quality and market share.

In our empirical experiment we study the effects of a reduction of the trading fees that leads to an increase of the total fee. Prediction 4 suggests that the final results on market quality and market share may depend on the market conditions and therefore may not be unique. To illustrate, consider Figure 2 which graphs the results from an Experiment that consists in a reduction of both the MF and the TF taken from Table 2, that are consistent with those presented in Figure 1 and discussed for Prediction 3 except for the market share of liquid stocks. Figure 2 shows that a reduction in both the MF and the TF that results in an increase in the total fee (MF changes from 0.05 to 0.02 and TF changes from 0.03 to 0.01) has a negative effect on the market share of the liquid stocks rather than a positive effect as shown in Figure 1. The reason is that when the MF decreases more than the TF, the direct negative effects on limit orders that the reduction of the MF generates overwhelms the positive effects on market orders that the reduction of the TF produces so that volume (hence market share), which is the product of the probability to observe limit orders times the probability to observe market orders that execute those limit orders, decreases.

Our results for a market with a competing venue are new in the literature and show how important the effects of competition are when studying trading fees in a market with discrete prices. Colliard and Foucault (2012) have competition from a crossing network but they do not have frictions (no tick size). This means that in their model, following a change in fees, traders adjust their strategies and the cum-fee spread does not change. Foucault et al. (2013) do have a tick size so that the breakdown between make and take fees affects the spread; however, they do not have a competing venue and therefore they cannot show the effects that a migration of orders following a change in trading fees has on the quality of the limit order book.

4 Data Description and Methodology

4.1 Market Structure and Intermarket Competition

We study the January 1, 2013, changes in BATS make-take fees. During our sample period, November 2012 - February 2013, BATS operated two European lit venues, BXE and CXE, and each platform featured a continuous order book executing orders based on price, display, and time priority, and both offered very similar maker-taker pricing at the end of 2012. Table 3 illustrates the trading fee schedules in basis points (bps) that apply for LSE listed firms in each venue in our sample as of December, 2012. It shows that the take fee was 0.28 bps (0.30 bps) and the rebate was 0.18 bps (0.20 bps) on BXE (CXE).[20]

[Insert Table 3 about here]

BXE and CXE in each market faced competition from the exchange where firms are listed. The European listing exchanges all operate transparent, continuous order books, executing orders based on price, display, and time priority. LSE charged trading fees based on the

[20]Trading fees for other listing exchanges in our Pan-European sample are similar to those used by the LSE. The MTF trading fees are the same for all European markets with the exception of country-specific short promotions that do not conflict with our sampling windows.

value-traded using a scale ranging from 0.45 bps to 0.20 bps for orders beyond £10bn of value traded (Table 3).[21] Value-tiers are typically determined based on monthly value traded, and rebates are distributed and fees collected ex post on a monthly basis. Furthermore, BATS venues also faced competition from the transparent MTF Turquoise (TQ) which also operated a continuous order book executing orders based on price, display, and time priority.[22] TQ charged takers 0.30 bps and used a value-based maker fee ranging from -0.14 bps to -0.28 bps for monthly value traded above €2.5bn.

Several dark venues were also actively trading European stocks during our sample period, including: two venues operated by BATS - BXE-Dark and CXE-Dark - both operated as dark midpoint order books; a venue operated by the LSE - TQ-Dark - a dark midpoint order book with both continuous and uncross trading which executed orders based on size followed by time priority; and a venue operated by the broker UBS - UBS-MTF which operates as a continuous midpoint order book with price followed by time priority.[23] BXE-Dark charged 0.15 bps for executed orders, while CXE-Dark charged 0.30 bps for executed Immediate or Cancel (IOC) orders and 0.15 bps for executed Non IOC orders. TQ-Dark charged 0.30 bps for executed orders. The UBS-MTF charged 0.10 bps for executed orders.

To illustrate the degree of intermarket competition in our sample of stocks, we manually collect daily data from Fidessa (Fragulator) on share volume reported by each venue, and use it to compute the distribution of market shares across venues based on our sample of stocks. Figure 3, Panels A and B (column 1) report the distribution of market share across our covered venues for our sample of LSE and Pan-European samples, respectively, for November and December, 2012.[24] Figure 3, Panel A shows that LSE trades (continuous and auction) represent 67.0% of share volume, while lit MTFs capture 27.8%, and dark MTFs capture 5.2% of share volume for UK stocks. BATS lit venues' market share is 21.6% and BATS overall market share is 24.5%. Figure 3, Panel B shows a similar distribution of market share across the covered venues for our Pan-European sample. As the figure shows, listing exchanges trades represent 67.1%, whereas lit MTFs capture 29.5%, and dark MTFs capture 3.37% of total volume.

[Insert Figure 3 about here]

[21] The LSE briefly used maker-taker pricing in 2009.

[22] TQ was originally launched by a consortium of investment banks on August 15, 2008, but was acquired by the LSE on December 21, 2009. See Gresse (2017) for a discussion of the fragmentation of European equity trading.

[23] BXE Dark, CXE Dark, and TQ Dark all use the midpoint from the primary market as their reference price.

[24] We exclude off-market trades when we calculate market share, which represented 56.5% of share volume for LSE listed firms during November and December 2012, The percentage of off-market trades remained constant across the period the fee changing events (2013, 2014 and 2015) under investigation; The off-market trades in February and March 2015 represented 56.3% of share volume for LSE listed firms. We find similar results for the Pan-European sample as well.

4.2 Data and Sample

We rely on two universes of stocks: a LSE and a Pan-European sample, each consisting of 120 stocks, to study the effect of BATS' January 2013 fee changes on market share and market quality.[25] The LSE sample is constructed using the following stratification methodology. We begin with a sample of all publicly traded companies listed on the LSE that are also traded on either BXE or CXE (using information provided on the BATS website). The reason we screen on existing BATS trading activity is that we cannot measure changes in market quality and market share at the venue-level unless the stock was traded on BATS both before and after the fee change. For these firms we acquire information on daily average market capitalization and daily price for the month of January 2012 using COMPUSTAT Global and Bloomberg. This initial sample consists of 355 firms. We then only focus on firms where market capitalization is greater than £500m in order to have sufficient liquidity when we calculate our measures of market quality. From this set of 258 firms, we sample 12 firms (with 6 firms above the median price and six below) within each market capitalization decile and end up with a representative final sample of 120 LSE firms that also traded on BATS.

In a similar manner, our Pan-European sample was constructed from the universe of publicly traded companies in Europe that are also traded on either BXE or CXE. We again collect information on market capitalization and price (from COMPUSTAT Global and Bloomberg) for January 2012. This initial European sample consists of 949 firms. Furthermore, we impose a market capitalization screen of €500m. We group stocks according to their primary market and sample 120 firms so as to match each country's frequency of firms traded in the January 2012 population of firms. Within each country we use stratified sampling with respect to market capitalization and price, similarly to the LSE sample. Our final sample for the January 2013 event covers 13 listing exchanges with the following distribution of firms: Amsterdam (5 firms), Brussels (2 firms), Copenhagen (3 firms), Frankfurt (10 firms), Helsinki (8 firms), Lisbon (3 firms), London (45 firms), Madrid (4 firms), Milan (5 firms), Oslo (4 firms), Paris (15 firms), Zurich (4 firms), and Stockholm (12 firms).

For each of our sample stock-venue combinations, we calculate our daily market quality and volume measures (to compute market shares) using Thompson Reuters Tick History (TRTH) cash equities market data. The data includes all intraday best bid and ask prices and associated depth, as well as all trades (price and size) for each covered venue (exchanges and transparent MTFs), time-stamped to the microsecond. We also use TRTH end-of-day data to obtain volume, high, low and closing prices.

[25] We follow the same sampling procedure to create samples around maker-taker pricing changes in 2014 and 2015 respectively. These are discussed in Appendix 2.

4.3 Descriptive Statistics

Our model speaks to the effect of a change in maker-taker fees on market quality at the venue level. Therefore, we calculate market quality measures both for the venues that are changing fees, BXE and CXE, and for the competing venues, the listing exchange and TQ. We calculate five different measures of market quality for each universe-venue combination as follows: Volume is the daily number of shares (in 000s) traded using the end-of-day files from TRTH; Depth is the daily average of the intraday quoted BBO depth in shares at the ask-side and the bid-side of each quote respectively; Spread is the time-weighted average of the intraday difference between the ask price and the bid price of each quote in units of currency (£ or €); %Spread is the time-weighted average of the intraday ask price minus the bid price of each quote divided by the midquote (average of the ask and bid prices); Volatility is the difference between the high and low trading price each trading day (using the end-of-day files from TRTH) divided by the high price.

Table 4 reports summary statistics across stocks based on average daily values for each market quality measure at the listing exchange during December 2012 for both the LSE (Panel A) and Pan-European samples (Panel B). We also report summary statistics for the distribution of market capitalization in millions as well as price levels (£ for Panel A and € for Panel B, respectively). For reference, the average December 2012 exchange rate was £0.813/€. We report summary statistics for the overall sample (Overall) and for the subsamples of the highest (Large) and lowest (Small) market capitalization terciles.

[Insert Table 4 about here]

As can be seen in Table 4, Panel A, the average (median) market capitalization of our LSE sample firms is £7.62bn (£1.68bn) and the stratified sampling generates a wide distribution of firms along the size dimension (interquartile range is £3.36bn). Similarly, the average (median) stock price is £6.91 (£4.12) and the distribution across stocks in terms of price is significant (interquartile range is £7.56). In terms of market quality measures for our LSE sample stocks, the average (median) share volume is 4.5mn (0.93mn), depth 7,421 (3,172) shares, spread 1.667 (0.889) pence, %spread 0.228% (0.146%), and volatility is 1.886% (1.575%). Hence, our sampling methodology ensures that we have a significant dispersion in market quality measures across firms. As expected, size and price are higher and market quality better for large than for small firms.

Panel B of Table 4 illustrates that the Pan-European sampling methodology also generates a significant distribution across firms in terms of size, price, and market quality. The average market capitalization is slightly larger for the Pan-European sample (€12,870*£0.813/€ = £10,463mn) compared to the LSE sample, but the average stock price is considerably higher

(€24.52*£0.813/€ = £19.93). Given the much higher average stock price, it is not surprising that average depth is smaller for the Pan-European sample (5,108 shares) than for the LSE sample. Note also that the average %spread for the Pan-European sample (0.137%) is 40 percent lower than the LSE sample %spread (0.228%).

We compare market quality measures for each venue, BXE, CXE, and TQ, to the listing exchange for each sample and subsamples by size in Figure 4. For each venue, we report the average market quality measure for the pre-event period. Filled bars indicate that a venue mean is significantly different from the listing exchange mean based on a simple differences in group means test.[26] As we already highlighted in Section 4.1, the listing exchange is the dominant venue in terms of share volume both for LSE stocks (Panel A) and Pan-European stocks (Panel B), and this is true both overall, and for large and small stocks. CXE captures the second largest fraction of share of volume both for LSE and Pan-European stocks overall, and its share of average volume is higher for large than for small stocks. By comparison, both TQ and BXE are smaller players in terms of market share.

The distribution of average depth is also skewed towards the listing exchange for both universes, but much less so than share volume. For LSE stocks, MTFs depth relative to the listing exchange depth is higher for large stocks than for small stocks. The situation is the opposite for Pan-European stocks; MTF depth relative to the depth on the listing exchange is higher for small than for large stocks.

[Insert Figure 4 about here]

By comparison, the differences in average relative spreads across venues trading LSE stocks is smaller. Quoted relative spreads for both universes are on average lowest on the listing exchanges, followed by CXE and TQ, while BXE has the widest relative quoted spreads. For large LSE stocks, the MTFs are much more competitive relative to the listing exchange. By contrast, for small LSE stocks, the MTFs all have at least fifty percent wider spreads than the listing exchange. For large Pan-European stocks MTF spreads are consistently wider than the spreads on the listing exchange. The situation is even worse for small Pan-European stocks where MTF spreads are more than double the spread on the listing exchange.

Finally, the differences in volatility measured as (high-low)/high for each venue for each universe and subsample. Volatility is significantly lower on the MTFs compared to the listing exchange for LSE and Pan-European stocks overall. Volatility is also more muted on the MTFs for small than for large stocks for both universes.

[26]Based on pair-wise t-tests, all differences in Figure 4 are statistically significant.

4.4 Methodology

In order to examine whether the fee changes have a significant effect on market quality and market share for BATS' and its competitors, we conduct an event study using an event window of two months centered on the fee-change event. We face the usual trade-off when selecting the event window. Using a longer time series would enable us to more precisely measure variables pre- and post-event and also capture longer term effects of the pricing changes. However, a narrower window would allow us to minimize the potential effects of confounding factors.[27]

We face a challenge when conducting cross-market tests for changes in market quality and market shares because stocks in the Pan-European sample trade in different currencies. It is tempting to simply convert all prices into a common currency. However, doing so would inevitably add more noise to our estimates of trading costs. Moreover, stock price levels are very different across markets, and this is true even after correcting for the exchange rate. We deal with the cross-sectional heterogeneity arising from currencies and different nominal price levels by standardizing our variables as follows. We divide venue-stock-day volume by total daily volume, depth by average depth, and quoted spread by average quoted spread where the total and averages are taken over all four venues (BXE, CXE, TQ, and listing exchange) for that stock-day. For ease of exposition, we will call these measures relative volume, relative depth, and relative spread respectively.

We start by collapsing the panel into a time-series of average daily standardized market quality measures. Specifically, for each universe, we compute equal-weighted daily means across stocks for each venue both for the overall sample (120 firms) and for subsamples based on size terciles. Firms are classified into size terciles based on market capitalization of the firms for each universe one year before the first month of the event (i.e., January 2012).[28] The result is four time-series (overall, large, medium, and small) of roughly fourty-two daily observations (trading days) for each venue (BXE, CXE, TQ and listing exchange), and universe (LSE and Pan-European).[29] As a first pass, we evaluate the change in market share, relative depth, and relative spread for each universe, venue, and sample following the fee changes based on a time-series regression:

$$y_t^V = \mu + \delta \cdot Event_t + \varepsilon_t \tag{2}$$

where y_t^V is the standardized measure of market quality for venue V and $Event_t$ is a dummy

[27]Our results are qualitatively robust for longer windows (four months before and four months after the fee changes), but the statistical significance is, as expected, lower.

[28]Similarly, in unreported results we examine subsamples based on the median price level (low and high priced stocks).

[29]We exclude the week of Christmas in December, and instead add the last week of November for the 2013 and 2015 events. We winsorize extreme values of the dependent variable at the 1% level for the overall samples, to reduce the influence of extreme observations.

variable that takes on a value of one for days in the post-event period and zero otherwise. Standard errors are computed using the Newey-West correction for autocorrelation with ten lags.

Recall from the model that the fee changes affect traders' order choice and order routing decisions, and this in equilibrium produces market outcomes that we can measure such as venue market share, depth and spreads. In our empirical setting, all orders routed to a particular venue experience the same fee change so we do not have any within-venue variation across stocks in terms of the fees to exploit for the creation of a control sample (e.g., matching stocks on pre-event characteristics). By contrast, we do have variation in terms of fees across venues trading the same stocks - e.g., BATS changes its fees but fees on the listing exchange and other MTFs remain unchanged. It is therefore tempting to use market quality on competing platforms as a control sample. However, our model shows that traders' response to fee changes affects not just their order choice on the venue which changes its fees, but also affects order inflow from, and order outflow to, competing venues. As a result, market quality on competing venues are likely to be indirectly affected by the BATS fee changes which violates the exclusion restriction for difference in difference analysis (Boehmer, Jones, and Zhang (2017)).

Therefore, we resort to a regression framework where we use relative market quality on the listing exchange as an explanatory variable in an attempt to control for the variation in relative market quality for the venue experiencing fee changes that can be explained by the day-to-day competitive interaction with the listing exchange. Specifically, to evaluate if the changes in trading fees are associated with changes in standardized venue market quality, we run the following time-series regressions:

$$y_t^V = \mu + \beta \cdot y_t^{LE} + \delta \cdot Event_t + \gamma \cdot VIX_t + \eta_t \tag{3}$$

where y_t^V is the standardized measure of market quality for venue V , y_t^{LE} is the standardized measure of market quality for the listing exchange, t denotes time in days, and $Event_t$ is a dummy variable that takes on a value of one for days in the post-event period and zero otherwise. We include the daily FTSE 100 volatility index (VIX) in an attempt to control for marketwide effects. Standard errors are computed using the Newey-West correction for autocorrelation with ten lags. The estimated coefficient $\hat{\delta}$ measures the change in market quality associated with the change in trading fees that cannot be explained by the day-to-day variation in standardized market quality for the listing exchange captured by $\hat{\beta}$. Note that the latter coefficient absorbs any indirect effect caused by spillover from the listing exchange's response to the fee changes in venue V.

Furthermore, we estimate a panel version of the relationship between relative market quality and the fee changes controlling for relative market quality on the listing exchange to evaluate the robustness of our results. Specifically, we estimate the following regressions:

$$y^{V}_{i,t} = \mu_i + \beta \cdot y^{LE}_{i,t} + \delta \cdot Event_t + \gamma \cdot VIX_t + \eta_{i,t} \tag{4}$$

where the subscript i indicates an individual stock. For this analysis, we account for firm fixed effects and cluster standard errors by firm. We acknowledge that we cannot claim causality using our regression analysis. Nevertheless, we believe that we can learn from comparing the empirical results to our model predictions to better understand the changes in market outcomes that we observe following changes of trading fees in a market with significant intermarket competition.

5 Empirical Results

In this section, we estimate the changes in volume and market quality on CXE, BXE, and TQ associated with the BATS fee changes for each universe of stocks, and sub-sample and compare these to our model predictions. We start by discussing the model predictions and the results based on the time-series event-study methodology for each MTF: BXE, CXE, and TQ. We then report the results using panel regressions in a separate subsection to confirm that our results are robust. Finally, we estimate changes in revenues associated with the BATS fee changes.

5.1 Fee Change

In late 2012, BATS announced a plan to change its pricing effective January 1, 2013, of its two transparent trading venues. Specifically, as reported in the second sets of columns in Table 3, BATS reduced the CXE liquidity rebate from 0.20 bps to 0.15 bps while leaving the take fee at 0.30 bps. Thus, CXE became less attractive for liquidity providers seeking to harvest rebates. Furthermore, BATS eliminated the liquidity rebate from its BXE venue completely (from 0.18bps to zero), and reduced the take fee from 0.28 bps to 0.15 bps. This move clearly made BXE unattractive for traders seeking to harvest rebates, but at the same time making the venue more attractive to traders relying more heavily on marketable orders. Although TQ did not change its fees, it became less attractive for liquidity takers relative to BXE, and it became more attractive for liquidity suppliers both relative to BXE and CXE.

Finally, note that the total fee became 0.15 bps for both BATS' platforms after the pricing change, an increase of 50% (from 0.10 bps). This means that traders using mixed limit and market order strategies all else equal would find it more expensive to trade on BATS' venues after the fee changes and may have decided to route their orders elsewhere.

5.2 BXE

The January 2013 BXE fee changes were significant: the rebates were completely eliminated and the take fee cut in half. Both the BXE make and take fees are 0.13 bps lower than the corresponding make and take fee on CXE following the fee change, and the total fee increase by 0.05 bps in both venues. The BXE fee changes also resulted in a 0.18 bps decrease in the rebate, a 0.13 bps reduction in the take fee, and an increase in the total fee of 0.05 bps relative to TQ, and therefore amplify the effects on BXE market quality and market share. Referring to Predictions 1-4 (in Section 3) and our Figure 2, the effect of a simultaneous reduction of rebates and take fees will depend on which effect dominates, the outflow of orders to competing venues due to the rebate reduction or the inflow of orders from competing venues due to the take fee reduction. If the effect of the take fee reduction dominates, we should see an improvement in market quality and an increase in market share. By contrast, if the effect of the rebate reduction dominates we should see a deterioration of market quality and a decrease in market share. Hence, the overall effect on market quality and volume will depend on the sensitivity of traders to the rebate elimination (spreads widen, depth and volume decline) relative to the take-fee reduction (spreads narrow, depth and volume increase).

We first examine the changes in relative volume, depth, and spread based on a simple collapsed time-series regression with an Event dummy that takes on a value of one following the fee change and 0 otherwise. The results in Table 5, Panel A show that for the overall LSE sample, BXE relative volume increases significantly by 0.80%, relative depth decreases significantly by 2.41%, while relative spreads do not change significantly. For large stocks, BXE market quality clearly deteriorates (depth declines by 4.92% and spreads widen by 3.74%) while relative volume does not change significantly. By contrast, for small stocks, BXE market quality improves significantly (spreads narrow by 7.57%) while volume increases by 1.40%. This suggests that there are significant cross-sectional differences in terms of traders' sensitivities to make fees versus take fees. We explore this conjecture further in our multivariate time-series and panel regressions below.

[Insert Table 5 about here]

Table 6 reports the results from our collapsed time-series regressions of relative volume, depth, and spread respectively on a dummy that takes on a value of one following the fee change and 0 otherwise. We also include VIX to control for market-wide changes that may affect market shares and relative market quality independently of the fee changes, and the listing exchange relative volume, relative depth, and relative spread respectively to control for the day-to-day competitive interaction between the MTFs and the listing market.

[Insert Table 6 about here]

The coefficients on our Event dummy reported in Table 6, Panel A show that for LSE stocks overall BXE relative volume increases significantly by 0.49%, while relative depth declines significantly by 2.25%, and relative spreads narrow albeit not quite significantly following BXE's fee changes. To understand these results, it is helpful to study the corresponding coefficients for our LSE subsamples by market capitalization. For large stocks, relative depth declines by 5.31% while relative spreads widen by 2.97% and relative volume decreases significantly by 0.27%. For small stocks relative depth increases albeit insignificantly by 1.47%, relative spread narrows significantly by 6.58%, and volume increases significantly by 1.45%,. Hence, the depth, spread, and market share outcomes are what our model predicts will happen if BXE traders in large capitalization stocks are primarily focused on the rebate reduction while BXE traders in small capitalization stocks are primarily focused on the take fee reduction (Figure 2). Hence, the results we observe for LSE stocks overall, mask significant cross-sectional differences between large stocks where the make fee reduction appears to be the primary concern for traders and small stocks for which the take fee reduction appears to be the primary concern.

5.3 CXE

In 2013 the CXE rebate was reduced by 0.05 bps, keeping the take fee constant. As mentioned above, this implies that CXE's rebate and take fee increase by 0.13 bps relative to the BXE, while the total fee increases by 0.05 bps in both venues. At the same time, CXE's rebate decreases by 0.05 bps and its total fee increases by 0.05 bps relative to TQ, which dampens the effect of the rebate increase on CXE market quality and market share.

Referring again to Predictions 1-4 (in Section 3) and our Figure 2, the effect of a simultaneous increase of rebates and take fees relative to BXE will depend on which effect dominates, the inflow of orders from competing venues due to the rebate increase or the outflow of orders to competing venues due to the take fee increase. If the effect of the take fee increase dominates, we should see deterioration in market quality and a decrease in market share. By contrast, if the effect of the rebate increase dominates we should see an improvement of market quality and an increase in market share. Hence, as above, the overall effect on market quality and volume will depend on the sensitivity of traders to the rebate increase (spreads narrow, depth and volume increase) relative to the take-fee increase (spreads widen, depth and volume decrease).

Consider first the results based on the simple collapsed time-series regression of relative volume, depth, and spreads respectively on an Event dummy reported in Table 5, Panel A. Overall, we find no change in CXE relative volume, while relative depth declines by 1.65%

and relative spreads widen significantly by 2.59%. Broken down by sub-samples, the results show that for large stocks CXE relative depth declines significantly by 3.55% without a significant change in relative spreads or volume while for small stocks CXE relative spreads widen significantly by 5.59% and volume declines significantly by 1.00%.

Table 6, Panel B reports the estimated coefficients on the Event dummy after controlling for the corresponding variables for the listing exchange and VIX. CXE relative volume decreases significantly by 0.77%, relative depth declines significantly by 1.61%, and relative spread increases significantly by 2.46% for the overall LSE sample. This is what our model suggests that we should expect to see if the relative increase in the CXE take fee and/or the loss of attractiveness of the CXE make fee relative to TQ was the most important driving forces for changes in CXE market quality and market share. Furthermore, the results are similar both for large and small LSE stocks, albeit with insignificant coefficients for relative spreads for large capitalization stocks and for relative depth for small capitalization stocks.

Hence, although CXE did not change its take fee in 2013, its take fee became relatively less attractive due to the simultaneous cut of the BXE take fee. As a result, CXE experienced an outflow of orders to BXE. Furthermore, the CXE rebate reduction meant that limit orders that were previously routed to the CXE were now to a larger extent redirected to TQ.

5.4 Turquoise

As we already discussed, the BATS fee changes also affected the relative attractiveness of TQ. Specifically, TQ's rebate schedule became more attractive relative to the rebates offered by BXE and CXE while its take-fee became less attractive than the one offered by BXE. We can use our model to predict what should happen to market quality and market share on TQ following BATS' fee changes. The relative increase in rebates should cause orders to migrate from BXE and CXE to TQ, and we expect spreads to decline, and depth and volume to increase. At the same time, TQ take fee became relatively less attractive and this should cause orders to be routed away from TQ, resulting in wider spreads, narrower depth and lower volume.

Overall, Table 5 Panel A shows that TQ relative volume and depth increased significantly by 2.19% and 3.69% respectively while there was no significant change in relative spreads following the BATS fee changes. Furthermore, TQ relative spreads do not change significantly for either subsample by market capitalization. However, TQ relative volume and depth increases significantly for large stocks by 3.88% and 4.47% respectively, while TQ relative depth declines significantly by 7.90% and volume remained unchanged for small stocks.

Table 6, Panel C reports the Event dummy estimated coefficients in a multivariate framework (controlling for the corresponding variables for the listing exchange and VIX). The results show that TQ relative volume and relative depth increased significantly by 0.24% and 3.80%

respectively while relative spreads declined albeit not significantly for LSE stocks overall following the BATS fee changes. Hence, overall the effect of the relatively more attractive TQ make-fee schedule dominated the outflow of orders due to the less attractive take fee. Note also that there are significant differences across sub-samples. As was the case for BXE, we clearly see that the effect of the relatively more attractive TQ make-fee dominates for large stocks (spreads decline significantly and depth and volume increase significantly) while the relatively less attractive TQ take-fee dominates for small stocks (spreads increase and depth and volume decline significantly).

5.5 Panel Regressions

We repeat the analysis of the effects of the BATS fee changes on relative volume, depth, and spreads on an event dummy and the same control variables but now using a panel regression with stock fixed effects and standard errors clustered by firm. Table 7, Panel A reports the results for BXE. These results support our earlier conclusion that the BXE make fee elimination was the driving force for traders of large LSE stocks causing market quality deteriorate and market share to decline. Similarly, the BXE take fee reduction was the driving force for traders for small LSE stocks and we document an improvement in spreads (while the change depth is not significant) and an increase in market share. For the overall LSE sample, the results for the panel regression are consistent with the fact that they are a combination of the effects for large stocks driven by traders concerned about rebates and small stocks driven by traders concerned about take fees.

[Insert Table 7 about here]

We report the results for CXE in Panel B and also here the results confirm our findings based on the time-series analysis. Specifically, both the higher take fee relative to BXE and the relatively less attractive make fee relative to TQ cause an outflow of market and limit orders from CXE after the fee changes. As a result, we document a deterioration in market quality and a decrease in market share for the CXE following the BATS fee changes and this is true both for the overall sample, and for subsamples by market capitalization.

Finally, we report the results using panel regressions to evaluate the changes in market quality and market share for TQ in Panel C. In terms of signs and significance, the results are very similar to those reported in Table 6, Panel C. Hence, we conclude that TQ market quality overall improved and its market share increased following the fee changes suggesting that the elimination of the rebates on BXE and reduction of CXE rebates benefited TQ through the intermarket competition channel. We again document significant differences for stocks in the cross section. The effect of relatively more attractive rebates drive the outcome for large stocks causing market quality and market share to improve while the effect of relatively less attractive take fees drives the outcome for small stocks causing market quality and market share to deteriorate.

5.6 Trading Revenues

While outside the scope of our model, a venue operator is likely to consider anticipated changes in market share when setting its maker-taker pricing. Revenues related to trading fees are the lion's share of revenues for many markets (Harty, 2018) and changes to maker-taker pricing can have potentially devastating effects on the bottom line. The previous section shows that BATS fee changes were associated with a loss of market share for CXE for both large and small stocks, and a loss of market share for BXE for large stocks which generate the bulk of the trading revenues. This begs the question: Did the fee changes lower BATS' fee revenues?

We calculate a proxy for trading-fee revenues (hereafter trading revenues) that relies on the total fee charged by each venue and its volume traded each day. In particular, for each venue, we define revenues to be equal to the nominal volume traded each day times the total fee for that venue. We run the same event study analysis and look at the period of one month pre- to one month post- the January 1st, 2013, event. We calculate daily trading revenues for both the BXE and CXE markets, where the total fee increased from 10 bps in the pre-period to 15 bps in the post-period. We also calculate trading revenues for the rival market TQ and the listing exchange. Unlike the BATS markets, in the TQ market and the listing exchange, the total fee charged remained constant during our event period. As shown in Table 3, however, since both the TQ and listing exchanges follow a value-traded based trading fee schedule, we calculate revenues for these markets based on both the lower (0.20 bps for listing exchange and 0.02 bps for TQ) and upper (0.45 bps for listing exchange and 0.16 bps for TQ) total fees, which represent the lower and upper bound of the trading revenues in each market.

We first calculate actual trading revenues in British pounds for BXE and CXE using our LSE sample (120 firms). Specifically, for BXE we find daily average (median) trading revenues of £1,575 (£357) in the pre-period and £2,768 (£662) in the post-period. Similarly, for the CXE market, we find daily average (median) revenues of £5,614 (£1,268) in the pre-period versus £9,627 (£2,186) in the post-period. These results show a significant increase in revenues for both markets driven primarily by the increase in total fees and less so by changes in volume. Indeed, when we calculate trading revenues for our subsamples of large and small capitalization firms, we find increases in both subsamples for both markets. Specifically, for the CXE market we find daily average (median) trading revenues of £14,890 (£8,146) in the pre-period and £25,640 (£13,750) in the post period for large firms and £345 (£152) in the pre-period and £595 (£220) in the post period for small firms. This indicates that even though the change in make-take fees for the CXE market results in a decrease in relative volume—documented in Section 5.3—, the CXE market more than compensates for this with increases in revenue through the increase in total fee.[30] BXE also shows large increases in trading revenues for large and small firms after the fee changes.

To provide a more representative picture of trading revenue changes across all markets (CXE, BXE, TQ, and listing exchange) for both our LSE and Pan-European samples (as well as the subsamples based on market capitalization), we run similar collapsed time-series regressions as in Section 5.3. Since the nominal daily volume that is used to define trading revenues for each stock can be in different currencies for our Pan-European sample, and in order to avoid issues related to differences in nominal price levels across countries, we run regressions on relative trading revenues. Thus for each stock, each day, we divide revenues in each market by that stock's total revenues measured across all venues for that day. The results of the 2013 event regressions are reported in Table 8.

[Insert Table 8 about here]

Table 8, Panel A (Columns 1-3) shows the results for the LSE sample based on an upper bound of revenues in TQ and the listing exchange. For both BXE and CXE markets, we find an increase in relative trading revenues in the post-period. In particular, for the BXE market we find an increase in relative revenues of 1.2% overall, 1.3% for small capitalization firms and 0.99% for large capitalization. The larger increase for small capitalization stocks is consistent with the evidence we present in Section 5 which shows that relative BXE volume inceases significantly for small stocks while relative volume falls for large stocks which of course dampens the effect of higher total fees on revenues. . The CXE shows increases of 2.54% overall, 3.73% for the large firms, and 1.07% for the small firms. Thus, despite the fact that relative CXE volume falls for both large and small stocks as discussed in Section 5, the higher total fee again delivers higher trading revenues. Interestingly, the listing exchange experiences a decrease in relative trading revenues by 4.01% overall, 5.36% for large firms, and 2.05% for small firms. For the rival market TQ the results show an increase in revenues market share of 0.24% overall, with a 0.64% increase for large firms, but a 0.32% decrease for small firms. This is consistent with Section 5 finding of an increase in TQ relative volume for large firms but a decrease for small firms. The results appear similar both when we use the lower bound of revenues for the TQ and listing exchange (Table 8, Columns 4-6), and when we use our Pan-European sample (Table 8, Panel B).

[30]This suggests an inelastic relationship between total fee and trading volume.

6 Robustness

6.1 Normalization

In our main analysis, we normalize each daily observation for a venue by the contemporaneous market-wide total/average in order to control for cross-sectional heterogeneity in currency denomination of prices as well as differences in nominal price levels across countries. An alternative is to use the same denominator for the pre- and the post-periods. The advantage of a constant denominator is that the entire effect on market quality arising from changes in the make-take fees comes from the numerator, i.e., the change in volume, depth, and spreads. However, the drawback of this approach is that we would observe changes in for example market share even if the venue did not capture a larger or smaller market share than it had in the pre-period. Nevertheless, for robustness we repeat our time-series regressions with variables normalized by a constant denominator and find that our results are qualitatively unchanged.[31]

6.2 Pan-European Sample

As a further robustness check, we repeat both the time-series and the panel regressions for the stratified sample of Pan-European stocks we described in Section 4 above. Table 5, Panel B reports the simple collapsed time series regression in an event dummy for the three MTFs for Pan-European stocks.

The results for the multivariate time-series regressions are reported in Table 9 and the results for the panel-regressions in Table 10. While at times slightly weaker statistically, the results are qualitatively the same as those reported earlier for the LSE sample. We find strong evidence that the elimination of the make fee on BXE was the driving force for large Pan-European stocks, resulting in poorer market quality and loss of market share. By contrast, the more attractive BXE take-fee resulted in narrower spreads and improved market share (but no significant change in depth) for small Pan-European stocks. The effects of the fee changes on CXE depth and market share remain negative also for the Pan-European sample overall and the effects on small stock market quality and market shares echo those from the LSE sample. By contrast, the results for large Pan-European stocks are weaker. This is most likely due to the opposite effects of the make-fee changes arising from competition from BXE and TQ respectively. Finally, it appears that TQ also benefited from BATS' reduction in make-fees for large Pan-European stocks. Specifically, TQ market quality and market share both improved for large Pan-European stocks following BATS' fee changes. By contrast, TQ market quality deteriorated (albeit not significantly) and market share declined for small Pan-European stocks.

[31] Tables reporting these results are available from the authors on request.

[Insert Tables 9 and 10 about here]

6.3 Further Tests

We run two more tests in order to verify the robustness of our results.

Following Malinova and Park (2015) we investigate the effect of the fee change on cum-fee spreads (quoted spread plus twice the take fee). We run both univariate and multivariate (time-series and panel) regressions for both the LSE and Pan-European samples. Since the listing exchanges (LSE, Pan-European exchanges) usually follow a take fee schedule, we calculate cum-fee spreads for these markets based on both the lower (e.g., 0.20 bps for LSE) and upper (e.g., 0.45 bps for LSE) take fees. In contrast to Malinova and Park (2015)—who base their model on Colliard and Foucault (2012) without a tick size—but in support of our model, we find that cum-fee spreads are affected by fee changes. In particular, for the 2013 fee change event, our cum-fee results show: (1) an overall increase in CXE cum-fee spreads driven by small firms, (2) a decrease (increase) in BXE cum-fee spreads in small (large) firms, (3) a decrease in cum-fee spreads for large firms in TQ. These results are similar to our quoted spread results, though the economic significance appears to be smaller.[32]

In addition, we introduce stocks from the Australian market as an alternative control group in our event study analyses. The Australian market is similar to Europe, both in terms of the degree of fragmentation and HFT activity.[33] Moreover, there are no trading fee changes in either one of our event windows for the venues trading Australian stocks, making this an advantageous control group. We rely on a stratified sample of Australian stocks that is stratified based on market capitalization and price. We run both univariate and multivariate (time-series and panel) regressions for the LSE and Pan-European samples. Results for our LSE sample are reported in Table 11.[34] In support of our main findings, we find qualitatively similar results. We believe this indicates that our results are robust to a change in experimental design in which the control group is not considered to be a competing venue to the BATS markets that experience the fee changes but does capture global market-wide factors as well as stock-specific characteristics.

[Insert Table 11 about here]

[32] Due to space considerations, these results are not reported but are available from the authors upon request.

[33] HFT activity for European markets for 2013 and 2014 are roughly 25% according to TABB Group, and the level of HFT trading is reasonably steady at 27% of total turnover according Australian Securities and Investments Commission (2015).

[34] Results for the Pan-European sample are also available from the authors upon request.

7 Conclusions and Policy Implications

Maker-taker pricing is actively debated among academics, practitioners, market operators, and is currently under review by U.S. and European regulators. The SEC in March 2018, proposed a Transactions Fee Pilot for NMS stocks that would mandate a reduction or elimination of rebates (make fees) and a significant reduction in the cap for take fees. We shed light on this debate by studying the effects on venue market quality and market shares of a reduction of liquidity rebates and take fees in fragmented markets in which intermarket competition plays an important role.

We first develop a theoretical model of a primary market and a competing venue, both operating limit order books with price and time priority. It shows that order flow between venues is key to understanding what will happen to the venue's market quality and market share when it changes its maker-taker pricing structure. We then empirically examine the effects on market quality and market shares of changes in make-take fees implemented by BATS on its two lit European venues - BXE and CXE - in 2013 and compare the outcomes to the model's predictions.

We find that when BXE eliminates its rebates and reduces it take fee, BXE market quality deteriorates for large stocks. By contrast, BXE market quality improves and its market share increases for small stocks. These results are what our model predicts we should see on market quality when rebates are relatively more important for traders in large capitalization stocks, and what our model predicts on market quality and market share when take fees are relatively more important for traders in small capitalization stocks. Our findings are consistent with traders like HFT that pursue rebate-capture strategies and are active in large stocks, but much less so in small stocks. In other words, the composition of traders and their relative sensitivity to fee changes varies significantly for stocks with different characteristics.

Market quality worsens but there is no change in volume (market share) following CXE's rebate reduction that leaves the take fee unchanged. The reason is instructive as it illustrates the role of intermarket competition. The contemporaneous elimination of rebates and reduction of take fees by BXE implies that CXE's rebate becomes more attractive and the take fee less attractive relative to BXE. These relative fee changes have opposite effects on market quality and market share. However, in addition CXE's rebate becomes less attractive relative to the one offered by TQ. This helps explain why orders flow out of CXE to TQ and BXE causing market quality to deteriorate.

To further high-light intermarket competition, we also study TQ which does not change its fees during our sample. Relative to BXE, both the make and the take fee increased. Our results show that the fee changes are associated with an increase in depth and volume for large capitalization stocks. By contrast, depth deteriorates significantly and volume falls significantly for small capitalization stocks. These results are again consistent with traders in large capitalization stocks being more sensitive to the make fee while traders in small capitalization stocks are more influenced by the take fee.

In Appendix 2, we examine introductions by BATS of value-tiers which imply that HFTs that execute significant volume on BATS venues enjoy a higher rebate (2014, CXE) and a lower take fee (2015, CXE). BATS was hoping to create a virtuous cycle where both limit and market orders from HFTs were attracted to their venues. Their experimentation illustrates how difficult it is to achieve a virtuous cycle in a market with significant intermarket competition. Traders easily shift their order flow across venues in response to fees, and the composition of traders is ever changing.

Based on our empirical results, we conclude that the effects on market quality and the distribution of volume of a proposal such as the one put forth by ICE and SIFMA are likely to differ across stocks. Specifically, our evidence suggests that an elimination of the make fee and a reduced take fee cap would result in worse market quality for large capitalization stocks but better market quality for small capitalization stocks. This suggests that the elimination of make-fees are going to be particularly detrimental for liquid stocks. In light of our findings, BATS' proposal to eliminate rebates and reduce take fees for the most liquid stocks, while allowing higher rebates and take fees for less liquid stocks, may be ill advised.

We caution that our empirical setting is one where fees are changed by a subset of the market operators, and hence traders can shop across venues for the combination of fees that best fit their trading strategies. If a regulator like the SEC mandates an elimination of rebates for all market operators in a particular stock, our model predicts that market quality will deteriorate and volume will increase. However, note that even if the fee structure is mandated to be the same for all venues trading a particular stock, traders will likely substitute across stocks focusing their rebate strategies in stocks with the most attractive rebates and their more aggressive strategies in those with low take fees. This means that it is going to be challenging to use the proposed SEC Transaction Fee Pilot to infer what would happen to market quality following a universally lower cap on fees.

Documenting cross-sectional differences of the effect of fee changes on market quality and volume leads naturally to the following question: was the BATS fee fight successful? This is a challenging question to answer as we are unable to observe the counterfactual, what would have happened had BATS not changed their fees. In order to evaluate the success of the BATS fee changes we have to both take into account what happened to market share and estimate changes in fee revenues due to the now higher fees. Figure 3 shows that BATS combined market share in LSE listed firms declined from 24.6% in November and December 2012 to 22.4% in February and March 2015. Similarly, BATS combined market share for the Pan-European sample declined from 26.51% to 25.15%, but BXE's market share increased. The distribution across BATS venues also shows that the loss of market share was primarily caused by traders leaving CXE which is where the bulk of the fee experimentation took place. By contrast, BXE actually gained market share suggesting that there is a role for a venue without liquidity rebates and low take fees. Nevertheless, our analysis shows that BATS' total fee increases were large enough to imply that trading revenues rise significantly. For LSE (Pan-European) stocks, we conservatively estimate a revenue increase of 1.20% (0.75%) for BXE and 2.54% (2.31%) for CXE. Moreover, the revenues for BATS rise at the expense of the listing exchange which experiences a concomittant decline in revenues. Thus, our results suggest that the BATS fee changes were successful.

We close by highlighting our contributions to the literature. We take intermarket competition between two limit order books into account in both our theoretical and empirical analyses of maker-taker fee changes. Given the significant fragmentation of today's equity markets, this is clearly an important consideration. We show empirically that the spillover effects on competing venues are significant. Our evidence is corroborated by recent fee experiments conducted by both the Nasdaq and the TSX which lost market share after reducing liquidity rebates (Appendix 3).

We also study a multi-platform reduction in rebates which are only partially subsidized by reductions in take fee, hence leading to an increase in total fees. The previous literature has mainly studied the elimination of a charge for liquidity provision (Lutat, 2010) and increases in the make and take fees (Malinova and Park, 2015). The current policy debate is focused on reducing rather than increasing make-take fees, and our evidence is therefore directly relevant to the current SEC Transactions Fee Pilot proposal.

Furthermore, we document significant cross-sectional differences in the response to changes in maker-taker fees. Specifically, our evidence suggests that traders in large capitalization stocks are relatively more sensitive to make fees, while traders in small capitalization stocks are more concerned about take fees. We conjecture that the reason for this is that HFTs concentrate their trading in liquid large capitalization stocks, and it is well known that they pursue rebate-capture strategies and engage in voluntary market making activities.

Lastly, we study changes in fees that took place in 2013 (and 2014 and 2015 in Appendix 2) while the previous empirical work on the topic of maker-taker pricing has evaluated this type of pricing based on data from 2008-2010. Given how fast market structure and the ecosystem of traders are changing, it is important to evaluate fee changes in recent years when regulators consider mandating a reduction in liquidity rebates.

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Table 1: **Order Submission Strategies**

This Table reports the payoffs of the order submission strategies (Column 1). Column 2 reports the payoffs of orders sent to the primary market and column 3 the payoffs of orders sent to the competing market. Market orders to sell $(MO^j_{t_z}(B^{j,b}_i))$ and market orders to buy $(MO^j_{t_z}(S^{j,b}_i))$ always execute against the best bid price, $B^{j,b}_{t_z} = max\left\{B^j_{t_z,i} | l^{B^j}_{t_z,i} > 0\right\}$, or the best ask price, $S^{j,b}_{t_z,i} = min\left\{S^j_{t_z,i} | l^{S^j}_{t_z,i} > 0\right\}$ of the LOB respectively, where $l^{B^j}_{t_z,i}$ ($l^{S^j}_{t_z,i}$) is the number of shares available at the $i-th$ price level of the bid side (ask side) of the $j-th$ market at time t_z, and where $j = Prim$ for the primary market and $j = C$omp for the competing market. Traders have a personal evaluation of the asset which is truncated Normal, $\gamma \sim N(\mu, \sigma^2)$ and lies in the domain $\gamma \in (0.8, 1.2)$ for liquid stocks and in the domain $\gamma \in (0.0, 2.0)$ for illiquid stocks $AV = \mu = \sigma^2 = 1$. MF (mf) is the make fee and TF (tf) is the take fee for the Primary (Competing) market. Limit orders to sell, $LO^j_{t_z}(S^j_i)$, and limit orders to buy, $LO^j_{t_z}(B^j_i)$, posted at time t_1 and t_2 may execute at the limit price, S^j_i and B^j_i, respectively. Limit orders have uncertain execution which depends on the probability - $Pr_{t_z}(S^j_i | lob^j_{t_{z+1} and/or\, t_{z+2}})$ and $Pr_{t_z}(B^j_i | lob^j_{t_{z+1} and/or\, t_{z+2}})$ - that a market order arrives with opposite direction in the subsequent periods; hence the limit orders' execution probability depends on the future states of the limit order book, $lob^j_{t_{z+1} and/or\, t_{z+2}} = \left\{P^j_{t_{z+1} and/or\, t_{z+2},i,}, l^{P^j}_{t_{z+1} and/or\, t_{z+2},i}\right\}$. The payoff of no-trade, NT_{t_z}, is 0 in both markets.

Strategy	Payoffs: Primary Market (Prim)	Payoffs: Competing Market (Comp)
Market Order to Sell: $MO^j_{t_z}(B^{j,b}_i)$	$B^{Prim,b}_i - \gamma AV - TF$	$B^{Comp,b}_i - \gamma AV - tf$
Limit Order to Sell: $LO^j_{t_z}(S^j_i)$	$(S^{Prim}_i - \gamma AV + MF)\, Pr_{t_z}(S^{Prim}_i | lob^{Prim}_{t_{z+1} and/or\, t_{z+2}})$	$(S^{Comp}_i - \gamma AV + mf)\, Pr_{t_z}(S^{Comp}_i | lob^{Comp}_{t_{z+1} and/or\, t_{z+2}})$
No Trade: NT_{t_z}	0	0
Limit Order to Buy: $LO^j_{t_z}(B^j_i)$	$(\gamma AV - B^{Prim}_i + MF)\, Pr_{t_z}(B^{Prim}_i | lob^{Prim}_{t_{z+1}+1 and/or\, t_{z+2}})$	$(\gamma AV - B^{Comp}_i + mf)\, Pr_{t_z}(B^{Comp}_i | lob^{Comp}_{t_{z+1} and/or\, t_{z+2}})$
Market Order to Buy: $MO^j_{t_z}(S^{j,b}_i)$	$\gamma AV - S^{Prim,b}_i - TF$	$\gamma AV - S^{Comp,b}_i - tf$

Table 2: **Equilibrium Order Submission Strategies and Market Quality**

This Table reports the equilibrium order submission probability of limit orders in the primary and in the competing market, LO^j, the equilibrium average market share, MS^j, and the equilibrium average market quality metrics, $Spread^j$ and $BBODepth^j$. Panel A reports results obtained by solving the model holding the take fee (TF) constant at 0.01 and changing the make fee (MF) from 0.01 to 0.05 in steps of 0.01. Panel B reports results obtained by solving the model holding the make fee (MF) constant at 0.05 and changing the take fee (TF) from 0.01 to 0.05 in steps of 0.01. We hold $mf = tf = 0.0$. Columns 7 and 13 report the percentage change (%Δ) of the metric considered between 0.01 and 0.05. Panel C reports results for sets of fees taken from Panel A and Panel B. Experiments I.a and II.a (I.b and II.b) report results for a change in fees, ΔMF =MFpost-MFpre and ΔTF =TFpost-TFpre, that leads to a change in Total Fee equal to 0.01 (0.02). Results are reported for both the primary (Prim) and the competing (Comp) market. For each market results are also reported for both liquid and illliquid stocks. Traders have a personal evaluation of the asset which is truncated Normal,$\gamma \sim N(\mu, \sigma^2)$ and lies in the domain $\gamma \in (0.8, 1.2)$ for liquid stocks and $\gamma \in (0.0, 2.0)$ for illiquid stocks. AV=μ=$\sigma^2 = 1$.

Panel A: Change in Make Fee (MF)

	Liquid stocks: $\gamma \in (0.8, 1.2)$						Illiquid stocks: $\gamma \in (0.0, 2.0)$					
Take fee (TF)	0.01	0.01	0.01	0.01	0.01	%Δ	0.01	0.01	0.01	0.01	0.01	%Δ
Make fee (MF)	0.01	0.02	0.03	0.04	0.05		0.01	0.02	0.03	0.04	0.05	
LO^{Prim}	0.1249	0.1763	0.2025	0.2427	0.3012	141.1096	0.0186	0.0234	0.0233	0.0231	0.0244	31.3084
MS^{Prim}	0.1312	0.1840	0.2097	0.2477	0.3013	129.6366	0.0229	0.0289	0.0287	0.0285	0.0301	31.3039
LO^{Comp}	0.7010	0.6554	0.6359	0.6047	0.5588	-20.2913	0.6055	0.6004	0.6002	0.6000	0.5982	-1.2110
MS^{Comp}	0.8688	0.8160	0.7903	0.7523	0.6987	-19.5818	0.9771	0.9711	0.9713	0.9715	0.9699	-0.7339
$Spread^{Prim}$	0.4750	0.4647	0.4595	0.4489	0.4310	-9.2758	0.4963	0.4953	0.4953	0.4954	0.4951	-0.2341
$Spread^{Comp}$	0.2997	0.3057	0.3064	0.3114	0.3226	7.6489	0.3359	0.3363	0.3362	0.3361	0.3361	0.0639
$BBODepth^{Prim}$	0.1249	0.1763	0.2025	0.2555	0.3452	176.3476	0.0186	0.0234	0.0233	0.0231	0.0244	31.3084
$BBODepth^{Comp}$	1.0889	1.0489	1.0362	0.9995	0.9304	-14.5584	0.9106	0.9103	0.9101	0.9099	0.9081	-0.2758

Panel B: Change in Take Fee (TF)

	Liquid stocks: $\gamma \in (0.8, 1.2)$						Illiquid stocks: $\gamma \in (0.0, 2.0)$					
Take fee (TF)	0.01	0.02	0.03	0.04	0.05	%Δ	0.01	0.02	0.03	0.04	0.05	%Δ
Make fee (MF)	0.05	0.05	0.05	0.05	0.05		0.05	0.05	0.05	0.05	0.05	
LO^{Prim}	0.3012	0.2514	0.2243	0.1823	0.1252	-58.4490	0.0244	0.0234	0.0230	0.0215	0.0175	-28.3087
MS^{Prim}	0.3013	0.2395	0.2005	0.1502	0.0937	-68.9124	0.0301	0.0285	0.0277	0.0255	0.0205	-31.8130
LO^{Comp}	0.5588	0.5921	0.6068	0.6436	0.7008	25.4158	0.5982	0.5995	0.5999	0.6015	0.6056	1.2360
MS^{Comp}	0.6987	0.7605	0.7995	0.8498	0.9063	29.7241	0.9699	0.9715	0.9723	0.9745	0.9795	0.9865
$Spread^{Prim}$	0.4310	0.4476	0.4551	0.4635	0.4750	10.2136	0.4951	0.4953	0.4954	0.4957	0.4965	0.2786
$Spread^{Comp}$	0.3226	0.3128	0.3107	0.3051	0.2947	-8.6465	0.3361	0.3361	0.3361	0.3359	0.3355	-0.1567
$BBODepth^{Prim}$	0.3452	0.2621	0.2243	0.1823	0.1252	-63.7473	0.0244	0.0234	0.0230	0.0215	0.0175	-28.3087
$BBODepth^{Comp}$	0.9304	0.9853	0.9999	1.0315	1.0887	17.0143	0.9081	0.9093	0.9098	0.9098	0.9098	0.1937

Panel C: Change in Make&Take Fee (MF&TF)

Experiment	MFpre	TFpre	MFpost	TFpost	ΔMF	ΔTF	ΔTotalFee	ΔMS^{Prim}	$\Delta Spread^{Prim}$	$\Delta BBODepth^{Prim}$	ΔMS^{Comp}	$\Delta Spread^{Comp}$	$\Delta BBODepth^{Comp}$
Liquid stocks: $\gamma \in (0.8, 1.2)$													
I.a	0.05	0.03	0.02	0.01	-0.03	-0.02	0.01	-0.0166	0.0096	-0.0480	0.0166	-0.0050	0.0491
I.b	0.05	0.02	0.02	0.01	-0.03	-0.01	0.02	-0.0555	0.0172	-0.0858	0.0555	-0.0071	0.0637
II.a	0.05	0.04	0.01	0.01	-0.04	-0.03	0.01	-0.0190	0.0115	-0.0574	0.0190	-0.0054	0.0574
II.b	0.05	0.03	0.01	0.01	-0.04	-0.02	0.02	-0.0693	0.0199	-0.0994	0.0693	-0.0110	0.0890
Illiquid stocks: $\gamma \in (0.0, 2.0)$													
I.a	0.05	0.03	0.02	0.01	-0.03	-0.02	0.01	0.0012	-0.0001	0.0004	-0.0012	0.0002	0.0006
I.b	0.05	0.02	0.02	0.01	-0.03	-0.01	0.02	0.0004	-0.0000	0.0000	-0.0004	0.0002	0.0010
II.a	0.05	0.04	0.01	0.01	-0.04	-0.03	0.01	-0.0026	0.0006	-0.0029	0.0026	-0.0001	0.0008
II.b	0.05	0.03	0.01	0.01	-0.04	-0.02	0.02	-0.0048	0.0009	-0.0045	0.0048	-0.0002	0.0008

Table 3: Trading Fee Schedules for UK and Irish listed firms

The table reports the trading fee schedules that apply for the LSE-listed firms during our sample period right before December 31st, 2012 to the period right after January 1st, 2013. The venues that we examine are: BXE-Lit, CXE-Lit, TQ-Lit, LSE-Lit, BXE-Dark, CXE-Dark, TQ-Dark and UBS-Dark. Our study focuses on the fee changes for the BXE-Lit and CXE-Lit markets implemented on January 1st, 2013. No other venue incurred any changes in fees. The fee changes are highlighted in the table.

		Effective December 31, 2012			Effective January 1, 2013		
	Tiers/Order Type	Maker fee (bps)	Taker Fee (bps)	Total Fee (bps)	Maker fee (bps)	Taker Fee (bps)	Total Fee (bps)
A. Transparent MTFs							
BXE-Lit		-0.18	0.28	0.10	0.00	0.15	0.15
CXE-Lit		-0.20	0.30	0.10	-0.15	0.30	0.15
TQ-Lit	< €1.5bn	-0.14	0.30	0.16	-0.14	0.30	0.16
	€1.5 - €2.5bn	-0.24	0.30	0.06	-0.24	0.30	0.06
	> €2.5bn	-0.28	0.30	0.02	-0.28	0.30	0.02
B. Primary/Listing Exchange							
LSE-Lit*	< £2.5bn	0.00	0.45	0.45	0.00	0.45	0.45
	£2.5 - £5.0bn	0.00	0.40	0.40	0.00	0.40	0.40
	£5.0 - £10.0bn	0.00	0.30	0.30	0.00	0.30	0.30
	> £10.0bn	0.00	0.20	0.20	0.00	0.20	0.20
C. Dark Venues							
BXE-Dark		0.15	0.15	0.30	0.15	0.15	0.30
CXE-Dark	Non-IOC Orders	0.15	0.15	0.30	0.15	0.15	0.30
	IOC Orders	0.30	0.30	0.60	0.30	0.30	0.60
TQ-Dark		0.30	0.30	0.60	0.30	0.30	0.60
UBS-Dark		0.10	0.10	0.20	0.10	0.10	0.20

Notes: * LSE enforced a minimum per order charge of £0.10. Furthermore, LSE offered two Liquidity Taker Scheme Packages for Equities: 1) for a monthly fee of £50,000 the taker fee is 0.15 bps; 2) for a monthly fee of £5,000 the taker fee is 0.28 bps. Effective June 3, 2013, the hurdles for these packages were reduced to £40,000 and £4,000 respectively.

Table 4: Descriptive Statistics

This table reports summary statistics for our main variables. Panel A reports statistics for the 2013 Event LSE sample and Panel B reports similar statistics for the 2013 Event Pan-European sample. In particular, the 120 LSE stocks sample is stratified by price and market capitalization, based on daily average numbers for the month of Jan 2012. The 120 European stocks sample is a similar stratified sample from 13 different listing exchanges according to their frequency of BATS market venue traded symbols. All variables reported in the table, measured at the stock level, are for the listing exchange only. *Volume* is defined as the daily number of shares (in 000s) at the end-of-day files from Thomson Reuters Tick History (TRTH). *Depth* is defined as the daily average of the intraday quoted depth at the ask-side and the bid of each quote respectively. *Spread* is defined as the time weighted average of the intraday difference between the ask price and the bid price of the quotes. *%Spread* is defined time weighted average of the intraday ask price minus the bid price divided by the midquote. *Volatility* is defined as the difference between the high and low trading prices each trading day (from the end-of-day files from TRTH) divided by the high price of that day. The four measures of market quality are based on daily numbers for each stock in the one-month pre-period (Dec 2012). We also report *market capitalization* in millions of the local currency (GBP and Euro respectively) and *price* levels both measured at the daily level for the month of Jan 2012. In addition to the *overall* samples, for all of our variables we also report summary statistics for the subsamples of the highest (*Large*) and lowest (*Small*) market capitalization terciles.

Panel A: 2013 Event, LSE Sample

Market Quality Measures		Mean	Median	ST dev	Q1	Q3
Volume (000s)	Large	10,980	3,352	23,692	1,478	7,718
	Small	767	329	1,140	119	910
	Overall	4,457	931	14,560	307	2,854
Depth	Large	11,500	7,082	16,730	4,094	11,080
	Small	6,211	1,922	14,336	867	4,882
	Overall	7,421	3,172	13,899	1,403	7,271
Spread	Large	0.898	0.722	0.812	0.215	1.486
	Small	2.050	0.891	2.748	0.369	2.658
	Overall	1.667	0.889	3.576	0.310	1.717
% Spread	Large	0.092%	0.096%	0.038%	0.060%	0.120%
	Small	0.357%	0.264%	0.330%	0.182%	0.435%
	Overall	0.228%	0.146%	0.276%	0.108%	0.246%
Volatility (High-Low)/High	Large	1.602%	1.402%	0.819%	1.101%	1.899%
	Small	2.068%	1.706%	1.387%	1.207%	2.552%
	Overall	1.886%	1.575%	1.284%	1.163%	2.211%
Market Capitalization (£ Mill)	Large	20,290	8,896	24,684	4,373	25,200
	Small	789	792	169	634	926
	Overall	7,622	1,676	16,835	931	4,289
Price	Large	9.280	5.620	8.633	2.502	14.180
	Small	4.970	2.910	4.994	1.195	5.768
	Overall	6.909	4.115	6.932	2.148	9.705

Panel B: 2013 Event, Pan-European Sample

Market Quality Measures		Mean	Median	ST dev	Q1	Q3
Volume (000s)	Large	9,037	2,586	21,052	816	7,102
	Small	509	233	738	64	605
	Overall	3,791	674	12,893	198	2,351
Depth	Large	9,254	3,804	16,984	1,248	8,367
	Small	1,786	981	2,079	452	2,045
	Overall	5,108	1,851	12,542	681	4,529
Spread	Large	0.171	0.022	0.345	0.012	0.130
	Small	0.741	0.231	1.701	0.041	0.526
	Overall	0.439	0.084	1.122	0.022	0.332
% Spread	Large	0.068%	0.063%	0.030%	0.047%	0.080%
	Small	0.219%	0.180%	0.133%	0.132%	0.246%
	Overall	0.137%	0.108%	0.107%	0.070%	0.164%
Volatility (High-Low)/High	Large	1.577%	1.385%	0.809%	1.068%	1.879%
	Small	2.072%	1.675%	3.312%	1.227%	2.451%
	Overall	1.813%	1.675%	2.056%	1.152%	2.150%
Market Capitalization (€ Mill)	Large	34,310	18,090	52,253	9,226	36,860
	Small	1,055	1,015	348	811	1,286
	Overall	12,870	2,894	33,772	1,296	8,494
Price	Large	38.100	16.200	61.014	6.281	43.230
	Small	12.950	8.322	12.242	3.810	17.640
	Overall	24.520	12.070	40.540	4.227	26.440

Table 5: Measures of Market Quality – Time-Series Changes for the 2013 Event

This table reports the changes in market quality measures (Volume, Depth, and Spread) for the 2013 event using a one-month pre- and one-month post-event window. We investigate three market venues: Chi-X (CXE) and BATS (BXE) and Turquoise (TQ). To deal with cross-sectional heterogeneity in each of the three market quality measures we standardize them as follows: we divide venue-stock-day volume by total daily volume, depth by average depth, and quoted spread by average quoted spread where total and averages are taken over all four venues (BXE, CXE, TQ, and listing exchange). Our post minus pre (diff) estimation methodology is based on running daily time-series regressions of the mean values of each measure of market quality on a dummy variable *Event* to indicate post-event period. We run regressions for the overall sample and two subsamples of the highest (*Large*) and lowest (*Small*) market capitalization terciles. Panel A reports estimated coefficients and t-statistics (in parentheses) for the LSE sample and Panel B reports similar statistics for the Pan-European sample. For all specifications we employ the Newey-West correction for autocorrelation in the error terms using 10 day lags. ** and *** indicate significance at the 5% and 1% levels, respectively.

Panel A: 2013 Event for LSE Sample -- Time Series (Post Minus Pre) Differences

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
BXE									
Event	0.0012	0.0140***	0.0080**	-0.0492***	-0.0097	-0.0241***	0.0374***	-0.0757**	-0.0136
(t-statistic)	(0.79)	(3.51)	(3.53)	(-4.93)	(-0.84)	(-3.20)	(7.57)	(-2.52)	(-0.80)
CXE									
Event	0.0048	-0.0100**	-0.0007	-0.0355**	-0.0068	-0.0165	-0.0013	0.0559***	0.0259***
(t-statistic)	(1.33)	(-2.63)	(-0.15)	(-2.05)	(-0.77)	(-1.98)	(-0.19)	(3.67)	(2.81)
TQ									
Event	0.0388***	-0.0053	0.0219***	0.1494***	-0.079***	0.0369**	-0.0130	-0.0076	0.0051
(t-statistic)	(5.59)	(-0.75)	(3.40)	(4.47)	(-2.68)	(2.50)	(-0.88)	(-0.31)	(0.30)

Panel B: 2013 Event for Pan-European Sample -- Time Series (Post Minus Pre) Differences

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
BXE									
Event	-0.0011	0.0079***	0.0026***	-0.0142	-0.0246	-0.0070	0.0597***	-0.0424***	0.0165***
(t-statistic)	(-0.88)	(6.14)	(3.56)	(-1.41)	(-1.43)	(-0.69)	(4.86)	(-2.99)	(3.11)
CXE									
Event	0.0013	-0.0037	-0.0009	-0.0062	-0.0067	-0.0178***	-0.0235***	0.0282**	-0.0032
(t-statistic)	(0.29)	(-0.91)	(-0.24)	(-0.72)	(-1.26)	(-3.85)	(-3.64)	(2.12)	(-0.65)
TQ									
Event	0.0085	-0.0008	0.0072	0.0166	-0.0323	0.0177	-0.0314**	-0.0041	-0.0162
(t-statistic)	(1.49)	(-0.12)	(1.57)	(1.01)	(-0.84)	(0.96)	(-2.29)	(-0.27)	(-1.51)

Table 6: Measures of Market Quality – Time-Series Multivariate Regressions of the 2013 Event for the LSE Sample

This table reports the changes in market quality measures (Volume, Depth, and Spread) using time-series multivariate regressions for the 2013 event using a one-month pre- and one-month post-event window for the LSE sample. Following Boehmer Jones and Zhang (2015), we use a regression framework to run daily time-series regressions of the mean values of each measure of market quality on a dummy variable *Event* to indicate post-event period where we also control for market quality in competing venues (using the listing exchange market quality measures) and volatility index VIX (using the FTSE 100 volatility index). To deal with cross-sectional heterogeneity in each of the three market quality measures we standardize them as follows: we divide venue-stock-day volume by total daily volume, depth by average depth, and quoted spread by average quoted spread where total and averages are taken over all four venues (BXE, CXE, TQ, and the listing exchange). We run regressions for the overall sample and two subsamples of the highest (*Large*) and lowest (*Small*) market capitalization terciles. Panel A reports estimated coefficients and t-statistics (in parentheses) for the BXE market, whereas Panels B and C reports similar statistics for the CXE and TQ markets, respectively. For all specifications we employ the Newey-West correction for autocorrelation in the error terms using 10 day lags. ** and *** indicate significance at the 5% and 1% levels, respectively.

Panel A: 2013 Event for LSE sample -- Time Series Regression Results for BXE

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.1766***	0.2473***	0.2090***	0.7249***	1.5134***	1.0706***	1.6974***	2.0009***	1.7989***
(t-statistic)	(9.72)	(8.98)	(11.56)	(13.53)	(15.94)	(12.86)	(38.42)	(18.57)	(22.73)
Event	-0.0027***	0.0145***	0.0049**	-0.0531***	0.0147	-0.0225***	0.0297***	-0.0658***	-0.0201
(t-statistic)	(-3.67)	(4.06)	(2.22)	(-6.62)	(1.74)	(-2.97)	(10.05)	(-3.58)	(-1.89)
Listing Exchange	-0.1811***	-0.2637***	-0.2208***	-0.1825***	-0.4699***	-0.2881***	-0.5538***	-0.89178***	-0.6428***
(t-statistic)	(-7.40)	(-7.54)	(-9.74)	(-7.97)	(-6.30)	(-6.52)	(-15.57)	(-7.59)	(-7.08)
VIX	0.0003	0.0008	0.0003	0.0057***	0.0055	0.0030	-0.0034***	-0.0064	-0.0040
(t-statistic)	(0.99)	(1.69)	(1.20)	(3.92)	(1.11)	(1.05)	(-3.27)	(-1.84)	(-1.33)
Nobs	41	41	41	41	41	41	41	41	41
Adj R^2	0.67	0.58	0.63	0.71	0.55	0.48	0.83	0.60	0.48

Panel B: 2013 Event for LSE sample -- Time Series Regression Results for CXE

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.6095***	0.4676***	0.5145***	2.3467***	1.2921***	1.8839***	0.8184***	0.9655***	0.9975***
(t-statistic)	(39.55)	(23.17)	(27.41)	(35.89)	(17.15)	(22.39)	(18.38)	(13.63)	(18.50)
Event	-0.0081***	-0.0093***	-0.0077***	-0.0553***	0.0039	-0.0161***	0.0001	0.0553***	0.0246**
(t-statistic)	(-4.19)	(-3.76)	(-2.80)	(-8.94)	(0.56)	(-3.22)	(0.02)	(3.83)	(2.63)
Listing Exchange	-0.5919***	-0.4797***	-0.5061***	-0.5709***	-0.2489***	-0.0032***	-0.0083	-0.0094	-0.1121
(t-statistic)	(-27.94)	(-18.63)	(-21.93)	(-14.57)	(-4.01)	(-11.87)	(-0.20)	(-0.09)	(-1.42)
VIX	0.0008**	0.0010***	0.0013***	-0.0036***	-0.0032	-0.0010	0.0041**	-0.0020	-0.0013
(t-statistic)	(2.16)	(3.30)	(3.85)	(-4.45)	(-0.79)	(-0.45)	(2.38)	(-0.59)	(-0.46)
Nobs	41	41	41	41	41	41	41	41	41
Adj R^2	0.91	0.82	0.83	0.85	0.37	0.57	0.08	0.32	0.27

Panel C: 2013 Event for LSE sample -- Time Series Regression Results for TQ

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.2139***	0.2851***	0.2757***	0.9284***	1.1945***	1.0370***	1.4800***	1.0336***	1.2407***
(t-statistic)	(25.19)	(19.54)	(29.62)	(25.29)	(20.48)	(24.34)	(40.79)	(17.36)	(24.08)
Event	0.0109***	-0.0052***	0.0024**	0.1083***	-0.0187***	0.0380***	-0.0300***	0.0105	-0.0037
(t-statistic)	(7.51)	(-3.62)	(2.21)	(20.90)	(-3.97)	(10.16)	(-11.85)	(1.40)	(-0.72)
Listing Exchange	-0.2270***	-0.2567***	-0.2743***	-0.2466***	-0.2812***	-0.2431***	-0.4323***	-0.0988	-0.2881***
(t-statistic)	(-19.73)	(-14.60)	(-22.51)	(-9.98)	(-7.92)	(-10.49)	(-11.85)	(-1.82)	(-5.70)
VIX	-0.0011***	-0.0018***	-0.0016***	-0.0021	-0.0023	-0.0020**	-0.0008	0.0084***	0.0045***
(t-statistic)	(-3.95)	(-4.01)	(-6.45)	(-1.43)	(-1.23)	(-2.01)	(-0.70)	(3.82)	(3.78)
Nobs	41	41	41	41	41	41	41	41	41
Adj R^2	0.90	0.59	0.78	0.93	0.69	0.75	0.66	0.08	0.28

Table 7: Measures of Market Quality – Panel Regressions of the 2013 Event for the LSE Sample

This table reports the changes in market quality measures (Volume, Depth, and Spread) using panel regressions for the 2013 event using a one-month pre- and one-month post-event window for the LSE sample. Following Boehmer Jones and Zhang (2015), we use a regression framework to run panel regressions of each stocks daily values of each market quality measure on a dummy variable *Event* to indicate post-event period where we also control for market quality in competing venues (using the listing exchange market quality measures) and volatility index VIX (using the FTSE 100 volatility index). To deal with cross-sectional heterogeneity in each of the three market quality measures we standardize them as follows: we divide venue-stock-day volume by total daily volume, depth by average depth, and quoted spread by average quoted spread where total and averages are taken over all four venues (BXE, CXE, TQ and the listing exchange). We run panel regressions for the overall sample and two subsamples of the highest (*Large*) and lowest (*Small*) market capitalization terciles. Panel A reports estimated coefficients and t-statistics (in parentheses) for the BXE market, whereas Panels B and C reports similar statistics for the CXE and TQ markets, respectively. For all specifications we account for stock fixed effects and clustered standard errors by date (time clusters). ** and *** indicate significance at the 5% and 1% levels, respectively.

Panel A: 2013 Event for LSE sample -- Panel Regression Results for BXE

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.1792***	0.21512***	0.2021***	0.7459***	1.1525***	0.9086***	1.6128***	1.8823***	1.5819***
(t-statistic)	(23.26)	(19.98)	(28.15)	(25.03)	(18.62)	(23.02)	(79.16)	(30.19)	(48.35)
Event	-0.0028***	0.0145***	0.0050***	-0.0539***	0.0076	-0.0223***	0.0303***	-0.0731***	-0.0209**
(t-statistic)	(-3.09)	(6.45)	(3.71)	(-9.25)	(0.92)	(-4.20)	(8.56)	(-4.34)	(-2.31)
Listing Exchange	-0.1850***	-0.2819***	-0.2333***	-0.2053***	-0.3362***	-0.2855***	-0.5175***	-0.4498***	-0.4357***
(t-statistic)	(-24.39)	(-24.33)	(-27.46)	(-28.41)	(-19.71)	(-31.17)	(-38.83)	(-13.92)	(-28.15)
VIX	0.0003	0.0008	0.0004	0.0055***	0.0035	0.0029	-0.0033***	-0.0099**	-0.0057**
(t-statistic)	(0.62)	(1.27)	(0.87)	(2.84)	(0.78)	(1.05)	(-3.14)	(-2.43)	(-2.42)
Nobs	1640	1640	4920	1640	1640	4920	1640	1640	4920
Adj R^2	0.65	0.76	0.70	0.74	0.68	0.80	0.85	0.66	0.73

Panel B: 2013 Event for LSE sample -- Panel Regression Results for CXE

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.6267***	0.4694***	0.5425***	2.3152***	1.5935***	2.0420***	1.0280***	0.9356***	1.139***
(t-statistic)	(82.06)	(55.07)	(72.76)	(81.98)	(29.92)	(52.83)	(41.74)	(22.30)	(49.03)
Event	-0.0088***	-0.0093***	-0.0072***	-0.0544***	0.0098	-0.0160***	-0.0016	0.0596***	0.0251***
(t-statistic)	(-6.76)	(-5.69)	(-5.19)	(-8.97)	(1.35)	(-3.11)	(-0.37)	(4.76)	(3.62)
Listing Exchange	-0.6192***	-0.4124***	-0.4865***	-0.5467***	-0.3587***	-0.4217***	-0.1662***	-0.2707***	-0.2486***
(t-statistic)	(-78.61)	(-35.26)	(-53.05)	(-58.83)	(-22.96)	(-45.56)	(-9.86)	(-10.14)	(-20.51)
VIX	0.0007	0.0010***	0.0013***	-0.0034**	-0.0016	-0.0014	0.0039***	0.0000	0.0010
(t-statistic)	(1.75)	(2.97)	(4.22)	(-2.31)	(-0.42)	(-0.62)	(2.85)	(0.01)	(0.57)
Nobs	1640	1640	4920	1640	1640	4920	1640	1640	4920
Adj R^2	0.86	0.90	0.93	0.82	0.74	0.87	0.74	0.63	0.67

Panel C: 2013 Event for LSE sample -- Panel Regression Results for TQ

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.1941***	0.3155***	0.2554***	0.9389***	1.2541***	1.0494***	1.3600***	1.1821***	1.2810***
(t-statistic)	(34.47)	(31.32)	(36.91)	(36.95)	(39.63)	(38.17)	(52.19)	(27.98)	(64.59)
Event	0.0116***	-0.0052***	0.0022**	0.1083***	-0.0174***	0.0383***	-0.0287***	0.0135	-0.0043
(t-statistic)	(10.88)	(-3.38)	(2.04)	(20.17)	(-3.60)	(9.57)	(-7.59)	(1.45)	(-0.86)
Listing Exchange	-0.1958***	-0.3057***	-0.2803***	-0.2479***	-0.3051***	-0.2927***	-0.3166***	-0.2795***	-0.3157***
(t-statistic)	(-32.99)	(-28.00)	(-38.14)	(-30.62)	(-30.26)	(-36.99)	(-20.96)	(-16.65)	(-41.66)
VIX	-0.0010***	-0.0018***	-0.0016***	-0.0021	-0.0019	-0.0016	-0.0006	0.0099***	0.0046***
(t-statistic)	(-3.44)	(-3.11)	(-4.27)	(-1.16)	(-1.21)	(-0.95)	(-0.50)	(3.96)	(3.48)
Nobs	1640	1640	4920	1640	1640	4920	1640	1640	4920
Adj R^2	0.72	0.77	0.72	0.84	0.73	0.75	0.73	0.58	0.66

Table 8: Trading Revenues

This table reports the changes trading revenues for the 2013 event using a one-month pre- and one-month post-event window. We investigate all four market venues in our analysis: Chi-X (CXE) BATS (BXE), Turquoise (TQ), and listing exchange. Trading revenues are defined to be equal to the nominal volume traded each day times the total fee for that venue. To deal with cross-sectional heterogeneity in each of the three market quality measures we standardize trading revenues as follows: we divide venue-stock-day trading revenues by total trading revenues taken over all four venues (BXE, CXE, TQ and listing exchange) for that stock that day. Our post minus pre (diff) estimation methodology is based on running daily time-series regressions of the mean values of trading revenues on a dummy variable *Event* to indicate post-event period. We run regressions for the overall sample and two subsamples of the highest (*Large*) and lowest (*Small*) market capitalization terciles. Since both the TQ and listing exchange follow a trading fee schedule, we calculate revenues for these markets based on both the lower (0.20 bps for listing exchange and 0.02 bps for TQ) and upper (0.45 bps for listing exchange and 0.16 bps for TQ) total fees. The latter is reported in columns 1-3 and the former in columns 4-6. Panel A reports estimated coefficients and t-statistics (in parentheses) for the LSE sample and Panel B reports similar statistics for the Pan-European sample. For all specifications we employ the Newey-West correction for autocorrelation in the error terms using 10 day lags. ** and *** indicate significance at the 5% and 1% levels, respectively.

Panel A: 2013 Event for LSE Sample -- Time Series (Post Minus Pre) Differences

	Revenues Highest LSE Total Fees Used: 0.45 bps Highest TQ Total Fees Used: 0.16 bps			Revenues Lowest LSE Total Fees Used: 0.20 bps Lowest TQ Total Fees Used: 0.02 bps		
	Large	Small	Overall	Large	Small	Overall
BXE						
Event	0.0099***	0.0130***	0.0120***	0.0173***	0.0253***	0.0221***
(t-statistic)	(12.42)	(9.48)	(14.11)	(12.30)	(9.21)	(13.15)
CXE						
Event	0.0373***	0.0107***	0.0254***	0.0645***	0.0189***	0.0445***
(t-statistic)	(22.53)	(7.66)	(14.17)	(22.72)	(6.94)	(13.63)
TQ						
Event	0.0064***	-0.0032***	0.0024**	0.0012***	-0.0011***	0.0002
(t-statistic)	(4.47)	(-3.09)	(2.09)	(3.59)	(-4.03)	(0.70)
LSE						
Event	-0.0536***	-0.0205***	-0.0401***	-0.0823***	-0.0431***	-0.0674***
(t-statistic)	(-16.93)	(-8.36)	(-15.76)	(-19.93)	(-11.16)	(-17.99)

Panel B: 2013 Event for Pan-European Sample -- Time Series (Post Minus Pre) Differences

	Revenues Highest Primary Total Fees Used: 0.45 bps Highest Primary Total Fees Used: 0.16 bps			Revenues Lowest Primary Total Fees Used: 0.20 bps Lowest PrimaryTotal Fees Used: 0.02 bps		
	Large	Small	Overall	Large	Small	Overall
BXE						
Event	0.0006***	0.0089***	0.0075***	0.0116***	0.0170***	0.0136***
(t-statistic)	(5.68)	(19.49)	(24.14)	(7.79)	(18.43)	(24.03)
CXE						
Event	0.0257***	0.0155***	0.0231***	0.0468***	0.0286***	0.0414***
(t-statistic)	(6.80)	(10.50)	(13.17)	(8.95)	(9.64)	(12.83)
TQ						
Event	-0.0007***	-0.0023**	-0.0004	-0.0003**	-0.0009***	-0.0004***
(t-statistic)	(-0.81)	(-2.65)	(-0.74)	(-2.35)	(-3.73)	(-2.81)
Primary						
Event	-0.0313***	-0.0222***	-0.0304***	-0.0580***	-0.0448***	-0.0550***
(t-statistic)	(-5.72)	(-10.29)	(-14.82)	(-8.63)	(-14.67)	(-15.72)

Table 9: Measures of Market Quality – Time-Series Multivariate Regressions of the 2013 Event for the Pan-European Sample

This table reports the changes in market quality measures (Volume, Depth, and Spread) using time-series multivariate regressions for the 2013 event using a one-month pre- and one-month post-event window for the Pan-European sample. Following Boehmer Jones and Zhang (2015), we use a regression framework to run daily time-series regressions of the mean values of each measure of market quality on a dummy variable *Event* to indicate post-event period where we also control for market quality in competing venues (using the listing exchange market quality measures) and volatility index VIX (using the FTSE 100 volatility index). To deal with cross-sectional heterogeneity in each of the three market quality measures we standardize them as follows: we divide venue-stock-day volume by total daily volume, depth by average depth, and quoted spread by average quoted spread where total and averages are taken over all four venues (BXE, CXE, TQ, and listing exchange). We run regressions for the overall sample and two subsamples of the highest (*Large*) and lowest (*Small*) market capitalization terciles. Panel A reports estimated coefficients and t-statistics (in parentheses) for the BXE market, whereas Panels B and C reports similar statistics for the CXE and TQ markets, respectively. For all specifications we employ the Newey-West correction for autocorrelation in the error terms using 10 day lags. ** and *** indicate significance at the 5% and 1% levels, respectively.

Panel A: 2013 Event for Pan-European sample -- Time Series Regression Results for BXE

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.1825***	0.1587***	0.1588***	1.4419***	1.4339***	1.4302***	1.5858***	1.8113***	1.7509***
(t-statistic)	(17.98)	(6.30)	(11.64)	(7.29)	(13.72)	(15.99)	(4.87)	(11.33)	(17.46)
Event	-0.0018***	0.0077***	0.0020**	-0.0136**	-0.0097	-0.0053	0.0567***	-0.0382**	0.0151***
(t-statistic)	(-5.40)	(4.40)	(2.15)	(-2.40)	(-1.50)	(-0.93)	(6.35)	(-2.59)	(3.93)
Listing Exchange	-0.1867***	-0.1560***	-0.1587***	-0.4647***	-0.4338***	-0.4561***	-0.3685	-0.7240***	-0.6074***
(t-statistic)	(-14.49)	(-5.61)	(-9.85)	(-5.25)	(-6.24)	(-9.97)	(-0.82)	(-2.64)	(-4.47)
VIX	0.0002	0.0003	0.0003	-0.0007	0.0030	0.0017	-0.0053	-0.0052	-0.0030***
(t-statistic)	(0.91)	(0.79)	(1.95)	(-0.37)	(0.73)	(0.87)	(-1.22)	(-1.36)	(-2.83)
Nobs	41	41	41	41	41	41	41	41	41
Adj R^2	0.70	0.52	0.57	0.49	0.64	0.59	0.55	0.31	0.36

Panel B: 2013 Event for Pan-European sample -- Time Series RegressionResults for CXE

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.6100***	0.5471***	0.5930***	1.4793***	1.1455***	1.3143***	0.4897***	0.9119***	0.6139***
(t-statistic)	(53.10)	(21.71)	(30.92)	(9.49)	(17.53)	(16.67)	(6.50)	(6.35)	(6.17)
Event	-0.0010	-0.0042***	-0.0031	-0.0034	-0.0008	-0.0160***	-0.0211***	0.0278**	-0.0033
(t-statistic)	(-0.92)	(-2.69)	(-1.87)	(-0.68)	(-0.12)	(-5.27)	(-7.34)	(2.07)	(-0.84)
Listing Exchange	-0.6075***	-0.5615***	-0.5975***	-0.2924***	-0.1799***	-0.2278***	0.4305***	0.0248	0.3715**
(t-statistic)	(-36.17)	(-16.81)	(-21.14)	(-3.92)	(-6.68)	(-5.81)	(4.15)	(0.09)	(2.55)
VIX	0.0009***	0.0012***	0.0010***	0.0060***	0.0004	0.0034***	0.0030	-0.0006	-0.0009
(t-statistic)	(3.85)	(4.07)	(3.62)	(2.73)	(0.12)	(4.71)	(1.53)	(-0.18)	(-0.57)
Nobs	41	41	41	41	41	41	41	41	41
Adj R^2	0.92	0.79	0.85	0.38	0.27	0.51	0.55	0.14	0.15

Panel C: 2013 Event for Pan-European sample -- Time Series Regression Results for TQ

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.2075***	0.2942***	0.2402***	1.0788***	1.4206***	1.1973***	1.9166***	1.3070***	1.6151***
(t-statistic)	(20.85)	(26.05)	(12.62)	(8.59)	(12.16)	(13.25)	(5.26)	(11.80)	(9.42)
Event	0.0028***	-0.0035***	0.0012	0.0170**	0.0105	0.0210***	-0.0340***	0.0110	-0.0107**
(t-statistic)	(2.61)	(-3.11)	(1.23)	(2.17)	(1.68)	(4.61)	(-3.95)	(1.33)	(-2.77)
Listing Exchange	-0.2058***	-0.2825***	-0.2355***	-0.2429***	-0.3863***	-0.3006***	-1.0465**	-0.3475**	-0.7434***
(t-statistic)	(-12.37)	(-18.52)	(-8.16)	(-4.24)	(-5.24)	(-5.76)	(-2.03)	(-2.28)	(-3.05)
VIX	-0.0011***	-0.0014***	-0.0012***	-0.0053**	-0.0033**	-0.0035**	0.0018	0.0060	0.0034**
(t-statistic)	(-4.63)	(-4.04)	(-5.94)	(-2.28)	(-2.15)	(-2.57)	(0.41)	(1.85)	(2.09)
Nobs	41	41	41	41	41	41	41	41	41
Adj R^2	0.61	0.54	0.56	0.32	0.56	0.60	0.45	0.02	0.27

Table 10: Measures of Market Quality – Panel Regressions of the 2013 Event for the Pan-European Sample

This table reports the changes in market quality measures (Volume, Depth, and Spread) using panel regressions for the 2013 event using a one-month pre- and one-month post-event window for the Pan-European sample. Following Boehmer Jones and Zhang (2015), we use a regression framework to run panel regressions of each stocks daily values of each market quality measure on a dummy variable *Event* to indicate post-event period where we also control for market quality in competing venues (using the listing exchange market quality measures) and volatility index VIX (using the FTSE 100 volatility index). To deal with cross-sectional heterogeneity in each of the three market quality measures we standardize them as follows: we divide venue-stock-day volume by total daily volume, depth by average depth, and quoted spread by average quoted spread where total and averages are taken over all four venues (BXE, CXE, TQ and listing exchange). We run panel regressions for the overall sample and two subsamples of the highest (*Large*) and lowest (*Small*) market capitalization terciles. Panel A reports estimated coefficients and t-statistics (in parentheses) for the BXE market, whereas Panels B and C reports similar statistics for the CXE and TQ markets, respectively. For all specifications we account for stock fixed effects and clustered standard errors by date (time clusters). ** and *** indicate significance at the 5% and 1% levels, respectively.

Panel A: 2013 Event for Pan-European sample -- Panel Regression Results for BXE

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.1955***	0.2208***	0.1983***	1.2133***	1.3171***	1.1162***	1.9197***	1.7322***	1.7536***
(t-statistic)	(31.28)	(15.24)	(29.45)	(18.28)	(23.14)	(35.51)	(10.07)	(31.31)	(26.19)
Event	-0.0099***	0.0076***	0.0018**	-0.0134**	-0.0121	-0.0054	0.0558***	-0.0398***	0.0166***
(t-statistic)	(-2.66)	(5.27)	(2.36)	(-2.24)	(-1.63)	(-1.18)	(5.93)	(-3.51)	(2.84)
Listing Exchange	-0.1986***	-0.2424***	-0.2066***	-0.3714***	-0.3330***	-0.3376***	-0.8934***	-0.4930***	-0.6857***
(t-statistic)	(-32.89)	(-16.53)	(-26.61)	(-14.67)	(-20.59)	(-29.26)	(-4.11)	(-9.30)	(-10.04)
VIX	0.0001	0.0002	0.0002	-0.0003	0.0037	0.0014	-0.0020	-0.0058	-0.0031
(t-statistic)	(0.42)	(0.50)	(0.79)	(-0.14)	(0.94)	(0.82)	(-0.55)	(-1.67)	(-1.55)
Nobs	1640	1640	4920	1640	1640	4920	1640	1640	4920
Adj R^2	0.81	0.68	0.74	0.72	0.72	0.79	0.75	0.72	0.76

Panel B: 2013 Event for Pan-European sample -- Panel Regression Results for CXE

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.6131***	0.4907***	0.5632***	1.5609***	1.1295***	1.5157***	0.6397***	0.9680***	0.9696***
(t-statistic)	(67.39)	(39.11)	(64.93)	(33.47)	(19.93)	(47.10)	(8.47)	(22.97)	(20.34)
Event	-0.0010	-0.0042***	-0.0026**	-0.0032	0.0003	-0.0161***	-0.0212***	0.0316***	-0.0025
(t-statistic)	(-0.99)	(-2.71)	(-2.22)	(-0.53)	(0.06)	(-4.04)	(-4.63)	(3.46)	(-0.51)
Listing Exchange	-0.6115***	-0.4726***	-0.5391***	-0.3122***	-0.2145***	-0.2706***	0.2657***	-0.2950***	-0.0539
(t-statistic)	(-58.16)	(-46.60)	(-70.81)	(-18.44)	(-13.29)	(-24.18)	(-3.48)	(-5.15)	(-1.07)
VIX	0.0009**	0.0012**	0.0011**	0.0060***	0.0001	0.0030**	0.0040	0.0002	0.0015
(t-statistic)	(2.44)	(2.50)	(2.56)	(2.77)	(0.05)	(2.53)	(1.82)	(0.06)	(0.91)
Nobs	1640	1640	4920	1640	1640	4920	1640	1640	4920
Adj R^2	0.95	0.89	0.94	0.88	0.55	0.79	0.55	0.69	0.65

Panel C: 2013 Event for Pan-European sample -- Panel Regression Results for TQ

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
Intercept	0.1913***	0.2885***	0.2386***	1.2259***	1.5534***	1.3681***	1.4449***	1.2252***	1.2772***
(t-statistic)	(28.90)	(21.87)	(33.40)	(26.70)	(34.20)	(59.10)	(6.73)	(28.53)	(16.16)
Event	0.0029***	-0.0034**	0.0009	0.0165**	0.0118	0.0215***	-0.0315***	0.0089	-0.0098
(t-statistic)	(3.01)	(-2.52)	(0.88)	(2.65)	(1.66)	(4.92)	(-3.36)	(0.87)	(-1.47)
Listing Exchange	-0.1899***	-0.2850***	-0.2543***	-0.3164***	-0.4525***	-0.3918***	-0.3789	-0.2139***	-0.2670***
(t-statistic)	(-23.42)	(-22.32)	(-35.00)	(-17.98)	(-31.71)	(-47.61)	(-1.49)	(-4.26)	(-2.94)
VIX	-0.0011***	-0.0014***	-0.0013***	-0.0057**	-0.0039	-0.0044***	-0.0020	0.0056	0.0019
(t-statistic)	(-3.59)	(-4.36)	(-4.48)	(-2.55)	(-1.56)	(-2.90)	(-0.58)	(1.83)	(0.91)
Nobs	1640	1640	4920	1640	1640	4920	1640	1640	4920
Adj R^2	0.80	0.78	0.77	0.70	0.63	0.71	0.59	0.74	0.69

Table 11: Alternative Control Group – Australian Exchange

This table reports the changes in market quality measures (Volume, Depth, and Spread) of both time-series and panel multivariate regressions for the 2013 event for the LSE Sample where we use the Australian exchange measures for same period and for similar size firms as one of the controls. We run the regressions for the overall sample and two subsamples of the highest (*Large*) and lowest (*Small*) high frequency trading activity (HFT) terciles. HFT activity is captured using the ratio of daily number of quote updates for the same microsecond over the total number of quote updates for the day for each firm. We use the median daily ratio for the first three weeks of November 2012 (right before the pre-event period) to define our subsamples. Following Boehmer Jones and Zhang (2015), we use a regression framework to run both daily time-series and panel regressions of each market quality measure on a dummy variable *Event* to indicate post-event period where we also control for market quality in competing venues (using the Australian listing exchange market quality measures) and volatility index VIX (using the FTSE 100 volatility index). To deal with cross-sectional heterogeneity in each of the three market quality measures we standardize them as follows: we divide venue-stock-day volume by total daily volume, depth by average depth, and quoted spread by average quoted spread where total and averages are taken over all four venues (BXE, CXE, TQ, and Australian listing exchange). For all time-series specifications (Panel A) we employ the Newey-West correction for autocorrelation in the error terms using 10 day lags. For all panel regression specifications (Panel B) we account for stock fixed effects and clustered standard errors by date (time clusters). ** and *** indicate significance at the 5% and 1% levels, respectively.

Panel A: 2013 Event for LSE sample -- Time Series Regression Results

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
BXE									
Event	0.0003	0.0120***	0.0072***	-0.0471***	0.0062	-0.0133**	0.0365***	-0.0806***	-0.0208
(t-statistic)	(0.28)	(2.98)	(2.91)	(-7.79)	(0.71)	(-2.09)	(8.60)	(-3.05)	(-1.24)
CXE									
Event	0.0026	-0.0167***	-0.0044**	-0.0349**	-0.0096	-0.0089	0.0009	0.0569***	0.0270***
(t-statistic)	(0.78)	(-8.21)	(-2.14)	(-1.98)	(-1.21)	(-0.55)	(0.15)	(4.07)	(3.35)
TQ									
Event	0.0156***	-0.0079***	0.0055**	0.1175***	-0.0304***	0.0423***	-0.0256***	0.0114	-0.0023
(t-statistic)	(6.36)	(-3.36)	(2.41)	(12.28)	(-4.37)	(5.56)	(-3.37)	(1.76)	(-0.37)

Panel B: 2013 Event for LSE sample -- Panel Regression Results

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
BXE									
Event	0.0003	0.0120***	0.0074***	-0.0471***	0.0062	-0.0129	0.0366***	-0.0806***	-0.0220
(t-statistic)	(0.30)	(3.97)	(3.85)	(-6.41)	(0.47)	(-1.26)	(5.70)	(-3.85)	(-1.82)
CXE									
Event	0.0026	-0.0167***	-0.0044	-0.0349**	-0.0096	-0.0094	0.0009	0.0569***	0.0283***
(t-statistic)	(0.77)	(-4.71)	(-1.76)	(-2.33)	(-0.98)	(-0.78)	(0.19)	(4.69)	(3.98)
TQ									
Event	0.0156***	-0.0079***	0.0053***	0.1175***	-0.0304***	0.0425***	-0.0256***	0.0114	-0.0021
(t-statistic)	(9.43)	(-2.91)	(2.78)	(14.62)	(-3.72)	(4.51)	(-4.60)	(1.22)	(-0.35)

Figure 1: **Order Submission Strategies and Market Quality: Symmetric Change in the Make Fee (MF) and the Take Fee (TF)** These figures reports on the vertical axes the average of the equilibrium order submission probabilities of limit orders (LO^j) and the average of the derived measures of market quality ($Spread^j$ and $BBODepth^j$) over the periods t_1 and t_2. It also reports the average of the market share (MS^j) over the periods t_2 and t_3. The model is solved by changing both the make fee (MF) and the take fee (TF) from 0.01 to 0.05 in steps of 0.01 (horizontal axis). Results are reported for both the primary (Prim) and the competing (Comp) market. For each market results are also reported for both liquid and illliquid stocks. Traders have a personal evaluation of the asset which is truncated Normal,$\gamma \sim N(\mu, \sigma^2)$ and lies in the domain $\gamma \in (0.8, 1.2)$ for liquid stocks and $\gamma \in (0.0, 2.0)$ for illiquid stocks. $AV = \mu = \sigma^2 = 1$.

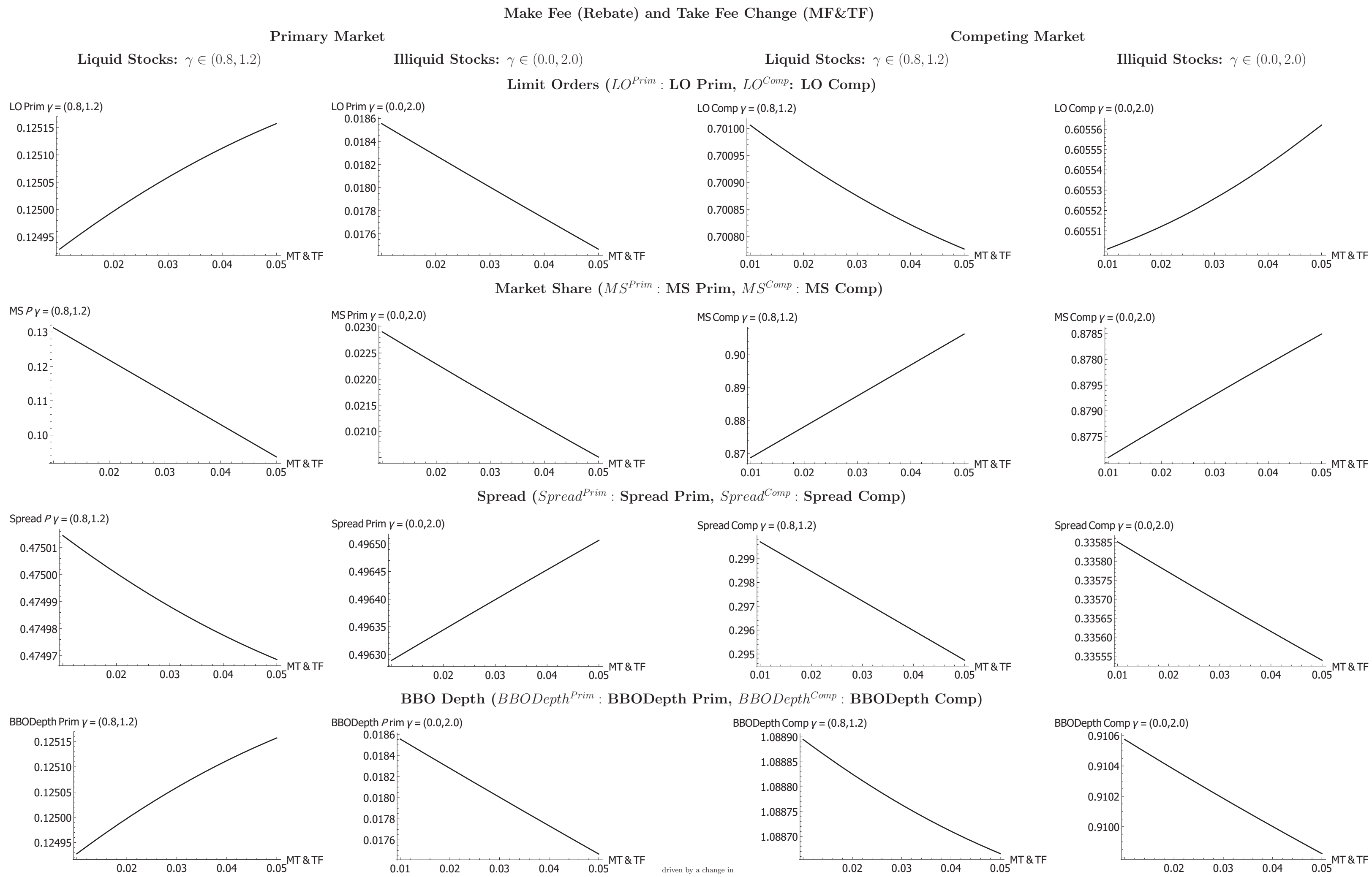


Figure 2: **Order Submission Strategies and Market Quality: Asymmetric Change in the Make Fee (MF) and the Take Fee (TF)** These figures reports on the vertical axes the average of the equilibrium order submission probabilities of limit orders (LO^j) and the average of the derived measures of market quality ($Spread^j$ and $BBODepth^j$) over the periods t_1 and t_2. It also reports the average of the market share (MS^j) over the periods t_2 and t_3. The model is solved by discretizing one of the cases presented in Table 2 and changing the make fee (MF) from 0.02 to 0.05 in steps of 0.006 (horizontal bottom axis) and the take fee (TF) from 0.01 to 0.03 in steps of 0.004 (horizontal top axis). Results are reported for both the primary (Prim) and the competing (Comp) market. For each market results are also reported for both liquid and illliquid stocks. Traders have a personal evaluation of the asset which is truncated Normal, $\gamma \sim N(\mu, \sigma^2)$ and lies in the domain $\gamma \in (0.8, 1.2)$ for liquid stocks and $\gamma \in (0.0, 2.0)$ for illiquid stocks. $AV = \mu = \sigma^2 = 1$.

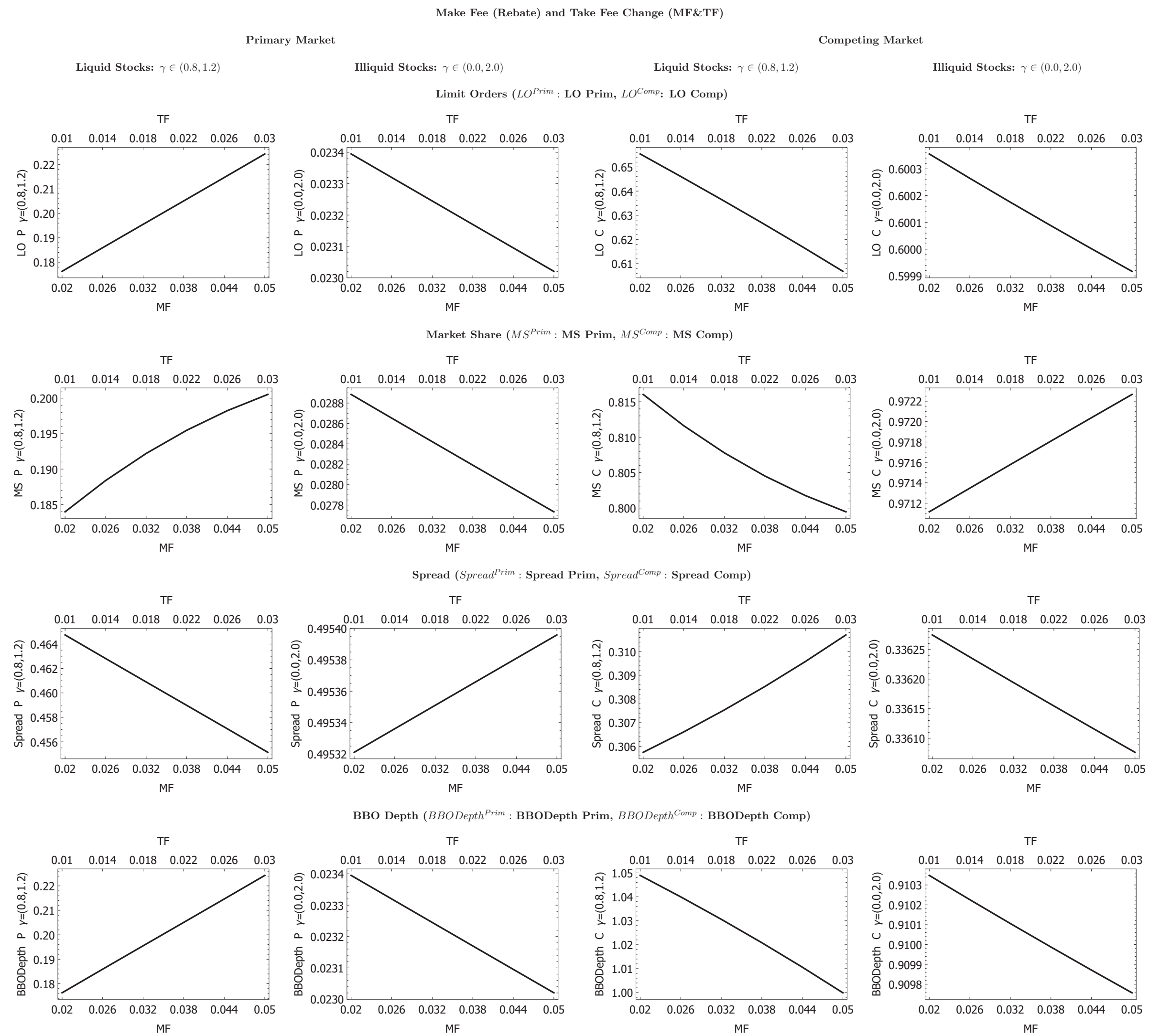


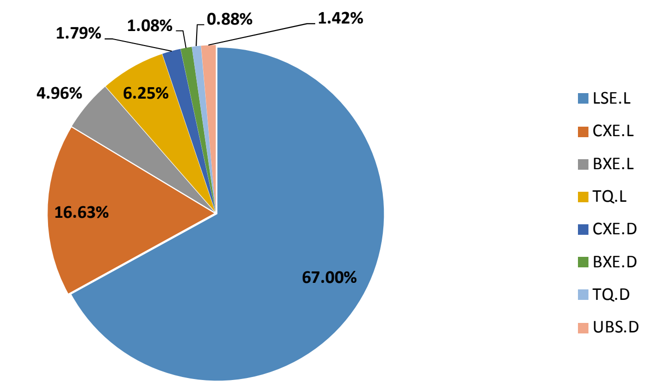
Figure 3: Market Share Pie-Charts of both the LSE and Pan-European samples in 2012 (Pre-Event) and 2015 (Post-Event)

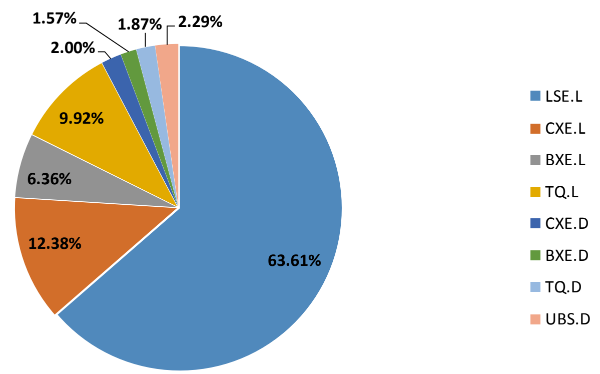
The pie-chart figures show average daily market share of each market venue used in the analysis for the LSE and Pan-European samples in the pre-period of the 2013 event (November and December 2012) and in the period after the 2015 event (February and March 2015). In particular, we look at both lit markets (LSE.L, CXE.L, BXE.L, and TQ.L) and dark pool venues (CXE.D, BXE.D, TQ.D, and UBS.D) market share. We exclude other trading venues and off-market trades for the pie-charts. Market share data were collected from Fidessa (Fragulator).

<u>**2013 Event Pre-Period (November and December 2012)**</u>

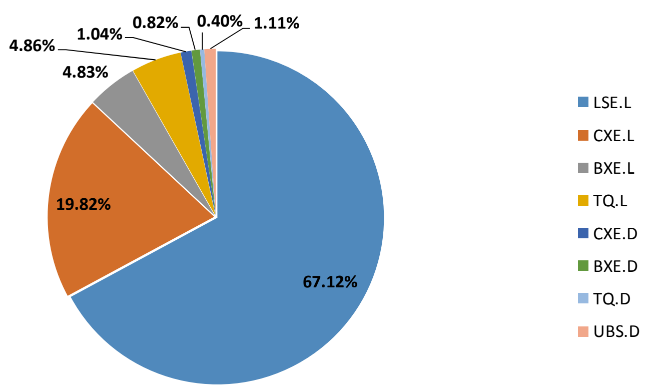
<u>**2015 Event Post-Period (February and March 2015)**</u>

Panel A: LSE Sample





Panel B: Pan-European Sample



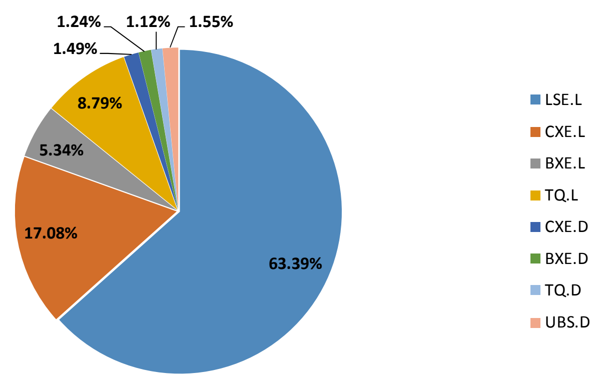
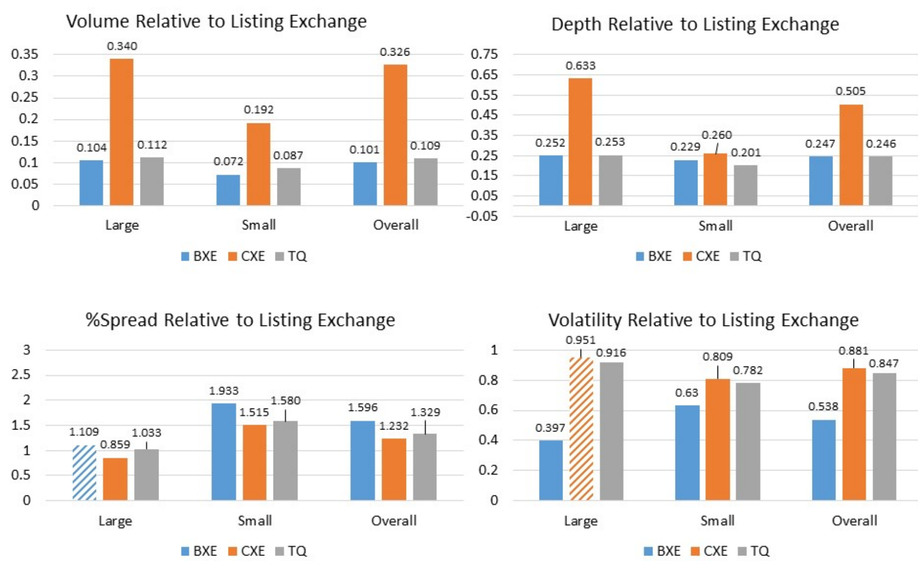


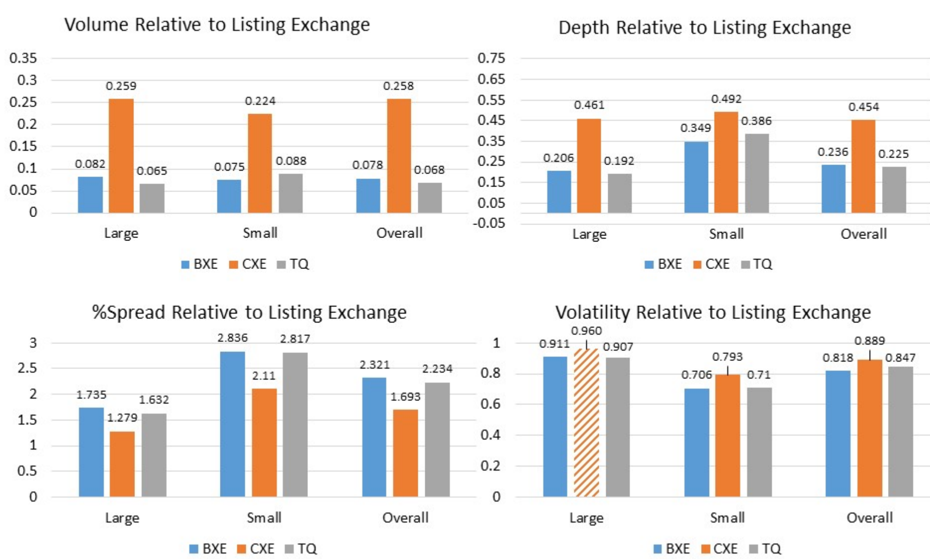
Figure 4: Market Quality Measures across Markets

The figures show average daily market quality measures (Volume, Depth, %Spread, and Volatility) of the three market venues (BXE, CXE, TQ) relative to the listing exchange in the pre-period (Nov/Dec 2012) of the 2013 Event. Panel A reports results for the LSE sample and Panel B for the Pan-European sample. The figures depict relative market quality measures for the overall sample and two subsamples of the highest (*Large*) and lowest (*Small*) market capitalization terciles. Filled bars indicate that a venue mean is significantly different from the listing exchange mean based on a simple differences-in-group-means test.

Panel A: LSE Stocks November-December 2012



Panel B: Pan-European Stocks November – December 2012



Internet Appendix

Appendix 1: Model Solution

At each period t_z, a trader uses the information from the state of the book of both the primary and the competing market to rationally compute and compare the payoffs from the available strategies (Table 1). However, to compare the payoffs across these strategies, the trader has to compute the execution probabilities of limit orders, which are uncertain as they depend on the probability of the t_{z+1} (and possibly t_{z+2}) market order submissions. To overcome this issue, the model is solved by backward induction starting from the last period of the trading game, t_3. At t_3 the execution probabilities of limit orders, $LO_{t_3}(P_i^j)$, are equal to zero and therefore to choose the order submission strategy ($ST_{t_3}^*$) that maximizes the expected payoff ($\pi_{t_3}^e$) conditional on their personal evaluation of the asset, γ, traders solve problem (5) by choosing between market orders, $MO_{t_3}(P_i^{j,b})$, and no-trade $NT_{t_3}(0))$:

$$max_{ST_{t_3}^*} \pi_{t_3}^e \left\{ MO_{t_3}(P_i^{j,b}),\, NT_{t_3}(0) \mid \gamma,\, lob_{t_3}^j \right\} \tag{5}$$

Table 1 shows that the non-zero traders' payoffs are a function of $\gamma \in (\overline{\gamma}, \underline{\gamma})$. We can therefore rank the payoffs of adjacent optimal strategies in terms of γ and equate them to determine the t_3 equilibrium γ thresholds in the following way:

$$\gamma_{t_3}^{ST_n^*, ST_{n-1}^*} = \left\{ \gamma \in \mathbb{R} \,:\, \pi_{t_3}^e \left(ST_n^* \,|\, lob_{t_3}^j \right) - \pi_{t_3}^e \left(ST_{n-1}^* \,|\, lob_{t_3}^j \right) = 0 \right\} \tag{6}$$

By using the γ thresholds together with the cumulative distribution function (CDF) of γ, $F(\centerdot)$, we can now derive the probability of each equilibrium order submission strategy, $ST_{\centerdot}^*$, conditional on all the possible combinations of the t_3 states of the book:

$$Pr[ST_n^* \,|\, lob_{t_3}^j] = F(\gamma_{t_3}^{ST_{n+1}^*, ST_n^*} \,|\, lob_{t_3}^j) - F(\gamma_{t_3}^{ST_n^*, ST_{n-1}^*} \,|\, lob_{t_3}^j) \tag{7}$$

Clearly, the probability to observe a $MO_{t_3}(P_i^{j,b})$ at t_3 is the execution probability of a $LO_{t_2}(P_i^j)$ at t_2, therefore, we can now compute and compare the t_2 payoffs to determine the equilibrium γ thresholds and therefore the equilibrium order submission probabilities conditional on each possible combination of the states of the book in the two markets at t_2. The t_1 equilibrium order submission strategies can then be recursively obtained, as the t_2 market orders' equilibrium probabilities are the execution probabilities of the limit orders posted at t_1.

As a general example, consider a case at t_3 with the book that opens empty and with one sell order standing on the first level of the competing market and one buy order standing on the second level of the primary market. This means that the payoffs from the t_3 strategies are:

$$\begin{aligned} \pi^e_{t_3}(MO_{t_3}(S^C_1)\,|\,lob^j_{t_3}) &= \gamma AV - S^C_1 - tf \\ \pi^e_{t_3}(NT_{t_3}(0)\,|\,lob^j_{t_3}) &= 0 \\ \pi^e_{t_3}(MO_{t_3}(B^P_2)\,|\,lob^j_{t_3}) &= B^P_2 - \gamma AV - TF \end{aligned} \tag{8}$$

Hence the t_3 equilibrium strategies are:

$$ST^*_{(\bullet)} = \begin{cases} MO_{t_3}(S^C_1) & \text{if } \gamma \in [\underline{\gamma},\, \frac{S^C_1 - tf}{AV}) \\ NT_{t_3}(0) & \text{if } \gamma \in [\frac{S^C_1 - tf}{AV},\, \frac{B^P_2 + TF}{AV}) \\ MO_{t_3}(B^P_2) & \text{if } \gamma \in (\frac{B^P_2 + TF}{AV},\, \overline{\gamma}] \end{cases} \tag{9}$$

and the t_3 equilibrium order submission probabilities are:

$$Pr[ST^*_{(\bullet)}\,|\,lob^j_{t_3}] = \begin{cases} \int_{\gamma \in \left\{\gamma \,:\, ST^*_{(\bullet)} = MO_{t_3}(1, S^C_1)\right\}} g(\gamma)\, d\gamma \\ \int_{\gamma \in \left\{\gamma \,:\, ST^*_{(\bullet)} = NT_{t_3}(0)\right\}} g(\gamma)\, d\gamma \\ \int_{\gamma \in \left\{\gamma \,:\, ST^*_{(\bullet)} = MO_{t_3}(1, B^P_2)\right\}} g(\gamma)\, d\gamma \end{cases} \tag{10}$$

where $g(\gamma)$ is the probability density function (PDF) of γ.
Note that $Pr[MO_{t_3}(S^C_1)\,|\,lob^j_{t_3}]$ and $Pr[MO_{t_3}(B^P_2)\,|\,lob^j_{t_3}]$ correspond to the execution probabilities of the previous period (t_2) limit orders respectively posted to the competing and to the primary market, i.e., $[LO_{t_2}(S^C_1)\,|\,lob^j_{t_2}]$ and $[LO_{t_2}(B^P_2)\,|\,lob^j_{t_2}]$, which are the dynamic link between periods t_3 and t_2.

As an example, we now solve the model to obtain the results shown in Table 2 for one set of trading fees: $MF = TF = 0.01$ and $mf = tf = 0.0$. Results for the other sets of fees can be obtained in a similar way. Tables A1, A2 and A3 show the equilibrium strategies (column 1) at t_3, t_2 and t_1 respectively for all the possible states of the book starting from an empty book at t_1. Each table also shows the payoff associated to each equilibrium strategy (column 2), the γ thresholds indicating the corresponding support of the TN distribution for each equilibrium strategy (column 3), and the resulting submission probabilities (column 4).[35]

The model is solved by backward induction, so as an example, following the branch of the trading game that starts at t_1 with $LO_{t_1}(S^C_2)$, the book opens at t_2 as [0000-1000].[36] Given the four equilibrium strategies that result when we condition to this opening book at t_2, [$LO_{t_2}(S^C_1)$, $LO_{t_2}(S^P_1)$, $LO_{t_2}(B^C_2)$ and $MO(S^C_2)$], at t_3 the book may open with four different states of the book, [0000-1100], [0100-1000], [0000-1001] and [0000-0000], respectively. The last column of each table shows the submission probability of the equilibrium orders which are then used to compute both the metrics of order flows (average limit orders, LO^j, and average

[35]The γ thresholds indicate the optimal trading strategies that result from comparing the payoffs of all the possible orders a trader can choose conditional on each state of the book in any trading period (equation 6).

[36][0000-1000] indicates the state of the primary and of the competing market respectively, $[l^{S^P_2} l^{S^P_1} l^{B^P_1} l^{B^P_2} - l^{S^C_2} l^{S^C_1} l^{B^C_1} l^{B^C_2}]$.

market share MS^j), and the metrics of market quality, (average quoted spread, $Spread^j$ and average depth at the best bid-offer, $BBODepth^j$), shown in Table 2 for the above mentioned set of trading fees: $MF = TF = 0.01$ and $mf = tf = 0.0$. Finally, Tables A4 and A5 show how to obtain both the order flows and the market quality metrics for this set of fees, starting from the equilibrium order submission strategies. Therefore, Tables A4 and A5 link Tables A1, A2 and A3 with Table 2.[37] Results for different sets of fees can be obtained in a similar way.

[Insert Tables A1, A2, A3, A4 and A5 about here]

Appendix 2: BATS fee changes 2014 and 2015

On April 3, 2014, BATS announced a new pricing model for CXE that was designed specifically to attract traders that routinely supply a large amount of liquidity (effective retroactively as of April 1, 2014). CXE introduced rebate pricing tiers, ranging from 0.15 bps to 0.25 bps for monthly value exceeding £4bn. Compared to the rebate schedule offered by TQ, CXE introduced more tiers, but the increase in the rebate was less aggressive.[38] The take fee remained at 0.30 bps as a default, but an optional Removal Package was also introduced where a broker could pay a fixed £25,000 (€25,000) fee per calendar month in order to enjoy a lower take fee of 0.20 bps. The new pricing scheme applied only to the CXE platform (there were no changes to BXE Lit or BATS two Dark platforms) for UK & Irish stocks (LSE listed firms) and French, Dutch, Belgian, and Portuguese stocks (Euronext listed firms). We use the same stratified methodology described in Section 4.2 to construct our samples and study the 2014 BATS fee changes.

The April 2014 introduction of CXE value tiers for determining the rebate rate combined with a Removal Package targeted HFTs and was intended to create a virtuous cycle. The Removal Package would encourage HFTs to route more aggressive orders to CXE to meet the value tiers, and as a reward they would obtain a higher rebate and therefore route also more passive orders to the CXE platform. This would in theory improve market quality, encouraging also other traders to route their aggressive and passive orders to CXE. A rebate increase on its own should result in an improvement in market quality as it encourages liquidity provision, but also a decrease in volume as traders switch from active to passive strategies. However, BATS' hope was that the Removal package would entice traders seeking better liquidity and the high volume traders already on CXE seeking to meet value-tiers would be sufficient to cause volume to instead increase. If successful, the virtuous cycle would also strenghten the

[37]Results for average values reported in Tables A4 and A5 have been obtained by rounding at the third decimal value and they may slightly differ from the results reported in column 8 of Table 2 which have been obtained without any rounding.

[38]The rebates were 0.15 bps for monthly value traded below £1.5bn, .175 between £1.5 and £2bn, 0.20 bps between £2.0 and £3, 0.225 between £2.0 and £3.0bn, and 0.25 bps for value traded above £4bn.

positive effect on market quality. So we would expect an improvement in CXE market quality and an increase in CXE market share.

Table A6 Panels A and B report the estimated changes in volume and market quality measures for the 2014 CXE fee change. CXE market shares for LSE and Pan-European stocks decrease, but the change is not statistically significant. Similarly, depth tends to decline but the change is not statistically significant but spreads for LSE stocks widen significantly by 3.62% overall, and by 2.11% for large stocks. Spreads also widen by a significant 2.04% for Pan-European stocks overall. In other words, the 2014 CXE fee-change was unsuccessful in terms of generating the desired increase in market share and the associated increase in fee revenue. Moreover, the fee change did not entice rebate seeking HFTs, and hence it did not result in consistently better market quality.

[Insert Table A6 about here]

Evidence suggesting that it was even worse can be seen from examining the effect of the CXE fee change on BXE and TQ. Note that neither BXE nor TQ changed its make-take fees in the event window surrounding April 3, 2014. Table A6, Panel A shows that BXE market share for LSE stocks increases significantly both overall and for large and small stocks. At the same time, BXE depth increases significantly for large stocks and spread decreases overall. For Pan-European stocks in Panel B, we see similar effects: market share increases significantly overall and for large stocks, depth increases significantly for large stocks and spread decreases overall. TQ does not gain markets share (it even loses market share and depth for small stocks) for LSE stocks, but market quality improves significantly for large stocks and overall depth increases significantly. For the Pan-European sample, TQ gains market share and market quality improves significantly for large stocks. Hence, it appears that the April 2014 fee change instead of attracting more volume and improving market quality on CXE resulted in more aggressive orders being routed to BXE and more passive orders particularly in large stocks being routed to TQ.

On November 24, 2014, BATS announced yet another update to its pricing model, to be effective January 1, 2015, on CXE. The main innovation was to allow a participant's total notional value traded across all BATS Europe's four platforms, dark and lit, to be combined to determine the value traded for the purposes of meeting the new volume tiers on CXE. However, note that the rate at which the new rebates rose with increased value traded is much flatter than before, ranging from a rebate of 0.15 bps to a rebate of 0.225 bps for monthly value traded in excess of £16bn. In addition, CXE take fee tiers were introduced, ranging from 0.30 bps to 0.240.1249 bps for monthly value traded exceeding £16bn. This new pricing model applied to all CXE order books throughout Europe.[39]

The January 2015, CXE fee structure was specifically designed to entice HFTs. The hope was that the take-fee tiers would result in more active orders being routed to CXE, which inturn would ideally entice rebate-seeking HFTs to route even more passive orders to CXE, starting a virtuous cycle. However, the fact that orders executed on any platform counts toward both the value-tiers means that traders will send fewer market orders to CXE and instead remain on BXE to enjoy the lower take fee or stay dark. In other words, fee sensitive HFT traders could essentially separate the order flow and send passive orders to CXE (to capture rebates) and active orders to BXE (which has lower take fees) or to one of the two BATS dark venues. As a result, it is unclear if the take-fee tiers would be sufficient to start a virtuous cycle.

Panels C and D of Table A6 report the estimated changes in market share and market quality measures for CXE. Market share does not change significantly for either universe or subsample. However, depth declines significantly both overall and for large stocks for both LSE and Pan-European samples following the fee change. CXE depth falls significantly both overall and for large LSE and large Pan-European stocks. CXE spreads widen significantly for LSE stocks overall and for large stocks, and also for large Pan-European stocks overall. In other words, CXE market quality deteriorates without an increase in market share suggesting that the 2015 fee changes failed to ignite a virtuous cycle for large stocks. By contrast, while CXE market share did not change significantly, both spreads and depth declined for small stocks for both universes.

Evidence that aggressive orders migrated to BXE both in search of lower take-fees and to meet CXE value-tiers can be seen in Panels C and D of Table A6. BXE volume increases significantly overall and for large stocks regardless of universe. At the same time, BXE market quality for large stocks improves significantly, depth increases and spreads decline . Hence, the inflow of market orders from CXE also enticed traders to route more limit orders to BXE in spite of the fact that they would receive no rebates. Although there is only evidence of a significant increase in TQ market share for large Pan-European stocks, TQ depth increases and spreads widen significantly both overall and for most subsamples by size. This result suggests that limit orders leaving TQ in search of more attractive rebates schedules on CXE.

[39] The rebate (take-fee) tiers were 0.15 bps (0.30 bps) for monthly value traded below £8.0bn, .175 (0.28 bps) between £8.0 and £12bn, 0.20 bps (0.26 bps) between £12.0 and £16.0, 0.225 bps (0.24 bps) for value traded above £16.0bn.

Appendix 3: Nasdaq and Toronto Stock Exchange fee experiments

Nasdaq Fee Pilot

To provide initial empirical evidence on the likely effects of imposing a lower cap on access fees, Nasdaq on November 4, 2014, announced a fee pilot experiment which lowered the Nasdaq take fee to $0.0005/share and the liquidity rebate to $0.0004/share for fourteen stocks.[40]

Hatheway (2015a, 2015b) shows that the pilot resulted in a reduction in Nasdaq's time and size at the National Best Bid Offer (NBBO) and also a reduction in Nasdaq's market share. However, there were no significant difference in changes in Nasdaq quote quality between pilot and control stocks. Hatheway concludes that more rebate sensitive traders, such as HFT market makers, left Nasdaq but that other liquidity providers (both market makers and algorithmic traders) replenished some of the lost liquidity.[41]

Based on these results, several market participants advocated that the SEC should require NYSE-ARCA and BATS-Direct Edge to participate in any new access fee pilot to avoid the prisoner dilemma introduced by the fee cap, and also proposed that the new access fee pilot should cover a broader cross-section of stocks.[42]

TSX Maker-Taker Reduction Program

In response to industry concerns about maker-taker pricing, Toronto Stock Exchange (TSX) implemented a phased program of reductions to its maker-taker fees. TSX encouraged competing platforms to follow their example with limited success. Only minor changes were undertaken by Aequitas (non-interlisted and ETFs) and Chi-X Canada (ETFs). Hence, no competing market changed its fees for interlisted stocks in June, 2015.

The first phase of the program entailed a TSX reduction of both taker fees and rebates for interlisted stocks priced above $1 of 5 bps (to 30/26) and for ETFs by 7 bps (to 23/19). For non-interlisted stocks above $1, the TSX take fee was reduced 7 bps (35 to 28) while the rebate was reduced 12 bps (31 to 19). As a result, the total fee became 4 bps for all segments of the market. At the same time, TSX introduced reductions to the maker-taker fees for its TSX Alpha (TSX-A) platform to a take fee of 18 bps and a rebate of 14 bps for all segments, resulting in a total fee of 4 bps.

The TSX impact report for the three months following the 2015 fee changes (June, July, and August) shows that quoted and effective spreads increased significantly (19%) both market-wide

[40] For information on the Nasdaq Fee Pilot, and access to the Nasdaq reports, please see: http://www.nasdaqomx.com/transactions/trading/access-fee-experiment.

[41] Pearson (2015) commented that the Nasdaq Fee Pilot allowed ITG to achieve higher queue positions on Nasdaq to the benefit of their clients.

[42] For example, Bloomberg and Themis Trading, LLC

(Canadian Best Bid Offer (CBBO)) and for TSX following the fee change. While there was no significant change in CBBO depth overall, both CBBO and TSX depth declined significantly (11% and 18% respectively) for highly liquid, low-priced ($1 to $5) interlisted stocks. There were also changes in market shares associated with the fee changes. TSX-A particularly lost market share relative to TSX, which suggests that rebate sensitive HFTs shifted away from TSX-A which had lower rebates (14 bps) than TSX (19 to 26 bps) following the fee change. The TSX impact report highlights that there were significant macro even during this time period, and that a major market structure event took place in September. Therefore, they recommend caution in terms of extrapolating from these findings.

Table A1: **Equilibrium Strategies at** t_3 This table shows how to derive the equilibrium order submission strategies at t_3 for the following set of trading fees: $MF = TF = 0.01$ and $mf = tf = 0.0$ and for $\gamma \in (0.0, 2.0)$. At t_1 both the primary and the competing markets open with an empty book, [0000-0000], where each element in the square bracket, $l_{t_z}^{S_i^j}$, corresponds to the depth of the book at each price level of both the primary and the competing market at time t_z, $[l^{S_2^{Prim}} l^{S_1^{Prim}} l^{B_1^{Prim}} l^{B_2^{Prm}} - l^{S_2^{Comp}} l^{S_1^{Comp}} l^{B_1^{Comp}} l^{B_2^{Comp}}]_{t_z}$.Given the chosen set of fees, four are the equilibrium strategies at t_1, $LO_{t_1}(S_1^{Comp})$, $LO_{t_1}(S_2^{Comp})$, $LO_{t_1}(B_1^{Comp})$ and $LO_{t_1}(B_2^{Comp})$. We only consider the sell side of the market, the buy side being synmmetrical. Given the equilibrium limit sell orders, the possible states of the books at the beginning of t_2 are: [0000-0100] and [0000-1000]. Given the equilibrium strategies at t_2 and therefore the possible states of the books at the beginning of t_3, this table shows the equilibrium Strategies at t_3 (column 1), their payoffs (column 2), the γ threesholds (column 3) and the order submission probabilities (column 4).

Equilibrium Strategy	**Payoff**	γ **Threshold**	**Order Submission Probability**
at t_1 **Prim and Comp books open empty [0000-0000]: equilibrium strategy** $LO_{t_1}(S_1^{Comp})$			
at t_2 **Prim and Comp books open [0000-0100]**			
t_2 **equilibrium strategy** NT_{t_2}			
at t_3 **Prim and Comp books open [0000-0100]**			
$NT_{t_3}(0)$	0	$\{0.000, 1.050\}$	0.5292
$MO_{t_3}(S_1^{Comp})$	$\gamma AV - S_1^{Comp} - tf = \gamma - 1.05$	$\{1.050, 2.000\}$	0.4708
t_2 **equilibrium strategy** $MO_{t_2}(1, S_1^{Comp})$			
at t_3 **Prim and Comp books open [0000-0000]**			
$NT_{t_3}(0)$	0	$\{0.000, 2.000\}$	1
t_2 **equilibrium strategy** $LO_{t_2}(1, B_2^{Comp})$			
at t_3 **Prim and Comp books open [0000-0101]**			
$MO_{t_3}(B_2^{Comp})$	$B_2^{Comp} - \gamma AV - tf = 0.85 - \gamma$	$\{0.000, 0.850\}$	0.4126
$NT_{t_3}(0)$	0	$\{0.850, 1.050\}$	0.1166
$MO_{t_3}(S_1^{Comp})$	$\gamma AV - S_1^{Comp} - tf = \gamma - 1.05$	$\{1.050, 2.000\}$	0.4708
at t_1 **Prim and Comp books open empty [0000-0000]: equilibrium strategy** $LO_{t_1}(S_2^{Comp})$			
at t_2 **Prim and Comp books open [0000-1000]**			
t_2 **equilibrium strategy** $LO_{t_2}(S_1^{Comp})$			
at t_3 **Prim and Comp books open [0000-1100]**			
$NT_{t_3}(0)$	0	$\{0.000, 1.050\}$	0.5292
$MO_{t_3}(S_1^{Comp})$	$\gamma AV - S_1^{Comp} - tf = \gamma - 1.05$	$\{1.050, 2.000\}$	0.4708
at t_2 **equilibrium strategy** $LO_{t_2}(S_1^{Prim})$			
at t_3 **Prim and Comp books open [0100-1000]**			
$NT_{t_3}(0)$	0	$\{0.000, 1.060\}$	0.5350
$MO_{t_3}(S_1^{Prim})$	$\gamma AV - S_1^{Prim} - TF = \gamma - 1.06$	$\{1.060, 2.000\}$	0.4650
at t_2 **equilibrium strategy** $LO_{t_2}(B_2^{Comp})$			
at t_3 **Prim and Comp books open [0000-1001]**			
$MO_{t_3}(B_2^{Comp})$	$B_2^{Comp} - \gamma AV - tf = 0.85 - \gamma$	$\{0.000, 0.850\}$	0.4126
$NT_{t_3}(0)$	0	$\{0.850, 1.150\}$	0.1748
$MO_{t_3}(S_2^{Comp})$	$\gamma AV - S_2^{Comp} - tf = \gamma - 1.15$	$\{1.150, 2.000\}$	0.4126
at t_2 **equilibrium strategy** $MO_{t_2}(S_2^{Comp})$			
at t_3 **Prim and Comp books open [0000-0000]**			
$NT_{t_3}(0)$	0	$\{0.000, 2.000\}$	1

Table A2: **Equilibrium Strategies at t_2** This table shows how to derive the equilibrium order submission strategies at t_2 for the following set of trading fees: $MF = TF = 0.01$ and $mf = tf = 0.0$ and for $\gamma \in (0.0, 2.0)$. At t_1 both the primary and the competing markets open with an empty book, [0000-0000], where each element in the square bracket, $l_{t_z}^{S_i^j}$, corresponds to the depth of the book at each price level of both the primary and the competing market at time t_z, $[l^{S_2^{Prim}} l^{S_1^{Prim}} l^{B_1^{Prim}} l^{B_2^{rim}} - l^{S_2^{Comp}} l^{S_1^{Comp}} l^{B_1^{Comp}} l^{B_2^{Comp}}]_{t_z}$. Given the chosen set of fees, four are the equilibrium strategies at t_1, $LO_{t_1}(S_1^{Comp})$, $LO_{t_1}(S_2^{Comp})$, $LO_{t_1}(B_1^{Comp})$ and $LO_{t_1}(B_2^{Comp})$. We only consider the sell side of the market, the buy side being synmmetrical. Given the equilibrium limit sell orders, the possible states of the books at the beginning of t_2 are: [0000-0100] and [0000-1000]. Column 1 shows the Equilibrium Strategies at t_2, column 2 shows their payoffs, and columns 3 and 4 shows the γ threesholds and the order submission probabilities respectively.

Equilibrium Strategy	**Payoff**	**γ Threshold**	**Order Submission Probability**
	at t_1 Prim and Comp books open empty [0000-0000]: equilibrium strategy $LO_{t_1}(S_1^{Comp})$		
at t_2 Prim and Comp books open [0000-0100]			
$NT_{t_2}(0)$	0	$\{0.000, 0.850\}$	0.4127
$LO_{t_2}(B_2^{Comp})$	$(\gamma AV - B_2^{Comp} + mf) \times Pr(MO_{t_3}(B_2^{Comp}) \mid [0000-0101]) = -0.351 + 0.413\gamma$	$\{0.850, 1.191\}$	0.1980
$MO_{t_2}(S_1^{Comp})$	$\gamma AV - S_1^{Comp} - tf = -1.05 + \gamma$	$\{1.191, 2.000\}$	0.3893
	at t_1 Prim and Comp books open empty [0000-0000]: equilibrium strategy $LO_{t_1}(S_2^{Comp})$		
at t_2 Prim and Comp books open [0000-1000]			
$LO_{t_2}(S_1^{Comp})$	$(S_1^{Comp} - \gamma AV + mf) \times Pr(MO_{t_3}(S_1^{Comp}) \mid [0000-1100]) = 0.494 - 0.471\gamma$	$\{0.000, 0.253\}$	0.1009
$LO_{t_2}(S_1^{Prim})$	$(S_1^{Prim} - \gamma AV + MF) \times Pr(MO_{t_3}(S_1^{Prim}) \mid [0100-1000]) = 0.493 - 0.465\gamma$	$\{0.253, 0.961\}$	0.3764
$LO_{t_2}(B_2^{Comp})$	$(\gamma AV - B_2^{Comp} + mf) \times Pr(MO_{t_3}(1, B_2^{Comp}) \mid [0000-1001]) = -0.351 + 0.413\gamma$	$\{0.961, 1.361\}$	0.2290
$MO_{t_2}(S_2^{Comp})$	$\gamma AV - S_2^{Comp} - tf = -1.15 + \gamma$	$\{1.361, 2.000\}$	0.2937

Table A3: **Equilibrium Strategies at t_1** This table shows how to derive the equilibrium order submission strategies at t_2 for the following set of trading fees: $MF = TF = 0.01$ and $mf = tf = 0.0$ and for $\gamma \in (0.0, 2.0)$. At t_1 both the primary and the competing markets open with an empty book, [0000-0000], where each element in the square bracket, $l_t^{S_i^j}$, corresponds to the depth of the book at each price level of both the primary and the competing market at time t_z, $[l^{S_2^{Prim}} l^{S_1^{Prim}} l^{B_1^{Prim}} l^{B_2^{Prim}} - l^{S_2^{Comp}} l^{S_1^{Comp}} l^{B_1^{Comp}} l^{B_2^{Comp}}]_{t_z}$. Given the chosen set of fees, four are the equilibrium strategies at t_1, $LO_{t_1}(S_1^{Comp})$, $LO_{t_1}(S_2^{Comp})$, $LO_{t_1}(B_1^{Comp})$ and $LO_{t_1}(B_2^{Comp})$ which are shown in column 1. Column 2 shows their payoffs, and colmns 3 and 4 shows the γ threesholds and the order submission probabilities respectively.

Equilibrium Strategy	**Payoff**	**γ Threshold**	**Order Submission Probability**
	at t_1 Prim and Comp books open empty [0000-0000]		
$LO_{t_1}(S_1^{Comp})$	$(S_1^{Comp} - \gamma AV + mf) \times [(Pr(MO_{t_2}(S_1^{Comp}) \mid [0000-0100]) + (1 - Pr(MO_{t_2}(S_1^{Comp}) \mid [0000-0100])) \times Pr(MO_{t_3}(S_1^{Comp}) \mid [0000-0100]))] = 0.711 - 0.677\gamma$	$\{0.000, 0.916\}$	0.4507
$LO_{t_1}(S_2^{Comp})$	$(S_2^{Comp} - \gamma AV + mf) \times [(Pr(MO_{t_2}(S_2^{Comp}) \mid [0000-1000]) + (1 - Pr(MO_{t_2}(S_2^{Comp}) \mid [0000-1000]) - Pr(LO_{t_2}(S_1^{Comp}) \mid [0000-1000]) - Pr(LO_{t_2}(S_1^{Prim}) \mid [0000-1000])) \times Pr(MO_{t_3}(S_2^{Comp}) \mid [0000-1000]))] = 0.446 - 0.388\gamma$	$\{0.916, 1.000\}$	0.0493
$LO_{t_1}(B_2^{Comp})$	$(\gamma AV - B_2^{Comp} + mf) \times [(Pr(MO_{t_2}(B_2^{Comp}) \mid [0000-0001]) + (1 - Pr(MO_{t_2}(B_2^{Comp}) \mid [0000-0001]) - Pr(LO_{t_2}(B_1^{Comp}) \mid [0000-0001]) - Pr(LO_{t_2}(B_1^{Prim}) \mid [0000-0001])) \times Pr(MO_{t_3}(B_2^{Comp}) \mid [0000-0001]))] = -0.330 + 0.388\gamma$	$\{1.000, 1.084\}$	0.0493
$LO_{t_1}(B_1^{Comp})$	$(\gamma AV - B_1^{Comp} + mf) \times [(Pr(MO_{t_2}(B_1^{Comp}) \mid [0000-0010]) + (1 - Pr(MO_{t_2}(B_1^{Comp}) \mid [0000-0010])) \times Pr(MO_{t_3}(B_1^{Comp}) \mid [0000-0010]))] = -0.643 + 0.677\gamma$	$\{1.084, 2.000\}$	0.4507

Table A4: **Equilibrium Order Submission Strategies, Order Flows and Market Quality**

This Table shows how to obtain the metrics on order flows and market quality (column 1) presented in Table 2 for the following set of trading fees: $MF = TF = 0.01$ and $mf = tf = 0.0$. Column 2 reports the equilibrium order submission probability of limit and market orders in the primary and in the competing market in each period t_z, $LO^j_{t_z}$ and $MO^j_{t_z}$, and the equilibrium average of limit orders, market orders and market share, LO^j, MO^j and MS^j. Column 3 shows how the values reported in column 2 are computed from the equilibrium strategies. Results are reported for both the primary (Prim) and the competing (Comp) market. Traders have a personal evaluation of the asset which is truncated Normal,$\gamma \sim N(\mu, \sigma^2)$ and lies in the domain $\gamma \in (0.0, 2.0)$. $AV = \mu = \sigma^2 = 1$.

Metric	**Value**	**Analytical Computation**
$LO^{Prim}_{t_1}$	0	0
$LO^{Prim}_{t_2}$	0.037	$(2\times Pr(LO_{t_1}(S^{Comp}_2)\vert .))\times Pr(LO_{t_2}(S^{Prim}_1)\vert 0000-1000) + (2\times Pr(LO_{t_1}(S^{Comp}_1)\vert .))\times Pr(LO_{t_2}(P^{Prim}_i)\vert 0000-0100) = (2\times 0.0493)\times 0.3764 + (2\times 0.4507)\times 0$
LO^{Prim}	0.019	$(LO^{Prim}t_1 + LO^{Prim}t_2)/2 = (0+0.037)/2$
$MO^{Prim}_{t_2}$	0	0
$MO^{Prim}_{t_3}$	0.017	$(2\times Pr(LO_{t_1}(S^{Comp}_2)\vert .))\times Pr(LO_{t_2}(S^{Prim}_1)\vert 0000-1000)\times Pr(MO_{t_3}(S^{Prim}_1)\vert 0100-1000) + (2\times Pr(LO_{t_1}(S^{Comp}_1)\vert .))\times Pr(LO_{t_2}(P^{Prim}_i)\vert 0000-0100) =$
		$(2\times 0.0493)\times 0.3764\times 0.4650 + (2\times 0.4507)\times 0$
MO^{Prim}	0.009	$(MO^{Prim}_{t_2} + MO^{Prim}_{t_3})/2 = (0+0.017)/2$
MS^{Prim}	0.024	$MO^{Prim}/(MO^{Prim} + MO^{Comp}) = 0.009/(0.009+0.368)$
$LO^{Comp}_{t_1}$	1	$(Pr(LO_{t_1}(S^{Comp}_1)\vert .) + Pr(LO_{t_1}(S^{Comp}_2)\vert .))\times 2 = (0.4507+0.0493)\times 2$
$LO^{Comp}_{t_2}$	0.211	$(2\times Pr(LO_{t_1}(S^{Comp}_1)\vert .))\times Pr(LO_{t_2}(B^{Comp}_2)\vert 0100-0000) + (2\times Pr(LO_{t_1}(S^{Comp}_2)\vert .))\times(Pr(LO_{t_2}(S^{Comp}_1)\vert 0000-1000) + Pr(LO_{t_2}(B^{Comp}_2)\vert 0000-1000)) =$
		$= (2\times 0.4507)\times 0.1980 + (2\times 0.0493)\times(0.1009+0.2290)$
LO^{Comp}	0.606	$(LO^{Comp}_{t_1} + LO^{Comp}_{t_2})/2 = (1+0.211)/2$
$MO^{Comp}_{t_2}$	0.380	$(2\times Pr(LO_{t_1}(S^{Comp}_1)\vert .))\times Pr(MO_{t_2}(S^{Comp}_1)\vert 0100-0000) + (2\times Pr(LO_{t_1}(S^{Comp}_2)\vert .))\times Pr(MO_{t_2}(S^{Comp}_2)\vert 0000-1000)=$
		$= (0.4507\times 2)\times(0.3893) + (0.0493\times 2)\times(0.2937)$
$MO^{Comp}_{t_3}$	0.356	$(2\times Pr(LO_{t_1}(S^{Comp}_1)\vert .))\times[Pr(LO_{t_2}(B^{Comp}_2)\vert 0000-0100)\times(Pr(MO_{t_3}(B^{Comp}_2)\vert 0000-0101) + Pr(MO_{t_3}(S^{Comp}_1)\vert 0000-0101))+$
		$+Pr(NT_{t_2}(0)\vert 0000-0100)\times Pr(MO_{t_3}(S^{Comp}_1)\vert 0000-0100)] + (2\times Pr(LO_{t_1}(S^{Comp}_2)\vert .))\times[Pr(LO_{t_2}(S^{Comp}_1)\vert 0000-1000)\times$
		$\times Pr(MO_{t_3}(S^{Comp}_1)\vert 0000-1100) + Pr(LO_{t_2}(B^{Comp}_2))\vert 0000-1000)\times(Pr(MO_{t_3}(S^{Comp}_2)\vert 0000-1001) + Pr(MO_{t_3}(B^{Comp})\vert 0000-1001))]=$
		$= (0.4507\times 2)\times[0.1980\times(0.4126+0.4708) + 0.4127\times 0.4708] + (0.0493\times 2)\times[0.1009\times 0.4708 + 0.2290\times(0.4126+0.4126)]$
MO^{Comp}	0.368	$(MO^{Comp}_{t_2} + MO^{Comp}_{t_3})/2 = (0.380+0.356)/2$
MS^{Comp}	0.976	$MO^{Comp}/(MO^{Prim} + MO^{Comp}) = 0.368/(0.009+0.368)$

Table A5: **Equilibrium Order Submission Strategies, Order Flows and Market Quality**

This Table shows how to obtain the metrics on order flows and market quality (column 1) presented in Table 2 for the following set of trading fees: $MF = TF = 0.01$ and $mf = tf = 0.0$. Column 2 reports both the equilibrium market quality metrics for periods $t_1$and t_2, $Spread^j_{tz}$ and $BBODepth^j_{tz}$, and the equilibrium average market quality metrics, $Spread^j$ and $BBODepth^j$. Column 3 shows how the values reported in column 2 are computed from the equilibrium strategies. Results are reported for both the primary (Prim) and the competing (Comp) markets. Traders have a personal evaluation of the asset which is truncated Normal,$\gamma \sim N(\mu, \sigma^2)$ and lies in the domain $\gamma \in (0.0, 2.0)$. $AV = \mu = \sigma^2 = 1$. We assume that when the book is empty the quoted spread is equal to 5 ticks, i.e., 0.5. To economize space we indicate the empty book, $0000 - 0000$, as $|$.

Metric	**Value**	**Analytical Computation**
$Spread^{Prim}_{t_1}$	0.500	$(2\times Pr(LO_{t_1}(S^{Comp}_2)\|.))\times 0.5 + (2\times Pr(LO_{t_1}(S^{Comp}_1)\|.))\times 0.5 = (2\times 0.0493)\times 0.5 + (2\times 0.4507)\times 0.5$
$Spread^{P}_{t_2}$	0.493	$(2\times Pr(LO_{t_1}(S^{Comp}_2)\|.))\times[0.3\times Pr(LO_{t_2}(S^{Prim}_1)\|0000-1000) + 0.5\times(1 - Pr(LO_{t_2}(S^{Prim}_1)\|0000-1000))] + (2\times Pr(LO_{t_1}(S^{Comp}_1)\|.))\times[0.5\times(Pr(NT_{t_2}(0)\|0000-0100)+$ $+Pr(LO_{t_2}(B^{Comp}_2)\|0000-0100) + Pr(MO_{t_2}(S^{Comp}_1)\|0000-0100))] = (2\times 0.0493)\times[0.3\times 0.3764 + 0.5\times(1 - 0.3764)] + (2\times 0.4507)\times 0.5\times(0.4127 + 0.1980 + 0.3893)$
$Spread^{Prim}$	0.497	$(Spread^{Prim}_{t_1} + Spread^{Prim}_{t_2})/2 = (0.5 + 0.493)/2$
$Spread^{Comp}_{t_1}$	0.310	$(2\times Pr(LO_{t_1}(S^{Comp}_2)\|.))\times 0.4 + (2\times Pr(LO_{t_1}(S^{Comp}_1)\|.))\times 0.3 = (2\times 0.0493)\times 0.4 + (2\times 0.4507)\times 0.3$
$Spread^{Comp}_{t_2}$	0.362	$(2\times Pr(LO_{t_1}(S^{Comp}_2)\|.))\times[0.3\times Pr(LO_{t_2}(S^{Comp}_1)\|0000-1000) + 0.4\times Pr(LO_{t_2}(S^{Prim}_1)\|0000-1000) + 0.3\times Pr(LO_{t_2}(B^{Comp}_2)\|0000-1000) + 0.5\times Pr(MO_{t_2}(S^{Comp}_2)\|0000-1000)]+$ $+(2\times Pr(LO_{t_1}(S^{Comp}_1)\|.))\times[0.3\times Pr(NT_{t_2}\|0000-0100) + 0.2\times Pr(LO_{t_2}(B^{Comp}_2)\|0000-0100) + 0.5\times Pr(MO_{t_2}(S^{Comp}_1)\|0000-0100)] =$ $= (2\times 0.0493)\times[0.3\times 0.1009 + 0.4\times 0.3764 + 0.3\times 0.2290 + 0.5\times 0.2937] + (2\times 0.4507)\times[0.3\times 0.4127 + 0.2\times 0.198 + 0.5\times 0.3893]$
$Spread^{Comp}$	0.336	$(Spread^{Comp}_{t_1} + Spread^{Comp}_{t_2})/2 = (0.310 + 0.362)/2$
$BBODepth^{Prim}_{t_1}$	0	$(2\times Pr(LO_{t_1}(S^{Comp}_2)\|.))\times 0 + (2\times Pr(LO_{t_1}(S^{Comp}_1)\|.))\times 0 = (2\times 0.0493)\times 0 + (2\times 0.4507)\times 0$
$BBODepth^{Prim}_{t_2}$	0.037	$\text{rim}(2\times Pr(LO_{t_1}(S^{Comp}_2)\|.))\times[1\times Pr(LO_{t_2}(S^{Prim}_1)\|0000-1000) + 0\times(1 - Pr(LO_{t_2}(S^{P}_1)\|0000-1000))] + (2\times Pr(LO_{t_1}(S^{Comp}_1)\|.))\times[0\times(Pr(NT_{t_2}(0)\|0000-0100)+$ $+Pr(LO_{t_2}(B^{Comp}_2)\|0000-0100) + Pr(MO_{t_2}(S^{Comp}_1)\|0000-0100))] = (2\times 0.0493)\times[1\times 0.3764 + 0\times(1 - 0.3764)] + (2\times 0.4507)\times 0\times(0.4127 + 0.1980 + 0.3893)$
$BBODepth^{Prim}$	0.019	$(BBODepth^{Prim}_{t_1} + BBODepth^{Prim}_{t_2})/2 = (0 + 0.037)/2$
$BBODepth^{Comp}_{t_1}$	1	$(2\times Pr(LO_{t_1}(S^{Comp}_2)\|.))\times 1 + (2\times Pr(LO_{t_1}(S^{Comp}_1)\|.))\times 1 = (2\times 0.0493)\times 1 + (2\times 0.4507)\times 1$
$BBODepth^{Comp}_{t_2}$	0.821	$(2\times Pr(LO_{t_1}(S^{Comp}_2)\|.))\times[1\times Pr(LO_{t_2}(S^{Comp}_1)\|0000-1000) + 1\times Pr(LO_{t_2}(S^{Prim}_1)\|0000-1000) + 2\times Pr(LO_{t_2}(B^{Comp}_2)\|0000-1000) + 0\times Pr(MO_{t_2}(S^{Comp}_2)\|0000-1000)]$ $+(2\times Pr(LO_{t_1}(S^{Comp}_1)\|.))\times[1\times Pr(NT_{t_2}\|0000-0100) + 2\times Pr(LO_{t_2}(B^{Comp}_2)\|0000-0100) + 0\times Pr(MO_{t_2}(S^{Comp}_1)\|0000-0100)] =$ $= (2\times 0.0493)\times[1\times 0.1009 + 1\times 0.3764 + 2\times 0.2290 + 0\times 0.2937] + (2\times 0.4507)[1\times 0.4127 + 2\times 0.198 + 0\times 0.3893]$
$BBODepth^{Comp}$	0.911	$(BBODepth^{Comp}_{t_1} + BBODepth^{Comp}_{t_2})/2 = (1 + 0.821)/2$

Appendix Table A6: Measures of Market Quality – Time-Series Changes for the 2014 and 2015 Events

This table reports the changes in market quality measures (Volume, Depth, and Spread) for the 2014 and the 2015 events using a one-month pre- and one-month post-event window. We investigate three market venues: CXE, BXE and TQ. To deal with cross-sectional heterogeneity in each of the three market quality measures we standardize them as follows: we divide venue-stock-day volume by total daily volume, depth by average depth, and quoted spread by average quoted spread where total and averages are taken over all four venues (BXE, CXE, TQ, and listing exchange). Our post minus pre (diff) estimation methodology is based on running daily time-series regressions of the mean values of each measure of market quality on a dummy variable *Event* to indicate post-event period. We run regressions for the overall sample and two subsamples of the highest (*Large*) and lowest (*Small*) market capitalization terciles. Panels A and B report estimated coefficients and t-statistics (in parentheses) of the LSE and the Pan-European sample, respectively, for the 2014 event. Panels C and D report similar statistics for the 2015 event. For all specifications we employ the Newey-West correction for autocorrelation in the error terms using 10 day lags. ** and *** indicate significance at the 5% and 1% levels, respectively.

Panel A: 2014 Event for LSE sample -- Time Series (Post Minus Pre) Differences

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
BXE									
Event	0.0068***	0.0090***	0.0078***	0.0179**	-0.0052	-0.0154	-0.0217	-0.0739	-0.0497**
(t-statistic)	(6.86)	(4.95)	(7.97)	(2.33)	(-0.11)	(-0.83)	(-1.57)	(-1.45)	(-2.18)
CXE									
Event	-0.0063	-0.0069***	-0.0069**	-0.0322	0.0144	-0.0063	0.0211***	0.0510***	0.0362***
(t-statistic)	(-0.97)	(-3.50)	(-2.00)	(-1.83)	(1.49)	(-1.22)	(4.99)	(2.80)	(5.02)
TQ									
Event	0.0133	-0.0194***	-0.0023	0.1558***	-0.0570**	0.0215***	-0.0316***	0.0231	0.0076
(t-statistic)	(1.04)	(-2.61)	(-0.22)	(16.30)	(-2.59)	(2.85)	(-8.84)	(1.03)	(0.70)

Panel B: 2014 Event for Pan-European sample -- Time Series (Post Minus Pre) Differences

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
BXE									
Event	0.0030***	0.0074***	0.0047***	0.0279***	-0.0276	-0.0074	0.0022	-0.0555	-0.0384***
(t-statistic)	(3.08)	(6.01)	(4.58)	(2.61)	(-1.22)	(-1.00)	(0.12)	(-1.68)	(-2.78)
CXE									
Event	0.0037	-0.0018	-0.0016	-0.0061	0.0279**	0.0043	0.0041	0.0448***	0.0204***
(t-statistic)	(1.01)	(-0.59)	(-0.42)	(-0.56)	(2.50)	(1.55)	(0.59)	(4.39)	(3.84)
TQ									
Event	0.0347***	-0.0021	0.0072	0.1500***	0.0080	0.0466***	-0.0464***	-0.0095	-0.0182***
(t-statistic)	(4.90)	(-0.21)	(0.80)	(8.55)	(0.36)	(8.63)	(-5.63)	(-1.12)	(-4.49)

Panel C: 2015 Event for LSE sample -- Time Series (Post Minus Pre) Differences

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
BXE									
Event	0.0292***	0.0013	0.0119***	0.1584***	-0.0763***	0.0278	-0.2672***	-0.0709***	-0.1198***
(t-statistic)	(15.89)	(0.66)	(10.28)	(9.29)	(-2.60)	(1.62)	(-5.20)	(-3.11)	(-4.96)
CXE									
Event	0.0020	-0.0014	-0.0009	-0.0707***	-0.1608***	-0.1043***	0.0838***	-0.0562***	0.0020
(t-statistic)	(0.64)	(-0.83)	(-0.39)	(-6.68)	(-5.88)	(-7.59)	(7.55)	(-3.94)	(0.23)
TQ									
Event	0.0130	0.0011	0.0024	0.0475	0.8243***	0.4720***	0.0698***	0.1671***	0.1157***
(t-statistic)	(1.31)	(0.24)	(0.53)	(0.52)	(4.37)	(3.83)	(3.60)	(3.49)	(5.07)

Panel D: 2015 Event for Pan-European sample -- Time Series (Post Minus Pre) Differences

	Volume/Total Volume			Depth/Average(Depth)			Spread/Average(Spread)		
	Large	Small	Overall	Large	Small	Overall	Large	Small	Overall
BXE									
Event	0.0239***	0.0011	0.0133***	0.1513***	-0.0518***	0.0595***	-0.1993***	-0.0149	-0.1014***
(t-statistic)	(14.99)	(0.53)	(10.56)	(22.60)	(-2.91)	(6.51)	(-15.42)	(-0.81)	(-8.47)
CXE									
Event	-0.0024	0.0033	0.0022	-0.0761***	-0.0577***	-0.0569***	0.0770***	-0.0082	0.0313***
(t-statistic)	(-0.43)	(1.09)	(0.73)	(-7.05)	(-4.61)	(-5.25)	(13.08)	(-0.97)	(7.40)
TQ									
Event	0.0270**	-0.0079	0.0113	0.0835**	0.1562**	0.0852***	0.0164	0.0565**	0.0395**
(t-statistic)	(2.30)	(-1.09)	(1.43)	(2.51)	(2.36)	(2.72)	(0.71)	(2.05)	(2.04)