February 24, 2016

Brent J. Fields
Secretary
Securities and Exchange Commission
100 F Street, N.E.
Washington, DC 20549-1090

Dear Mr. Fields:

We thank the Securities and Exchange Commission ("SEC") for the opportunity to comment on Investors' Exchange LLC's ("IEX") application for registration as a national securities exchange. Having undertaken empirical research on TSX Alpha Exchange's ("Alpha") speed bump in Canada, we support the principles underlying IEX's application and believe that it will benefit its clients without negatively impacting overall market quality within the National Market System ("NMS"). Further, we note IEX's application may be improved by extending the benefits offered to orders routed through its affiliated broker-dealer ("IEXS") to orders routed via all members.

<u>Lessons from the Introduction of a Speed Bump in Canada</u>

In our recent working paper "The Value of a Millisecond: Structural Segmentation of Uninformed Order Flow" (attached), we have examined the impact of a market structure innovation in Canada that introduced a randomized 1 - 3 millisecond speed bump against all marketable orders on Alpha in 2015. We find that the speed bump benefits low latency (fast) liquidity suppliers who are able to utilize order types that are exempt from the delay and gain critical information on likely future price movements occurring within the next millisecond. While incoming marketable orders are held up in the speed bump, low latency liquidity suppliers are able to remove or "fade" their quotes on Alpha after observing substantial trade executions or order book revisions on other markets. This mechanism enables these low latency (fast) traders to selectively avoid those incoming marketable orders that are likely to have originated from multi-venue smart order router sprays that, had they not been avoided, would have imposed instantaneous adverse selection costs. Our work suggests that this selective avoidance of these specific incoming orders increases the profitability of low latency liquidity provision strategies on Alpha to the detriment of the market as a whole.

IEX's application varies from the Alpha system in some important respects, however. One important distinction between the two is the randomized delay in the Alpha system as opposed to the fixed order processing delay proposed by IEX. Systematic order processing delays, especially if they are of fixed duration as in IEX's application, do not inherently eliminate the speed advantages possessed by different traders. Market participants who arrive at the fixed duration speed bump first will also arrive at the exchange matching engine first and have their order processed first, maintaining their speed advantage. Rather, the impact of any speed bump hinges on its discriminatory application to some market participants (or order types) and the exemption of others.

IEX's application contains two speed bumps. The first imposes a fixed 350 microsecond delay on all incoming orders from all market participants. IEX's re-pricing of non-displayed pegged orders is exempted from the first speed bump to minimize "sniping" of "stale" dark quotes. The second imposes a fixed 350 microsecond delay on the dissemination of order handling information. Message prints to the SIP and the IEXS order routing to away venues are exempted from the second speed bump.

Below, in Table 1, we compare the IEX application with the TSX Alpha system:

Table 1: Market Structure Comparison between IEX Application and TSX Alpha

Specification	IEX Application	TSX Alpha	Implications for IEX
Inbound Speed Bump Discrimination	All inbound orders except repricing of non-displayed pegged orders	All inbound orders except post only non-marketable orders	Dark pegged orders on IEX are protected from "stale quote snipers". All other IEX orders face equal application of the delay.
Outbound Speed Bump Discrimination	All outbound messages except to the SIP and IEXS routing to away venues	No outbound speed bump	Non-IEXS routers face an order handling confirmation delay, hindering liquidity access on away venues.
Speed Bump Duration	Fixed 350 microsecond	Randomized between 1 and 3 milliseconds	Smart order routers are able to incorporate a fixed delay into their multi-venue spray
Order Protection Rule Status[1]	Protected marketplace	Unprotected marketplace	Order protection for venues with speed bumps may be unreasonable if they exhibit persistently poor fill rates

Inbound Speed Bump Discrimination

The first speed bump in IEX's application imposes a 350 microsecond delay on all incoming orders from all market participants. The repricing of IEX's pegged orders without pre-trade transparency is exempted from this speed bump. This mechanism provides these orders with structural protection from "stale quote snipers" who observe price movements on other venues and may race to IEX to execute against orders that are pegged to a stale reference price.

[1] The Order Protection Rule applies to the NBBO in the United States and full depth of book in Canada

Participants who post non-displayed pegged orders on IEX are likely to face lower adverse selection costs, resulting in more profitable liquidity provision. Additionally, IEX will charge a higher fee for the execution of these order types. Notwithstanding the limited scope of benefits, we believe that the inbound speed bump will not impose negative impacts on overall market quality within the NMS. Since non-displayed pegged orders are not observed by participants submitting marketable orders, IEX's speed bump exemption for their repricing is unlikely to increase the prevalence of visible quote fade. Alpha's speed bump exemption for post only non-marketable orders enabled low latency liquidity providers to fade against multi-venue smart order router sprays. This ability to fade leads to a reduction in such sprays hitting Alpha, which leads to Alpha's popularity amongst active retail orders. Unlike the Alpha delay, IEX's inbound speed bump is applied equally to all marketable and non-marketable orders from all members. Therefore this innovation is unlikely to attract specific groups of market participants and segment the composition of order flow within the NMS.

Outbound Speed Bump Discrimination

The second speed bump in IEX's application imposes a 350 microsecond delay on the dissemination of order handling information. Message prints to the SIP and IEXS order routing to away venues are exempted from this speed bump. Due to inherent latencies in the SIP (as documented by Ding, S., Hanna, J. and Hendershott, T. (2014), "How Slow Is the NBBO? A Comparison with Direct Exchange Feeds." *Financial Review*, 49: 313-332.), proprietary data feeds are likely to be faster at disseminating information from IEX's order book, even with the speed bump. Therefore the main issue that warrants discussion is providing IEXS with a 350 microsecond "head start" in routing any unfilled portion of a marketable order to away venues, after accessing liquidity on IEX and before other market participants observe the trade. This "head start" is likely to reduce information leakage and "electronic front running", which may occur when HFTs who have invested more heavily in low latency infrastructure observe trades on IEX and race IEXS to cancel standing limit orders or consume liquidity on away venues. We commend IEX on developing a commercial solution to improve fill rates on away venues for participants who choose to utilize IEXS.

Under IEX's application, if a marketable order submitted via a router other than IEXS is not fully filled, the member faces a 350 microsecond additional delay in receiving a confirmation message. This delay places third-party routers at a systematic disadvantage in reliably accessing liquidity on away venues after marketable orders are sent to IEX, which may be problematic if fill rates on IEX are consistently lower than other national securities exchanges. In contrast with IEX's letter to the SEC dated November 23, 2015,[2] we stress that this issue concerns re-routing after an incomplete fill rather than information leakage, and cannot be resolved with a spray

[2] http://www.sec.gov/comments/10-222/10222-26.pdf

router that accounts for inherent latencies. Prior to routing any unfilled portions to away venues, all routers must receive an order handling confirmation to advise it of the size of any unfilled portions on that venue. By imposing an artificial delay on transmitting this information back to third-party routers, they may face lower fill rates on all away venues and difficulty in accessing liquidity at depth, especially during volatile market periods when substantial order book movements can occur during such a delay.

The structural disadvantage imposed on third-party routers in IEX's application may be mitigated by exempting from the speed bump the dissemination of order handling information to the member who submitted each order, placing IEXS on an equal footing with other routers. An alternative solution that may offer simpler implementation is to only subject the dissemination of IEXS routed order information to the outbound speed bump, protecting orders routed via IEXS from information leakage without systematically disadvantaging orders from third-party routers.

Speed Bump Duration

In contrast to Alpha's randomized 1 to 3 millisecond software speed bump, IEX's application proposes a fixed 350 microsecond hardware speed bump. The fixed nature of IEX's inbound speed bump enables individual marketable orders from a smart order router spray to be timed to arrive at IEX's speed bump point-of-presence 350 microseconds prior to arrival at other markets, minimizing any potential for information leakage.

Order Protection Rule Status

In contrast to Alpha's status as an unprotected market under the Canadian Order Protection Rule,[3] IEX's application seeks to be a protected market under the SEC's Order Protection Rule. If IEX's application is approved, we urge the SEC to monitor its fill rates and compare them with those achieved on other national securities exchanges. IEX's outbound speed bump on message prints will result in members submitting marketable orders based on observations of its limit order book that are stale by 350 microseconds, potentially resulting in systematically lower fill rates than other trading venues and inferior accessibility of displayed liquidity. In this situation, IEX's status as a protected market may need to be reconsidered, since it would be unreasonable to protect the orders displayed on a market if they cannot be reliably accessed.

[3] http://www.osc.gov.on.ca/en/Marketplaces_alpha-exchange_20150421_noa-proposed-changes.htm

Conclusion

Based on our empirical analysis of Alpha's speed bump in Canada, we believe that IEX's application will not result in detrimental impacts on overall market quality in the United States. IEX proposes commercial solutions to combat several market structure issues faced by its clients. The inbound speed bump is likely to reduce instantaneous adverse selection costs for liquidity providers utilizing its non-displayed pegged orders. The outbound speed bump is likely to improve the ability of IEXS routed orders to reduce information leakage and access consolidated liquidity on away venues. IEX's application may be improved by extending the benefits of the outbound speed bump exemption on order handling confirmation to the member that submitted each order. The opinions expressed in this letter are our own, and originate from the findings in our recent empirical research, which is attached to this letter, and do not necessarily reflect the position of our respective universities, nor our co-authors.

If IEX's application is approved, we would be happy to assist the SEC in conducting an impact analysis on market quality within the NMS, as well as any future market structure research that supports evidence-based policy making to *"maintain fair, orderly and efficient markets"*.

Yours sincerely,

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ATTACHMENT: WORKING PAPER

The Value of a Millisecond:
Structural Segmentation of Uninformed Order Flow

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22 January 2016

Abstract

We exploit a recent market design change on the Canadian trading venue TSX Alpha to investigate the impact of a sudden segmentation of informed order flow between venues on overall market quality, transaction costs and welfare of market participants. We show that by combining a randomized speed bump for marketable orders only with an inverted fee structure, the new TSX Alpha overwhelmingly attracts uninformed order flow, leaving other venues to absorb relatively more informed trading. Despite its modest 8 percent market share, this segmentation negatively impacts liquidity on other Canadian trading venues, increasing costs for liquidity demanders and lowering profits for liquidity suppliers, but increasing profits for liquidity providers on TSX Alpha. Our paper has implications for market quality in the United States, where virtually all retail and uninformed order flow is segmented away from lit exchanges.

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[4] Contact Author: sean.foley@sydney.edu.au. We thank the Securities Industry Research Centre of Asia-Pacific (SIRCA) for data. Haoming Chen thanks the Capital Markets Cooperative Research Centre (CMCRC) for funding, and was a visiting researcher at the Ontario Securities Commission (OSC) for part of the time spent on this study. We thank Mike Aitken, Amy Kwan, Richard Phillip and Talis Putnins for their thoughtful feedback, as well as staff at the OSC for sharing their knowledge on Canadian equity market structure. The internet appendix that accompanies this paper may be found at https://goo.gl/TVSc1T.

1. Introduction

The modern equity trading landscape in the United States exhibits a vast degree of fragmentation of order flow and liquidity across many, competing trading venues combined with a very large fraction of trading occurring outside of the traditional lit exchanges. There are currently 11 lit markets with publicly displayed limit order books, 44 dark trading venues (without pre-trade transparency) and approximately 200 broker-operated alternative trading systems (ATS) competing for order flow[5], with non-lit trading accounting for 35 percent of total volume.[6]

The distribution of order flow across different types of venues is not random, however. In particular, retail order flow (and other uninformed order flow) seldom interacts with other orders on lit exchanges in the United States. Instead, retail orders are typically executed against the broker's own inventory (broker internalization) or alternatively, sold by the broker to a third party, whereby all marketable orders that fulfil certain criteria are passed on to that party in return for a fee in so-called payment for order flow (PFOF) arrangements (see e.g. Battalio and Holden, 2001; Parlour and Rajan, 2003). This largely uninformed flow is valuable to some parties because it carries significantly lower adverse selection costs (Chakravarty, 2001).

In a single exchange world, standard microstructure theory (Glosten and Milgrom, 1985; Kyle, 1985) would suggest that lowering the fraction of uninformed traders increases the toxicity of order flow and adverse selection costs for market makers and as a consequence, transaction costs for all investors. The effects of shifting uninformed order flow *between* venues on overall market quality in a multi-venue world are much less clear already. Furthermore, because the practices of order flow internalization and related off-exchange trading have grown steadily over several decades and are omnipresent in the United States today, it has always been difficult to empirically measure their consequences in isolation.[7]

To overcome these limitations and shed more light on how the segmentation of less informed order flow affects overall market quality and trading costs in a modern, fragmented financial market environment, we exploit a recent market design change on one of several exchanges in Canada that – virtually overnight – created a venue uniquely suited to attract uninformed order flow. This natural experiment in the Canadian market presents a great testing ground to study the consequences of segregating uninformed order flow, because Canadian regulators do not allow either broker internalization or PFOF, and the market share of dark trading has been hovering around a relatively low 6 percent since the implementation of the minimum price improvement regulations in 2012.

On September 21st, 2015, TMX Group implemented several market structure changes on its TSX Alpha Exchange, henceforth "Alpha". First, all marketable orders entering Alpha face a systematic order processing delay, randomized between 1 and 3 milliseconds. Second, the trading fee structure was amended to an inverted maker-taker model, i.e. liquidity takers are paid a rebate, while suppliers pay a

[5] SEC public statement, dated May 11th, 2015 (http://www.sec.gov/news/statement/us-equity-market-structure.html)
[6] US estimates are provided by industry participants, including Tabb Group who run a consultancy and Rosenblatt Securities who are a US brokerage. The corresponding dark trading fraction are 6 percent for Canada (See IIROC market share by marketplace report 2015) and 10 percent for Australia (See ASIC equity market data for September 2015).
[7] First attempts to capture retail order flow off-exchange may have started as early as 1979 (SEC Rule 19c-3).

fee.[8] Third, limit orders that want to be exempt from the randomized delay must be post-only (unable to remove liquidity) and require a minimum lot size (usually 500 shares).

In light of the implemented systematic delay, Canadian regulators decided to allow brokers to bypass this venue in their order routing decisions, i.e. order protection rules no longer apply to Alpha, effectively breaking cross-venue linkages with other exchanges and transforming Alpha into a separate pool of liquidity.[9] Further, (high frequency) liquidity providers on Alpha acquire the option to cancel their limit orders during the delay should they observe activity on other venues.[10] Consistent with continuous monitoring of all venues, we show that fill rates on Alpha fall by roughly 50 percent after the change, making Alpha unattractive for large, informed traders. By contrast, the inverted fee model makes Alpha an attractive venue for marketable orders small enough to execute completely on Alpha. We show that brokers of retail clients in particular increase their market share of aggressive orders on this venue, whereas limit orders on Alpha are now more likely to originate from brokers associated with high frequency traders.

Effectively, the innovative combination of these three features creates a lit venue that is rather similar to an OTC payment for order flow (PFOF) scheme, whereby HFT liquidity providers pay the exchange, which in turn pays the broker routing the market order to the venue, while providing the ability to avoid institutional orders. And the similarity goes even further in that broker internalization, like Alpha thanks to its speed bump, represents a separate pool of liquidity, because in many cases clients cannot access the internal market and other venues simultaneously; rather the broker chooses first which orders to internalize and which to route to other venues.

Over the years, there has been considerable academic interest in the negative side effects that arise from such internalization arrangements.[11] In particular, the question of whether so-called cream-skimming (the siphoning off of uninformed order flow), results in negative externalities for the consolidated market is of major concern for both market participants and regulators (Lee, 1993).

However, earlier studies of internalization and PFOF (Easley, Kiefer and O’Hara, 1996; Battalio, 1997) take place in an exchange landscape markedly different from today along many important dimensions. Competition between exchanges was relatively new and venues were not yet linked via a national best bid and offer system; high frequency trading was unheard of; stocks were quoted in 1/8 of a dollar until 1997 and full decimalization did not occur until April 9, 2001. The vastly larger tick size in particular, presumably earning market makers monopoly rents (Christie and Schultz, 1994), makes it hard to infer changes to trading costs from changes to the extent of internalization.

Easley et al. (1996) summarize the mixed evidence on the effects from cream-skimming vs. increased competition between venues available at the time as follows: “In effect, all prices are too high, and hence

[8] At launch, these payments amounted to 0.1 cents per share on either side.

[9] In the United States, order protection rules protect displayed quotations at the best bid or best offer from being traded through at other venues. In Canada, this protection extends to all levels of the order book, not just the top.

[10] In a study of market making activity by a high frequency trader, Menkveld (2013) finds that the latency of the participant analysed has an upper bound of 1.67 milliseconds.

[11] A separate strand of the literature (Battalio, Corwin and Jennings, 2015; Battalio and Loughran, 2008; Chordia and Subrahmanyam, 1995) investigates potential conflicts of interest between the broker and the customer, such as violations of best execution duties of the broker to the client.

comparisons between them are misleading". Consequently, most event-type studies at the time do not find a measurable impact on overall market quality (Battalio, 1997; Battalio, Greene and Jennings, 1997), but some document significant differences in the information content of segmented flows (Lin, Sanger and Booth, 1995; Bessembinder and Kaufman, 1997).

Theoretical contributions on off-exchange competition also yield mixed predictions. Parlour and Rajan (2003) suggest that PFOF redistributes welfare gains from liquidity demanders to suppliers. Chakravarty and Sarkar (2002) imply that internalization hurts retail customers and market quality, while Malinova (2012) predicts larger (smaller) execution costs for large (small) traders, while market quality may improve in some equilibria.

Closely related to the discussion of internalization is the study of the other type of off-exchange trading, dark pools. But there are differences. Dark venues evolved from so-called upstairs markets and were originally designed to help institutions transact large blocks of shares without price impact, not to segregate uninformed flow. The lack of pre-trade transparency makes the decision to submit an order to a dark venue much more strategic and depends on the trader's expectations about current dark liquidity and the difficulty of executing that same order in the lit market.

Current trading in dark pools also attracts many small orders, with some evidence that dark trades are less informed (Hatheway, Kwan and Zheng, 2014). Empirically, however, the evidence on market quality is mixed. Hatheway et al. (2014) document a generally negative relationship between the degree of dark trading and market quality in the cross-section of stocks, but positive effects for small stocks and large transactions. Buti, Rindi and Werner (2011) do not find detrimental effects on market quality. Foley and Putnins (2015) show that two-sided dark trading improves market quality while one-sided dark trading, which facilitates information leakage, does not engender such benefits. Comerton-Forde and Putnins (2015) do not directly investigate liquidity, but show that small amounts of dark trading are beneficial to price discovery, while large amounts are detrimental. These results echo the disagreement in the theoretical literature around the desirability of dark trading (Ye, 2012; Zhu, 2014).

In this study, we ask the following questions: Do the mechanisms established by the "new" Alpha result in the segregation of retail order flow? Do existing cross-market linkages across Canadian venues break down, allowing liquidity providers the opportunity to "fade" when they observe large institutional orders? What is the impact of this virtual segregation of order flow on broader market quality, transaction costs and gains from trading?

Our analysis starts by investigating the degree to which uninformed flow becomes concentrated on Alpha after the re-launch. Apart from the telling change in the composition of broker types submitting marketable vs. limit orders mentioned above, we more formally construct a novel measure for the information content of trade strings across all venues and show that uninformed flow now accounts for 71 percent of volume on the "new" Alpha relative to 45 percent previously. Controlling for other potential drivers of market quality, we find a large positive change in realized spreads on Alpha on the order of 6-7 basis points, while adverse selection costs decline by 4-5 basis points. These findings provide strong evidence that order flow on "new" Alpha is decidedly less informed about future stock price changes than before.

In the second part of the analysis, we study the causal impact of this design change on the other trading venues, as well as trading costs and market quality overall. Relative to the pre-event period, we find that quoted bid/ask spreads consolidated across all exchanges widen, increasing the cost of demanding liquidity ex-ante. In addition, order books are now less resilient after the change in the sense that trades are more likely to consume the entire first level and access the second level of the limit order book.

For the remaining venues (excluding Alpha), we find a significant increase in adverse selection cost due to a higher fraction of informed order flow that is routed to these venues post-change in line with standard theory (Kyle, 1985). Most of these costs are passed on to liquidity demanders in the form of higher effective spreads, increasing overall transaction costs. The remaining portion of adverse selection cost increases result in more negative realized spreads, reducing the profits for liquidity providers on these venues.

Lastly, we split our sample of stocks into deciles according to their order book resiliency, which we define as the fraction of trading volumes that displace the first level of the consolidated limit order book, measured over the 10 weeks prior to the event. Overall, we find that the negative effects on market quality are most pronounced among the low resiliency stocks while high resiliency stocks are affected relatively little.

Overall, these effects translate into a sizeable redistribution of gains from trading. Liquidity demanders have to pay approximately $6.1 million more per month to access liquidity on venues other than Alpha. At the same time, liquidity providers on these venues experience a reduction in profit on the order of $1.4 million per month due to being adversely selected more often.

On Alpha, liquidity providers are the clear winners, gaining $1.5 million per month. The effect for traders sending active order flow to Alpha is less clear. On the one hand, they lose due to the overall widening spreads; on the other hand, those losses are approximately offset by the taker rebate. However, in the case of retail clients, it is unclear whether the executing broker passes on those rebates, either directly or over time in the form of additional services. Likely, retail investors are losing, too.

Despite its modest 8 percent market share, our findings imply that most market participants are worse off after the change. The effect of new Alpha seems welfare reducing overall, very much in line with standard theory on adverse selection (Kyle, 1985) and cream-skimming (Easley et al., 1996). Unlike the US, where PFOF has long been an institutional feature, accounting for around 20 percent of traded volume, most other developed markets, such as the UK, Australia and Canada have expressly prohibited this conduct, ensuring retail trades remain on the main market places. Our evidence can shed new light on the desirability of the impacts of this practice.

While not the main focus of the analysis, to our knowledge, our paper is also the first to investigate a rather novel feature of financial markets, namely speed bumps or intentional delays en route to the exchange matching engine. Trading venue IEX, of Lewis (2014) fame, was the first to intentionally delay all incoming messages by 0.35 milliseconds with the stated goal of defusing the speed advantage of HFTs, while Aequitas NEO in Canada explicitly discriminates against HFTs.[12] The only other study of

[12] See for example http://www.bloombergview.com/articles/2015-09-16/the-flash-boys-exchange-is-growing-up for recent developments at IEX.

speed bumps, albeit not in a strictly financial market, is Brown and Yang (2015), who investigate the effect of varying the duration of the order delay in the British sports betting market.

Considering that trading venues such as IEX, Aequitas NEO and Alpha are adopting and marketing speed bumps as "desirable" market features, it seems timely to analyse their effects as the increasing use of speed bumps may facilitate phantom liquidity and hinder participants' ability to access liquidity across fragmented markets. Our evidence will be of interest not only to market participants and exchanges, but also to regulators considering whether to allow such delays, and the more nuanced issue of how such delays should be structured.

Lastly, we extend the toolbox for microstructure research in two ways. First, we develop a new classification of trade sequences into informed and uninformed based on whether they displace the entire NBBO depth, inspired by O'Hara's (2015) notion that trade size is analogous to information in a high-frequency world. Second, we formulate a new metric that measures the accessibility of on-screen orders during liquidity drawdowns. In other words, we ask how much of pre-trade, visible liquidity can actually be accessed by a trade string that displaced the entire NBBO depth. A low fill rate across venues would indicate weak cross-market linkages from the perspective of a liquidity demander.

This paper is organized as follows. Section 2 outlines the institutional details of the Canadian trading landscape, and in particular the newly implemented design changes on Alpha. Section 3 describes the data and methodology. Section 4 demonstrates these design changes lead to a segmentation of order flow across exchange venues. Section 5 assesses the impact on the market quality of other Canadian trading venues. Section 6 concludes.

2. Institutional Details

The Canadian equities trading marketplace is fragmented across multiple venues. Securities are listed on the Toronto Stock Exchange, which is operated by TMX Group and retains approximately 60 percent market share of trading activity. The TMX Group also operates the Alpha and TMX Select trading venues, whilst Chi-X operates both Chi-X Canada and CX2 venues. Other venues include Omega, Pure Trading, Aequitas Neo, Aequitas Lit and a dedicated continuous dark pool ITG Match Now.

Unlike the US, internalization of retail order flow has been significantly constrained since 1998 when the TSX required brokers wishing to internalize trades of less than 5000 shares to provide one full tick of price improvement.[13] This mechanism prevented the growth of retail internalizing venues such as those that exist in the United States, which account for around 22 percent of trading (Kwan, Masulis and McInish, 2015). As a result of this regulation, and the subsequent banning of payment-for-order-flow, retail orders remain predominantly on-exchange in Canada.

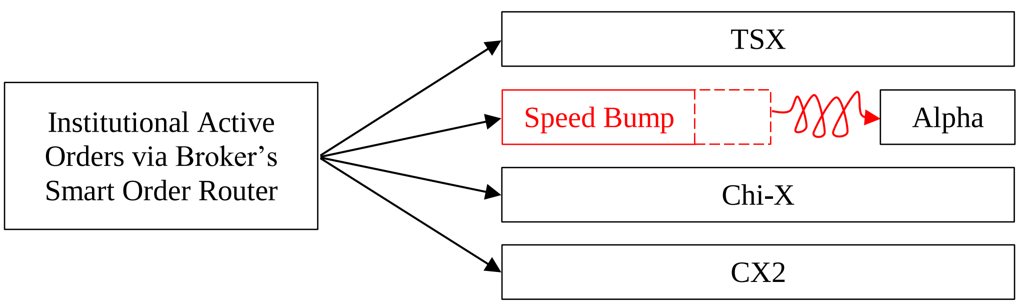
2.1 The Alpha Speed Bump

Alpha Exchange was launched in 2008 and was merged with the TMX Group in 2012. On the 21st of September 2015, the trading venue was relaunched as TSX Alpha with several changes, including:

[13] For further details of this change, see Larrymore and Murphy (2009).

1. A randomized speed bump for all non-post only orders of between 1-3 milliseconds.
2. Minimum size requirements for post-only orders, typically 5 board lots per quote.[14]
3. Inverted maker-taker pricing model.
4. Orders on Alpha are no longer subject to the Order Protection Rule.
5. TMX Select was decommissioned.

Prior to Alpha's speed bump implementation, several market participants noted that it may result in undesirable consequences. For example, TD Securities[15] argued that *"the introduction of speed bumps on both Alpha and Aequitas will slow down the operation of smart order routers … aggravating quote fade across all marketplaces"* and ITG Canada[16] claimed that *"the new Alpha design will allow passive post only resting orders the ability to fade should they see trading on another venue"*. These concerns are depicted in the diagram below. Institutional investors who require more liquidity than what is displayed on any single trading venue may utilise a broker's smart order routing technology to simultaneously spray marketable orders across multiple trading venues, efficiently accessing consolidated quoted depth at the national best bid or offer price. Alpha's randomized speed bump enable its liquidity suppliers to observe the first legs of any large smart order router spray being executed on other venues, and have sufficient time to cancel their limit orders and avoid adverse selection costs, should they deem those orders informed.



The application of the speed bump to incoming marketable orders provides interesting market dynamics. As reported by Van Kervel (2015) many liquidity suppliers duplicate their quotes across multiple venues. This enables them to maximize the probability of execution, but also necessitates that liquidity demanders enter orders across a variety of venues in order to access all available liquidity. As noted by Van Kervel (2015), however, this duplication of orders allows liquidity suppliers the opportunity to remove duplicate orders upon the first execution, leading to what many term "phantom liquidity". The introduction of a speed bump for incoming marketable orders *but not limit order entries or cancellations* allows liquidity suppliers who are able to continuously monitor the market in under 1-3 milliseconds[17] to cancel their standing limit orders upon observing trades in other venues. Such conduct makes it unattractive for traders using smart order routers (SORs) to execute large orders to include Alpha in their routing table, as

[14] Minimum post only volumes for each security are available at http://api.tmxmoney.com/en/research/minpo.csv
[15] https://www.osc.gov.on.ca/documents/en/Marketplaces/com_20141208_td-securities.pdf
[16] https://www.osc.gov.on.ca/documents/en/Marketplaces/com_20141208_itg-canada-corp.pdf
[17] Given co-location and Menkveld's (2013) upper bound estimate of 1.67ms round trip latency it seems likely fast participants are able to cancel orders within the speed bump.

the speed bump would provide an opportunity for liquidity suppliers on Alpha to remove orders upon observing trades on other venues.

A trader may be tempted to put Alpha *first* on the routing table, and to route to other venues once the order has resolved. While this strategy may provide superior access to limit orders on Alpha, the randomized delay of 1-3ms provides uncertainty about when to send the remainder of the order. This random delay provides an opportunity for fast liquidity suppliers to pull their limit orders from non-Alpha venues. In such a situation, the optimal trading strategy may be to send *all* orders to Alpha when the desired quantity can be filled, and send *none* of the order to Alpha otherwise. This ability to "fade" away from institutional orders makes the "new" Alpha an undesirable venue for large institutional traders. However, it is much less relevant for retail traders.

To further attract retail traders, Alpha has employed an inverted maker-taker model. The maker-taker pricing model has been used to reward the provision of lit market liquidity in Canada since 2005,[18] and since 2011, the proliferation of alternative trading venues in Canada led many venues to adopt inverted maker-taker pricing (such as CX2, TMX Select and Omega). Inverted maker-taker pricing provides a rebate to the demander of liquidity, which is paid for by the liquidity supplier. On the 21st of September (when the "new" Alpha was launched as an inverted maker-taker market) the existing TMX Select inverted market was decommissioned. Table 1 provides an explanation of the current fee structure of each of the major Canadian markets.

< Insert Table 1 Here >

Alpha's provision of an inverted maker-taker structure encourages fee-sensitive brokers to route aggressive orders to their venue, particularly if the taker rebate is not passed through to the client (such as when a flat fee is levied regardless of maker-taker rebates, as cited in Brolley and Malinova (2013)). Such a flat fee structure is most common for retail brokers, where maker-taker rebates are seldom passed on to clients.

The "new" Alpha was also removed from the order protection rule, which requires any incoming marketable order to be sent to the venue displaying the best price prior to accessing liquidity on any other market at an inferior price. A condition of Alpha's regulatory approval was that it would not be a "protected marketplace" under the order protection rule, owing to its randomized delay that would make it impractical for marketable orders to have to execute at prices quoted with a speed bump.[19] This provides "permission" for large orders working through the book (such as institutional orders) to avoid Alpha.

The minimum passive post only volume requirement, typically 5 board lots per quote for large securities, is also attractive to retail investors, as retail brokers are likely to want to execute active orders in one trade with rebates, if possible. The requirement that liquidity suppliers post a minimum size ensures that most average size retail orders can be completed, while the speed bump ensures that this minimum size requirement does not expose the liquidity supplier to orders with larger adverse selection costs.

[18] For further details on the introduction of the maker-taker pricing regime to Canada see Malinova and Park (2015).
[19] https://www.osc.gov.on.ca/en/Marketplaces_alpha-exchange_20150421_noa-proposed-changes.htm

The decommissioning of TMX Select which used inverted maker-taker pricing to target active retail traders would have resulted in active retail volume being redistributed amongst other trading venues, potentially reducing the toxicity of aggregate order flow. As such, any observed liquidity deterioration would need to overcome this redistributive effect on the consolidated Canadian equities market.

In Canada, payment for order flow is prohibited and meaningful price improvement rules apply to trades on dark venues, including regulations designed to ensure orders sent to the US would also be subject to minimum price improvement regulations. As such, unlike in the US internalisation is not a common practice.

<Insert Figure 1 Here >

3. Data and Methodology

3.1 Data

The data for this study was sourced from Thomson Reuters Tick History (TRTH), supplied by the Securities Industry Research Centre of Asia Pacific (SIRCA). Data for seven Canadian trading venues is available from TRTH, namely TSX, Alpha, Chi-X, CX2, TMX Select, Omega and Pure Trading. This encompasses all Canadian trading venues with partial or full pre-trade transparency, except Aequitas NEO and Aequitas Lit, which together account for less than one percent of trading activity.[20] Pure Trading also has a market share of less than one percent, and is dropped from the analysis. Lastly, both TMX Select and Omega currently use a legacy data feed with time stamp inaccuracies that can exceed 200-300 milliseconds, making it impossible to calculate reliable NBBO prices and volumes. Weighing data accuracy and quality against sample completeness, we exclude these two venues as well[21]. This leaves TSX, Alpha, Chi-X and CX2 as the venues of interest in this paper. Our observation period runs from the 13th of July 2015 to the 27th of November 2015, accounting for ten weeks on either side of Alpha's market structure changes. We exclude the 26th of November, a NYSE trading holiday, the 27th of November, a partial NYSE trading holiday, the 21st of October, during which extreme volatility occurred in Canadian equities, and the 24th of August, a US stock market "flash crash". Our universe of securities spans the S&P TSX Composite Index components. We remove index additions and deletions during our observation period, leaving 236 securities that were part of the index for the full period.

TRTH provides data for each exchange including the state of the limit order book at each quote update, as well as all trade records. The data fields include exchange, security, date, millisecond time stamp, trade price, trade volume, trade qualifiers, buyer and seller broker ID[22], as well as the bid and ask price and size. We request trades and quotes concurrently within the same exchange to preserve ordering within the same millisecond to enable accurate trade direction classification. Although several venues operate

[20] Aequitas Lit and Neo combined accounted for less than 1% of total on-market trading in TSX listed securities during our sample according to IIROC's Report of market share by marketplace.

[21] TMX Select and Omega each account for less than 3 percent of trading volume.

[22] Broker identifiers for buyer and sellers are available for TSX and Alpha, unless the broker chose to remain anonymous and forgo participation in broker preferencing. Although CX2 offers broker preferencing, the data does not include these identifiers. Chi-X does not offer broker preferencing, but some trades contain broker identifiers.

extended trading hours, we restrict our analysis to the trading hours of the TSX listing market, being 9.30am to 4.00pm.

3.2 Traditional Market Quality Metrics

Our empirical methodology creates one dataset containing the trades on each venue and another dataset containing the national best bid and offer (NBBO) prices and depths. Firstly, we assign trade direction for on-market trades from the time and sales data within that venue. We remove trades whose qualifiers identify them as off-market crossings or odd lot trades. We also remove trades with a value above $2 million, even if they do not have off-market qualifiers.[23] We then assign trade initiation direction based on whether the trade happened at the best prevailing bid or offer price on that venue. Dark trades occurring with price improvement are discarded as we are unable to assign trade direction. Having preserved the ordering of trades and quotes within each venue we are able to observe each trade consuming the displayed liquidity, with each (partial) execution of a market order followed by a quote update identifying the remaining liquidity at that price step. These trades and quote updates will be within the same millisecond, but retain their ordinal ranking. This approach assigns trade direction with near certainty and avoids the issues associated with the midpoint or tick tests used in previous studies such as Lee and Ready (1991), Ellis et al. (2000), Bessembinder (2003) and Holden and Jacobsen (2014). A detailed outline of the full methodology is provided in Section A of the Internet Appendix.[24] This process creates a file containing exchange, symbol, date, millisecond time stamp, price, volume, trade direction, buyer and seller broker ID for each trade.

Next, we construct the national best bid and offer prices and sizes. From the time and sales data for each exchange, we create a file that contains the last order book update per millisecond timestamp. The order book update files for each trading venue are merged by symbol, date, then time, and filled down. We then create new variables for the national best bid and offer prices, equal to the highest bid price and lowest offer price displayed on any venue, respectively. If the NBBO would be locked or crossed, we take the prevailing quotes on the TSX as being the NBBO.[25] The NBBO quoted spread is calculated for each stock (i) and day (d) as the difference between the prevailing national best bid (NBB) and national best offer (NBO) prices and is time-weighted throughout each day. We also calculate the NBBO quoted depth as the total volume quoted at the national best bid and offer prices, updated for each quote (q) across all venues, and measured for the total duration for which that quote prevailed ($Alive_q$).

[23] Trade qualifiers in the TRTH data may be incomplete, and we are aware of trades exceeding $100 million in the TRTH data without off-market qualifiers. Trades are recorded from the perspective of the liquidity supplier. Therefore a trade of $2 million would require the liquidity supplier to have submitted a single limit order for $2 million and the liquidity demander to have also submitted a single marketable order larger than $2 million. A frequency distribution of large trade sizes is available upon request.

[24] The internet appendix that accompanies this paper may be found at https://goo.gl/TVSc1T.

[25] IIROC's Universal Market Integrity Rules stipulate that limit orders that would lock or cross with visible orders on another market are not permitted. In the Reuters data, this occurs for short periods of time due to lack of clock synchronisation across venues. Generally the venues are synchronized to within 20 milliseconds. Appendix B provides further details on benchmarking of cross-venue clock synchronisation.

$$NBBO\ Quoted\ Depth_{i,d} = \frac{\sum_{q=1}^{Q}(NBO\ Depth_q + NBB\ Depth_q) * Alive_q}{\sum_{q=1}^{Q} Alive_q} \tag{1}$$

Additionally, we calculate the proportion of time each venue (*v*) displayed quotes at the NBBO, as well as its share of total NBBO depth.

$$\%\ Time\ at\ NBBO_{i,d,v} = \frac{\sum_{q=1}^{Q}(I_{Venue\ v\ at\ NBB} * Alive_q) + \sum_{q=1}^{Q}(I_{Venue\ v\ at\ NBO} * Alive_q)}{2 * \sum_{q=1}^{Q} Alive_q} \tag{2}$$

$$\%\ Depth\ at\ NBBO_{i,d,v} = \frac{\sum_{q=1}^{Q}\left(\frac{Venue\ NBB\ Depth_q + Venue\ NBO\ Depth_q}{Total\ NBB\ Depth_q + Total\ NBO\ Depth_q} * Alive_q\right)}{\sum_{q=1}^{Q} Alive_q} \tag{3}$$

Effective half-spreads are calculated as the difference between the trade price and the prevailing NBBO midpoint. Realized spreads compare trade prices with the NBBO midpoint twenty seconds after the trade. Similar to Conrad et al. (2015), we calculate realized spreads at intervals of one, five, ten and twenty seconds after each trade. For brevity, we report this metric after twenty seconds as our primary result. Price impacts are computed as the effective spread minus the realized spread. Following Malinova and Park (2015) in markets with maker-taker pricing, effective spreads may be increased by the taker fee for a net cost of demanding liquidity, whilst realized spreads may be reduced by the maker rebate for a net revenue attributable to liquidity provision. Per trade (*t*), these metrics are volume weighted.

$$Effective\ Spread_{i,d} = 2 * \frac{\sum_{t=1}^{T}\{D_t * (Price_t - Midpoint_t) * Turnover_t\}}{\sum_{t=1}^{T} Turnover_t} \tag{4}$$

$$Realized\ Spread_{i,d} = 2 * \frac{\sum_{t=1}^{T}\{D_t * (Price_t - Midpoint_{t+20sec}) * Turnover_t\}}{\sum_{t=1}^{T} Turnover_t} \tag{5}$$

$$Price\ Impact_{i,d} = Effective\ Spread_{i,d} - Realized\ Spread_{i,d} \tag{6}$$

3.3. Construction of High Frequency Trade Strings

Motivated by the importance of linkages between markets highlighted by O'Hara (2015), we investigate the ability of liquidity demanders to access quoted liquidity across venues. To this end, we construct new metrics that rely solely on trade and quote data and are able to estimate the impact of high-frequency quote fade across venues.

To the best of our knowledge, we are the first to benchmark timestamps across venues, using either a regulatory tape or academic data feeds. Section B of the Internet Appendix provides a detailed outline of the methodology.[26] We find that the venues in our dataset are generally synchronized within 20-30 milliseconds and almost always within 50 milliseconds, which is in line with the Securities and Exchange Commission's proposed Rule 613 Consolidated Audit Trail National Market System (CAT NMS) that will require clock synchronisation for each trading venue to be within 50 milliseconds of Coordinated Universal Time.[27]

We construct high frequency trade strings by grouping together all buyer or seller initiated trades for each security that occur within 50 milliseconds of the last trade in the same direction. Whilst timestamps for any individual trade may exhibit latency, jitter, caching and lack of cross-venue synchronisation, strings of trades that occur over short time intervals minimise potential errors. Section C of the Internet Appendix describes the construction of high frequency trade strings in detail.[28] If there are multiple trades within a string, each trade may have originated from a smart order router spray by a single participant or active competition for order flow by multiple participants.

The median length of a trade string that executed across multiple venues was 11 milliseconds, comparable to the findings of Malinova and Park (2015b), who analyse HFT liquidity provision using regulatory data from IIROC. They group together trades originating from a smart order router as being separated by less than 5 milliseconds from trade to trade, and less than 9 milliseconds for the full string. These intervals are significantly smaller than the snapshots taken at fixed 100 millisecond intervals by Van Kervel (2015), and more consistent with the time horizons high frequency traders are known to operate in. Since Bessembinder (2003) finds that trades tend to occur immediately after order book cancellations in the opposite direction, our methodology also improves on Van Kervel (2015) by minimising the potential for associating order book changes *before* each trade with the trade itself, avoiding endogeneity.

For each trade string, we snapshot the state of the limit order books across each venue 1 millisecond before the start of the first trade, since order book updates are produced to show trades consuming liquidity. We also snapshot the limit order books across all venues 20 milliseconds after the end of the last trade, to allow sufficient time for the venues with the slower clocks to update their order books to reflect the information of the new trade. Since this is less than the 50 milliseconds required to group trades together, we are certain that neither snapshot overlaps into the previous or the next trade string for the same security. Buyer initiated trade strings are compared with changes in the offer prices and sizes, whilst seller initiated trade strings are compared with changes in the bid prices and sizes, on each venue. For trades that occurred at the best price within each string, generally the prevailing NBBO price at the start of the string, we record the start time, end time and trade price, as well as trade volume, start price, start volume, end price and end volume on each trading venue. Only trades occurring at the best prices within

[26] The internet appendix that accompanies this paper may be found at https://goo.gl/TVSc1T.
[27] http://www.catnmsplan.com/web/groups/catnms/@catnms/documents/appsupportdocs/p571933.pdf
[28] The internet appendix that accompanies this paper may be found at https://goo.gl/TVSc1T.

each string are analyzed, to enable trade attribution to the consumption of visible liquidity at each venue's best bid or offer price.

3.4. Informed Trade Strings

O'Hara (2015) suggests that in a high-frequency world, large traders become potentially informed traders due to their ability to move prices. We extend this idea to develop a novel metric to measure the information content of a trade sequence. We consider a trade string to be informed if it displaces an entire level of NBBO depth. Note that this definition of information is not merely a proxy of trade size. An order smaller than pre-trade NBBO depth can also displace an entire price level if it leads to a large number of cancelations by liquidity suppliers.

More precisely, buyer (seller) initiated trades are deemed to be informed if they originated from a trade string where the national best bid (or offer) price at the end of the string was higher (or lower) than the best price traded during the string. Trade strings that do not displace the entire NBBO depth are deemed to be uninformed. Our definition is akin to the traditional adverse selection metric, however, we are utilising a virtually instantaneous horizon of twenty milliseconds rather than a few minutes (Hendershott et al., 2011; Carrion, 2013) or seconds (Conrad et al., 2015) after the trade.

In addition, in the spirit of Van Kervel (2015), we define multi-venue sweep trades as those that are part of a string also containing trades on at least one other venue. These trades likely originate from a smart order router (SOR) spray of a single trader that sought to access the consolidated pools of liquidity across multiple venues. This allows us to divide trade string into four separate categories: informed vs. uninformed on the one hand; and likely multi-venue sweep orders vs. single-venue orders on the other.

For informed trade strings (*s*), we calculate an NBBO fill rate as the proportion of starting liquidity at the national best offer (bid) price for buyer (seller) initiated trades that resulted in trades. Since the entire level of NBBO depth on that side of the order book was depleted by the end of the string, a fill rate less than 100% measures the occurrence of fleeting liquidity. Fill rates may be higher than 100% if iceberg orders refilled, marketable orders were submitted instantaneously in response to new limit orders as in Hasbrouck and Saar (2009), or liquidity suppliers replenished their orders soon after trades occurred.

$$Fill\ Rate_{i,d,v} = \frac{\sum_{s=1}^{S} Trade\ Volume_{i,d,v,s}}{\sum_{s=1}^{S} Start\ Liquidity_{i,d,v,s}} \quad (7)$$

Finally, within each trade string we calculate the relative proportion of trades that occurred at the next best price behind the national best bid (offer) price for seller (buyer) initiated trades, to measure the tendency for trades to walk the book. This metric captures the sufficiency of top-of-book liquidity where liquidity demanders sought to trade large amounts.

$$Level\ Two\ Trade\ Ratio_{i,d,v} = \frac{\sum_{s=1}^{S} Level\ two\ trade\ volume_{i,d,v,s}}{\sum_{s=1}^{S} Total\ trade\ volume_{i,d,v,s}} \quad (8)$$

3.4. Summary Statistics

For each liquidity metric and control variable formulated, Table 2 presents summary statistics for the ten weeks before and after Alpha's relaunch, along with the difference in means and t-statistics from a univariate test of statistical significance. In the post-relaunch period, quoted spreads averaged 3.67 cents whilst quoted depths averaged $92,690 at the national best bid and offer prices. Trades originating from strings that displaced the entire NBBO depth accounted for 60% of volume, and 13% of trading volume "walked the book" and occurred at the next best price behind the national best bid or offer price within a trade string. Consistent with a "matching" rather than "making" of the best price, Alpha's proportion of time quoting at the NBBO declined 25%, offset by increases on the TSX, Chi-X and CX2. Effective spreads on Alpha increased from 2.86 cents to 3.48 cents, whilst adverse selection decreased from 3.09 cents to 2.17 cents. Consistent with the ability to avoid institutional orders, Alpha's fill rate at the NBBO declined from an average of 94% to 40%. Average share prices declined from $31.84 to $29.65. Daily trade volume per security averaged slightly less than 1 million shares. Realized one minute intraday volatility decreased 3%.

< Insert Table 2 Here >

4. Order Flow Segmentation

In this section, we investigate how the introduction of a systematic order processing delay and shift to inverted maker-taker pricing on Alpha affect the routing of informed and uninformed order flow. To motivate why the new market design might lead to differential routing among trades with varying information content, we start by analysing the mechanism by which this segregation occurs, documenting the ability of liquidity suppliers on Alpha to fade against incoming orders after observing large trades on other venues. Then, we present changes in the market share of active and passive trades by broker type, as a proxy for the level of retail, institutional and proprietary trading. We also examine Alpha's market share of trade strings that incur and avoid adverse selection costs. Finally, we analyse changes in realized spreads and adverse selection costs for trades on Alpha.

4.1. Fleeting liquidity and the mechanics of reducing adverse selection costs

Alpha's speed bump of 1 to 3 milliseconds against incoming active orders provides an opportunity for liquidity suppliers to cancel their limit orders after observing large trades on other venues. Following O'Hara's (2015) argument that "large traders … are informed traders in the new high frequency world", we define informed trade strings as those that were sufficiently large to displace an entire level of NBBO depth. For informed trade strings, we calculate fill rates on each trading venue by comparing the visible liquidity at the start of the string with the actual volume traded. If there is no liquidity fade, all visible liquidity results in trades and a fill rate of 100% is observed. Fill rates may exceed 100% if iceberg orders refill, or if active orders are submitted immediately in response to new limit orders, as identified by Hasbrouck and Saar (2009). Our analysis of cross-venue liquidity access is at the NBBO only, unlike Van Kervel (2015) who examines liquidity up to 10 basis points away from the NBBO midpoint. Analysis at a single specified price level allows us to attribute the consumption of liquidity by incoming active orders to passive limit orders visible immediately prior to the trades.

Figure 2 presents daily aggregate NBBO fill rates on each trading venue, calculated as the total trade value among all informed trade strings, divided by the total dollar value of visible liquidity available at the national best bid (offer) price at the start of seller (buyer) initiated trade strings. A sharp decline in fill rates is observed on Alpha immediately after the relaunch, whilst fill rates increase slightly across TSX, Chi-X and CX2. Consistently high accessibility of consolidated market depth across all venues in the pre-event period confirms the hypothesis of O'Hara and Ye (2011) that trade-through prohibition and smart order routing in fragmented markets virtually replicate the network advantages of consolidated trading. We formally test for statistically significant changes in NBBO fill rates with equations of the form

$$Fill\ Rate_{i,d,v} = Post_d + Price_{i,d} + Turnover_{i,d,v} + Volatility_{i,d} + Depth_{i,d} + \ NBBO\ Depth\ Share_{i,d,v} + FE_i + \ e_{i,d} \quad (9)$$

where $Fill\ Rate_{i,d}$ is the total trade volume divided by the total starting liquidity among all trade strings, at the NBBO on venue *v* for stock *i* on day *d*, $Post_d$ is an indicator variable equal to one for observations after the 21st of September 2015 and zero prior, $Price_{i,d}$ is the natural logarithm of the time-weighted NBBO midpoint price, $Turnover_{i,d,v}$ is the natural logarithm of on-market trade turnover on each venue, $Volatility_{i,d}$ is the standard deviation of one minute NBBO midpoint returns, $Depth_{i,d}$ is the natural logarithm of the time-weighted consolidated depth at the national best bid and offer prices, $NBBO\ Depth\ Share_{i,d,v}$ is the percentage of consolidated depth at the national best bid and offer prices quoted by each venue, FE_i indicates stock fixed effects and $e_{i,d}$ is an error term. Observations are winsorized at the 1% level per day.

Table 3 presents the regression results. Alpha's fill rate declined 50%, demonstrating the liquidity fade phenomenon. The ability to fade against the majority of trades that incur adverse selection costs is the mechanism by which liquidity suppliers on Alpha reduce their interaction with informed trades, minimising adverse selection costs and increasing realized spreads. As a consequence, Alpha becomes very unattractive for larger parent orders that require access to the consolidated pools of liquidity across multiple venues simultaneously. The random nature of the delay makes it impossible to guarantee consistently high fill rates on multiple venues by a smart order router. In contrast, fill rates on CX2 increase 4%, indicating that liquidity demanders are more aggressive in accessing its displayed limit orders at competitive prices.

< Insert Figure 2 Here>

< Insert Table 3 Here >

4.2. Market share of active and passive trades by broker account

A further, albeit noisy, piece of evidence that the composition of traders on Alpha changes after the re-launch is shown in Figures 3 and 4. Figure 3 presents changes in active market share by broker type. We identify two domestic banks that dominate retail order flow and find that their combined active market share increases from 18.24% to 29.46%. Figure 4 presents changes in passive market share by broker type. We identify two global banks that offer direct market access facilities to proprietary trading firms and find that their combined passive market shares increase from 19.24% to 48.22%. These trends suggest that active uninformed retail order flow and liquidity provision by low latency proprietary traders both increase on Alpha after the speed bump and fee change implementation.

< Insert Figure 3 Here >

< Insert Figure 4 Here >

4.3. Market share of informed and uninformed trades

The existing empirical literature (e.g. Hendershott et al., 2011) calculates realized spreads and adverse selection five minutes after each trade. Carrion (2013) decreases the post-trade interval to one minute, whilst Conrad et al (2015) further decreases the delay to one second. Our approach of constructing trade strings to gauge the information content of each trade is equivalent to a snapshot *twenty milliseconds* after the end of each string of related trades. In untabulated results, we find that the vast majority of price impacts after a trade occur virtually instantaneously, since adverse selection costs result from trades displacing all available depth at the NBBO and moving the NBBO midpoint price.

Figure 5 presents Alpha's trade composition by information content and multi-venue sweep. We define informed trades as buyer (seller) initiated trades that were part of a string that displaced the entire national best offer (bid) depth. Additionally, we define multi-venue sweep trades as those that were part of a string also containing trades on at least one other venue. These trades may have originated from a smart order router spray that sought to access the consolidated pools of liquidity across multiple venues, utilising a similar definition to Van Kervel (2015). The proportion of uninformed trades that did not originate from a string with trades on another venue surges from 18.38% to 46.17%. The proportion of uninformed cross-venue sprays decreases slightly from 26.74% to 24.76%, with informed cross-venue sprays experiencing a much larger decline from 46.05% to 23.60%. Finally, the volume of informed trades that are not part of a string that also accesses other venues decreases from 8.82% to 5.47%.

< Insert Figure 5 Here>

4.4. Trade-based liquidity metrics

To formally test for statistically significant changes in Alpha's market quality following the relaunch, with utilise equations of the form

$$y_{i,d} = Post_d + Price_{i,d} + Turnover_{i,d} + Volatility_{i,d} + FE_i + e_{i,d} \quad (10)$$

where $y_{i,d}$ is a measure of market quality for stock i on day d, $Post_d$ is an indicator variable equal to one for observations after the 21st of September 2015 and zero prior, $Price_{i,d}$ is either the natural logarithm or inverse of the time-weighted NBBO midpoint price, $Turnover_{i,d}$ is the natural logarithm of on-market trade turnover on Alpha, $Volatility_{i,d}$ is the standard deviation of one minute NBBO midpoint returns, FE_i indicates stock fixed effects and $e_{i,d}$ is an error term. Observations are winsorized at the 1% level per day.

Changes in effective spreads, realized spreads and adverse selection costs on Alpha after its relaunch are presented in Table 4. Effective spreads on Alpha increase 0.66 cents, or 1.95 basis points, following the market structure changes. Control variables for price, volume and volatility have the expected directionality and are statistically significant. Alpha previously had an active trading fee of 0.18c per share traded, for shares priced above $1. For these shares, active trades under the revised fee structure receive a rebate of 0.10c per share traded. The fee for removing liquidity declined 0.28c per share traded, which is slightly smaller than the observed 0.33c increase in effective half-spread. Applying the net-of-fees implicit transaction cost analysis of Malinova and Park (2015), we conclude that total transaction costs for liquidity demanders on Alpha increased slightly. Consistent with Malinova and Park (2015), we document that liquidity suppliers pass on changes in explicit trading fees, even in markets transitioning to inverted maker-taker pricing schemes.

< Insert Table 4 Here >

Following Conrad et al. (2015), we calculate realized spreads by comparing traded prices with NBBO midpoint quotes at intervals of 1, 5, 10 and 20 seconds after each trade, to proxy the profits from liquidity provision in a low latency environment. Realized spreads increase 1.24 cents after one second and 1.40 cents after twenty seconds. In relative terms, realized spreads increase 6.29 basis points after one second and 7.52 basis points after twenty seconds. Alpha previously had a passive trading rebate of 0.14c per share traded, for shares priced above $1. For these shares, passive trades under the revised fee structure paid a fee of 0.10c per share during the observation period.[29] The fee for adding liquidity increased 0.24c per share traded, which is substantially smaller than the 0.70c increase in realized half-spread 20 seconds after the trade. Multiplying by trading volumes, net-of-fees profits attributable to liquidity provision on Alpha increase by approximately $1.48 million per month. Figure 6 presents average net-of-fees realized half-spreads across each of the major Canadian trading venues.

< Insert Figure 6 Here >

Adverse selection costs measure the directional change in the NBBO midpoint price after a trade. Under Alpha's new market structure, we observe a decline in adverse selection costs of 0.58 cents 1 second after a trade and 0.72 cents after 20 seconds. In relative terms, price movements away from the liquidity supplier decline 4.31 basis points and 5.53 basis points, 1 second and 20 seconds after each trade respectively. The increase in the realized spread of trades on Alpha indicates that liquidity suppliers are able to either widen their spreads or avoid adverse selection. The observed decreases in adverse selection costs are slightly larger than the increases in effective spreads, indicating that increased profitability of liquidity provision on Alpha is driven mainly by the ability to avoid toxic order flow. Figure 7 presents average adverse selection costs across each of the major Canadian trading venues.

< Insert Figure 7 Here >

5. Impact on Market Quality for Other Trading Venues

Section 4 establishes that Alpha's systematic order processing delay against marketable orders enables the segmentation of uninformed order flow. In this section, we address the question of whether order flow segmentation increases flow toxicity on TSX, Chi-X and CX2, the other large Canadian trading venues. The existing literature suggests that the segregation of uninformed active orders on dark venues increases the toxicity of the remaining order flow on public lit markets (e.g. Easley et al., 1996; Comerton-Forde and Putnins, 2015). We also analyse the impact on consolidated market quality at the national best bid and offer prices.

To formally test for statistically significant changes in market quality metrics consolidated across Alpha, TSX, Chi-X and CX2, as well as traded liquidity metrics on the three venues excluding Alpha, we utilise equations of the form

$$y_{i,d} = Post_d + Price_{i,d} + Turnover_{i,d} + Volatility_{i,d} + FE_i + e_{i,d} \quad (11)$$

[29] From the 1st of December 2015, passive trading fees will increase to 0.16c per share for post only orders and 0.14c for non- post only orders.

where $y_{i,d}$ is a measure of consolidated market quality for stock i on day d, $Post_d$ is an indicator variable equal to one for observations after the 21st of September 2015 and zero prior, $Price_{i,d}$ is either the natural logarithm or inverse of the time-weighted NBBO midpoint price, $Turnover_{i,d}$ is the natural logarithm of total on-market trade turnover across either the four venues or three venues, $Volatility_{i,d}$ is the standard deviation of one minute NBBO midpoint returns, FE_i indicates stock fixed effects and $e_{i,d}$ is an error term. Observations are winsorized at the 1% level per day.

5.1. Impact on Consolidated NBBO Liquidity

Table 5 presents regression results for changes in liquidity metrics across all four trading venues consolidated at the national best bid and offer prices. Quoted spreads increase 0.35 cents in absolute terms and 0.66 basis points in relative terms. Figure 8 illustrates that Alpha's proportion of time quoting at the NBBO decreases substantially whilst there was a slight increase across the other venues. Total quoted depths at NBBO increase 13%. However, Figure 9 shows that Alpha's share of total NBBO quoted depth increases substantially whilst Figure 2 shows that the accessibility of orders at NBBO on Alpha declines sharply after the 21st of September. This indicates that the minimum size of post only orders on Alpha is effective at increasing visible liquidity, but that the speed bump allows this liquidity to fade before being accessed. The proportion of turnover at the NBBO that consumes all depth visible at the NBBO and imposes adverse selection costs increases 1.93%. As a proportion of trades at the prevailing NBBO price, trade volumes that "walk the book" and occur within each trade string at the next best price behind NBBO increase 1.60%. Therefore, although overall displayed market depths were larger, trades across all venues were more likely to consume the entire depth available and "walk the book", filling at inferior prices.

< Insert Table 5 Here >

< Insert Figure 8 Here >

< Insert Figure 9 Here >

5.2. Traded Liquidity Metrics on Other Venues

Alpha's relative avoidance of informed trades that sweep multiple venues and impose adverse selection costs may increase the toxicity of residual order flow on the other large Canadian trading venues. Table 6 examines changes in effective spreads, realized spreads and adverse selection costs against the NBBO midpoint, volume-weighted among trades on TSX, Chi-X and CX2. All control variables have the expected directionality and are statistically significant. After Alpha's relaunch, effective spreads increase 0.27 cents in absolute terms, or 0.46 basis points in relative terms. Multiplying by trading volumes, the cost of demanding liquidity increases by $6.12 million per month. Effective spreads increase by a smaller magnitude than quoted spreads, potentially due to the concurrent increase in market depths.

Similar to Conrad et al. (2015), we calculate a range of realized spreads and adverse selection costs from 1 second to 20 seconds after each trade. For brevity, we report results after 20 seconds as our base specification. Realized spreads decline 0.06 cents, signalling a reduction in profits attributable to liquidity provision. Multiplying by traded volume, liquidity provider profitability decreases by $1.36 million per month. Although effective spreads widen, the narrowing in realized spreads result from a sharp increase in adverse selection costs of 0.38 cents, or 0.67 basis points. Since adverse price movements after each trade are a proxy for order flow toxicity, we conclude that Alpha's segmentation of order flow increases residual order flow toxicity and imposes negative liquidity externalities on other trading venues.

< Insert Table 6 Here >

Next, we separately examine traded liquidity metrics on each venue against the national best bid and offer midpoint, to identify where the largest impact of Alpha's order flow segmentation occurs. Table 7 presents regression results for changes in effective spreads, as well as realized spreads and adverse selection after 20 seconds, separately for TSX, Chi-X and CX2. Effective spreads increase 0.24c on TSX and 0.29c on Chi-X, consistent with the observed widening in quoted spreads at the national best bid and offer prices. No significant change in effective spreads occurred on CX2, potentially due to its relatively low proportion of time quoting at the NBBO. Adverse selection costs increase 0.36c on TSX and Chi-X, and 0.29c on CX2. As Alpha captures a larger proportion of the uninformed order flow, flow toxicity amongst the remaining trades on all other venues increases and order book resiliency declines. Realized spreads decline 0.07c, 0.10c and 0.21c on TSX, Chi-X and CX2 respectively. Alpha's new inverted maker taker pricing and larger quoted depths from minimum post only order sizes enable it to compete with CX2 for active retail order flow, substantially reducing the profitability of liquidity provision on this venue.

< Insert Table 7 Here >

5.3. Consolidated Liquidity Metrics by Proportion of Informed Trading Deciles

Alpha's speed bump is designed to enable its liquidity suppliers to avoid interacting with large sprays of trades that execute across multiple venues simultaneously and displace all available market depth at a price level, resulting in immediate adverse selection costs for liquidity suppliers. Therefore the largest market quality impact is likely to be observed amongst securities with the highest proportion of trade strings that displace the entire NBBO depth ("informed trades") and have the least resilient order books.

To compare changes in consolidated market quality among a cross section of stocks, we formally test for changes in the market quality of securities by their proportion of informed trading in the pre-event period

(13th of July, 2015 to the 18th of September, 2015). As in earlier analyses, trade strings are defined as informed if they displace an entire level of depth quoted at the national best bid or offer prices across all venues. Deciles one and ten have average informed trading proportion of 72% and 39% respectively. Separate analysis by deciles of securities also serves as a robustness test, by demonstrating that changes in market quality are not isolated to a small subset of securities in the sample.

We repeat the regression analysis of consolidated market quality metrics conducted in the previous section, but allow for differential effects of the event by deciles. To conserve space, Table 8 only reports the coefficients and t-statistics of the post-launch dummy and omits those for the standard controls.

Quoted spreads increase the most for low resiliency stocks, by about 1c for the lowest 2 deciles, while they stay about the same for high resiliency stocks. Quoted depths increase by between 5 and 20 percent across all deciles, with the highest increases again concentrated among low-resiliency stocks. The proportion of trades executing at an inferior price to the NBBO within each trade string increases across all deciles, with statistical significance at the 1% level for deciles two to ten.

Adverse selection costs show a somewhat monotonic pattern with increases being concentrated again among lower resiliency stocks. Effective spreads of trades on TSX, Chi-X and CX2 calculated against the prevailing NBBO midpoint significantly widen across the lowest 5 deciles, but do not change by much for the other half of the sample. As a consequence, to a large extent realized spreads do not change across deciles. Higher adverse selection costs faced by liquidity suppliers are being passed on to liquidity demanders in the form of higher quoted and effective spreads, with no net impact on the trading profits attributable to liquidity provision.

These results indicates that our findings are robust across various classes of stocks, with those stocks that experience the greatest adverse selection costs due to liquidity demanders consuming entire levels of depth displaying the highest market-wide impact of segmentation. As Alpha's speed bump allows liquidity suppliers to effectively avoid being adversely selected by larger orders which sweep all markets, it results in increased adverse selection and effective spreads for the remainder of the market.

< Insert Table 8 Here >

6. Conclusion

It has been long standing practice in the United States that retail order flow, or more precisely, flow deemed to be uninformed, rarely reaches the lit exchanges. Instead, most of this flow is internalized by brokers or sold to a third party in a practice called payment for order flow. This is in addition to a very fragmented trading landscape where internalization accounts for about 20 percent of trading volume, and another 15 percent of volume is executed in dark trading venues.

In this paper, we investigate the consequences of segregating retail order flow away from incumbent exchanges on overall market quality and trading costs, as well as identifying the welfare gains and losses for different groups of market participants. We exploit an exogenous shock to the equity market landscape in Canada, where one of the exchange venues, TSX Alpha, implemented a set of market design changes that make it attractive for small orders, while simultaneously making it very unattractive for large informed orders that are more likely to impose adverse selection costs. Canada is uniquely suited for this analysis, because it previously disallowed any type of internalization or payment for order flow, and dark trading is limited due to minimum price improvement regulations.

We first document that the design changes led to a sizeable increase in the proportion of uninformed order flow on the relaunched Alpha. Second, we analyse market quality after the change. Among the other exchanges, we find widening effective spreads for liquidity demanders at the same time as reduced realized spreads for liquidity suppliers, resulting in welfare losses for both groups. We find that this is driven by increases in the adverse selection costs that liquidity suppliers face due to a higher probability of facing informed traders. The clear winners are liquidity suppliers on new Alpha who benefit from wider spreads and lower adverse selection, which outweigh increases in passive trading fees. Overall, the segmentation of uninformed order flow appears detrimental to market quality and aggregate welfare, in line with the standard theory (Kyle, 1985).

Speed bumps are new and novel features in market microstructure and have recently attracted increasing attention from exchange operators, market participants, securities regulators and theoretical researchers. Our findings and research approach have numerous implications for these groups. We show that the implementation of a speed bump in conjunction with other market structure changes can attract increased liquidity provision from low latency participants and uninformed active flow that might otherwise be internalized, particularly in markets where payment for order flow is prohibited, outlining the potential for their introduction on other trading venues and in other jurisdictions. Both researchers and practitioners should heed the consequences such innovations may have, with special attention paid to the operation of the speed bump and how it may facilitate the segregation of uninformed order flow.

Finally, we develop several innovative empirical techniques that enable the analysis of cross-market linkages and fairness, which O'Hara (2015) argues are two especially important issues in current market structure research and regulation. We highlight the importance of looking beyond traditional measures of market quality when evaluating market structure changes that involve fragmented order flow and low latency trading. To this end, we propose techniques to correctly assign trade direction in datasets with trades and quotes from a single data feed, benchmark clock synchronization across multiple trading venues and join trades that potentially originated from a smart order router spray. From these methods, we develop metrics that empirically validate the conjecture of O'Hara and Ye (2011) that trade-through prohibition and smart order routing in fragmented markets virtually replicate the network advantages of consolidated trading, but show that these market linkages have been circumvented by Alpha's speed bump and its ability to segregate uninformed order flow.

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Table 1
Specifications of Major Canadian Lit Trading Venues

This table presents institutional details for each of the major Canadian lit trading venues, including trading fees, order protection rule status, speed bump status and continuous trading hours. Negative trading fees, i.e. rebates, are enclosed in parentheses.

	New Alpha	**Old Alpha**	**TSX**[30]	**Chi-X**	**CX2**
Taker Fee (above $1)	(0.0010)	0.0018	0.0030 for interlisted 0.0023 for non-interlisted	0.0028	(0.0010)
Maker Fee (above $1)	0.0016 for post only, otherwise 0.0014[31]	(0.0014)	(0.0026) for interlisted (0.0019) for non-interlisted	(0.0024)	0.0014
Speed Bump	1 – 3 ms randomized[32]	No	No	No	No
OPR Protected	No	Yes	Yes	Yes	Yes
Continuous Trading Hours	8:00am – 5:00pm	9:30am – 4:00pm	9:30am – 4:00pm	8:30am – 5:00pm	8:30am – 5:00pm
Average Daily Volume[33]	14,812,413	27,724,226	152,553,868	39,564,726	15,876,833

[30] At the start of each month, TSX updates a list of securities for which the interlisted trading fees apply during that month, available at http://www.tsx.com/resource/en/1130/tsx-symbols-subject-to-applicable-interlisted-trading-fees.csv
[31] New Alpha offers a discounted maker fee of 0.0010 for both post only and non- post only until the 1st of December 2015
[32] Alpha's speed bump applies to all orders except those designated as post-only, which are unable to remove liquidity
[33] Average daily trading volume of on-market lit trades in TSX Composite Index component securities

Table 2
Summary Statistics

This table reports univariate descriptive statistics across the 247 TSX Composite Index component securities. The first and second observation periods include the ten weeks prior to and following Alpha Exchange's relaunch on the 21st of September 2015. Quoted spreads and quoted depths are time-weighted and presented at the national best bid and offer prices across Alpha, Chi-X, CX2 and TSX. Trades are deemed to be informed if they were part of a string that displaced the entire NBBO depth, where strings are constructed by grouping trades in the same direction separated by less than 50 milliseconds. Level two trades are those that occur at the next best price behind NBBO within each trade string. Time at NBBO is the proportion of time from 9:30am to 4:00pm that each venue is quoting at the NBB plus the proportion of time quoting at the NBO, divided by two. Depth at NBBO is the proportion of total dollar depth at the NBBO that is quoted by each venue. Metrics are presented separately for Alpha and Chi-X, CX2 and TSX. Effective spreads are calculated against the prevailing NBBO midpoint. Realized spreads are calculated against the NBBO midpoint twenty seconds after the trade. For all informed trades on each venue, the NBBO fill rate is the proportion of the total visible liquidity at NBB or NBO at the start of the trade string that resulted in trades. Price is the time-weighted NBBO midpoint. Volume is the total quantity of on-market trades. Volatility is the standard deviation of one minute NBBO midpoint returns.

	13 JUL 2015 – 18 SEP 2015			21 SEP 2015 – 27 NOV 2015			Change	T Stat
	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.		
A: Consolidated Liquidity								
NBBO Quoted Spread (cents)	3.58	1.83	5.33	3.67	1.83	5.89	0.09	1.49
NBBO Quoted Depth ($'000s)	81.76	49.64	85.97	92.69	57.33	91.60	10.93	7.08
Informed Trades (%)	58.84	59.83	12.31	59.59	60.50	11.73	0.75	2.32
Level Two Trades (%)	11.78	11.19	5.92	12.98	12.42	6.30	1.20	7.89
B: Transaction Costs								
Alpha Effective Spread (cents)	2.86	1.49	4.13	3.48	1.84	5.57	0.62	7.67
Other Effective Spread (cents)	2.92	1.62	4.12	2.94	1.57	4.52	0.02	0.36
Alpha Adverse Selection (cents)	3.09	1.88	4.25	2.17	1.16	3.62	-0.92	-9.40
Other Adverse Selection (cents)	3.65	2.28	4.78	3.66	2.16	5.64	0.02	0.22
C: Percentages at NBBO								
Alpha Time (%)	59.08	59.51	21.95	34.18	31.66	17.59	-24.90	-22.09
Chi-X Time (%)	64.87	68.70	24.13	68.60	71.77	22.29	3.73	5.13
CX2 Time (%)	38.48	35.81	17.75	44.88	44.78	14.55	6.40	8.00
TSX Time (%)	94.23	96.35	6.32	96.14	97.65	4.37	1.91	9.16
Alpha Depth (%)	13.84	13.17	5.72	15.86	14.63	9.49	2.02	2.54
Chi-X Depth (%)	16.61	16.32	6.17	16.89	16.92	5.93	0.28	0.87
CX2 Depth (%)	7.30	6.37	4.15	7.50	6.89	3.46	0.20	0.73
TSX Depth (%)	62.17	62.03	8.07	59.64	59.46	9.59	-2.53	-4.02
Alpha Fill Rate (%)	93.62	95.42	15.84	40.49	32.96	27.52	-53.13	-44.03
Chi-X Fill Rate (%)	84.61	86.25	16.49	84.84	85.99	14.70	0.23	0.59
CX2 Fill Rate (%)	85.73	85.82	17.79	90.21	90.73	14.35	4.49	8.65
TSX Fill Rate (%)	102.11	103.10	12.61	102.33	103.27	12.63	0.22	0.73
D: Control Variables								
Price ($)	31.84	21.21	42.15	29.65	20.26	33.93	-2.19	-2.97
Volume (millions)	0.90	0.41	1.23	0.97	0.46	1.33	0.07	2.19
Volatility (basis points)	11.84	9.69	6.96	11.44	9.61	6.35	-0.40	-1.24

Table 3
Fill Rates at the National Best Bid and Offer Prices Relative to the Pre-Relaunch Period

This table reports changes in fill rates at the national best bid and offer prices on Alpha, Chi-X, CX2 and TSX for TSX Composite Index securities, after Alpha's relaunch relative to previous levels. We construct trade strings by joining all trades in the same direction separated by less than 50 milliseconds. We define trade strings where the entire NBBO depth was displaced as being informed, and for informed trade strings we calculate the NBBO fill rate as the proportion of starting liquidity that resulted in trades. Econometrically, the NBBO fill rate for stock *i* on day *d* is expressed as the sum of a stock specific mean, indicator variable for the post-relaunch period, control variables for price, volume, volatility, total NBBO quoted depth and each venue's NBBO depth share, and an error term. The pre-relaunch period runs from the 13th of July 2015 to the 18th of September 2015 and the post-relaunch period from the 21st of September 2015 to the 27th of November 2015. We calculate the change in NBBO fill rates from the pre-relaunch period to the post-relaunch period, as well as for changes in each control variable, and add a "*/**/***" to the t-statistic if they are significantly different at the 90%/95%/99% levels. We double cluster standard errors by stock and date.

	Alpha	Chi-X	CX2	TSX
$Post_d$	-49.88	0.17	4.34	0.52
	(-50.23)***	(0.39)	(8.07)***	(1.70)*
$Price_{i,d}$	3.61	1.13	-3.08	1.48
	(1.29)	(0.52)	(-1.75)*	(0.86)
$Turnover_{i,d,v}$	2.84	8.82	2.11	6.22
	(3.77)***	(18.75)***	(4.49)***	(15.46)***
$Volatility_{i,d}$	-0.32	-0.57	-0.20	-0.29
	(-3.40)***	(-9.60)***	(-3.40)***	(-5.84)***
$Depth_{i,d}$	-8.94	-4.73	-1.92	-5.86
	(-7.32)***	(-3.93)***	(-1.85)*	(-5.72)***
$Depth\ Share_{i,d,v}$	-85.54	-30.28	-18.32	-1.35
	(-14.20)***	(-8.07)***	(-3.00)***	(-0.97)
Adjusted R^2	71.7%	8.8%	2.8%	7.8%
# Obs	21822	21934	21674	21948

Table 4
Trade-Based Liquidity Metrics on Alpha Relative to the Pre-Relaunch Period

This table reports changes in effective spreads against the prevailing NBBO midpoint, and realized spreads and adverse selection costs against the reference NBBO midpoint 20 seconds after the trade, on Alpha for for TSX Composite Index securities, after Alpha's relaunch relative to previous levels. Econometrically, the liquidity metric for stock *i* on day *d* is expressed as the sum of a stock specific mean, indicator variable for the post-relaunch period, control variables for price, volume and volatility, and an error term. Panel A presents metrics in cents whilst panel B presents metrics in basis points. The pre-relaunch period runs from the 13th of July 2015 to the 18th of September 2015 and the post-relaunch period from the 21st of September 2015 to the 27th of November 2015. We calculate the change in liquidity metrics from the pre-relaunch period to the post-relaunch period, as well as for changes in each control variable, and add a "*/**/***" to the t-statistic if they are significantly different at the 90%/95%/99% levels. We double cluster standard errors by stock and date.

Panel A: Cents

	Effective	Realized Spread		Adverse Selection	
	Spread	1 second	20 seconds	1 second	20 seconds
$Post_d$	0.66	1.24	1.40	-0.58	-0.72
	(6.34)***	(10.57)***	(10.99)***	(-9.69)***	(-8.14)***
$Price_{i,d}$	2.11	-0.01	-0.97	2.57	3.59
	(2.59)***	(-0.02)	(-1.39)	(3.85)***	(3.82)***
$Turnover_{i,d}$	-0.20	-0.09	-0.07	-0.03	-0.06
	(-3.88)***	(-1.55)	(-1.00)	(-0.51)	(-0.61)
$Volatility_{i,d}$	0.11	0.03	-0.01	0.07	0.11
	(5.48)***	(2.00)**	(-0.58)	(7.99)***	(8.58)***
Adjusted R^2	6.1%	9.8%	13.1%	8.4%	8.7%
# Obs	21870	21870	21870	21870	21870

Panel B: Basis Points

	Effective	Realized Spread		Adverse Selection	
	Spread	1 second	20 seconds	1 second	20 seconds
$Post_d$	1.95	6.29	7.52	-4.31	-5.53
	(10.71)***	(14.98)***	(15.14)***	(-11.04)***	(-11.70)***
$Price_{i,d}$	89.43	72.04	69.87	9.79	11.04
	(42.89)***	(8.78)***	(7.67)***	(1.36)	(1.38)
$Turnover_{i,d}$	-0.61	0.15	0.40	-0.80	-1.03
	(-4.91)***	(0.85)	(1.87)*	(-5.26)***	(-5.28)***
$Volatility_{i,d}$	0.34	-0.26	-0.47	0.60	0.83
	(12.71)***	(-4.86)***	(-7.59)***	(14.56)***	(15.06)***
Adjusted R^2	33.2%	27.5%	27.7%	19.7%	22.5%
# Obs	21870	21870	21870	21870	21870

Table 5
Consolidated Liquidity Metrics at NBBO Relative to the Pre-Relaunch Period

This table reports changes in quoted spreads and quoted depths constructed from the national best bid and offer prices available across TSX, Alpha, Chi-X and CX2 for TSX Composite Index securities, after Alpha's relaunch relative to previous levels. Changes are also reported for the percentage of informed trades that displaced a full level of NBBO depth, and the ratio of trading turnover that executed within each trade string at a price inferior to the starting NBBO. Econometrically, the liquidity metric for stock *i* on day *d* is expressed as the sum of a stock specific mean, indicator variable for the post-relaunch period, control variables for price, volume and volatility, and an error term. The pre-relaunch period runs from the 13th of July 2015 to the 18th of September 2015 and the post-relaunch period from the 21st of September 2015 to the 27th of November 2015. We calculate the change in liquidity metrics from the pre-relaunch period to the post-relaunch period, as well as for changes in each control variable, and add a "*/**/***" to the t-statistic if they are significantly different at the 90%/95%/99% levels. We double cluster standard errors by stock and date.

	Quoted Spread		Quoted Depth	Informed	Level Two
	Cents	Basis Points		Percentage	Ratio
$Post_d$	0.35	0.66	0.13	1.93	1.60
	(4.05)***	(3.90)***	(8.98)***	(6.45)***	(10.70)***
$Price_{i,d}$	3.15	85.56	0.33	11.51	5.58
	(2.99)***	(32.01)***	(4.58)***	(8.38)***	(9.85)***
$Turnover_{i,d}$	-0.96	-3.17	0.24	-4.74	-0.38
	(-9.57)***	(-14.13)***	(16.31)***	(-16.32)***	(-2.53)**
$Volatility_{i,d}$	0.13	0.43	-0.03	0.83	0.32
	(6.74)***	(14.29)***	(-17.61)***	(17.04)***	(16.08)***
Adjusted R^2	10.6%	47.5%	32.4%	11.6%	8.8%
# Obs	21948	21948	21948	21948	21948

Table 6
Consolidated Liquidity Metrics across Other Venues Relative to the Pre-Relaunch Period

This table reports changes in effective spreads against the prevailing NBBO midpoint, and realized spreads and adverse selection costs against the reference NBBO midpoint 20 seconds after the trade, consolidated across TSX, Chi-X and CX2 for TSX Composite Index securities, after Alpha's relaunch relative to previous levels. Econometrically, the liquidity metric for stock *i* on day *d* is expressed as the sum of a stock specific mean, indicator variable for the post-relaunch period, control variables for price, volume and volatility, and an error term. The pre-relaunch period runs from the 13th of July 2015 to the 18th of September 2015 and the post-relaunch period from the 21st of September 2015 to the 27th of November 2015. We calculate the change in liquidity metrics from the pre-relaunch period to the post-relaunch period, as well as for changes in each control variable, and add a "*/**/***" to the t-statistic if they are significantly different at the 90%/95%/99% levels. We double cluster standard errors by stock and date.

	Effective Spread		Realized Spread		Adverse Selection	
	Cents	Basis Points	Cents	Basis Points	Cents	Basis Points
$Post_d$	0.27	0.46	-0.06	-0.19	0.38	0.67
	(3.83)***	(4.54)***	(-1.83)*	(-1.21)	(3.82)***	(4.48)***
$Price_{i,d}$	2.63	89.47	-1.06	37.12	3.63	49.44
	(3.13)***	(39.11)***	(-6.24)***	(5.78)***	(3.33)***	(11.86)***
$Turnover_{i,d}$	-0.59	-1.58	0.16	1.49	-0.78	-3.22
	(-7.68)***	(-9.11)***	(4.72)***	(8.25)***	(-7.66)***	(-17.82)***
$Volatility_{i,d}$	0.11	0.36	-0.10	-0.66	0.22	1.06
	(6.43)***	(14.06)***	(-11.27)***	(-17.78)***	(6.99)***	(25.39)***
Adjusted R^2	8.9%	49.3%	7.8%	21.5%	11.8%	40.5%
# Obs	21948	21948	21948	21948	21948	21948

Table 7
Per-Venue Liquidity Metrics on Other Venues Relative to the Pre-Relaunch Period

This table reports changes in effective spreads against the prevailing NBBO midpoint, and realized spreads and adverse selection costs against the reference NBBO midpoint 20 seconds after the trade, on each of TSX, Chi-X and CX2 for TSX Composite Index securities, after Alpha's relaunch relative to previous levels. Econometrically, the liquidity metric for stock *i* on day *d* is expressed as the sum of a stock specific mean, indicator variable for the post-relaunch period, control variables for price, volume and volatility, and an error term. The pre-relaunch period runs from the 13th of July 2015 to the 18th of September 2015 and the post-relaunch period from the 21st of September 2015 to the 27th of November 2015. We calculate the change in liquidity metrics from the pre-relaunch period to the post-relaunch period, as well as for changes in each control variable, and add a "*/**/***" to the t-statistic if they are significantly different at the 90%/95%/99% levels. We double cluster standard errors by stock and date.

	Effective Spread			Realized Spread			Adverse Selection		
	TSX	Chi-X	CX2	TSX	Chi-X	CX2	TSX	Chi-X	CX2
$Post_d$	0.24	0.29	0.13	-0.07	-0.10	-0.21	0.36	0.36	0.29
	(3.59)***	(3.50)***	(1.64)	(-2.16)**	(-1.96)**	(-3.14)***	(3.80)***	(3.94)***	(4.46)***
$Price_{i,d}$	2.61	2.80	2.94	-1.27	-0.53	0.50	3.79	3.64	2.59
	(3.18)***	(3.26)***	(3.19)***	(-5.90)***	(-1.96)**	(1.24)	(3.41)***	(3.73)***	(5.87)***
$Turnover_{i,d,v}$	-0.52	-0.49	-0.49	0.25	-0.06	-0.28	-0.81	-0.44	-0.20
	(-7.39)***	(-8.54)***	(-7.25)***	(7.26)***	(-1.87)*	(-3.82)***	(-8.40)***	(-6.48)***	(-3.22)***
$Volatility_{i,d}$	0.11	0.11	0.11	-0.11	-0.06	-0.01	0.22	0.17	0.11
	(6.18)***	(6.81)***	(7.49)***	(-12.05)***	(-8.82)***	(-0.77)	(7.19)***	(8.26)***	(9.90)***
Adjusted R^2	8.7%	6.2%	5.1%	7.9%	1.6%	1.6%	11.9%	6.9%	4.9%
# Obs	21948	21939	21818	21948	21939	21818	21948	21939	21818

Table 8
Consolidated Liquidity Metrics on Other Venues Relative to Pre-Relaunch Period
By Proportion of Informed Trading Deciles

This table reports coefficient estimates and t-statistics for the post-relaunch indicator variable using the regression model specification in Equation 11 for changes in consolidated market quality metrics across deciles of TSX Composite Index securities. Deciles are constructed from the proportion of each stock's trading volume that was informed, and originated from trade strings that displace an entire level of consolidated market depth at the national best bid or offer price in the ten weeks prior to Alpha's relaunch. Quoted spreads, quoted depths and level two ratios are consolidated across TSX, Alpha, Chi-X and CX2. Effective spreads, realized spreads and adverse selection are consolidated across TSX, Chi-X and CX2. Econometrically, the liquidity metric for stock *i* on day *d* is expressed as the sum of a stock specific mean, indicator variable for the post-relaunch period, control variables for price, volume and volatility, and an error term. The pre-relaunch period runs from the 13th of July 2015 to the 18th of September 2015 and the post-relaunch period from the 21st of September 2015 to the 27th of November 2015. We calculate the change in liquidity metrics from the pre-relaunch period to the post-relaunch period, and add a "*/**/***" to the t-statistic if they are significantly different at the 90%/95%/99% levels. We double cluster standard errors by stock and date.

Decile	Average Informed	Quoted Spread	Quoted Depth	Level Two Ratio	Effective Spread	Realized Spread	Adverse Selection
1	72%	**1.03**	**0.20**	**1.18**	**0.68**	**-0.01**	**0.90**
		(3.02)***	(7.23)***	(2.16)**	(2.54)**	(-0.05)	(2.16)**
2	68%	**1.03**	**0.22**	**2.50**	**0.87**	**-0.16**	**1.25**
		(2.75)***	(7.72)***	(5.99)***	(2.40)**	(-1.29)	(2.40)**
3	65%	**0.36**	**0.17**	**2.45**	**0.28**	**-0.02**	**0.38**
		(2.91)***	(7.44)***	(4.60)***	(2.54)**	(-0.30)	(2.11)**
4	62%	**0.35**	**0.17**	**1.36**	**0.23**	**-0.06**	**0.29**
		(2.36)**	(6.75)***	(2.77)***	(2.05)**	(-0.92)	(2.24)**
5	60%	**0.27**	**0.16**	**2.08**	**0.19**	**0.01**	**0.15**
		(2.00)**	(6.37)***	(5.06)***	(2.00)**	(0.20)	(2.88)***
6	59%	**0.02**	**0.12**	**1.33**	**0.01**	**0.00**	**0.01**
		(0.42)	(4.45)***	(4.50)***	(0.48)	(0.07)	(0.16)
7	57%	**0.28**	**0.06**	**1.81**	**0.17**	**-0.14**	**0.30**
		(1.73)*	(2.34)**	(5.07)***	(1.46)	(-1.66)*	(2.18)**
8	54%	**0.10**	**0.10**	**1.36**	**0.11**	**0.00**	**0.10**
		(1.31)	(4.40)***	(4.76)***	(1.48)	(0.05)	(1.81)*
9	50%	**0.03**	**0.07**	**1.02**	**0.01**	**-0.05**	**0.10**
		(1.00)	(2.92)***	(3.09)***	(1.12)	(-2.66)***	(3.02)***
10	39%	**0.01**	**0.05**	**0.83**	**0.01**	**-0.06**	**0.06**
		(0.60)	(1.93)*	(3.87)***	(1.40)	(-3.32)***	(2.96)***

Figure 1
On-Market Volume Share per Venue

This figure presents each venue's market share of total daily on-market lit trading volume in TSX Composite Index securities. We present market share of volume, rather than dollar turnover, since trading fees in Canada are a fixed price per share instead of a fixed percentage of dollar value traded.

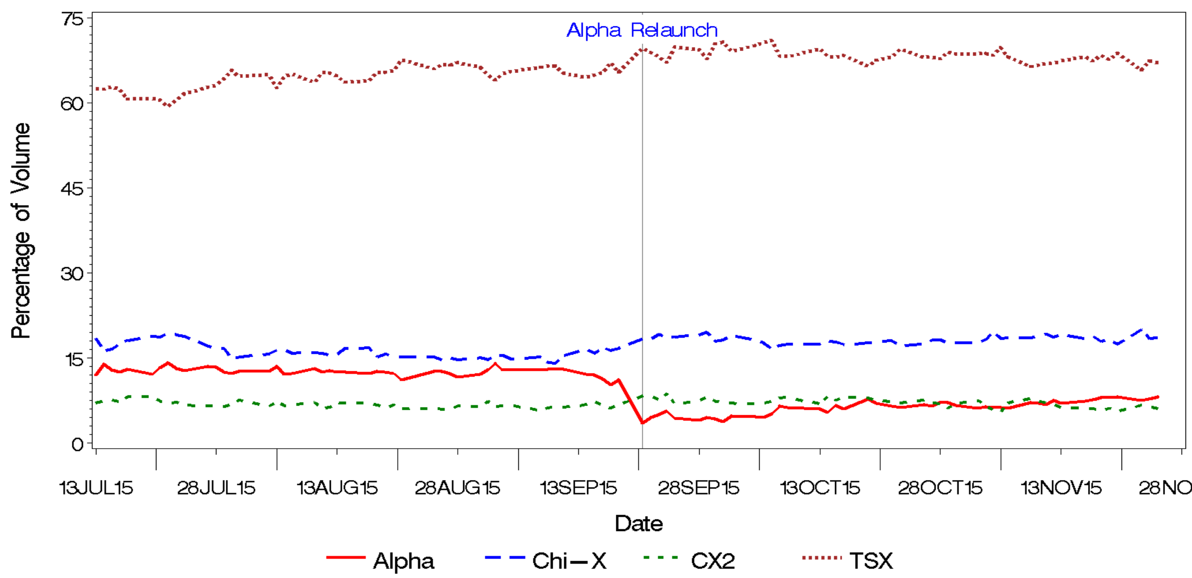

Figure 2
NBBO Fill Rates per Venue

This figure presents the aggregate fill rate within each market for informed trade strings that displaced an entire level of quoted depth at the NBBO. It measures the proportion of visible liquidity that active traders were able to access, which may be above 100% if icebergs refill. Fleeting liquidity results in low fill rates.

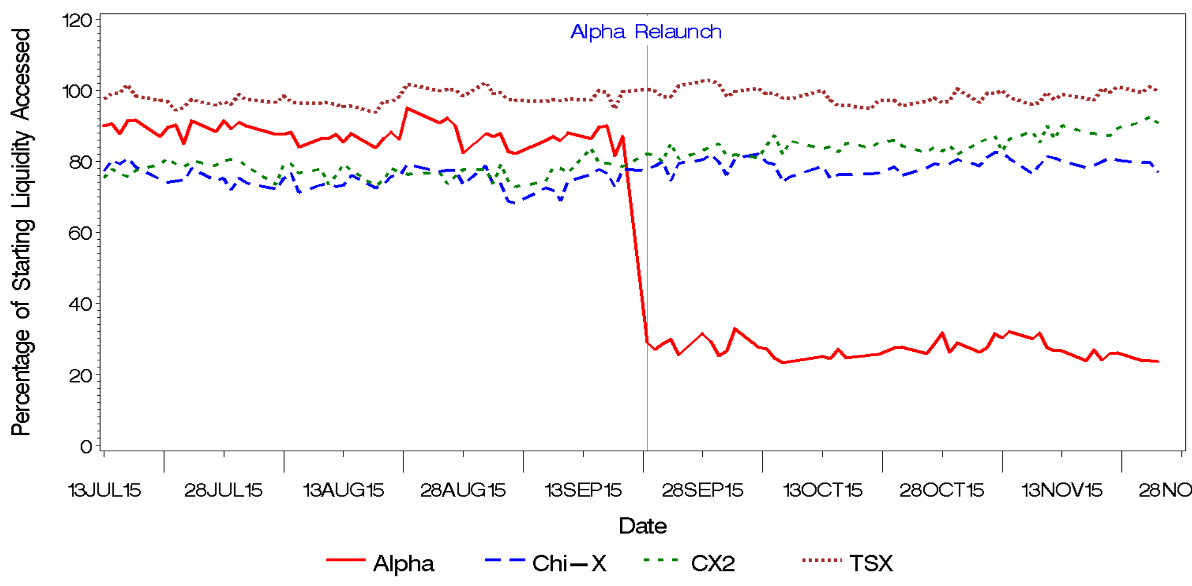

Figure 3
Active Market Share by Broker Type on Alpha

This figure presents Alpha's market share of active trade turnover by broker type. Retail consists of two local Canadian banks that are known to constitute a large proportion of retail broking activity.

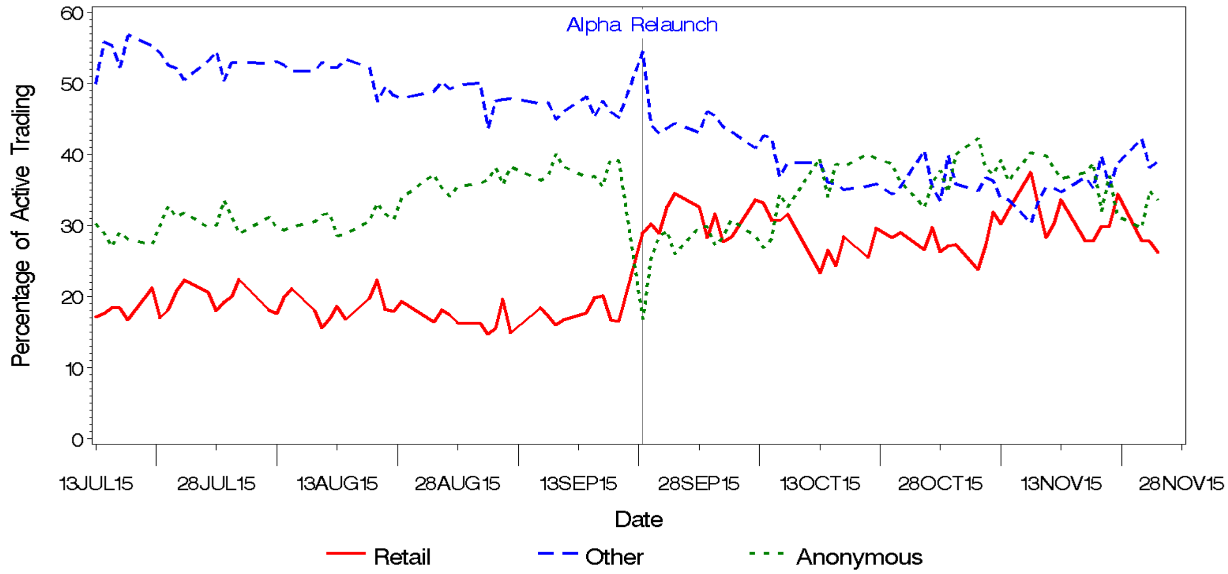

Figure 4
Passive Market Share by Broker Type on Alpha

This figure presents Alpha's market share of passive trade turnover by broker type. HFT DMA consists of two global investment banks that offer direct market access services to proprietary trading firms that act as low latency market makers.

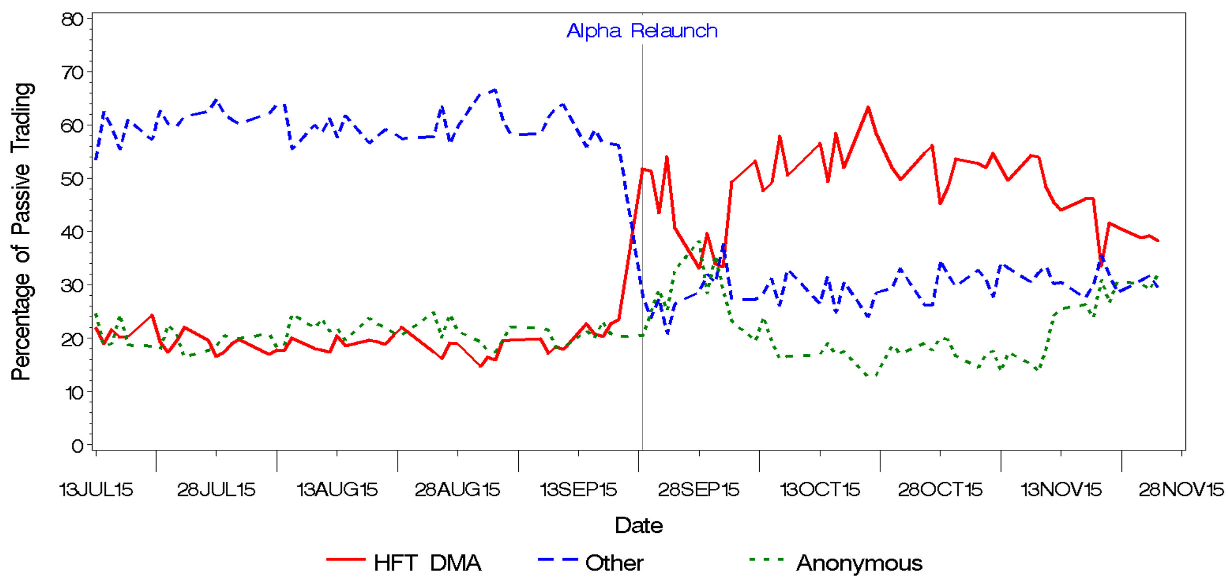

Figure 5
Trade Composition by Information Content and Multi-Venue Spray on Alpha

This figure presents a decomposition of Alpha's on-market turnover by trade string type. Trade strings that displaced an entire level of quoted depth at the NBBO are informed, whilst SOR strings contain trades across two or more venues and may have originated from a smart order router spray.

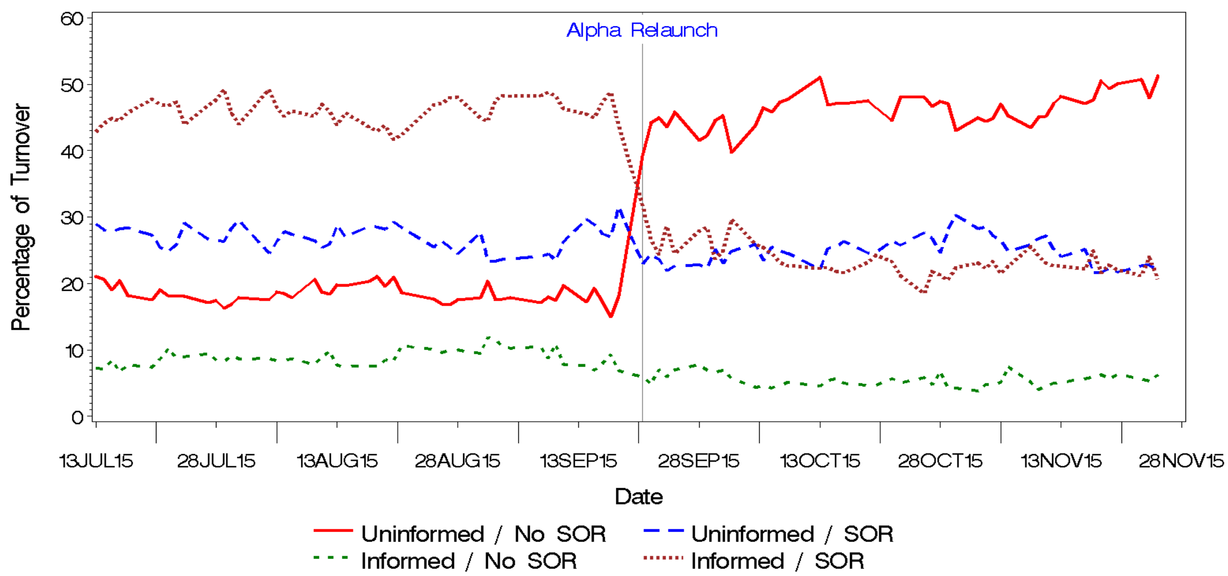

Figure 6
Net-of-Fees Realized Half-Spreads per Venue

This figure presents the volume-weighted average realized spreads of trades against the midpoint of the national best bid and offer prices twenty second after the trade, adjusted by the venue's passive trading fee or rebate. The net-of-fees realized spread proxies for the liquidity supplier's trading profits.

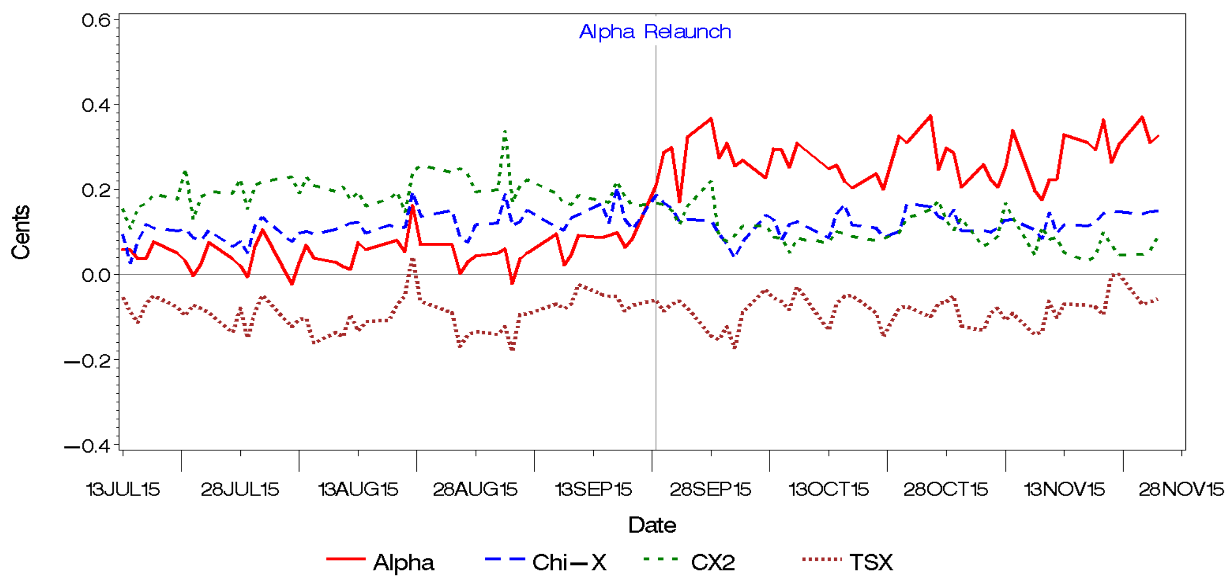

Figure 7
Adverse Selection Costs per Venue

This figure presents the volume-weighted average adverse selection costs of trades, measured as the directional change in midpoint of the national best bid and offer prices from immediately before the trade occurred to twenty seconds after the trade. This metric gauges the price impact as a result of the trade.

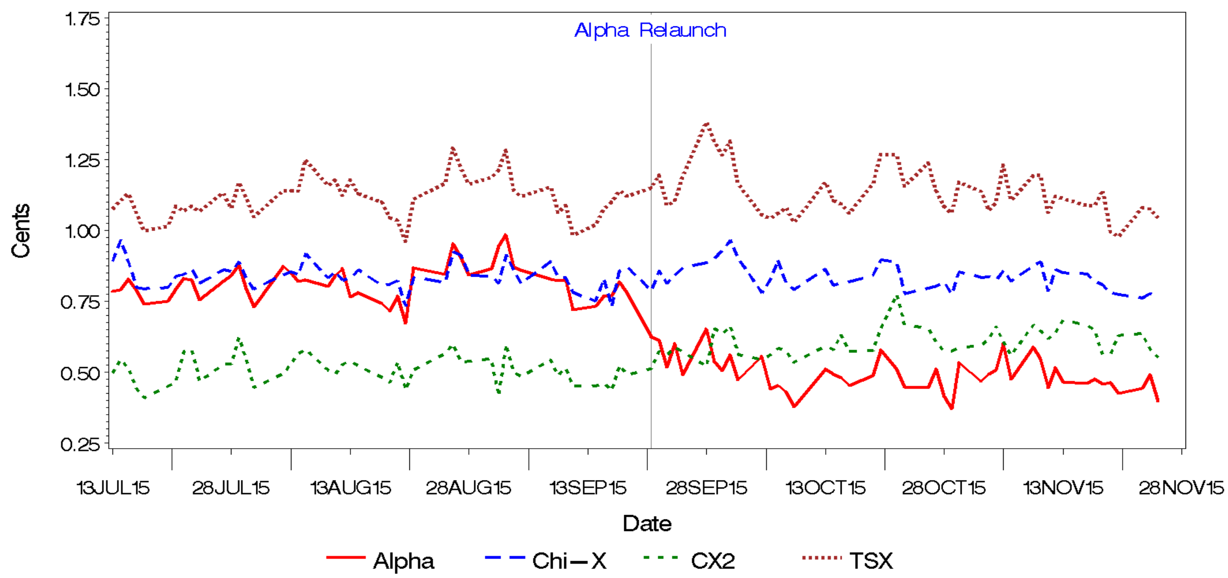

Figure 8
Percentage of Time Quoting at NBBO per Venue

This figure presents the average proportion of time each venue was quoting at the national best bid and offer prices, equal-weighted per security. A large decrease in the proportion of time the relaunched Alpha venue posts competitive quotes occurs.

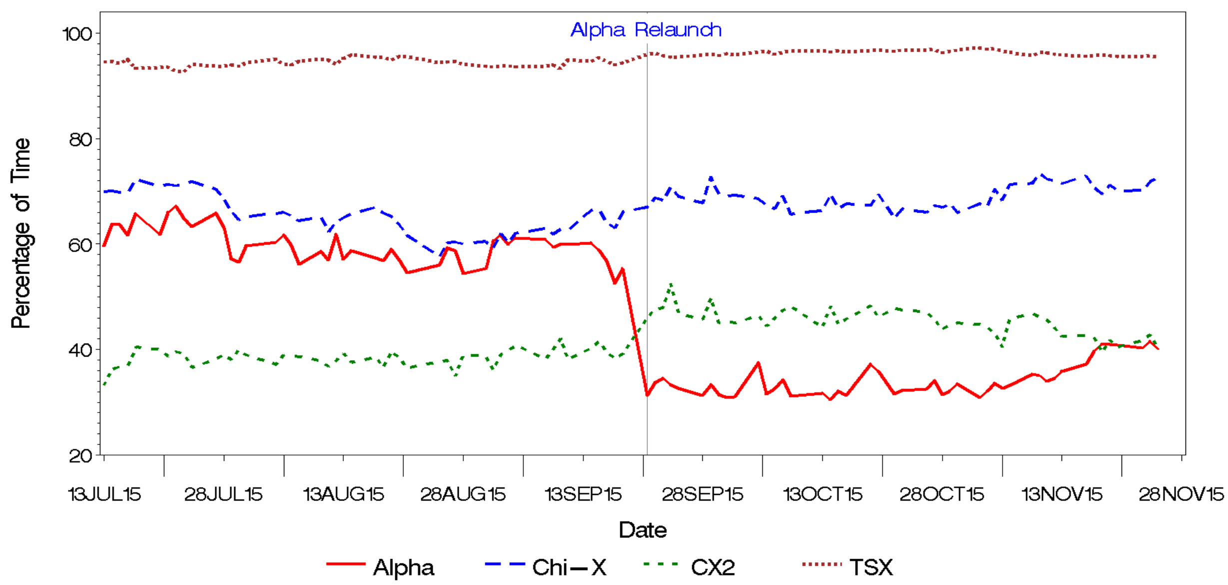

Figure 9
Percentage of Total Depth Quoted at NBBO per Venue

This figure presents the proportion of total dollar depth each venue quoted at the national best bid and offer prices, aggregated across all securities. NBBO depth share increases substantially on Alpha and trends lower on TSX, Chi-X and CX2.