Forming an orderly line — How queue-jumping drives excessive fragmentation

This version: January 2020

SEAN FOLEY, ELVIS JARNECIC, and ANQI LIU*

ABSTRACT

We identify queue-jumping as a key mechanism that causes markets to fragment. We use the introduction (and partial removal) of the Order Protection Rule, which enforces strict inter-venue price (not time) priority, to observe its impacts on fragmentation. We document that brokers increasingly fragment their liquidity provision activities amongst alternative venues, and liquidity providers attempt to jump long queues on larger venues by increasing submissions to venues with short (or empty) queues, which reduces their adverse selection costs. Our findings help explain the acceleration of fragmentation in markets with trade-through prohibitions as compared to best executions, providing clear policy implications.

Keywords: Liquidity; Fragmentation; Trade-Through Prohibition

JEL Codes: G10; G20

*Sean Foley (Email: sean.foley@sydney.edu.au). Elvis Jarnecic (Email: elvis.jarnecic@sydney.edu.au) and Anqi Liu are with the University of Sydney (Email: aliu2573@uni.sydney.edu.au). Anqi Liu is grateful for funding from the Capital Markets CRC and was a visiting researcher at Ontario Securities Commission for part of the time of the study. We are grateful for comments from Jonathan Brogaard, Hans Degryse, Thierry Foucault, Vincent van Kervel, Albert Menkveld, Talis Putnins, Marius Zoican and conference participants at the 8th Behavioral Finance and Capital Markets conference in Melbourne, the 2nd PANORisk conference, and all participants from the 2019 Summer School in Microstructure in Lugano.

When the SEC approved Regulation NMS in 2005, it could not have envisioned that 14 years later there would be 13 active equity exchanges, with a 14th recently approved, and two more rumored in the works, as well as more than 30 alternative trading systems.

- SIFMA Market Structure conference 2019[1]

Fragmentation is perhaps the most prominent structural change to occur in equity markets over the past decade, with the number of trading venues in the U.S. alone increasing from 26 in 2002 to more than 80 in 2019.[2] In particular, there has been a proliferation of 'micro-exchanges' in North America, trading venues which execute less than 2% of total market volume, with about 10% of exchange traded volume in the US in 2019 occurring in such venues. The existence of excess fragmentation has raised concerns for both market quality and fairness; creating a cost burden through excessive fees for end users; and heightened concerns amongst regulators. SEC Chairman Mary Jo White, for example, identified 'excess fragmentation' as a major concern in modern market structure.[3]

Many studies have considered the impacts of fragmentation, with more recent empirical evidence suggesting that fragmentation does not harm market quality, with more fragmented stocks experiencing greater market efficiency but higher short term volatility (O'Hara and Ye 2011). Related literature has also argued that both regulation and trader preferences may drive fragmentation (e.g. Madhavan 1995, Chao, Yao, and Ye 2018). Many cite Reg NMS as having facilitated fragmentation. Most recently, SEC Commissioner Elad Roisman suggested that the Order Protection Rule should be revisited in light of the rapid growth of the number of exchanges.[4]

The Order Protection Rule, or OPR (also known as the 'trade-through rule'), specifically Reg NMS Rule 611 in the U.S. and the Order Protection Rule in Canada.[5], eliminates the possibility of orders on different markets trading at suboptimal prices. This forces market centres to route trades to alternate venues if better prices exist, no matter how small the quoted quantity.[6] However, the

[1] `https://www.sec.gov/news/speech/roisman-remarks-sifma-equity-market-structure-conference-091919`

[2] `https://business.nasdaq.com/media/Nasdaq_TotalMarkets_2019_tcm5044-69828.pdf`

[3] `https://www.sec.gov/news/speech/2014-spch060514mjw`

[4] `https://tabbforum.com/opinions/exchange-landscape-gearing-up-for-expansion-in-2020/`

[5] The trade-through prohibition was introduced with the purpose of linking the markets together to create virtual consolidation (O'Hara and Ye 2011), but the industry and literature also recognized fragmentation as an unintended consequence of this rule.

[6] The SEC recently re-opened the discussion around the trade-through rule in a meeting of the Equity Market Structure Advisory Committee in 2017 Committee (2017), citing concerns of market fragmentation. In the recent TotalMarkets release by NASDAQ in April 2019, to stem costs of fragmentation it was proposed that venues that do not trade adequate volume be removed from the protection of the trade-through prohibition. This step was taken by the Canadian regulator (CSA) in 2016 when the market share threshold was set at 2.5%, providing a test case for EMSAC. Securities Industry and Financial Markets Association (SIFMA) has also submitted to the EMSAC, suggesting an order volume threshold be implemented for the trade-through prohibition.

mechanism by which this occurs, or how traders go about fragmenting markets remains unexplained. We show that a key reason markets fragment is to jump long queues on primary exchanges, we further show that such orders experience reduced transaction costs and adverse selection. Such improvement in transaction cost for the queue jumpers comes at the cost of the orders at the back of the queue on the primary exchange, which experiences increase in cost, measured by effective spread. [7]

The queue-jumping mechanism was first identified by Foucault and Menkveld (2008), where absent time priority across venues, liquidity providers jumped long queues on primary exchanges by submitting limit orders to alternative venues with short queues. However, the drivers of such queue-jumping has not been empirically documented.

To explore whether queue-jumping is a mechanism by which fragmentation occurs, one needs to overcome three challenges. First, it is necessary to exploit a setting where we can observe fragmentation occurring. The introduction of new trading venues or smart order routers, while potentially facilitating fragmentation, in isolation do not necessarily cause traders to fragment their orders. Rather, an exogenous event needs to be identified following which traders move orders to alternative venues. Foucault and Menkveld (2008) identify this as a 'chicken and egg' problem in their use of smart order router introductions to proxy for reductions in trade-throughs, pointing out that introducing smart routers will not result in their use unless an adequate number of counterparties are already using them. This can act as a barrier to entry for new venues. The existence of empty queues before the trade-through rule means that liquidity providers had the chance to queue jump on them. It is then puzzling why these empty queues were not better utilized in the pre-period. The introduction of the trade-through rule acts as a protection for venues with empty queues by forcing market orders to execute in those venues first. This provides queue-jumpers with the ex-ante expectation of a higher probability of execution, thereby attracting liquidity provision. Second, regulatory events that cause fragmentation may be introduced simultaneously with other regulatory initiatives. For example, Reg NMS 611 was introduced in the U.S. alongside changes to other rules, including the access rule, sub-penny rule etc, likely contaminating any analysis of fragmentation around that event. Third, to observe how brokers fragment by directing orders to non-central markets one needs detailed order level data across trading venues, at high frequency, and at the broker level. Such data has been typically unavailable for U.S. markets.

In this paper, we address these three challenges by examining the extent of quote matching on Canadian equity trading venues around the introduction (and subsequent partial removal) of

[7] It is important to clarify here that while the proliferation of exchanges facilitates fragmentation, it does not cause fragmentation per se. Fragmentation only occurs *when* traders elect to *provide* liquidity at other trading venues, rather than when new venues simply become available.

the trade-through rule. The trade-through rule has been recognised by regulators and academics alike as a possible cause of fragmentation (O'Hara and Ye 2011). We exploit the introduction of the trade-through rule in Canada, both because its introduction did not coincide with any other regulatory initiatives, and because Canada experienced both the introduction and partial removal of the trade-through rule, allowing us to study trader behaviour around its removal from a small venue. The Canadian market is structurally similar to U.S. markets, particularly with respect to the Order Protection Rule, the growth in fragmentation, and fee structures (see for example, Malinova and Park 2015). Crucially, Canadian broker identified transaction-level data allows us to observe transactions by individual brokers around the introduction of the trade-through rule.

Given this setting, our empirical analysis proceeds in four steps. First we provide evidence that the introduction of the trade-through rule caused the fragmentation of trading. After the introduction of the trade-through rule, trading activities on alternative venues increased significantly. Second, we examine the impact of the trade-through rule on Canadian market quality, and find results consistent with evidence from the U.S. markets (e.g. Hendershott and Jones 2005 and Battalio, Hatch, and Jennings 2004); we find that NBBO depth improves, while quoted spreads and transaction costs decrease for the market as a whole. We also provide new evidence that this effect is the strongest for smaller venues. Using pre-period measures of quote length, we find that the observed effects are strongest for stock-venues with shorter existing queues or fewer connected brokers, particularly venues with little or no queue where the top of queue position is the most valuable. Third, the removal of the trade-through prohibition from certain venues in 2016 provides the opportunity to examine the impact of the removal of the trade-through rule, provides an opposite test to that of the the introduction. We find the impact of the reversal on both the affected venue and the NBBO level are marginally significant, suggesting that liquidity remains on smaller venues once brokers are connected to the fragmented venues. Finally, we demonstrate the mechanism by which brokers routing behaviour fragments markets. We consider situations when each venue joins the queue at the NBBO level, computing a variety of novel metrics each time a new 'NBBO queue' is created. We find that venues with the shortest existing queues join the NBBO queue more frequently and quickly after the introduction of the trade-through rule.

Although the trade-through prohibition facilitates liquidity providers to jump the BBO queue, it does not force them to use the shorter queues. Therefore the marginal benefits have to be higher for them to actually utilize those queues. We examine the motivation for queue-jumping, documenting the execution costs faced by individual brokers as a result of queue-jumping. We find that brokers that queue-jump most frequently under the trade-through rule reduce both adverse selection and execution costs i.e. effective spreads. We show that limit orders resting at the back of short queues on alternative venues face lower adverse selection costs when compared to orders at the back of long queues on the primary exchange. This also implies that orders at the back of the queue on the primary exchange were disadvantaged by the queue-jumpers, incurring greater overall adverse selection costs. We find that liquidity providers that have increased usage of the short queues on alternative venues experience about 5 times more reduction in adverse selection costs. This idea is consistent with the findings of Van Kervel (2015), where price impact is linearly increasing in the size of incoming market orders. It is also comparable to the "soft-competition" as modelled in Degryse and Karagiannis (2018), where placing a limit order at the front of the queue on an alternative venue is weakly better than posting at the back of the queue on the primary venue, providing that the primary venue is not strictly preferenced as compared to the alternative venues.

Our key contribution, both to the literature and policy debates, is that we provide compelling evidence that queue-jumping is a mechanism which promotes fragmentation. We also establish that the introduction of the trade-through prohibition tends to improve market quality, particularly for smaller venues. Further, we show that once a fragmented market structure exists, the removal of the protection has a dampened impact, due to existing broker connectivity. By way of queue-jumping, we seek to answer the question posed by Stoll (2001) on whether price priority across venues alone would entice liquidity onto smaller venues. Additionally, from a policy perspective, while a trade-through rule tends to benefit liquidity in the short-term, an unintended consequence over the long-term is the proliferation of small venues, with brokers forced to 'check' liquidity on increasing numbers of smaller venues prior to trading. This coincides with anecdotal evidence of an increasing influence of micro-exchanges from countries with trade-through prohibitions such as the U.S. and Canada, whereas this is not the case for jurisdictions where trade occurs according to "best execution" rules, such as Europe and Asia. In addition, we find that introducing trade-through rule thresholds, once established, is generally not detrimental to overall market quality. This implies that policy initiatives like trade-through prohibition might be used as a temporary solution to introduce competition into the market. If we view the competitive market consisting of multiple exchanges and a monopoly exchange as two potential equilibriums in a coordination game, this policy helps the market to reach the competitive equilibrium. Our findings provide valuable evidence in the current regulatory debate surrounding the future of the trade-through prohibition in the U.S. and documents that there are limits to the beneficial impact of additional trading venues.

The rest of the paper is organised as follows. Section 2 explains the queue-jumping mechanism and provides hypotheses. Section 3 provides the methodology and description of the sample. Section 4 presents our findings, while section 5 concludes the paper, exploring future research directions and policy implications.

I. OPR, Queue-Jumping, and Hypotheses

A. Current Fragmentation in the Marketplace

The current level of fragmentation has evolved over the course of more than 10 years in both the U.S. and Canada. Anecdotally, the establishment of new venues accelerated after the implementation of U.S. trade-through rule in 2006 and the Canadian trade-through rule in 2011. Fig.1 shows the number of small venues, being those with market shares below 2.5%, whilst Fig. 2 shows the growth of the total market share attributable to these small venues.

[Insert Fig 1A here]

The number of venues with market share at or below 2.5% also grew significantly in recent years.

[Insert Fig 1B here]

The early literature argued that liquidity naturally consolidates as 'liquidity begets liquidity'. Paradoxically, fragmentation has been a long-existing feature of the modern market. Various reasons have been suggested as potential causes. Harris (1993) argues that traders might prefer different venues depending on their level of sophistication and trading motives. Pagano (1989)'s model shows that a stable equilibrium does not exist when trading venues offer differentiated liquidity and trading costs. In Chowdhry and Nanda (1991), when investors are allowed to split trades between venues, fragmentation can exist. In Parlour and Seppi (2003), multiple venues co-exist when liquidity providers have heterogeneous costs. Stoll (2001) and Bessembinder (2003) held the view that when price priority and time priority are enforced, it contributes to fragmentation because orders needs to be sent to small markets with low liquidity if better prices are quoted.

The role of regulation in the fragmentation of markets is also unclear. Madhavan (1995) argues that fragmentation would occur if trade disclosure rules were not mandatory but would remain consolidated otherwise. Chao, Yao, and Ye (2018) suggest discrete tick sizes may cause fragmentation and Kwan, Masulis, and McInish (2015) considered Reg NMS Rule 612 on tick sizes as a cause for the growth of dark trading venues. Harris (1993) suggests that differing needs of traders cause markets to fragment. O'Hara and Ye (2011) have pointed to OPR impacting the fragmentation of equity trading, while Blume (2007) argued that this rule might concentrate liquidity back to the primary exchanges.

Regarding whether fragmentation benefits stocks with market quality, findings have been mixed. Earlier theoretical papers including Amihud and Mendelson (1987) suggest markets may benefit from fragmentation while Pagano 1989 and Chowdhry and Nanda (1991) and Madhavan 1995 propose the opposite. Empirically, Gajewski and Gresse (2007) and Amihud, Lauterbach, and Mendelson (2003) suggest consolidated markets benefit market quality, while Battalio (1997), B. Boehmer and E. Boehmer (2003) and Foucault and Menkveld (2008) may be considered consistent with fragmentation improving liquidity in markets. For reviews on this topic, see for example Gomber et al. (2017), and Abergel et al. (2012).

However, in recent years, we have witnessed the proliferation of new small venues. While the initial increase in competition brought benefits to the whole market, the marginal benefit on NBBO market quality after the launch of each venue is diminishing.

[Insert Fig 2 here]

The grey bar in Fig.3 indicates the decrease in NBBO quoted spread after each venue launch (the venues are ordered in time sequence over the last 10 years), as we can see, the decrease becomes smaller and less statistically significant with every new additional venue launched, with TMX's 2011 launch actually increasing NBBO quoted spread. [8] In addition, the change in quoted spread is not mechanical, as it does not entirely coincide with the changes in primary exchange make and take fees.[9]

B. The Trade-Through Rule

O'Hara and Ye (2011) reviewed the U.S. market structure and considered the current marketplace as 'virtually consolidated' with many points of entry. This was one of the motives for introducing the trade-through prohibition in the U.S. (Reg NMS 611). This rule in the U.S. coincided with the beginning of fragmentation in the Canadian marketplace. As of 2010, several alternative venues were already established that traded TSX-listed securities, including Pure Trading (GO), Alpha, and Omega. The Canadian trade-through rule was introduced on the 1st February, 2011 to 'promote linkages across venues and to ensure fairness and efficiency in the market'. Before that, all dealers were bound by the best execution obligations imposed by IIROC. The trade-through rule formalized price priority as the obligation for traders and exchanges, orders were required to be re-routed to better prices by the exchange receiving it if it is not at NBBO. The rule came with a few exceptions, including Intermarket Sweep Orders (examined in Chakravarty et al. 2012), odd-lots, and unintentionally locked or crossed markets. [10]. One of the unique features of the Canadian rule is that it offers protection to the whole orderbook, beyond the top level.

In responding to recent debates on the trade-through rule, the Canadian Securities Commission removed several venues from trade-through protection on the 1st of October 2016. The removal is purely based on traded value market share with, the threshold set at 2.5% of total market volume.

[8]Note that ALP launched late 2008 which coincided with Global Financial Crisis, explaining the unusual high spread.

[9] Please see the Appendix for an illustration of primary exchange make and take fees during the period.

[10] Locked and crossed markets are evaluated in Shkilko, B. F. Van Ness, and R. A. Van Ness (2008). See Battalio, Hatch, and Jennings (2004) for explanation of orderbook "drilling"

This threshold is revised every 6 months. In the first revision, Pure Trading (GO) was the only venue to be removed.[11]

C. The Impact of the Trade-Through Rule on Market Quality

Via the mechanism of queue-jumping, Foucault and Menkveld (2008) modelled that potentially banning trade-through encourages liquidity provision, enhancing depth for the whole market. However, the literature has not reached consensus as to how the trade-through rule impacts overall market quality. Stoll (2001) suggests that a strict enforcement of time and price priority across venues encourages the posting of price-improving quotes. However, the absence of time-priority across venues might not be enough to attract liquidity onto smaller venues due to low execution probability. O'Hara and Ye (2011) also raise concerns that the lack of time priority across venues might cause quotes on small venues to be ignored.

The empirical evidence is also mixed. Battalio, Hatch, and Jennings (2004) found that prior to 2000, trade-throughs were mainly caused by the inability to obtain data on the NBBO, but trade-throughs after that are due to payment for order flow and large existing venues. Hendershott and Jones (2005) examine the exemption from the trade through prohibition of 3 ETFs in the U.S., and find no significant impact on market quality or price discovery. O'Hara (2015) identifies that the trade through prohibition could have various unintended effects, such as increasing internalization.

Van Kervel (2015) models a scenario where algorithmic market makers with unique speed advantage duplicate quotes on multiple venues to take the top-of-the-queue position and subsequently cancel upon execution on any one of the venues. This way, overall quoted depth improves following the rule change, but actual transaction costs for participants might not change.

HYPOTHESIS 1: With trade-through prohibition, there is a decrease in transaction costs and increase in NBBO depth on the smaller venues. When a venue becomes unprotected, its transaction costs increase, depth decreases and price impact increases.

D. Queue-jumping mechanism and testable hypotheses

With the existing level of fragmentation, brokers need to decide where to route orders. For market orders, the concern is not solely price, but also the availability of depth, timeliness, information leakages and so on. This can cause the limit orders resting on the smaller venues to be ignored.

Consider the following scenario (Fig 3A). Prior to the introduction of the trade-through prohibition, even though Pure Trading has a slightly better price compared with TSX and Alpha, there is not enough existing depth to execute the whole order at once. Therefore, routing the market order there means potential increased execution time, quotes fading on other venues and infor-

[11] Also included in our sample, Alpha exchange was excluded from the protection in September 2015 due to the introduction of a speed bump (Chen et al. 2017).

mation leakage. In order to obtain 'best execution', it is reasonable for brokers to route to larger exchanges, ignoring the existing depth on Pure Trading. However, such routing would constitute a 'trade-through' and therefore would be prohibited.

[Insert Fig 3A here]

Given that limit orders at the top of the book on smaller venues are less likely to be overlooked, liquidity providers can take advantage of the lack of time-priority across venues and effectively queue-jump the large venues. Consider the following scenario (Fig 3B). With a limit order, if routed to the large venue with large existing depth, the time-priority rule means the order needs to wait behind the existing queue to be executed. Alternatively, it can be routed to a small venue with little or no existing queue at that price level and take the top of the queue position. It is comparable to the model by Degryse and Karagiannis (2018), where participants have a chance of gaining priorities by submitting to those empty queues, which might get executed if a smaller orders gets routed to the smaller exchanges with random probabilities. Therefore empty queues create opportunities for 'soft competition', but the competition would be 'hard competition' if all queues are filled, as the incoming order can only wait behind existing orders.

[Insert Fig 3B here]

In this way, we expect the queue-jumping activities to increase the most where the existing queues are the shortest. The practical channel for small venues to survive is by having more brokers connected. Therefore we expect more brokers to connect to the small venues in order to take advantage of the shortest queues post introduction of trade through.

HYPOTHESIS 2: The improvement in liquidity is driven by shorter existing queues and more empty NBBO queues.

It is important to note that the enforcement of price priority across venues itself does not force brokers to use less liquid venues, for brokers to queue-jump there has to be positive marginal benefit. Therefore we expect that the limit order posted on smaller venues to queue-jump faces less adverse selection and generates less transaction costs for the queue-jumping brokers.

HYPOTHESIS 3: Queue-jumpers enjoy lower transaction costs and reduced adverse selection.

II. Methodology and Data

A. Data

We use data from Thomson Reuters Tick History (TRTH), supplied by the Securities Industry Research Centre of Asia Pacific (SIRCA). The data is millisecond-timestamped, and provides the broker ID associated with trades, as well as trade and quote price and volume data. We analyse the constituents of the TSX Composite index. We only examine stocks that continuously remained in the index during our sample period.

When examining the implementation of the trade-through prohibition, we use data from January 1, 2011 to March 1, 2011.[12], including one month before and after the event date. We include all activity at the Toronto Stock Exchange (TSX), Alpha (ALP), Pure Trading (GO), and Chi-X (CXC).[13] For the second event, the removal of the trade-through prohibition from Pure Trading, the event date was October 1, 2016. We collected data from September 1, 2016 to November 1, 2016, being one calendar month before and after the event date. The exchanges included in the sample are Toronto Stock Exchange (TSX), Alpha (ALP), Pure Trading (GO), Chi-X (CXC), Chi-X2 (CX2) and Omega (OMG). Data for the remaining lit venues, including Lynx, Aequitas Lit and Aequitas NEO are not provided in TRTH, and therefore excluded from the analysis. However, the market share of these venues collectively is about 2.5%.[14], meaning we capture the vast majority of market activity.

In the current study, only trades and quotes from the continuous trading period are included, which differs for different exchanges. For consistency and to minimize the impact of opening and closing auctions, only continuous trading sessions are included in the analysis (excluded first and last 15 minutes to minimize the impact from the auctions).

We use several filters to exclude potentially erroneous trades and quotes. We exclude trades and quotes when the market is locked or crossed, as locking and crossing a market is prohibited in Canada and such situations are likely to be caused by timestamp error and latency and these are deemed 'economically nonsensical' (Holden and Jacobsen 2014). Second, if a bid or ask is 0 in the data and the depth is also 0, we assume that indicates there is no available liquidity on that venue and we treat such 0 price as missing. We further exclude quotes where one or both sides of the BBO is missing when calculating spreads.

Trade direction is assigned according to the original sequence in the exchange-level database. If a trade was executed at a price equal to or lower than the best bid of that venue it is assumed to be a sell and if a trade was executed at or higher than the best ask on that venue it is assumed to be a buy (O'Hara 2015). We include instances where trade price is outside the best bid and ask on

[12] The 2-month sample window was chosen with the following trade-off: if the sample window is too narrow, we might not capture the change at broker level and the results might lack statistical power; if the sample window is too wide, the results are likely to be influenced by other factors. We also control for any influence of uncontrolled factors using a difference-in-difference setting in 2016. The impact of the rule change was literally overnight, therefore 2 month is sufficient to capture the impact of the change.

[13] After filtering by stocks that existed and quoted both at the beginning and end of the sample period, we are left with 227 stocks in 2011.

[14] `iiroc.ca` (Accessed 6 May 2018)

that venue because a trade can consume multiple levels of liquidity on a venue, executing a portion at prices inferior to the best prevailing price. Normally the order book does not update until the whole trade series is executed in this case. Trades at the mid-point are excluded as they are likely to be dark-midpoint trades.[15]

B. Metrics

In the current study we utilize standard market microstructure metrics as well as new, customized metrics. The standard microstructure metrics include liquidity measures and market share measures.

Liquidity measures used include *Quoted Spread*, *Effective Spread*, *Realized Spread*, *Price Impact*, *Depth at NBBO*, *Depth at NBBO levels 2 and 3*. Market share measures include *Value share*, *NBBO Depth share* and *NBBO time share*. In Table 1A, we compare the mean for these metrics before and after the event. All spreads are calculated in bps by dividing by the prevailing quote midpoint. [16].

The quantity is multiplied by the prevailing bid or ask price to arrive at the *$ quoted depth*. The measure is averaged across alternative venues in the table. In Table 1A we also include value, volatility and price which are used as control variables.

In addition, we have calculated the following customized metrics. The descriptive statistics for these metrics before and after the introduction event are provided in Table 1B.

NBBO depth share measures the percentage of NBBO depth offered on each venue, where all venues sum to 100%. In our sample, the TSX provides about 62% of all depth quoted at the NBBO while the alternative venues combined share the remaining 38%. *NBBO time share* measures the percentage of time during a trading day that a venue is at NBBO. When several venues are all at the NBBO, they are all counted, as such the sum across all venues can exceed 100%. *NBBO depth share* measures the distribution of the queue length at NBBO across venues, while *NBBO time share* measure how long the NBBO queue is being used or remains empty on each venue.

Percent time stale quote measures the percentage of time during a day the best bid or best ask of a venue is more than three ticks away from the NBBO. This metric seeks to capture the cases where the queue is empty for the first three levels on a venue. This ratio is only about 1% on TSX, but on the alternative venues it averages 25%.

As a novel measure of queue-usage to examine queue-jumping behaviour on each venue, we have computed metrics for every 'new queue at NBBO', which is calculated every time a new NBBO

[15] Results not displayed show the results are robust to the inclusion of these dark trades. For more information on dark trading in Canada see Foley and Putniņš (2016).

[16] For depth, the database records shares in board lots. For securities priced above $1 board lots are 100 shares, otherwise it represents 500 shares (there was no security priced under $0.1)

price is created. For this we have computed whether each venue joins the queue (*%Match NBBO*), how long it takes before they join the queue (*%Wait duration*), and the prevailing quoted spread on that venue when they join. *%Match NBBO* is calculated as a percentage of all NBBO quote updates of a stock-venue-day. Wait duration is the length of time before a venue posts at the new NBBO. This metric only considers the cases where NBBO improves to avoid capturing NBBO updates caused by large orders exhausting all liquidity at the NBBO level.

To capture queue-jumping behaviour when participants post liquidity of one board lot at the best bid or ask on a venue, we computed *one lot percentage*, which measures, for each broker's passive trades, what percentage is conducted when the prevailing depth on the passive side (queue length) is one board lot.

In conducting the broker connectivity analysis, we used the number of brokers trading each stock on each venue, which is obtained by examining the number of unique broker IDs associated with each trade. We calculate this measure for each venue, stock, day. For each broker, we have computed the prevailing effective spread and price impact for the trade when a broker is acting as the liquidity provider. Price impact has been used extensively as a measure of 'informed trading' or adverse selection cost (see for example, Conrad, Wahal, and Xiang 2015).

The final metric. *Back of queue* captures situations when a trade has depleted the liquidity available at that price level. This is characterized by two features: a quote update with a less favourable price (higher for ask and lower for bid), and when the volume of the executed trade consumes the entire current depth level. We consider the price impact on the "last" orders to determine if they face differential adverse selection, over the time horizon of 1s, 30s and 1m.

III. Findings

Our analysis is divided into three main parts. Section 1 examines the impact of the trade-through prohibition introduction and subsequent removal on market quality for each venue, and at the market level. Section 2 provides direct evidence on the queue-jumping mechanism by sub-grouping the stock-venues into quintiles based on queue length and broker connectivity. Section 3 provides evidence on the impact of the trade-through prohibition on broker's transaction costs and price impact, where the broker is acting as the liquidity provider.

A. Market Quality

The difference-in-means test for the standard market quality metrics pre and post both the trade-through prohibition introduction and partial removal events are provided in Table IA.

After the introduction event in 2011, quoted spread, effective spread and price impact all decreased significantly on all venues. Depth in all first three levels saw a significant increase after the introduction. The change on the alternative venues are more significant than that on the primary venue: TSX. Also, trading value increased more significantly on the alternative venues post the introduction, which supports the notion that the level of fragmentation has increased. The increase in depth for the first three levels is consistent with prior literature (see Foucault and Menkveld 2008 and Van Kervel 2015). The narrowing of spread and increase in depth is also significant at the NBBO level, consistent with the notion that prohibiting trade-through encourages limit order submissions and improves liquidity on the marketplace as a whole.

[Insert Table IA here]

Table IB also presents the means test for our customized metrics.

Both NBBO depth share and time share increased significantly on the alternative venues after the introduction of the trade-through rule, meaning both the queue length and the utilization of empty queues increased on those venues on average. For NBBO depth share, the computation of such metrics mechanically requires all venues to add to 100%, where we see TSX's percentage decrease commensurate with alternative venues' increase. This means that, for liquidity provision, the level of fragmentation among venues has increased and liquidity provision is more evenly distributed between primary and alternative venues.

NBBO time share increased more significantly on alternative venues, implying the filling of previously empty queues. Meanwhile, primary venues did not see a decrease in time share, implying the increase in queue utilization on the alternative venues occur with the NBBO queue on the primary has already been utilized, and the BBO is matched on the alternative venues.

The proportion of stale quotes decreases by 7% on the alternative venues, which corresponds to the economically significant decrease in quoted spread on the alternative venues of 3.9 bps on average. The increase in %Match NBBO and decrease in %Wait NBBO are also statistically and economically significant on the alternative venues, meaning those quotes are matching the NBBO more frequently and are posted more rapidly. Overall, this provides strong support for Hypothesis 1, with trade-through prohibition leading to improvements in market quality, both at venue and NBBO level.

[Insert Table IB here]

These findings are confirmed in the regressions in Table II. The regression allows for an event effect and differential impact on the primary and alternative venues. All regressions control for price, volume and volatility for that stock, venue, and venue and stock fixed effects.

$$\text{Metric}_{i,v,t} = \alpha_{i,v,t} + \beta_1 \text{Alternative}_{i,v,t} \cdot \text{OPR}_{i,v,t} + \text{Controls}_{i,v,t} + \delta + \theta + \varepsilon_{i,v,t} \quad (1)$$

where α is the intercept, δ is stock fixed-effects, and θ is venue fixed-effects.

The variable of interest is the interaction variable between alternative venue and the OPR event variable. Table II shows it is negative and significant at the 1% level for quoted spread, effective spread, price impact and percentage of stale quotes. This means the decrease in those measures are more significant on the alternative venues as compared with the primary venue. For NBBO depth share, NBBO time share, value share and log NBBO depth at first three levels, the interaction terms are positive and significant at the 1% level.

[Insert Table II here]

Table III presents the difference-in-differences regression for the removal of the trade-through rule in 2016. The event exogenously removed the protection for a single venue (GO), lending itself to a natural difference-in-differences setting where the treatment group is the venue being removed, and the remaining venues serving as a control group. The regression specification is similar to equation (1):

$$\begin{aligned}\text{Metric}_{i,v,t} = \alpha_{i,v,t} + \beta_1 \text{Removal}_{i,v,t} + \beta_2 \text{GO}_{i,v,t} + \beta_3 \text{Removal}_{i,v,t} \cdot \text{GO}_{i,v,t} \\ + \text{Controls}_{i,v,t} + \delta + \theta + \varepsilon_{i,v,t} \quad (2)\end{aligned}$$

where α is the intercept, δ is stock fixed-effects, and θ is venue fixed-effects.

The variable of interest is the interaction variable between treatment exchange GO and the removal event. The coefficient for effective spread and price impact are both significant and positive, implying that the removal event has increased spreads on the removed venue. However, the economic significance is much smaller. The impact on quoted spread is not significant at the 10% level. Similarly, the removal decreases both NBBO depth and time share on the impacted venue, and decreased NBBO depth at the first three levels, but to a much smaller extent compared with the introduction. This supports the notion that once brokers are connected to a venue, it is difficult to remove it, providing evidence on whether fragmentation is 'reversible'. This provides a negative test for Hypothesis 1 and supports that a reversal might not be possible even when the protection gets removed. This is consistent with practical frictions and sunk-costs once participants establish connections to a venue, infrastructure is not discarded simply because the venue is no longer protected.

After the removal of protection, we observe that the number of brokers that have no liquidity-providing activity on the unprotected venue increased significantly. This is consistent with our expectation that the incentive to use such venue for queue-jumping is weaker as brokers would adjust the prior that posting onto the smallest venue might no longer mean that the order joins the NBBO queue. If the order is ignored, the probability of execution becomes 0. However, such ex-ante expectation does not remove the need for brokers to remain connected in order to satisfy best-execution obligations.

[Insert Table III here]

Table IV presents the NBBO level regressions for the OPR introduction, to understand the impact on the market as a whole. The regression specification is documented in Equation (3):

$$\text{Metric}_{i,t} = \alpha_{i,t} + \beta_1 \text{OPR}_{i,t} + \text{Controls}_{i,t} + \delta_{i,t} + \varepsilon_{i,t} \tag{3}$$

where α is the intercept, δ represents stock fixed-effects.

NBBO results confirm the findings in the descriptive tables, with transaction costs declining narrows and depth improving for the market as a whole. It is interesting to note that the 1-second price impact also decreases market-wide, which is likely attributable to the improvement in depth for the whole market, making it harder to exhaust NBBO liquidity and generate immediate price impact. We note here that the increase in depth does not contradict the predictions of Van Kervel (2015)'s model, as trade-through prohibition does not make everyone a 'fast' trader and this is evidence that market makers have ex ante expectations of latency across venues. In the setting of the rule, 'fast' trading might be viewed as the DAO (Direct Action Orders), where participant direct orders to trade on several venues at the same time and avoid being checked for trade-through.

[Insert Table IV here]

B. Queue-Jumping

In this section, we provide direct evidence on the queue-jumping mechanism that causes the improvement in liquidity on the alternative venues. In order to understand the distribution of 'queues' on different venues, Fig. 4 presents the histograms of NBBO time shares in the pre-introduction period (1 month prior to 2011-02-01), where each individual observation is a stock-venue-day.

[Insert Fig 4 here]

Fig.4 shows that prior to the introduction of trade-through prohibition, most stock-days had NBBO time share near 100% on TSX, while smaller venues quoted at the NBBO far less frequently. This implies the queue was most empty on GO, the smallest venue, while CXC and ALP exhibited empty queues with some frequencies.

In the following set of results, we observe whether empty queues are increasingly utilized post-introduction of the OPR. The findings are presented in Table V. The regression specification is:

$$\text{Metric}_{i,v,t} = \alpha_{i,v,t} + \beta_1 \text{OPR}_{i,v,t} + \beta_2 \text{Controls}_{i,v,t} + \delta + \theta + \varepsilon_{i,v,t} \tag{4}$$

where α is the intercept, δ is stock fixed-effects, and θ is venue fixed-effects. Only the coefficients for the event variable are presented here.

On the left-hand-side of Table V, we present the event study regression on 5 quintiles classified according to the stock-venue's pre-period average NBBO time share. This classification represents the presence of queues at NBBO on each venue for each stock in the pre-period. Stock-venues in the lowest NBBO time share quintiles represent situations where the queue is mostly empty, while stock-venues where the NBBO queue is mostly full are captured in the high NBBO time share quintile. For brevity we use the lowest and highest quintiles where the contrast is most visible. The variables on the left-hand-side are the dependent variables for each regression.

As shown, the impact on the lowest quintile and highest quintile are typically opposite. The increase in NBBO depth share, time share, trade value share, depth and one lot percentages are most significant in the low pre-period NBBO time share group, while the impact can be negative for the highest quintile. This shows that liquidity improvements are mostly seen on stock-venues where the queue was previously empty, signaling liquidity shifts from full queues to previously-empty queues. The previously empty queues also join the NBBO race more frequently, which is shown in the increase in the frequency of NBBO matching and decrease in the waiting time. This means the empty queues are being used more frequently, and in a more timely fashion. In this way, liquidity shifts from places where it was mostly consolidated, to other places where liquidity was absent before the rule. This evidence strongly supports Hypothesis 2 where queue-jumping is the mechanism behind the improvement of market quality and the drivers of increased fragmentation.

In Table V, we also present an alternative grouping method that divides the sample into 5 quintiles based on pre-period broker connectivity. Quintile 1 is the stock-venue with the least number of brokers connected, while quintile 5 include those with the highest number of brokers connected. The practical channel of the trade-through prohibition is effectively requiring brokers to check quotes on all available venues to avoid re-routing and non-compliance. This grouping thus provides evidence on whether the change in liquidity can be explained more brokers connecting to previously unconnected venues. Similar to the fullness of the queues measure, a contrast is found between stock-venues which are least connected before the introduction and those that are most connected. The most significant liquidity improvement is observed on those stock-venues with the least number of brokers connected in the pre-period, demonstrating forced broker connectivity as another channel driving fragmentation.

[Insert Table V here]

C. Broker Transaction Costs

In this section we provide more direct evidence of the trade-through prohibition's impact on liquidity providers. For each transaction, we have identified the liquidity-providing side, and computed the effective spread and price impact (adverse selection) for those liquidity providers. Our regressions were run on broker-stock-venue-day observations. The specification is as follows, for stock i, venue v, broker n and day t:

$$\text{Metric}_{i,v,n,t} = \alpha_{i,v,n,t} + \beta_1 \text{OPR}_{i,v,n,t} + \text{Controls}_{i,v,n,t} + \delta + \theta + \phi + \varepsilon_{i,v,n,t} \tag{5}$$

where α is the intercept, δ is stock fixed-effects, and θ is venue fixed-effects, and ϕ is broker fixed-effects.

The evidence in Table VI indicates that the trade-through prohibition mostly benefits liquidity providers who are now utilizing the shorter queues alternative venues more frequently. They experience both a decrease in transaction costs and a reduction in adverse selection costs. In Table VI, 5 classifications are presented, each one representing a different grouping. For all groupings, group 1 represents brokers who increased their usage of short queues on the alternative venues or decreased the usage of long queues on the primary venue, while the second group represents brokers who decreased their usage of short queues or increased their usage of the primary venue.

For all grouping specifications, group 1 demonstrates a more significant decrease in both effective spread and price impact, that shows the motivation for brokers using the venues, supporting Hypothesis 3. This supports the notion that the adverse selection faced by an order at the top of the queue on the alternative venue is lower than a comparable order at the back of the queue on the primary venue, as that back of queue order would only be transacted if the current incoming market order depletes all available depth on that primary venue. This is further tested in Table VII.

[Insert Table VI here]

In VII, we have specifically examined the "back of queue" order, i.e. immediate transaction cost (effective spread), and adverse selection costs (price impact) for trades that have depleted the level of liquidity on the primary exchange and alternative exchanges, that is the trades from orders at the back of the queue on each exchange.

The orders at the back of queue on the alternative venues experienced much greater improvements in transaction costs, and reductions in adverse selection. Such improvement come from the lack of time-priority across venues, which enables orders in the short queues on alternative venues to be traded ahead of the orders at the back of queue on the primary exchange. By contrast, orders at the back of queue on the primary exchange experienced an increase in transaction costs because of the increased utilization of alternative-venue queues, due to increasing the consolidated queue length in front of them.

[Insert Table VII here]

IV. Conclusion

We provide compelling evidence that the trade-through prohibition increases fragmentation via queue-jumping. We utilize two natural experiments, the introduction of the trade-through prohibition and its subsequent removal from a single venue in Canada. The trade-through prohibition protects quotes at all venues which is particularly valuable for the previously less-liquid venues i.e. the 'empty queues', which liquidity providers can now use to jump the longer queues on the primary exchange. We are the first to directly document the queue-jumping mechanism, first suggested by Foucault and Menkveld (2008), and show its relevance to the excessive fragmentation predominately observed in North American markets. Further, while the existence of empty order books provides an opportunity for traders to form new queues, the motivation for such behaviour has also not been previously explored. In this paper, we provide evidence that queue-jumpers are motivated by improved transaction costs and decreased adverse selection costs when orders execute in these 'shorter' queues.

We begin by confirming the findings of the prior literature, that trade through prohibitions benefit market quality by encouraging limit order submissions, narrowing spreads and improving depth on the market as a whole. We show this benefit to be most pronounced on the smaller, less liquid venues. Our findings suggest that such a rule may have the unintended consequence of further fragmenting liquidity towards empty queues, potentially creating an excessive level of fragmentation.

We provide policy suggestions on the current debate surrounding the existence of trade-through prohibition in the U.S. and potential introduction in Europe. On the one hand, given the high fixed costs of starting an exchange, such a rule reduces barriers to entry and can effectively instigate competition between exchanges by ensuring better prices at smaller venues are not ignored. Trade-through prohibitions have been applauded for migrating markets from monopolies towards perfect competition. On the other hand, this encourages the creation of new 'empty queues' through time, which can increase data and connection fees which are ultimately borne by end investors. Universally protecting empty queues market-wide can also result in 'too much' competition. We document a diminishing benefit of additional exchange entry beyond the fourth in Canada, despite charging additional data and connection fees. These data fees now constitute a major part of exchange revenue, representing a direct cost for brokers, which will eventually passed on to end investors. Protecting an exchange forces brokers to pay for exchange data. The fact that 12 of the 13 major U.S. lit exchanges are owned by three operators (NYSE, NASDAQ and Cboe) means that they are able to charge higher fees than if these exchanges were consolidated.

In the SIFMA conference in 2019, various proposals have been brought to the SEC for imposing a market share threshold with the order protection, similar to the mechanism implemented in Canada in 2018. In this paper, we show that the removal of protection from a single small venue worsens liquidity on that venue, but not as significantly as the introduction. This is likely due to the 'stickiness' of brokers connectivity and smart order router technology.

Applying a value share threshold allows brokers to evaluate exchanges based on a trade-off between available liquidity and fixed connectivity costs. Striking a balance between sufficient and excessive competition is a difficult task faced by the regulators. We observe an immediate shock to the liquidity provision activities on the unprotected venues after they were removed. Consistently, the threshold on order protection has halted the fragmentation of liquidity in Canada, with no new venues added since the introduction, despite a number of new venues having been introduced in the U.S. in the same period. This suggests that such threshold may be effective in curbing the further fragmentation of liquidity in such settings.

However, we find that a simple removal of the protection for small venues is not enough to address excessive data feed connection created by such excessive fragmentation, as brokers need to remain connected to satisfy best execution requirements.

Figure 1A: Number of venues with less than 2.5% market share in U.S. and Canada

This plot illustrates the number of venues with smaller than 2.5% trade value share prevailing that that point in time. The metric is calculated on sample stocks: GE and Citigroup in U.S., TD and RBC in Canada

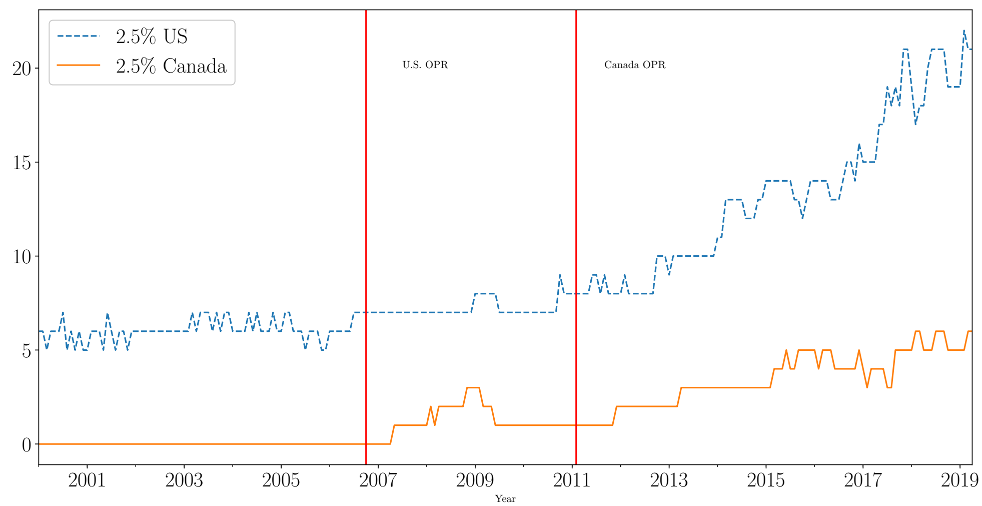

Figure 1B: Total market share of venues with less than 2.5% market share in U.S. and Canada

This plot illustrates the sum of trade value share with smaller than 2.5% trade value share prevailing that that point in time. The metric is calculated on sample stocks: GE and Citigroup in U.S. and TD in Canada

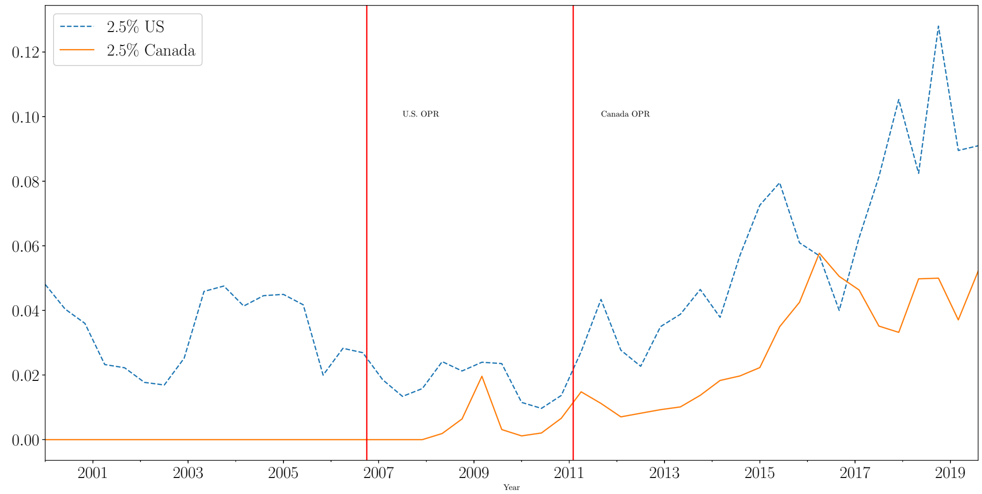

Figure 2: NBBO quoted spread (bps) after each venue launch in Canada

The following plot uses data 20 working days before and after the launch date of the included venue, the result is value-weighted across stocks and time-weighted during a day. TSX60 stocks at the time of the venue launch are used as the sample. The light bar indicates the difference (post − pre).while the dark bar indicates the corresponding t-stat.

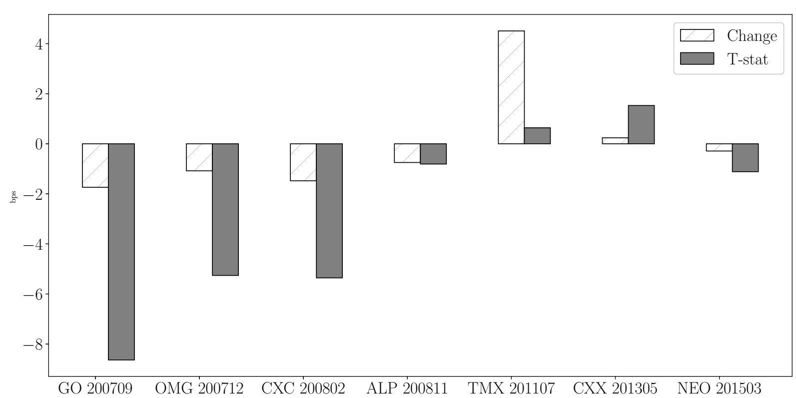

Figure 3A: Example of routing a marketable sell order

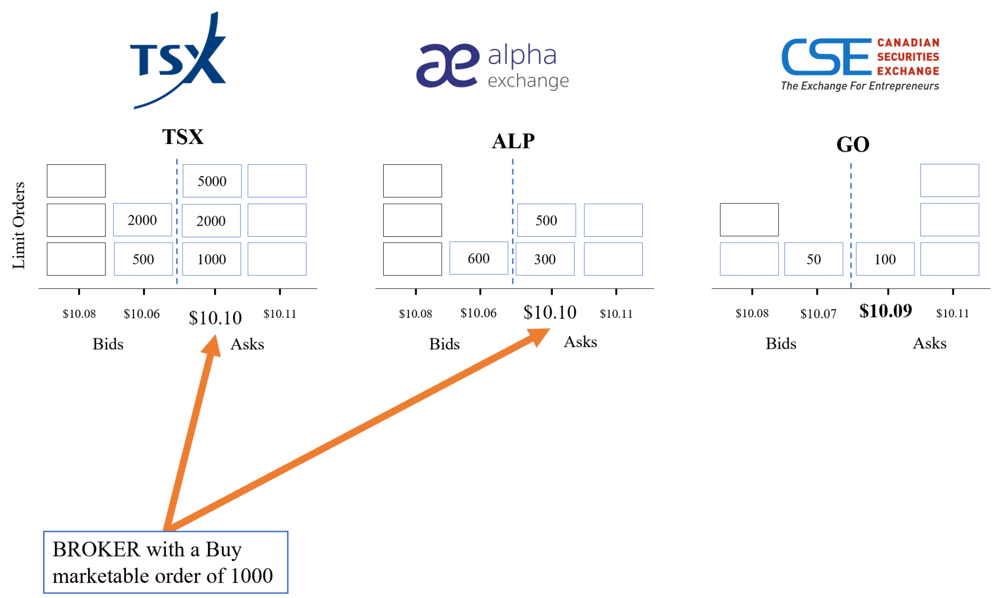

Figure 3B: Example of routing a limit buy order

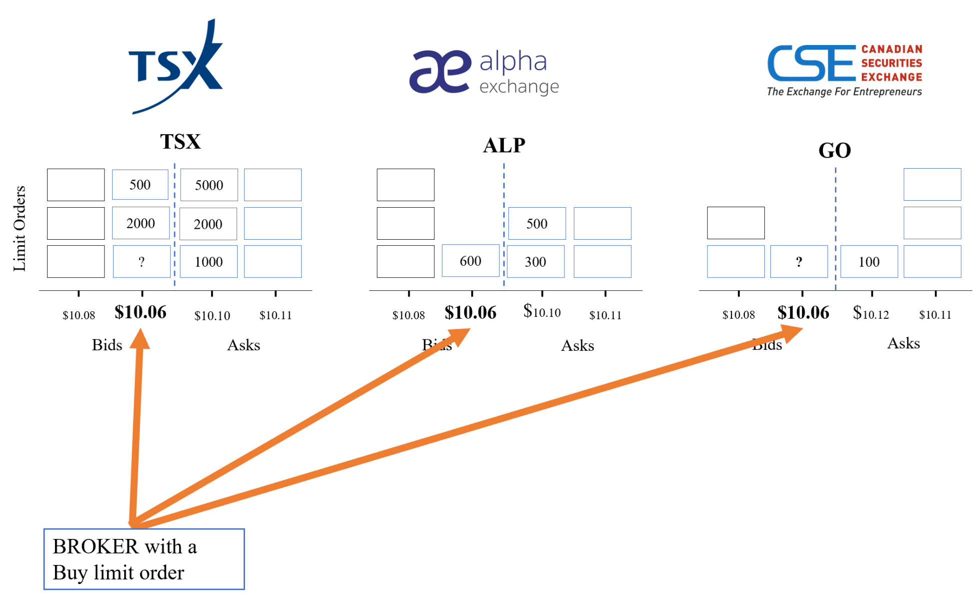

Figure 4: Histogram of Pre-Period NBBO Time Share on Each Venue

This figure shows the per stock per day NBBO time share on each venue during the pre-event period (2011-01-01 to 2011-01-31). NBBO time share is calculated as the percentage of time during a day the venue bid or ask is at NBBO. x axis is NBBO time share while y axis is the percentage frequency.

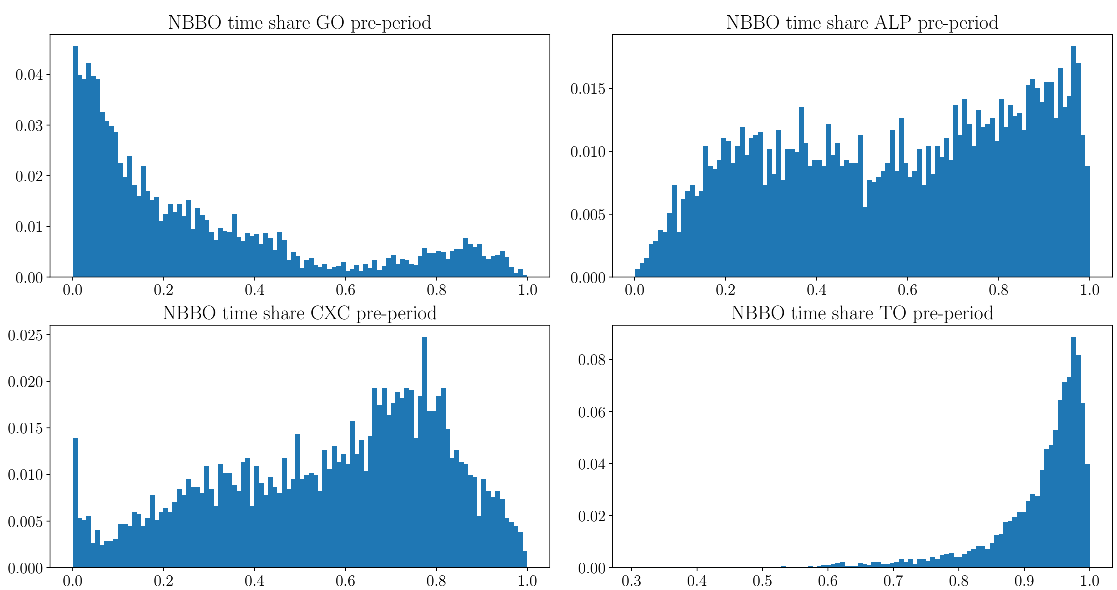

Table IA: Descriptive Statistics

This table provides the summary statistics for the TSX Composite constituents before and after the introduction and partial removal of OPR. Quoted Spread is calculated as the difference between the venue BO (Best Offer) and venue BB (Best Bid). This metric is time-weighted by the duration of the spread across the day. Effective Spread is calculated as the signed difference between trade Price and the prevailing quote Midpoint of the venue multiply by 2. Realised spread is calculated as the signed difference between the trade Price and the venue Quote Midpoint 1-second after the trade. Price Impact is calculated as the difference between Effective spread and Realised spread. Effective spread, realised spread and Price impact are all weighted by trade value across the day. It is averaged across stocks in each venue by taking an average. All spread measures are divided by the prevailing midpoint to arrive at a measure in bps. Daily Trade Value provides the sum of all the trades volume multiply by the corresponding trade price on a venue, summed over all the securities included in the sample. The unit of millions of dollars. The above measures are averaged across the 1 month window before and after OPR introduction (1st Feb 2011) on the left-hand-side and OPR removal on the right-hand-side (1st Oct 2016). Primary venue refers to TSX and alternative venues include all other prevailing venues that data is available in TRTH (GO, CXC, ALP in 2011; GO, CXC,ALP,OMG and CXX in 2016) $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$; Diff = Post − Pre

		OPR Introduction				OPR Removal			
		Pre	Post	Diff		Pre	Post	Diff	
Metric	Venues	Mean	Mean	Mean		Mean	Mean	Mean	
Quoted Spread (bps)	Primary	11.14	10.62	-0.52	***	11.04	11.00	-0.03	
	Alternative	27.80	23.92	-3.89	***	10.50	10.49	-0.01	
	NBBO	10.79	10.31	-0.25	***	10.69	10.74	0.05	
Effective Spread (bps)	Primary	10.96	10.51	-0.45	***	7.51	7.29	-0.22	*
	Alternative	21.81	17.63	-4.17	***	9.04	8.94	-0.10	
	NBBO	10.36	10.04	-0.32	*	7.54	7.36	-0.18	
Realised Spread 1s (bps)	Primary	0.71	0.70	-0.01		-1.31	-1.35	-0.05	
	Alternative	0.76	-0.35	-1.11	***	3.34	3.22	-0.12	*
	NBBO	1.44	1.41	-0.03		-0.18	-0.19	-0.01	
Price Impact 1s (bps)	Primary	10.25	9.81	-0.44	***	8.82	8.65	-0.17	
	Alternative	21.05	17.98	-3.06	***	5.71	5.72	0.01	
	NBBO	8.92	8.62	-0.30	**	7.72	7.55	-0.17	
NBBO Depth ($000)	Primary	81.49	126.44	44.95	***	54.67	55.46	0.79	
	Alternative	19.46	26.05	6.59	***	11.20	11.94	0.74	***
	NBBO	135.26	197.91	62.65	***	110.83	115.33	4.5	
NBBO Depth Level 3 ($000)	Primary	290.26	402.56	112.30	***	51.80	52.67	0.86	
	Alternative	75.41	89.38	13.97	***	10.91	11.16	0.25	
	NBBO	499.63	648.24	148.61	***	355.18	370.11	14.92	
Value ($M)	Primary	3129.29	3265.18	135.89		3828.30	3661.11	-167.19	
	Alternative	1470.85	1558.04	87.19		2285.82	2276.80	-9.02	
	NBBO	4600.14	4823.22	223.08	*	6114.12	5937.91	-176.21	
Price	Primary	26.83	27.20	0.37		34.55	34.52	-0.03	
	Alternative	26.88	27.17	0.29		34.46	34.37	-0.08	
	NBBO	26.85	27.18	0.33		34.51	34.45	-0.06	
Volatility	Primary	2.50	2.37	-0.12		2.39	2.34	-0.05	
	Alternative	2.19	2.13	-0.05		2.13	2.09	-0.04	
	NBBO	2.52	2.40	-0.12		2.26	2.22	-0.04	

Table IB: Descriptive Statistics

This table provides the summary statistics for the TSX Composite constituents before and after the introduction of OPR. NBBO Depth share is calculated as the number of shares available at NBBO divided by the total number of shares on offer at NBBO at that point in time, then the percentage is weighted by duration across the day to arrive at the per venue per stock per day measure. NBBO time share is calculated as the time during a day a venue's quote is at NBBO, as a percent over the total trading time during the day. If several venues quote are all at the NBBO at the same time, they are all counted. Stale quoted are counted as the percentage of time of the trading day the quoted spread is greater than 3 ticks from NBBO. % match NBBO is the percentage of times a venue matches the NBBO for all the new NBBO queues that are created during a stock-venue-day, this metric is calculated by NBBO update. % wait duration is the percentage of time a venue waited before it joined the NBBO queue, if it doesn't join, then it equals to 1 for that NBBO update. One lot percentage is the percentage of one-lot depth prevailing on a stock-venue for a broker, as a percentage of all trades on that stock-venue when broker is the liquidity providing side of the trade. One lot percentage is computed relative to the liquidity providing broker total trading activity, therefore exclude Chi-X. All the measures are in units of percentages. The above measures are averaged across the 1 month window before and after OPR introduction. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$; Diff = Post − Pre

Metric	Venues	Pre Mean	Post Mean	Diff Mean	
NBBO depth share %	Primary	63.13	61.22	-1.91	***
	Alternative	37.22	38.9	1.68	***
NBBO time share %	Primary	92.40	92.27	-0.13	
	Alternative	48.09	50.39	2.30	***
Stale quotes %	Primary	1.15	0.79	-0.36	***
	Alternative	28.2	20.23	-7.97	***
% Match NBBO	Primary	94.98	94.80	-0.18	
	Alternative	63.89	67.28	3.4	***
%Wait duration	Primary	6.82	6.93	0.11	
	Alternative	41.61	38.69	-2.92	***
One lot percentage	Primary	8.91	9.46	0.55	***
	Alternative	4.49	5.05	0.56	***

Table II: Liquidity Change with OPR Introduction

This table contains the regression for OPR introduction, where $\text{Metric}_{i,v,t} = \text{Intercept}_{i,v,t} + \beta_1 \text{OPR} \cdot \text{Alternative} + \text{Controls}_{i,v,t} + \text{stock : venueFE} + \text{dateFE} + \varepsilon_{i,v,t}$ for stock i, venue v and day t. Metric stands for various liquidity metrics, including Quoted Spread time weighted in cents, Effective Spread value weighted in cents, Realised Spread value weighted in cents, Price Impact value weighted in cents and log(DepthatNBBO), log(DepthatNBBOLevel2), and log(DepthatNBBOLevel3). Quoted Spread, Effective Spread, Realised spread and Price Impact are calculated the same way as Table 1. Log NBBO Depth X is the natural logarithm of the $ amount of shares offered on each venue at the NBBO price on level X.

Value share is measured as the total trade value of a stock on a venue divided by the total trade value of a stock across all the venues over a day. NBBO depth share is calculated as the number of shares available at NBBO divided by the total number of shares on offer at NBBO at that point in time. NBBO time share is calculated as the time during a day a venue's quote is at NBBO, as a percent over the total trading time during the day. If several venues quote are all at the NBBO at the same time, they are all counted. All the market share metrics are in the units of percentages. Stale quotes % the percent time ask or bid is more than three ticks away from the best ask or bid.

Controls include stock-venue-day measures of Price (Value Weighted Avg. Price), Value (Daily Trade Vol. $*$ Price)/100000, and Volatility (calculated as (Highest Price of the day – Lowest Price of the day)/ ((Highest Price of the day + Lowest Price of the day)/2) $\times$ 100%. OPR is a dummy variable that equals 0 before the date of the OPR introduction event, and 1 after. Standard errors are in brackets, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. All regressions standard errors are clustered by stock,date. We include stock-venue and time fixed effects for all regressions. R^2 adjusted for fixed effects.

	Quoted Spread	Effective Spread	Realised Spread	Price Impact	NBBO Depth Share	NBBO Time Share	Value Share	Log NBBO Depth	Log NBBO Depth Lvl. 3	Stale Quotes %
Alternative × OPR	-3.85***	-4.13***	-0.44**	-0.13	2.71***	2.99***	2.34***	0.20***	0.25***	-7.93***
	(-6.33)	(-7.55)	(-2.25)	(-0.85)	(3.26)	(4.12)	(3.49)	(4.47)	(5.99)	(-7.31)
Intercept	23.56***	18.81***	3.04***	4.79***	23.79***	62.81***	23.74***	9.06***	10.43***	18.26***
	(40.25)	(41.86)	(8.74)	(8.20)	(41.71)	(37.44)	(64.87)	(86.37)	(113.01)	(10.16)
Price	-0.05**	-0.03**	-0.00	0.01**	0.00	-0.11*	0.00	0.00	-0.00	0.13*
	(-2.44)	(-2.05)	(-0.64)	(1.98)	(0.01)	(-1.84)	(0.02)	(0.85)	(-0.06)	(1.92)
Volatility	0.62***	0.47***	-0.41***	0.79***	0.02	-0.51***	-0.04	-0.03***	-0.02***	-0.11
	(7.12)	(6.14)	(-3.95)	(3.71)	(0.65)	(-6.10)	(-0.92)	(-3.21)	(-2.93)	(-1.02)
Value	-0.03***	-0.02***	0.02***	-0.03***	0.05***	0.06***	0.11***	0.01***	0.01***	-0.01
	(-2.96)	(-2.91)	(4.39)	(-4.56)	(4.39)	(4.07)	(4.94)	(3.69)	(3.51)	(-0.97)
N	33796	33796	33796	33796	33796	33796	33796	33796	33796	33796
Adj. R^2	58%	51%	10%	45%	89%	78%	90%	80%	83%	59%

Table III: Difference-in-Differences Regression with the OPR Removal

Table 3 contains the difference-in-difference regression estimated for OPR removal in 2016, where $\text{Metric}_{i,v,t} = \text{Intercept}_{i,v,t} + \beta_1 \text{Removal}_{i,v,t} \cdot \text{Removal}_{i,v,t}\text{GO}_{i,v,t} + \text{Controls}_{i,v,t} + \text{stock} : \text{venueFE} + \text{dateFE} + \varepsilon_{i,v,t}$. GO stands for Pure Trading, which is the only treatment group in this case, Removal is a dummy variable that equals to 0 before the date of the removal event and 1 after the date of the removal event. The dependent variables and control variables are the same as in the Table II regression. Standard errors are in brackets, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. All regressions standard errors are clustered by stock,date. Both venue-stock fixed effects and time-fixed effects are controlled in all regressions. R^2 adjusted for fixed effects.

	Quoted Spread	Effective Spread	Realised Spread	Price Impact	NBBO Depth share	NBBO Time Share	Value Share	Log NBBO Depth	Log NBBO Depth Lvl 2	Log NBBO Depth Lvl 3
Removal × GO	0.01	0.94***	-0.67**	1.64***	-0.46***	-2.46***	-0.68***	-0.14***	-0.15***	-0.14***
	(0.13)	(3.68)	(-2.32)	(4.88)	(-3.43)	(-6.27)	(-6.10)	(-5.04)	(-5.52)	(-5.37)
Intercept	12.33***	17.03***	2.46***	15.66***	16.66***	62.98***	16.98***	8.85***	9.72***	10.03***
	(23.73)	(16.68)	(4.17)	(17.06)	(22.49)	(31.65)	(30.99)	(65.63)	(83.30)	(85.97)
Price	-0.06***	-0.09***	-0.02	-0.10***	-0.01	-0.29***	-0.02	0.00	0.00	0.00
	(-4.06)	(-2.83)	(-0.96)	(-3.45)	(-0.24)	(-4.80)	(-1.17)	(0.16)	(0.44)	(0.69)
Volatility	0.09***	1.02***	-0.02	1.01***	-0.01	-0.51***	-0.05	-0.03***	-0.02***	-0.02***
	(3.52)	(12.37)	(-0.50)	(11.55)	(-0.66)	(-7.89)	(-1.57)	(-7.41)	(-7.35)	(-7.77)
Value	-0.01***	-0.04***	0.02***	-0.06***	0.08***	0.07***	0.15***	0.01***	0.01***	0.01***
	(-3.23)	(-3.70)	(2.93)	(-3.53)	(3.63)	(3.43)	(3.09)	(3.58)	(3.80)	(3.76)
N	53217	53217	53217	53217	53217	53217	53217	53217	53217	53217
Adj. R^2	90%	51%	22%	45%	36%	43%	35%	56%	55%	55%

Table IV: Effects of OPR Introduction on NBBO Liquidity

For OPR introduction, an event-study style regression is estimated, where $\text{Metric}_{i,t} = \text{Intercept}_{i,t} + \beta_1 \text{OPR}_{i,t} + \text{Controls}_{i,t} + \text{stockFE} + \varepsilon_{i,t}$. For OPR removal, a similar event-study regression is estimated, where $\text{Metric}_{i,t} = \text{Intercept}_{i,t} + \beta_1 \text{Removal}_{i,t} + \text{Controls}_{i,t} + \text{stock} + \varepsilon_{i,t}$, for stock i and day t. Metric stands for various liquidity metrics including NBBO Quoted Spread, NBBO Effective Spread, NBBO Realised Spread, NBBO Price Impact and log(DepthatNBBO).

NBBO quoted spread is calculated by taking the difference between the NBO (lowest ask in the whole marketplace) and NBB (highest ask in the whole marketplace). NBBO Effective spread is calculated by taking the signed difference between trade price and the prevailing NBBO midpoint, then multiply by 2. NBBO Realised Spread is calculated by taking the signed difference between the trade price and the NBBO midpoint 1-second after the trade price, then multiply by 2. NBBO price impact is calculated by taking the difference between NBBO effective spread and NBBO realised spread. The NBBO spread measures are divided by the prevailing NBBO midpoint, and measured in bps. Controls include stock-day measures of Price (Value Weighted Average Price of each day averaged across venues), averaged across venues, Value (Daily Trade Volume × Price of each trade summed across venues), averaged across venues, and Volatility ((Highest Price of the day of all venues – Lowest Price of the day of all venues)/ ((Highest Price of the day of all venues+ Lowest Price of the day of all venues)/2) × 100%. Standard errors are in brackets, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. All regressions standard errors are clustered by stock,date. Stock fixed effects are controlled in all regressions. R^2 adjusted for fixed effects.

	NBBO Quoted Spread bps	NBBO Effective Spread bps	NBBO Realised Spread bps	NBBO Price Impact bps	Log NBBO Depth	Log NBBO Depth L2	Log NBBO Depth L3
OPR	-0.40*	-0.34*	-0.09	-0.25*	0.08*	0.06	0.06*
	(-1.87)	(-1.87)	(-0.55)	(-1.65)	(1.78)	(1.57)	(1.72)
Intercept	10.08***	9.81***	2.22***	7.59***	11.12***	11.99***	12.48***
	(30.96)	(28.47)	(8.20)	(23.30)	(140.35)	(159.98)	(161.61)
Price	-0.00	-0.01	-0.00	-0.00	0.00	-0.00	-0.00
	(-0.28)	(-0.75)	(-0.56)	(-0.55)	(0.16)	(-0.12)	(-0.55)
Volatility	0.28***	0.41***	-0.34***	0.74***	-0.06***	-0.06***	-0.05***
	(6.83)	(6.22)	(-4.70)	(7.10)	(-3.56)	(-3.39)	(-3.37)
Value	-0.01***	-0.01***	0.00**	-0.01***	0.00***	0.00***	0.00***
	(-5.20)	(-5.10)	(2.23)	(-5.25)	(3.13)	(2.97)	(2.97)
N	8501	8501	8501	8501	8501	8501	8501
Adj. R^2	88%	85%	60%	67%	86%	88%	89%

Table V: Queue-Jumping

This table contains the condensed regression output for sub-samples grouped by the pre-period NBBO time share on each venue. $\text{Metric}_{i,v,t} = \text{Intercept}_{i,v,t} + \beta_1 \text{OPR}_{i,v,t} + \text{Controls}_{i,v,t} + \text{stock : venueFE} + \varepsilon_{i,v,t}$. for stock i, venue v and date t. Stocks are divided into 5 equal number groups, quintile 1 to 5 containing stocks with lowest to highest share on that venue. The stocks are grouped by pre-period average NBBO time share for each stock-venue pairs. Quintile 1 contains the stock-venue pairs with the least time share while quintile 5 contains the stock-venues with the highest time share. The control variables are the same as in Table IV. Wait Duration % refers to the duration before a venue joins the NBBO queue, divided by the total duration of that NBBO price level, conditional on every time a new queue is established (NBBO price is improved). NBBO Depth refers to the $ Depth at NBBO on each venue by the time they join the queue. Quoted spread is the spread in ticks on each venue at the time they join the queue. Join percentage is the percent of NBBO queue joined by each venue. $*$, $**$, $***$: 10%, 5%,1%; All regressions standard errors are clustered by stock,date. Venue-stock fixed effects are controlled in all regressions. Note that here only quintile 1 and 5 are displayed because of space constraints.

	Queue Length Grouping		Broker Connections Grouping	
	Low Queue	High Queue	Least Connected	Most Connected
NBBO Depth Share	1.61***	-1.62***	1.76***	-1.51**
	(5.60)	(-2.78)	(4.57)	(-2.51)
NBBO Time Share	8.85***	-0.06	9.80***	-0.54
	(10.42)	(-0.15)	(9.23)	(-0.99)
Log NBBO Depth	0.59***	0.04	0.62***	0.10*
	(8.32)	(0.94)	(7.74)	(1.78)
Value Share	0.68***	-1.78***	0.64***	-1.05*
	(4.45)	(-3.23)	(2.68)	(-1.77)
Effective Spread (bps)	-14.70***	-0.17	-14.81***	-0.24
	(-8.54)	(-0.92)	(-7.62)	(-1.38)
Price Impact (bps)	-12.02***	-0.43	-11.06***	-0.48**
	(-8.10)	(-1.53)	(-7.11)	(-2.47)
Stale Quotes	-29.24***	-0.26	-32.74***	-0.33
	(-10.40)	(-1.05)	(-10.66)	(-0.87)
% Match NBBO	11.85***	-0.12	12.65***	-0.42
	(9.75)	(-0.48)	(8.70)	(-0.97)
% Wait Duration	-9.81***	0.13	-10.42***	0.52
	(-9.72)	(0.38)	(-8.58)	(0.95)
Quoted Spread (ticks)	-1.48***	-0.06**	-1.61***	-0.03
	(-8.10)	(-2.05)	(-7.91)	(-0.59)
One Lot Percentage	76.78***	15.77	60.52***	34.18
	(4.15)	(1.07)	(3.41)	(1.48)
One Lot Frequency	10.36***	-5.03	8.47***	25.68
	(4.27)	(-0.37)	(5.31)	(0.82)
	4708	5058	3995	3782

Table VI: Condensed Broker Evidence on Adverse selection and OPR Introduction

This table contains the condensed regressions with different sub-sample methods. $\text{Metric}_{i,v,n,t} = \text{Intercept}_{i,v,n,t} + \beta_1 \text{OPR}_{i,v,n,t} + \text{Controls}_{i,v,n,t} + \text{stock} : \text{venue} : \text{brokerFE} + \varepsilon_{i,v,n,t}$. for stock i, broker n, venue v and date t. The observations are all broker-stock-venue-day. (1) less vs more pre-period passive trading volume per broker-stock-venue. (2) increase vs decrease in the passive trading volume on alternative venue per broker. (3) decrease vs increase in change in passive trading volume on the primary venue (TSX) per broker. (4) is similar to (3), except it is calculated at broker-stock level. (5) is increase vs decrease in number of trades where the prevailing queue-length is one-lot per broker in the post period compared with pre. (6) is similar to (5), but calculated for each broker. The variables on the left-hand-side is the dependent variable in each regression. Only coefficients of interest (OPR variable) are reported for each regression. The controls and regression set-ups are identical to previous regressions in Table VI. All regressions have controlled for broker, stock, venue fixed effects. $*$, $**$, $***$: 10%, 5%, 1%; All regressions standard errors are clustered by stock,date. The left column always indicates the group where the improvement in liquidity is stronger.

Dependent	(1)		(2)		(3)		(4)		(5)		(6)	
	Less	More	Increase	Decrease	Decrease	Increase	Decrease	Increase	Increase	Decrease	Increase	Decrease
Price Impact 1s	-9.78***	-0.86***	-4.27***	-0.97**	-2.56***	-0.59**	-4.00***	-1.73***	-2.73***	-1.84***	-4.13***	-1.78***
Price Impact 1m	-9.55***	-1.39***	-4.34***	-1.58***	-2.89***	-1.31***	-4.22***	-2.22***	-3.09***	-2.25***	-4.41***	-2.22***
Price Impact 5m	-9.06***	-1.43***	-4.33***	-1.44***	-2.80***	-1.53***	-4.26***	-2.16***	-3.09***	-2.20***	-4.39***	-2.23***
N	53,012	235,463	155,482	119,233	218,313	32,664	108,433	77,848	123,464	155,055	86,936	114,188

Table VII: Adverse Selection of 'Back of Queue' Orders

This table present the effective spread and price impact for back of queue versus middle of queue orders on each exchange. $\text{Metric}_{i,v,t} = \text{Intercept}_{i,v,t} + \beta_1 \text{OPR}_{i,v,t} \cdot \text{Backofqueue}_{i,v,t} + \text{Controls}_{i,v,t} + \text{stock} : \text{venueFE} + \text{dateFE} + \varepsilon_{i,v,t}$. Back of queue is defined as when the trade has depleted the liquidity available at that price level. This is characterized by two features: the quote update with a less favourable price (higher for ask and lower for bid), and the volume of the executed trade consumes the entire current depth level. NBBO price impacts are defined the same way as Table IV. The controls and regression set-ups are identical to previous regressions in Table VI. All regressions have controlled for stock-venue-queue position fixed effects. $*$, $**$, $***$: 10%, 5%, 1%; All regressions standard errors are clustered by stock, date.

	NBBO Price Impact 1s		NBBO Price Impact 30s		NBBO Price Impact 1m	
	Alternative	Primary	Alternative	Primary	Alternative	Primary
OPR × Back of Queue	-0.26***	-0.20	-0.41***	-0.07	-0.40***	-0.02
	(-3.18)	(-0.89)	(-3.22)	(-0.26)	(-2.81)	(-0.08)
Intercept	4.47***	8.50***	6.07***	9.23***	6.34***	9.21***
	(42.38)	(48.74)	(26.13)	(45.73)	(24.46)	(45.73)
Price	-0.00	-0.01	-0.00	0.00	-0.00	0.01
	(-0.90)	(-1.06)	(-0.27)	(0.69)	(-0.05)	(1.47)
Volatility	0.38***	0.53***	0.73***	1.02***	0.83***	1.17***
	(14.96)	(13.87)	(22.95)	(19.76)	(20.31)	(19.38)
Value	-0.01*	-0.01***	-0.03***	-0.01***	-0.03***	-0.01***
	(-1.72)	(-4.88)	(-3.80)	(-4.72)	(-3.41)	(-4.42)
N	51177	17507	51177	17507	51177	17507
Adj. R^2	51%	71%	47%	65%	44%	61%

References

Abergel, Frédéric, et al. *Market microstructure: confronting many viewpoints.* John Wiley & Sons, 2012.

Amihud, Yakov, Beni Lauterbach, and Haim Mendelson. "The value of trading consolidation: Evidence from the exercise of warrants". *Journal of Financial and Quantitative Analysis* 38.4 (2003): 829–846.

Amihud, Yakov and Haim Mendelson. "Trading mechanisms and stock returns: An empirical investigation". *The Journal of Finance* 42.3 (1987): 533–553.

Battalio, Robert. "Third market broker-dealers: Cost competitors or cream skimmers?" *The Journal of Finance* 52.1 (1997): 341–352.

Battalio, Robert, Brian Hatch, and Robert Jennings. "Toward a national market system for US exchange–listed equity options". *The Journal of Finance* 59.2 (2004): 933–962.

Bessembinder, Hendrik. "Quote-based competition and trade execution costs in NYSE-listed stocks". *Journal of Financial Economics* 70.3 (2003): 385–422.

Blume, Marshall E. "Competition and fragmentation in the equity markets: The effect of Regulation NMS". *Available at SSRN 959429* (2007).

Boehmer, Beatrice and Ekkehart Boehmer. "Trading your neighbor's ETFs: Competition or fragmentation?" *Journal of Banking & Finance* 27.9 (2003): 1667–1703.

Chakravarty, Sugato, et al. "Clean sweep: Informed trading through intermarket sweep orders". *Journal of Financial and Quantitative Analysis* 47.2 (2012): 415–435.

Chao, Yong, Chen Yao, and Mao Ye. "Why discrete price fragments US stock exchanges and disperses their fee structures". *The Review of Financial Studies* 32.3 (2018): 1068–1101.

Chen, Haoming, et al. "The Value of a Millisecond: Harnessing Information in Fast, Fragmented Markets". *Fragmented Markets (November 18, 2017)* (2017).

Chowdhry, Bhagwan and Vikram Nanda. "Multimarket trading and market liquidity". *The Review of Financial Studies* 4.3 (1991): 483–511.

Commission, Ontario Securities, et al. "CSA Staff Notice 23-316 Order Protection Rule: Implementation of the Market Share Threshold and Amendments to Companion Policy 23-101 Trading Rules" (2016).

——."National Instrument: National Instrument 21-101 Marketplace Operation" (2009).

Committee, Equity Market Structure Advisory. "Memorandum" (2017).

Conrad, Jennifer, Sunil Wahal, and Jin Xiang. "High-frequency quoting, trading, and the efficiency of prices". *Journal of Financial Economics* 116.2 (2015): 271–291.

Degryse, Hans and Nikolaos Karagiannis. “Once Upon a Broker Time? Order Preferencing and Market Quality”. *Order Preferencing and Market Quality (April 8, 2018)* (2018).

Foley, Sean and Tālis J Putniņš. “Should we be afraid of the dark? Dark trading and market quality”. *Journal of Financial Economics* 122.3 (2016): 456–481.

Foucault, Thierry and Albert J Menkveld. “Competition for order flow and smart order routing systems”. *The Journal of Finance* 63.1 (2008): 119–158.

Gomber, Peter, et al. “Competition between equity markets: A review of the consolidation versus fragmentation debate”. *Journal of economic surveys* 31.3 (2017): 792–814.

Harris, Lawrence E. “Consolidation, fragmentation, segmentation, and regulation”. *Journal of Finance* 48.3 (1993): 1092–1093.

Hendershott, Terrence and Charles M Jones. “Trade-through prohibitions and market quality”. *Journal of Financial Markets* 8.1 (2005): 1–23.

Holden, Craig W and Stacey Jacobsen. “Liquidity measurement problems in fast, competitive markets: Expensive and cheap solutions”. *The Journal of Finance* 69.4 (2014): 1747–1785.

Kwan, Amy, Ronald Masulis, and Thomas H McInish. “Trading rules, competition for order flow and market fragmentation”. *Journal of Financial Economics* 115.2 (2015): 330–348.

Madhavan, Ananth. “Consolidation, fragmentation, and the disclosure of trading information”. *The Review of Financial Studies* 8.3 (1995): 579–603.

Malinova, Katya and Andreas Park. “Subsidizing liquidity: The impact of make/take fees on market quality”. *The Journal of Finance* 70.2 (2015): 509–536.

McInish, Thomas H and James Upson. “The quote exception rule: Giving high frequency traders an unintended advantage”. *Financial Management* 42.3 (2013): 481–501.

O’Hara, Maureen. “High frequency market microstructure”. *Journal of Financial Economics* 116.2 (2015): 257–270.

O’Hara, Maureen and Mao Ye. “Is market fragmentation harming market quality?” *Journal of Financial Economics* 100.3 (2011): 459–474.

Pagano, Marco. “Trading volume and asset liquidity”. *The Quarterly Journal of Economics* 104.2 (1989): 255–274.

Parlour, Christine A and Duane J Seppi. “Liquidity-based competition for order flow”. *The Review of Financial Studies* 16.2 (2003): 301–343.

Shkilko, Andriy V, Bonnie F Van Ness, and Robert A Van Ness. “Locked and crossed markets on NASDAQ and the NYSE”. *Journal of Financial Markets* 11.3 (2008): 308–337.

Stoll, Hans R. “Market fragmentation”. *Financial Analysts Journal* 57.4 (2001): 16–20.

Van Kervel, Vincent. “Competition for order flow with fast and slow traders”. *The Review of Financial Studies* 28.7 (2015): 2094–2127.

Appendix

Figure A1: Make-Take Fee on TSX Across Time

This fig illustrates the make and take fee for a small order smaller than $125 million with non-interlisted stocks above $1. The fees are plotted in units of bps.