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https://www.sec.gov/rules/submitcomments.htm.
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March 26, 2018

Dear Mr. Fields:

Transaction Fee Pilot for NMS Stocks

We thank the Securities and Exchange Commission (SEC) for the opportunity to comment on the Transaction Fee Pilot for NMS Stocks. Having undertaken theoretical and empirical research on the 2015 Nasdaq Access Fee Reduction Experiment, we believe differential components as well as the net exchange transaction fee matter. After Nasdaq lowered both maker and taker fees by an identical amount (i.e., holding the net exchange transaction fee relatively constant), we find Nasdaq's market share shifted to the other maker-taker exchanges with the highest rebate, and the cum-fee spread narrowed along with a reduction in price impact. Also, the HFT trading on Nasdaq shifted from adding liquidity to taking liquidity. In our recent working paper "Why Maker-Taker Fees Improve Exchange Quality: Theory and Natural Experiment Evidence" (attached), we have explained why the exchange transaction fee reduction had these counterintuitive impacts on liquidity, execution quality and high frequency trading.

Lessons from the Nasdaq Access Fee Reduction Experiment

NASDAQ has adopted a maker-taker fee model that charges a take fee for removing liquidity by submitting marketable orders and provides a make rebate for adding liquidity by submitting non-marketable limit orders that cannot be executed immediately. On February 2, 2015, NASDAQ implemented a maker-taker fee pilot for 14 traded stocks on NASDAQ where the take fee was lowered to 5 cents per 100 shares (CPS) from 30 CPS to remove displayed liquidity, and the make rebate for adding displayed liquidity was lowered to 4 CPS from an indicative 29 CPS.

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NASDAQ listed seven of these stocks on the NYSE and seven on NASDAQ. Simplifying somewhat, we summarize the indicative rebate for the PilotOff period in the table below. The pilot ended on May 31, 2015, when the fee reverted to its pre-pilot level.

Table 1: Nasdaq Maker-Taker Fee Structure

This table reports the Nasdaq pricing measured in cents per 100 shares (CPS) traded during (PilotOn) and pre/post (PilotOff) the Nasdaq access fee pilot implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. Net fee is defined as the sum of the take fee and the make rebate, which is the exchange revenue per 100 shares traded. The take fee is the highest rate Nasdaq can charge and make rebate is the most indicative rate Nasdaq provides in the Nasdaq pricing table.

Fee/ Rebate	**PilotOn (C*PS*)**	**PilotOff (C*PS*)**	**Difference**
Take Fee to Remove Liquidity:	5	30	-25
Make Rebate to Add Liquidity:			
Displayed Liquidity	4	29	-25
Non-Displayed Midpoint	2	25	-23
Other Non-Displayed Liquidity	0	10	-10
Net Fee:			
Displayed Liquidity	1	1	0
Non-Displayed Midpoint	3	5	-2
Other Non-Displayed Liquidity	5	20	-15

Our primary evidence that, holding the net fee (relatively) constant, the change in component fees and rebates does matter, is that in the fee pilot NASDAQ's market share declined by a significant percentage to the benefit of other high rebate-paying lit exchanges. In addition, we have shown changes in depth, the information content of trades, and in price volatility. Using difference-in-differences method designed for precisely this kind of research setting with cross-sectional differences in an uncontrolled sample experiment over time, we find venues differentiated by higher maker rebates show significantly greater depth, higher trade volume, more informed trading, and better price discovery.

We explain in theory why the fee pilot enhanced the fill rate and speed of fill on NASDAQ—i.e., because the reduced taker fee and maker rebate encouraged informed traders to switch to other high-rebate venues. With their relative routing position improved, adverse selection costs on NASDAQ declined due to the flight of these informed traders, and liquidity suppliers profited (their realized spread increased). Hence, what we have demonstrated is that NASDAQ's existing strategy, prior to and post their access fee pilot experiment, of providing the highest possible subsidy to liquidity makers encourages better price discovery and lower price volatility, resulting in higher market efficiency. Since the rebates directly enhance the profits of informed trades by subsidizing liquidity suppliers, with liquidity takers no worse off, higher rebates offer a clear Pareto improvement.

NASDAQ designed the fee pilot as a natural experiment to address in part the question of whether high exchange access fees had caused trading to shift from exchanges to dark pools. We find no evidence for such a shift, perhaps because only one exchange reduced its access fee unilaterally in a competitive trading environment. However, even if all exchanges had participated, the outcome may have remained the same, as the net fee did not substantially alter. Instead, something fundamental changed in the competition between lit exchanges—to wit, the *informed* equilibrium order flow decreased substantially on NASDAQ despite no fundamental mechanism design changes between exchange and off-exchange venues.

While standard quality measures such as the effective spread, realized spread, and price impact all appear to improve on a cum-rebate basis, these apparent improvements reflect the lower information content in NASDAQ's order flow during the experiment. Again, informed orders shifted to exchanges that maintained high rebates, and we find HFT traders switched from adding to taking liquidity. That is, given their relative inability to monitor the now less informed order flow dynamics, non-HFT firms increased liquidity making and decreased their liquidity taking while HFT firms did just the reverse, *albeit* with a less informed equilibrium order flow.

In short, we find that exchange venues have discovered by serendipity that a subsidy to LOB makers paid for by a levy on takers achieves a Pareto improvement in market making. The theoretical contribution of our enclosed paper shows why. The opening-up of trading so as promote the incorporation of more asymmetric information has resulted in greater pricing efficiency. This improved market design has been achieved by differential access fee components that are far from neutral despite no substantive change in the net access fee.

The opinions expressed in this letter are our own. These originate from the findings in our recent empirical paper with its revealing theoretical model, which is attached to this letter. They do not necessarily reflect the position of NASDAQ, nor the CMCRC research centre with which we are affiliated.

When the Transaction Fee Pilot for NMS Stocks officially starts, we would welcome the opportunity to assist the SEC inquiry into the impact of access fees and rebates on order routing behaviour, execution quality, and market quality, as announced by Chairman Jay Clayton.

Yours sincerely,

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Why Maker-Taker Fees Improve Exchange Quality: Theory and Natural Experimental Evidence[1]

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Abstract

This paper extends Glosten and Milgrom's (1985) modelling of the limit order book to encompass exchange fee structures in a competitive environment with continuous pricing. Informed traders control the degree of information in their orders to fully exploit make/take rebates and fees in a Pareto-improving manner. Fees do not wash out, unlike their portrayal in the extant literature. We examine the "natural" experiment of a unilateral maker-taker fee/rebate reduction to show that the cum-fee spread narrows due to the flight of highly informed orders to the remaining highest rebate venues resulting in a worsening of venue efficiency.

Keywords: Maker-Taker Fee, Exchange Competition, Market Quality, High Frequency Trading

JEL Classifications: G12, G14

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1. Introduction

Exchange venue fee structures and their impact on trading remain unresolved. Angel, Harris, and Spatt (2011) argue that the maker-taker fee breakdown is irrelevant for which Colliard and Foucault (2012) provide theoretical support. In addition, Foucault, Kadan, and Kandel (2013) support Colliard and Foucault in the case of continuous pricing but find that a finite minimum tick prevents price changes from neutralizing a maker-taker fee rebate. Malinova and Park (2015) show empirically for a monopoly exchange (Toronto at the time) that cum-fee price changes neutralize the introduction of a maker-taker fee structure. In this paper we provide a new model to show that, while these important contributions are correct given their assumptions, maker-taker (and inverted fee structures) do not cancel out in the presence of informed traders able to switch between trading venues with different pricing structures. This is still true even with continuous pricing. Moreover, a higher maker-taker take fee and matching rebate yields Pareto welfare improvements and more efficient pricing.

This extant literature is correct within its own framework but deficient in terms of its ability to explain the workings of contemporary exchanges because it abstracts from informed traders able and willing to switch venues in response to different fee structures. It is hard to conceive of the existence of limit order book (LOB) markets in the absence of informed trades as with close to zero cost, electronic trading spreads could be expected to be close to zero and uniform over both stocks and time. Moreover, there exist no regulatory or other barriers to confine informed traders to a given venue when trading profits are higher at a competing venue offering more conducive pricing arrangements.

It should come as no surprise, to theorists at least, that third-party (trading venue) fees and rebate structures improve on the standard non-intervention solution without maker-taker fees and rebates. It has been known for more than 50 years that it is essential in the presence of asymmetric information to have the intervention of a third party, such as an exchange or broker, to improve Pareto efficiency. Vickrey (1961) shows that in the absence of a third-party subsidy, it is impossible to achieve truthful revelation of preferences in first price auctions. Myerson and Satterthwaite (1983) prove that, even with the simplest form of asymmetric information such as the inability to know one's counterparty preferences perfectly, the intervention of a third party improves Pareto efficiency. Similarly, we prove that when a third party optimally intervenes to improve market efficiency by imposing differential fees and rebates in response to asymmetric information, the principle of fee neutrality no longer holds. In other words, the present paper establishes the practical, real world relevance for security markets of the theoretical contributions of Vickrey (1961) and Myerson and Satterthwaite (1983). The close analog and essential difference between their contribution and ours is that in their framework two

parties with sizeable potential gains from trade withdraw from bilateral bargaining due to each party wishing to understate its gain from trade; yet, an outside subsidy can induce trade to take place. Whereas in our framework, informed traders possessing too much asymmetric information cannot participate in a given venue unless the rebate on make orders is raised to the point at which the market remains open (the spread is not excessive). The raising of the fee/rebate yields a new and higher equilibrium degree of asymmetric information in order flow to that venue.

We show that it is in the interests of informed traders, here takers, that are endowed with the true value of the security prior to their trade to raise the information content of their trades by the full amount of the (scaled) make rebate to achieve an efficient corner solution in maker-taker markets. In inverted markets, the reverse occurs with information content falling by the full extent of the fee paid by limit orders, leaving the raw spread unchanged, together with a deterioration in market efficiency. Thus, far from washing-out, the maker-taker fee structure improves market efficiency and price discovery. Additionally, it raises the market share of trading volume to exchanges with the highest rebates by attracting more traders with information and more makers to act as counterparties to the newly recruited informed traders.

Since liquidity traders who place limit orders earn the same raw spread plus an additional rebate when their trades are executed, and since a rebate raises informed trader profitability, fee rebates are Pareto-improving. Additionally, maker-taker venues provide price discovery enhancement, a positive externality. In contrast, inverted taker-maker markets with a fee on makers and rebate to takers are Pareto-inefficient relative to tax-neutral zero-fee regimes as informed trader profitability falls while leaving the net fee paid by uninformed traders the same. Hence our model explains why most venues are maker-taker, with the market share of inverted venues small by comparison.

The continuing debate on the efficiency and trade volume effects of maker-taker fee structures in North American markets led NASDAQ to conduct a “quasi-natural” fee-pilot experiment by lowering both the maker rebate and taker fee by an identical amount (25 cents per 100 shares traded) for a select group of securities for a pre-specified period. This access fee pilot is described in greater detail in Section IV below. While NASDAQ’s fee-pilot experiment was motivated in part by competition from dark pools and other off-exchange venues, for us the real benefit lies in its ability to provide robust tests of our simple, stripped down, theoretical model that reveal for the first time why maker-taker fee structures are of critical importance for almost every aspect of market quality.

In this paper, we show that the maker-taker fee structure employed by NASDAQ has highly desirable features in that it improves price discovery and market efficiency while at the same time maximizing NASDAQ’s trading volume and market share. How can that be? In short, maker-taker tax-subsidy schemes

result in fundamental changes to the information content of equilibrium order flow across venues with no prospect of ever cancelling out, irrespective of the minimum tick size. Our findings from the fee pilot experiment support all the predictions from our (extreme Occam's Razor) theoretical model while rejecting the conclusions of those models which find either 1) that fees and offsetting rebates have effects that cancel out, or 2) that maker-taker venues exist due to the SEC's minimum tick, given that the SEC severely caps the maker-taker fee, and would benefit from a further increase in the minimum tick.

We also find empirically that non-High Frequency Traders (non-HFTs) with their less efficient monitoring of the order flow dynamics, switch from takers to makers as both the information content and the rebate are reduced, while HFTs do the reverse. This is not only because HFT can switch seamlessly from one side of the market to the other, but also because they focus on the most informed traders requiring more speed and expertise. Again, our theory explains why these outcomes occur in maker rebate-taker fee markets; higher access fees increase beneficial informed equilibrium order flow and lower access fees reduce it.

1.1. Our Contribution

Our model of maker-taker fees predicts that the introduction of a make fee rebate from an initial zero fee-subsidy regime will not narrow the raw (observed) effective spreads or quotes as wash-out requires, but will raise the expected market impact cost to the full extent of the make rebate due to increased market order information content. Hence, the raw realized spread, reflecting the new higher level of information content, must fall by the extent of the now-higher price impact due to the greater adverse selection, leaving the effective raw spread unaltered and the cum-fee spread widened. This is because the higher information content of trades fully absorbs the maker-taker rebate. This breakdown of fee neutrality has nothing to do with the minimum tick. Market orders now face a higher cost with the take fee now factored in; that said, informed trader profit (quasi-rent) nevertheless rises due to the greater information content of the order flow. Our model therefore predicts that the cum-fee effective spread and quotes will rise by the entire extent of the fee rebate but the rise in raw market impact costs will be fully absorbed by the fee rebate, leaving no change in cum-fee market impact costs. Hence, the rise in the cum-fee realized spread will precisely equal the rebate. This stark implication is the first prediction of our model. It has the virtue of being precisely tailored to the NASDAQ rebate-reduction pilot, enabling a very simple test of the predictive ability of our model to reject fee-structure neutrality.

Our model also predicts that alterations to the rebate, or its abolition, by a lit venue, will have little or no effect on competition between the altered venue and dark pools as the latter are designed to largely exclude informed traders. The sole effect of the rebate in lit markets is as a magnet to attract informed traders from

other high-rebate venues and to enhance the pool of makers willing to act as new counterparties to match the influx of informed traders. Revenue-neutral rebate modifications should therefore have no determinate bearing on dark pools. Instead, the second prediction of our model is that the unilateral removal of the make rebate in a high-rebate venue will reduce market share as informed traders flee to the next-highest lit high-rebate venue. In this study, we employ difference-in-differences (DiD) methodology to test both predictions when the maker-taker fee structure is largely eliminated, as it was during the NASDAQ fee pilot.

Moreover, our model rejects as redundant the claim made by Chao, Yao, and Ye (2017a) that competing fee venues can be explained by heterogeneous limit order providers in the presence of a binding minimum-tick size constraint without which fee structures would otherwise wash out. With no change in tick size, such a model cannot predict the alterations to asymmetric information and information content that occurred because of the NASDAQ fee experiment.

The strength of our analysis lies both in our novel theory, which is striking due to its simplicity, and in the structure of the NASDAQ fee pilot change. First, NASDAQ introduced the maker-taker fee reduction only for a predefined subset of 14 securities, allowing the analysis of the impact to use a rigorous DiD approach. Second, the pilot only lasted four months in 2015, enabling us to compare the relatively short span of PilotOn with PilotOff, both prior to and post the pilot, effectively halving the number of parameters to be estimated. Third, NASDAQ data allow us to analyze how HFT reacts to the maker-taker fee reduction compared with non-HFT across different resting order types, giving us new insights into the nature of HFT.

Our empirical results show that, as predicted, when NASDAQ reduces the maker-taker fee unilaterally without the cooperation of other exchanges, there are no significant changes in the market share of off-exchange trading venues (we separate these into dark pools and non-dark pools). Instead, we observe a redistribution of the traded volume away from NASDAQ to other lit exchanges with higher maker rebates. Hence, holding the exchange net fee relatively constant, when the make rebate is reduced, the queue of NASDAQ limit orders shrinks as informed traders shift to the most closely competing venues. This prediction is evidenced by the drop in the percentage of time and depth of NASDAQ at the National Best Bid and Offer (NBBO). Depth cannot be provided in the LOB if there are no highly informed market orders to hit limit orders placed away from the best bid and ask. Note that one cannot logically argue that this depth decline occurred *because of* the removal of the subsidy to limit orders (since in the extant "wash-out" models a subsidy removal does not alter the cum-fee spread and therefore should have no effect whatsoever on the depth in the LOB.

Our theoretical model predicts that a value-based metric of the information content of trades will decline by the precise amount of the rebate decline. The LOB becomes thinner because, deprived of informed traders who have switched to other high-rebate exchanges, limit order placements away from the best bid and ask lack

the essential informed counterparties. Realized spreads should then increase to reflect the falling proportion of informed traders, but the cum-rebate (i.e., the net realized spread) decreases because of the smaller proportion of informed traders hitting limit orders. Hence, not only does the pilot reduce the net realized spread, but the effective spread and market impact costs are also lower. This decline in all three spread measures is indicative of the switch in the informed order flow toward other high-rebate venues. As a net result, the NASDAQ market share declines on average and is captured by the other high rebate-paying exchanges in close competition with NASDAQ.

In sum, our theoretical model and empirical findings indicate that the components of the exchange access fee matter greatly in a competitive trading environment. Today, U.S. equity investors can trade on approximately 300 different venues, including thirteen registered exchanges each with different fee structures, approximately forty or so active alternative trading systems (ATSs) and numerous broker-dealer platforms. We prefer to describe this proliferation of venues with varying fee structures as being the result of Adam Smith's 'invisible hand' and the hidden forces of competition, rather than use the pejorative term, 'fragmentation'. This is especially so as these venues are currently unable to explain why it is that some fee structures work better than others; we hope to contribute to that understanding.

1.2. Maker-Taker Fees

The International Organization of Securities Commissions defines maker-taker fees as "a pricing model whereby the maker of liquidity, or passive [limit] order, is paid a rebate and the taker of liquidity, or aggressive [market] order, is charged a fee." Maker-taker fees for protected quotes in the equities markets are bound by Rule 610 of Regulation NMS which caps fees at 30 cents per 100 shares (CPS) traded, i.e., 0.3 cents per share.[1] Despite the capped rebate being exceedingly small relative to spreads, the NASDAQ fee pilot shows that it nonetheless has huge effects. The minimum tick of 1 cent for stocks priced at $1 or more is 3.33 times higher than the capped rebate and for the FINRA/SEC tick-size pilot, the minimum tick of 5 cents for small stocks is an incredible 16.66 times higher. While maker rebates aim to both improve liquidity, by rewarding its provision, and increase trading volume by raising execution quality, it is impossible for these laudable goals to be fully realized in the face of regulatory fiat.

The maker-taker payment model originated with electronic trading venues in the late 1990s. In 1997, the Island electronic communication network (ECN) was among the first markets to adopt maker-taker fees, which attract order flow through liquidity rebates. These rebates provide traders with an additional source of income other than the bid-ask spread, incentivizing liquidity providers to post more competitive quotes to attract order

[1] If the price of a protected quotation is less than $1, the fee cannot exceed 0.3% of the quotation price. See SEC Rule 610.

flows from other markets. Accordingly, Island's market share of reported NASDAQ trades increased from approximately 3% in 1997 to almost 13% in 1999 (Cardella, Hao, and Kalcheva, 2015). This sizeable rise in market share is unlikely to have either "washout" or a binding role for minimum tick as its explanation. Some alternative trading systems (ATSs) soon followed Island's lead (SEC, 2015a). And other alternative versions of maker-taker fee structures were soon introduced. For example, in 2008 the NYSE abolished its specialist system of market makers in favor of contractual Designated Market Makers (DMMs) that were rewarded with a maker-taker fee structure (i.e., a take fee of 0.275 cents and a make rebate of 0.27 cents by 2017). These contracts require DMMs to maintain competitive bids and offers for a fraction of the trading day that depends on the prior month trading volume. More stringent market making requirements are associated with increased depth, narrower bid-ask spreads, increased firm value, and improved price efficiency (Bessembinder, Hao, and Zheng, 2017).

In response to the competition from ATSs, many exchanges adopted maker-taker fees of their own. Over the past decade, the maker-taker pricing model has thus gained widespread adoption in the U.S. equities market, rewarding liquidity suppliers and charging liquidity demanders. Only three U.S. exchanges (BATS-Y, EDGA, NASDAQ/BX) adopt the inverted fee (taker-maker) model, offering rebates to take liquidity accompanied by a higher fee to add liquidity. As predicted by our model, the market shares of these inverted venues are small in comparison to those of maker-taker venues.

Despite fees and rebates appearing small relative to the mandated minimum tick, take fees and make rebates still comprise a sizeable proportion of overall trading costs. While most retail investors do not directly observe fees and rebates, all institutional investors and market makers who account for most trading activity are quite cognizant of them. Brokers commonly sell their marketable orders to wholesale dealers to capture the bid-ask spread and to avoid access fees, and send their non-marketable orders to exchanges for execution to gain maker rebates (Angel, Harris, and Spatt, 2015). Moreover, so-called "smart order routers" consider fee rebates along with real-time state information to formulate an order routing problem that decides whether to place a limit order or market order and the venue(s) at which to direct the order (Maglaras, Moallemi, and Zheng, 2012).

Policy questions are quite prominent in this maker-taker fee debate. The SEC has questioned whether "rebates [are] unfair to long-term investors because they necessarily will be paid primarily to [high-frequency] proprietary firms engaging in passive market making strategies. Or do they generally benefit long-term investors by promoting narrower spreads and more immediately accessible liquidity?" (SEC, 2010). Angel, Harris, and Spatt (2011, p. 39) further argue that the maker-taker model has "aggravated agency problems among brokers and their clients." Battalio, Corwin, and Jennings (2016) have shown that brokers do not

forward the exchange fees to their clients on a trade-by-trade basis and may have a conflict of interest with their clients regarding the choice of trading venue.

The rest of the paper is organized as follows. Section II exposits our theoretical model, Section III reviews prior literature in the light of our model, IV discusses the NASDAQ Fee Pilot. Section V describes the data, sample selection, and research methodology. Section VI tests our theoretical predictions on trading volume, market liquidity, and HFT trading behavior. Section VII presents the results of our robustness tests and Section VIII concludes.

2. Model

Following in the framework of the seminal contribution by Glosten and Milgrom (1985) (GM) and, additionally, Aitken, Garvey, and Swan (1995), we are the first to analyze access fees in the presence of informed order flow and asymmetric information. Our extension of GM's model of informed trading is both simple and tractable, providing intuitive answers, because liquidity traders have inelastic demands if transaction costs do not exceed their gains from trade.[2] We deliberately keep to this simple model to exploit Occam's razor to the full, as we find it more than adequate to explain our striking findings from NASDAQ's fee pilot. Moreover, it is amenable to our conveying the intuitive substance of the model using numerical values, as we do below.

There is one unit of a representative stock to be traded whose price can take on one of two values, high or low (V^H or V^L), with $V^H > V^L$. Setting the unconditional share price at $\left(V^H + V^L\right)/2 \equiv V$, namely, the valuation placed on a share by a risk-neutral uninformed liquidity trader, then $V^H \equiv (1+\alpha)V$ and $V^L \equiv (1-\alpha)V$, where $1 \geq \alpha \geq 0$ is the value of the information about the actual trade price revealed in advance by a perfect signal revealed only to risk-neutral informed traders prior to placing their order.[3] Low values for information (α) pose few problems for the market in terms of adverse selection as the unconditional price is a reasonable proxy for the true value but high values can temporarily or permanently close the market as the spread widens to reflect an expected increase in adverse selection. Risk-neutral liquidity traders allocate their trades randomly across venues with different fee structures due to the inelastic nature of their demands. One can think of α as the measure of the degree of "information content" in an informed market order. At $\alpha = 1$, the informed

[2] Glosten and Putniņš (2015) extend GM's model to uninformed traders with price elastic demands.

[3] Note that GM's high and low price is unrelated to stock price volatility. Volatility plays no role in the model.

trader's informational advantage is at its maximum since the current price differs in a major way from its true value and as $\alpha \to 0$ the informational advantage evaporates.

Throughout this model, the cost to the informed trader in gaining short-term informational advantage is treated as exogenous and bygone and thus the costs of acquiring information are irrelevant. Nonetheless, we wish to emphasize that the degree of informational advantage observed at any given trading venue is entirely endogenous and, we will show, highly dependent on the fee structure adopted by that venue. We analyze the informed trader's optimal choice of venue given his pre-existing degree of information content. We prove that for a given venue, the informed trader maximizes his quasi-rent by choosing to execute a trade with the highest sustainable information content, $\bar{\alpha} \geq \alpha,$ consistent with equilibrium in that particular venue. We show that as the make rebate rises, the equilibrium degree of adverse selection that is sustainable also rises.

A risk-neutral liquidity taker who is a potential seller values the share at a fraction, $(1-\lambda)V$, of the unconditional value for liquidity or portfolio rebalancing reasons while an equivalent potential buyer values the share at $(1+\lambda)V$, where λV is a measure of the gains from a trade, with $(1-\lambda)V$ and $(1+\lambda)V$ representing private valuations of the liquidity seller and buyer, respectively, where $0 \leq \lambda \leq 1$. So long as the liquidity trader has a non-negative gain from trade, trading is price inelastic. Liquidity traders are randomly assigned either a low valuation, $-\lambda,$ or high valuation, $\lambda,$ such that low-valuation traders are would-be sellers and high-valuation traders are would-be buyers, while $\lambda = 0$ for both informed traders and competitive liquidity providers (specialist dealers in the terminology of GM).

Free entry and exit decides the participation of competitive dealers facing a zero-profit constraint, while informed traders gain a quasi-rent based on their pre-existing information. This difference in private valuation motivation for liquidity takers is identical to that employed by Colliard and Foucault (2012), Foucault, Kadan, and Kandel (2013) and Chao, Yao, and Ye (2017a), except in those models there is no informed trading, and hence $\alpha = 0,$ such that our model yields their findings as a limiting case. Informed traders who know the true value of V prior to placing their order consist of a proportion $1/2 > \gamma \geq 0$ of the entire population of traders with this proportion known to specialist dealers. There is a cap, given by the probability of one-half, on their participation in the market Hence, dealers know that γ is the likelihood of an informed trade and uninformed liquidity traders make up the remaining $1-\gamma$.

Potential sellers with low valuation $(1-\lambda)V$ are offered the "bid", i.e., "sell", price, denoted as $p_s \geq (1-\lambda)V$ in the limit order market, so that, due to adverse selection, the price must equal or exceed the liquidity seller's private valuation, and potential buyers with high valuation are offered the "ask", i.e., "buy",

price $p_b \le (1+\lambda)V$ with the exogenously-fixed maximum width of the "inside" quotes, $\max\{p_b - p_s\} = 2\lambda V$, due to adverse selection, increasing in gains from trade, λV. In maker-taker markets, liquidity traders prefer to place limit orders and receive the rebate whereas in fee-free neutral markets they will be indifferent between the take or the make sides.

2.1. No Fees or Rebates

We begin with an examination of one of potentially many competing venues that charges no fee and offers no rebate. To maintain GM's simplicity, informed traders exclusively place market orders and are thus takers.[4] An informed trader will only buy when he knows the true value of the security is high at $(1+\alpha)V$ and sell when he knows it is low at $(1-\alpha)V$. The degree of adverse selection in the market cannot be too extreme for our model to work, and must have a probability which is less than one-half. Hence, a specialist dealer (maker) who encounters an informed seller with probability, $0 \le \gamma < 1/2$, by placing a limit order to buy loses the amount $(1-\alpha)V - p_s$, and one who encounters an informed buyer loses $p_b - (1+\alpha)V$. The dealer (maker) who places limit orders to buy breaks even if the expected profit from buying from uninformed sellers at the (low) sell price (i.e., the 'bid'), $p_s = (1-\lambda)V$, and selling to uninformed buyers at the unconditional value, V, with probability $1-\gamma$, makes up for his loss by buying from informed sellers at the (low) sell price and having to sell at the even lower 'true' price, $(1-\alpha)V$, known only to the informed seller prior to the trade.

The maker's expected profit, π_m, from placing an uninformed limit order to buy at the sell price, $p_s = (1-\lambda)V$, is given by:

$$\pi_m = (1-\gamma)\left[V - (1-\lambda)V\right] + \gamma\left[(1-\alpha)V - (1-\lambda)V\right] \ge 0, \tag{1}$$

consisting of his expected profit of $(1-\gamma)\lambda V$ obtained with probability $(1-\gamma)$ from uninformed liquidity traders that must at least compensate for his expected loss of $\gamma(\lambda-\alpha)V$, should the information content exceed the gains from trade obtained by his uninformed counter-party, $\alpha > \lambda$, if he encounters an informed trader with probability γ.

[4] This assumption of convenience markedly simplifies the GM model without biasing the analysis of access fees in favour of our distinguishable implication. Ricco, Rindi and Seppi (2017) analyse dynamic limit order markets with informed traders not confined to market orders. Foucault (1999) models the decision to place market versus limit orders as a trade-off between non-execution and picking-off risk.

When the dealer (maker) posts a limit order to sell at the buy price (i.e., the 'ask'), $p_b = (1+\lambda)V$, the maker (dealer) break even or makes a profit, π_m, if

$$\pi_m = (1-\gamma)\left[(1+\lambda)V - V\right] + \gamma\left[(1+\lambda)V - (1+\alpha)V\right] \geq 0, \tag{2}$$

depending on the inequality ≥ 0. The dealer (maker) receives the buy price $p_b = (1+\lambda)V$ from both informed and uninformed buyers when hit with a market order as he is selling and replenishes his inventory from uninformed traders at the unconditional price V with probability $(1-\gamma)$ and at the high price $(1+\alpha)V$ from informed traders with probability γ, when the market turns against him.

Solving either equation (1) or (2) for the dealer (maker) break-even equilibrium, $\pi_m = 0$, sets the zero-profit equilibrium condition with free-entry into market making by intrinsically uninformed dealers. Specifically, the expected loss to the maker due to the informed market order, given by the product of the maximal sustainable information content, $\bar{\alpha}$, and γ, the likelihood of encountering an informed order, must precisely exhaust the gains from trade, λ:

$$\bar{\alpha}\gamma = \lambda . \tag{3}$$

Any upward perturbation above the sustainable adverse selection cost that is expected, $\alpha\gamma > \bar{\alpha}\gamma$, or any downward perturbation in the gains from trade, λ, will, at least temporarily, close the market due to an excessive spread. This makes sense, as no stock ever trades continuously at its maximal level, with the market for illiquid stocks closed for much of the time. Why? The answer in this GM framework is that the spread is too wide to sustain trade given the upper limit to the gains from trade. That is, the equilibrium is an *ex post* no regrets rational expectations equilibrium; GM prove that the ask price is what the (revised) expectation of V will be if the dealer sells and, conversely, the bid price is the expectation of V if the dealer buys such that the dealer will not regret, *ex post*, any trade that he makes.

Fixing the likelihood of meeting an informed trader at $\gamma = \gamma_n$, namely, our initial *neutral*, i.e., no fee or rebate, equilibrium, then the maximal degree of information content in the informed order-flow is capped by the gains from trade deflated by the probability of encountering an informed trader:

$$\bar{\alpha}_n = \lambda / \gamma_n . \tag{4}$$

That is, GM's competitive equilibrium requires a precise relationship between what to the uninitiated might seem two unrelated parameters, the endogenous probability of adverse selection in the LOB and the exogenous gains from trade. Again, the expected adverse selection cost per unit of value, $\gamma_n \bar{\alpha}_n$, sustainable in GM's

competitive equilibrium, is set at the reservation level specified by the rate of gain from trade and thus equal to λ.

Solving for the buy price, $p_b = (1+\lambda)V = (1+\gamma_n\bar{\alpha}_n)V$, and the sell-price, $p_s = (1-\lambda)V = (1-\gamma_n\bar{\alpha}_n)V$, to obtain the equilibrium spread $p_b - p_s = 2\gamma_n\bar{\alpha}_n V = 2\lambda V$, we see that the equilibrium spread is widening in the expected loss due to asymmetric information given by the expected adverse selection cost, $\gamma_n\bar{\alpha}_n$. Thus, the spread cannot exceed the exogenously given rate of gains from trade, λ, and in equilibrium equals it.

Upon arrival, the investor can place either a limit order at the inside quotes not guaranteed to execute, a limit order away from the inside quotes that faces a greater risk of non-execution, or a market order guaranteed to execute, so long as a posted limit order exists on the opposite side of the market. An informed trader who places a market order to sell will receive the competitively decided sale price, $p_s = (1-\lambda)V = (1-\gamma_n\bar{\alpha}_n)V$, but the stock is only worth the low price, $(1-\bar{\alpha}_n)V$, , known to informed sellers. Hence, the informed seller's profit, π_{in}, is:

$$\pi_{in} = \bar{\alpha}_n (1-\gamma_n)V, \tag{5}$$

with an identical expression for an informed purchase. Hence, informed trader profitability is determined by the product of the maximum *sustainable* degree of information content, $\bar{\alpha}_n$, and the proportion of uninformed traders in the population to serve as counterparties, $1-\gamma_n > 1/2$, due to the upper-bound on the degree of adverse selection. In the absence of a maker-taker rebate, equation (4) makes clear that a venue's maximum sustainable degree of information content is strictly limited by the exogenously given level of gains from a trade, λ.

2.2. Numerical Example

Let $V = 1$, $\bar{\alpha}_n = 1/2$, $V^H = (1+\bar{\alpha}_n)V = 3/2$, $V^L = (1-\bar{\alpha}_n)V = 1/2$, and $1-\lambda = 7/8$, with $\lambda = 1/8$, $\gamma_n = 1/4$, $p_b = (1+\lambda)V = (1+\bar{\alpha}_n\gamma_n)V = 1+1/8$, $p_s = (1-\lambda)V = (1-\bar{\alpha}_n\gamma_n)V = 7/8$, and gains from trade of λV for each uninformed investor making $2\lambda V = 1/4$, taking into account both sides of the market. Hence, the "inside" spread $p_b - p_s = 1/4$ with a half-spread of $1/8$ and informed trader profit (quasi rent), $\pi_{in} = 3/8$. The degree of expected adverse selection meets the GM equilibrium requirement as $\bar{\alpha}_n = \lambda/\gamma_n = 1/2$.

Keeping the initial informed trader probability, $\gamma_n = 1/4$, and increasing the insider's informational advantage by 50% to $\alpha = 3/4 > \bar{\alpha}_n$, then sustainability of the LOB market requires that gains from trade, λ, must rise absolutely by $1/16$ from $1/8$ to $3/16$, which generally will not be possible. The inside quotes now widen to $p_b = 1 + 3/16 = 19/16$ and $p_s = 1 - 3/16 = 13/16$ with $p_b - p_s = 3/8$. Here, the corresponding gain from a trade has now increased to $2\lambda = 2 \times 3/16 = 3/8$. Consequently, to support a rise in the information in the stock price while keeping the same proportion of informed investors, uninformed investors need to gain a higher level of benefit from trading. If so, they willingly subsidize the higher level of losses incurred by market makers when facing more informed traders.

Since the gains from trade are exogenously fixed at 1/8, it would normally be pure coincidence if the equilibrium information content were increased by this means. Essentially, it cannot happen in the GM model specifications. What we show in this paper is that competition in so-called "fragmented" markets has led to the serendipitous discovery of an ingenious alternative means of raising the information content in trades without the trading venues necessarily being aware of precisely why they are achieving better outcomes. In short, the fee rebate is precisely equivalent to a rise in the gains from trade and thus presents the opportunity for a Pareto improvement.

2.3. Revenue-Neutral Fee Scheme with Offsetting Rebate still giving rise to Washout

The make rebate is applicable only to limit orders that are not certain of immediate execution. Pseudo limit orders, i.e., disguised aggressive market orders, placed at or above the best-ask or at or below the best bid, are certain to execute and thus pay the fee applicable to take orders. To the extent that the subsidy is simply passed-through as a lower cost of the spread to offset the fee, nothing alters, i.e., the cum-prices and cum-spread are unaltered, as neither the likelihood of a market order nor the information content of the market order is affected. This is the case in Colliard and Foucault (2012) in which the tax-subsidy system always washes out, or in Foucault, Kadan, and Kandel (2013), Panayides, Rindi and Werner (2016), and Chao, Yao, and Ye (2017a) in which the fee washes out if the minimum tick size is zero. To summarize this case, in the absence of informed traders, the inside spread must notionally contract by the amount of the subsidy to non-marketable limit orders when a revenue-neutral maker-taker fee structure with a fee for make orders and rebate for take orders is introduced.

For simplicity, the cost to the exchange of matching buyer and seller is set to zero. Nevertheless, there is an exchange matching fee, given by f_t, on takers in the maker-taker market with a precisely offsetting rebate,

$-f_t$, paid to dealers (makers) representing limit order providers. This fee structure raises zero net revenue. In the inverted taker-maker market, the fee applied to makers is f_m and the rebate applied to takers is $-f_m$. In maker-taker markets, the take fee applies to all "take" trades, i.e., market orders, and marketable "make" trades, i.e., limit orders at or outside the inside quotes, such that all buyers and sellers regardless of their information status pay fees on all trades certain to execute. In inverted markets, the reverse is true.

Commencing with the initial neutral, no-rebate, regime and initially (counterfactually) assuming no alteration to the degree of information content, when the liquidity supplier (maker) places a limit order to buy at the sell price he receives the make transaction rebate on a limit order not certain to execute of $-f_t$, which is payable as the amount $+f_t$ by the take order placer regardless of identity, uninformed or informed. The zero expected-profit condition of competitive equilibrium, equation (1), now becomes:

$$\pi_m = (1-\gamma_n)\left[V + f_t - p_s^{mt}\right] + \gamma_n\left[(1-\alpha_n)V + f_t - p_s^{mt}\right] = 0, \tag{6}$$

so that the (nominal) sell price in the *maker-taker* (denoted by the *mt* superscript) venue appears to be increased by the rebate to limit orders:

$$p_s^{mt} = (1-\alpha_n\gamma_n)V + f_t, \tag{7}$$

and, if the maker places a limit order to sell at the ask, the ask-price appears to be reduced by the rebate:

$$p_b^{mt} = (1+\alpha_n\gamma_n)V - f_t. \tag{8}$$

Hence the inside quotes appear to narrow to $p_b^{mt} - p_s^{mt} = 2\left[\alpha_n\gamma_n V - f_t\right] > 0$ on a nominal basis in the maker-taker regime for any given initial information content, $\alpha_n\gamma_n$. Under these assumptions, access fee structures affect nominal (observed) prices and spreads with cum-fee prices different again. However, the cum-fee (denoted by superscript f_t) sell price, remains unaltered once the offsetting take-fee is included:

$$p_s^{f_t} = (1-\alpha_n\gamma_n)V, \tag{9}$$

and, similarly, the cum-fee buy-price, $p_b^{f_t}$, remains unaltered at the pre-rebate level once the take fee is included:

$$p_b^{f_t} = (1+\alpha_n\gamma_n)V. \tag{10}$$

What we have derived here is the standard 'complete washout' result in which nothing alters so long as, either there is no information in trades, $\alpha_n = 0$, or informed traders are unable to switch venues, as is the case with an essential facility, monopoly venue.

This reasoning gives rise to our first proposition, *Proposition 1*, corresponding to Colliard and Foucault (2012): *If the degree of informational advantage,* α_n*, is zero in the neutral regime (or alternatively, information content* α_n *is unalterable, as in a monopoly venue), then* $p_b^{mt} = (1+\alpha_n\gamma_n)V - f_t$ *and* $p_s^{mt} = (1-\alpha_n\gamma_n)V + f_t$ *from equations (7) and (8), respectively, and hence a nominal spread of* $2(\gamma_n\alpha_n - f_t)$ *is generated. However, since takers' pay a fee of* f_t *on one side of the market, the maker-taker market clears with fees and rebates netting out with the cum-fee spread remaining at* $2(\gamma_n\alpha_n)$.

This is precisely what the models with no asymmetrically informed traders by Colliard and Foucault (2012), Foucault, Kadan, and Kandel (2013), and Chao, Yao, and Ye (2017a) show since $\alpha_n = 0$ in these models. Malinova and Park (2015) is also correct as at the time of the Toronto exchange's introduction of a maker-taker fee there were no alternative venues that would enable movements by informed traders. Thus, these authors are correct given their assumption that informed traders are either absent or unable to respond to their profit incentive.

Likewise, in the inverted taker-maker market, *Proposition 2* states: *If the degree of informational advantage,* α_n*, is zero in the neutral regime, then* $p_b^{tm} = (1+\alpha_n\gamma_n)V + f_m$ *and* $p_s^{tm} = (1+\alpha_n\gamma_n)V - f_m$*, and hence a raw spread of* $2(\gamma_n\alpha_n + f_m)$ *is generated which is precisely matched by the subsidy to market orders such that the cum-fee spread is effectively* $2(\gamma_n\alpha_n)$ *once again.*

2.4. A Fee-Rebate Model with Competition between Venues

In contrast to this 'washout' literature, our theory predicts that not only inverted taker-maker markets, but also maker-taker markets, would suffer an outflow of informed traders, thin markets, and reduced price discovery as LOB access fees increase. When NASDAQ's fee pilot experiment withdrew much of the rebate to non-marketable limit orders, lowering a take fee of 30 cents per 100 shares to 5 cents and a make rebate of 29 cents to 4 cents per 100, we see a severe departure of informed traders, a thinning of the LOB, and decreased pricing efficiency. How does our model explain this?

With informed traders and maker-taker fee competition between venues, as was the case during the 2015 NASDAQ fee experiment, the maker-taker regime is different from what we have modelled so far. For example, when an individual venue such as NASDAQ with a pre-existing maker-taker fee unilaterally removes its make fee and take subsidy, existing informed traders with a high degree of informational advantage can flee to the next highest fee-rebate venue. Hence, it will no longer be the case that the information advantage of venue-specific order flow remains unaltered when informed traders have a profit incentive to shift trading

venues. We model this inter-venue rebate competition by endogenizing the informed trader's choice of his maximum degree of information advantage for a given maker-taker venue, $\bar{\alpha}_t$, (where the subscripted *t* denotes the new maker-taker venue), under the new maker taker fee regime, commencing from the initial competitive equilibrium for this venue in the absence of a fee rebate. Recall from the discussion above that the cost to the informed trader of acquiring additional information is put to one side while this trader's job is to choose the venue which maximizes his profit, consistent with GM's asymmetric information equilibrium in that venue.

An informed buyer *could* use a market order to buy at the buy-price market-clearing condition, $p_b = (1+\alpha_n\gamma)V - f_t$, discounted by the rebate, and sell at the same high price as before, $p_s = (1-\alpha_n\gamma)V + f_t$, with receipts reduced by the same fee of f_t to achieve wash-out -- i.e., the cum-spread is unaltered, as in the existing literature and in Propositions 1 and 2 above. It will not pay him to do so, however, because by relocating his executions from the neutral to the maker-taker venue, he can maximize quasi-rents by increasing the information content of his trades to the new maximum sustainable level, $\bar{\alpha}_t - \bar{\alpha}_n$. He can now execute trades that were too information rich to be sustainable at the neutral venue if he raises his informational advantage by precisely the amount of the rebate normalized by the product of the probability of an informed trade and the stock price:

$$\bar{\alpha}_t - \bar{\alpha}_n = \Delta\alpha^{mt} = f_t / \gamma_n V, \tag{11}$$

where $\bar{\alpha}_t > \bar{\alpha}_n$ is the new and higher level of information content in the maker-taker market venue. This profit maximizing increment to information content leaves the new (nominal) maker-taker buy and sell prices unchanged at the initial neutral GM pricing equilibrium but raises the cum-fee spread by twice the fee rebate, $2f_t$.

With the purchase price unaltered, but with greater informational advantage (and with still the same proportion of informed traders), the informed trader can now sell at the high price, $(1+\bar{\alpha}_t)V - f_t$, net of the make fee, f_t. This higher information content (and accompanying increased adverse selection) raises the expected profit in the absence of the rebate $\pi_{in}^n = \alpha_n(1-\gamma_n)V$, from equation (5) above, to the higher level of informed trader's profit (net of the taker fee, f_t) in the maker-taker venue:

$$\pi_{in}^{mt} = \bar{\alpha}_t(1-\gamma_n)V - f_t. \tag{12}$$

Subtracting equation (5) from equation (12) yields the dollar amount of positive quasi-rent gain:

$$\Delta\pi_{in}^{mt} = \Delta\alpha(1-\gamma_n)V - f_t = f_t(1-\gamma_n)/\gamma_n - f_t = \left[(1-2\gamma_n)/\gamma_n\right] f_t > 0 \; iff \; \gamma_n < 1/2, \tag{13}$$

due to the information content increase, $\bar{\alpha}_t - \bar{\alpha}_n > 0$, once the increment to information content is eliminated utilizing equation (11). This quasi-rent gain is measured net of the new levy, - f_t, on the informed trader's market order. Maximal informed trader profit (quasi-rent) occurs when the expected incremental cost of information content, $(\bar{\alpha}_t - \bar{\alpha}_n)\gamma_n V$, fully absorbs the fee rebate.[5] Moreover, a rise in the take rebate is more efficacious in terms of its Pareto improvement the smaller is the likelihood of an informed trade since the magnitude of the scaling term, $\left[(1-2\gamma_n)/\gamma_n\right]$, is diminishing in γ_n.[6]

Hence, we have our main result, *Proposition 3*: *The raw effective spread and quotes must remain unaltered when the rebate is introduced with the cum-fee effective spread and cum-fee quotes rising precisely by the rebated fee amount. That is, fee structure neutrality fails. Nonetheless, as is always the case when information content (adverse selection) rises, the rebate will lower the raw realized spread and raise the raw market impact by the same amount, with the raw effective spread unaltered.* Proposition 3 provides, therefore, a bright-line test; either the effective spread is unaffected when a revenue-neutral maker-taker fee rebate is introduced (or, as in NASDAQ's natural experiment, removed) or it is not.

This maker-taker fee rebate induces a Pareto efficiency improvement since the rebate precisely compensates uninformed traders placing limit orders for the greater information content of taker order flow while informed traders receive enhanced trading profits and the market benefits from better price discovery and pricing efficiency. This is because the introduction of the take rebate has enabled informed traders to optimally raise the degree of information content despite the enhanced maker cost of adverse selection. Intuitively, this is because, as far as uninformed traders are concerned, the take rebate is equivalent to a rise in gains from trade (since their uniformed buy or sell limit orders receive the subsidy). This upping of the ante by informed traders raises the cum rebate spread by precisely the amount of the rebate, leaving the nominal spread unchanged and preventing the washout modelled by Colliard and Foucault (2012), Foucault, Kadan and Kandel (2013), and Chao, Yao, and Ye (2017a).

Conversely, in an inverted *taker-maker* regime, if the take fee and make rebate are replaced by a make fee, f_m, and equivalent take rebate, $-f_m$, the information content of the order flow falls by

$$\alpha_n - \alpha_m = -\Delta\alpha^{tm} = f_m/\gamma_n V\,, \tag{14}$$

[5] If there are no competing venues such that information content is a given, then the increase in informed trader profit is zero (i.e., remains no different from that given in equation (5)).

[6] Of course, as assumed at the outset, the upper bound to the probability of an informed trade remains less than one-half.

the amount of the tax, f_m, on make trades (limit orders) as the LOB thins, with a lower bound of zero, i.e., no information content, in the LOB market. An inverted market worsens Pareto efficiency as uninformed traders receive no benefit while the profitability of informed trades falls by the amount of the fee on make orders:

$$\Delta\pi_{in}^{tm} = -\left[\left(1-2\gamma_n\right)/\gamma_n\right] f_m < 0 . \tag{15}$$

What our model establishes is that in competitive (i.e., fragmented) markets there can exist simultaneously a potential continuum of apparently similar venues ranging from inverted markets to maker-taker markets, each with its own unique fee (rebate) structure. Each venue differs according to the degree of information, $\bar{\alpha}_t$, in the market orders of informed traders, with taker-maker (inverted) markets having the lowest information content and the maker-taker venue with the highest maker rebate, $\bar{\alpha}_t > \bar{\alpha}_n > \bar{\alpha}_{tm}$, benefitting from the highest information-content trades. The highest rebate venue attracts the highest volume as the maker rebate attracts more market makers who in turn provide liquidity to the most informed traders who can be found only in that venue, making its pricing more efficient.

2.5. Maker-Taker Numerical Example

Commencing with the same numerical example as in Section II.B above in the absence of a taker rebate, now introduce a rebate given by $f_t = 1/16$. Keeping the initial informed trader probability, $\gamma_n = 1/4$, the maker rebate increases the insider's informational advantage by 50% (0.25) from $\bar{\alpha}_n = 1/2$ to $\bar{\alpha}_t = 3/4$ as before, but this time without the need to raise gains from trade, λ, which remain at $1/8$. The 50% rise in information content, $\bar{\alpha}_n$ to $\bar{\alpha}_t$, raises the pre-rebate buy (bid) price by $1/16$, from $1/8$ to $3/16$, yielding a total (gross) price of $p_b + f_t = 1 + 3/16 = 19/16$ and hence leaves the observed (nominal) market-clearing bid price unaltered at the initial zero-fee level of $p_b = 1 + 1/8 = 9/8$ once the make rebate of $1/16$ is subtracted. With the informed buyer's initial information content level maintained, he could replenish his take sale at price $\left(1-\alpha_n\right)V = 1/2$ but at the new higher information content level the purchase price falls by half to only $1/4$. After paying the new take fee of $f_t = 1/16$, informed trader profitability has improved by $\pi_{in}^{mt} - \pi_{in}^{n} = 1/8$, as is shown by evaluating equation (13) above.

Precisely the same profit (quasi-rent) gain is achieved if an informed trader buys at the same ask price as prior to the maker-taker fee structure raising the degree of information content and then sells at the resulting higher price. This sale price enhancement arises from the informational advantage net of the make fee. The opposite process occurs in the inverted taker-maker market with the equilibrium level of information content

falling relative to the neutral benchmark. Hence, contrary to what one might think, GM's model is well suited to welfare analysis when one considers the benefit to the informed trader from the make rebate and the passive role played by uninformed traders (Glosten and Putniņš, 2015). Our extension of GM's model shows that maker-taker fee arrangements are Pareto-superior to the outcome without fee rebate, because during the NASDAQ pilot, informed traders suffered trading profit reductions while uninformed traders gained nothing.

2.6. Minimum Tick Size Constraint

So far, a continuously variable price has been assumed, but at the time of the NASDAQ experiment the SEC imposed a minimum one-cent (penny) tick size for stocks priced at one dollar or more. Hence, it is important to incorporate this constraint into our model as neglecting it could bias our testable implications.

Proposition 4: In the absence of varying informational advantage, in flexible fee structures rather than capped, both maker-taker and taker-maker inverted market fee structures can be utilized to remove minimum tick size constraints (i.e., preserving washout).

Proof: Denote the minimum-tick size constraint by θ and set the maker-taker fee, $f_t = (1/2)\theta$, and, likewise, the taker-maker fee, $f_m = (1/2)\theta$. Thus, from *Proposition 1*, the raw (observed) maker-taker spread meets the minimum tick size constraint of $-2f_t = -\theta$. Likewise, from *Proposition 2*, the spread in the inverted market becomes $2f_m = \theta$, which is also equal to the required minimum-tick size of θ.

Discussion: It should be clear from this proposition that the finding in Foucault, Kadan and Kandel (2013) and Chao, Yao, and Ye (2017a), that in the absence of informed trading, a minimum tick prevents tax neutrality, can be true only if the regulator sets an upper limit on the make rebate that is small relative to the minimum tick.[7] Moreover, there is no reason to think that broker agency rules prevent fee neutrality in the absence of a minimum tick since competition forces the brokers described by Battalio, Corwin, and Jennings (2016) to have regard for access fees when setting brokerage rates. Hence, one is left with our competing explanation. The endogenous variation in the informational content of the order flow as fee structures alter is the most plausible reason for the failure of fee neutrality.

[7] Since fee structures are not fully flexible, with the SEC imposed limit, $f_t, f_m \leq 0.3$ of one cent per share under current rules, fee arrangements can neutralize a minimum-tick size of 2*0.3 = 0.6 of 1 cent, but not neutralize the standard minimum tick size of a full cent or the 5-cent minimum tick size now in force for 1,200 small stocks. FINRA/SEC's current (2016-2018) minimum tick size experiment has been analyzed by Lin, Swan, and Mollica (2017). Of course, this finding puts to one side the role of asymmetric information and informed trades in generating positive cum-fee spreads. In none of our empirical tests of the fee experiment do we find that the minimum tick size of one-cent for stocks priced at a dollar or more played any role.

3. Comparison to Prior Literature

The reason the existing models of the maker-taker fee such as Colliard and Foucault (2012), Foucault, Kadan, and Kandel (2013) and Panayides, Rindi, and Werner (2016) reach a conclusion that differs from ours is that they do not consider informed traders. Hence, they obtain the limiting equilibrium in our model in which informationless trading leads to a precise cancelling out of the cum-fee and matching rebate in equilibrium.

That is, the current theoretical literature implicitly assumes that maker-taker and inverted fee structures inherently wash-out, while it has been known for many decades in the economic theory literature that the introduction of adverse selection and asymmetric information leads to a breakdown of such conventional wisdom and a requirement for a third party, other than two rational individuals wanting to trade, to provide necessary tax-subsidy arrangements. Here in the present paper, this third party is the venue (exchange) which imposes fees and provides rebates to different sides of the market. Coase (1960) in his seminal contribution claimed that bilateral voluntary negotiation could achieve efficient outcomes even in the absence of competitive markets. Analyzing asymmetric information about nothing more than counterparty preferences, Vickrey (1961) first showed the impossibility of achieving allocations which are always *ex post* Pareto efficient without outside subsidies. Farrell (1987) reviews some of the literature on why asymmetric information leads to a breakdown of the Coase theorem.

Rochet and Tirole (2006) analyze two-sided markets and appear to show that, even despite the failure of the Coase theorem due to asymmetric information, the price structure is still neutral such that fees and rebates wash-out. Armstrong (2006) points out the knife-edge fragility of such findings to variations in the underlying assumptions. Specifically, Rochet and Tirole (2006) rely on there being a unique preexisting equilibrium with an isomorphic solution when access charges are perturbed. So, theirs is a contribution concerning stability, not existence or uniqueness. Myerson and Satterthwaite (1983) show that for even the simplest trade between two asymmetrically informed individuals, it is impossible to construct Pareto-efficient mechanisms that are both incentive compatible and individually rational without invoking a third party such as a broker or venue. It is therefore unsurprising that there exists no robust existence proof of price structure/fee neutrality in the presence of asymmetric information.

Most relevant to our research, Foucault, Kadan, and Kandel (2013) examine maker and taker fees *in the absence of informed traders.* They argue that the breakdown of the total fee between makers and takers only becomes economically meaningful when the minimum tick size restricts adjustments to bid and ask prices, and they simulate a 1 to 12 cent tick size increase to establish this result. Chao, Yao, and Ye (2017b) demonstrate empirically using reverse split events for leveraged ETFs that even a modest minimum-tick size of 1 cent for

stocks priced at $2 or more can help explain market fragmentation. Our central point, however, is not about these magnitudes but rather that, in the presence of asymmetric information, we have shown a binding minimum tick size is unnecessary for the fee non-neutrality result because informed traders will seek to capture all of the available make rebate on offer.

Battalio, Corwin, and Jennings (2016) analyze the impact of differential exchange access fee schedules on broker routing decisions to find evidence that four of an examined ten national retail brokers sell orders to capture the maximum make rebates. As a result, they argue high rebate venues experience lower fill rates due to the length of the queue. Consequently, on this measure of execution quality, some clients of retail brokers who do not receive the broker rebate explicitly may suffer from a conflict of interest.

Brolley and Malinova (2012) argue that the effect of changes in the breakdown of the total fee into a make rebate and a take fee is not neutral if some traders (e.g., retail traders) only pay them on average, for example, through a flat commission to their brokers. In their model, only a fraction of traders receives make rebates for each executed limit order. As the make rebate increases, these traders improve their quotes, and the raw bid-ask spread thus declines. *Ceteris paribus*, traders who pay the flat fee base their order choices on the raw bid-ask spread rather than the cum fee bid-ask spread, thereby submitting relatively more market orders as the raw bid-ask spread declines. These authors then predict that trader behavior to improve quotes causes market orders to become less informative, the opposite of our prediction. Brolley and Malinova's result is driven by the monotonic behavior of two types of traders in their model whereby, like Kaniel and Liu (2006) and Rosu (2016), traders with a sufficiently large informational advantage use market orders and those with weaker information use limit orders. Instead, we wish to emphasize that HFT traders who rely on speed and more effective monitoring of the informed order flow dynamics place both limit orders and market orders depending on the circumstances.

Notably in our framework HFT, though not explicitly modeled, can freely and endogenously switch sides between maker and taker markets in response to imbalance in monitoring effectiveness whenever fee structures alter. We track the allocation of HFT across maker and taker markets during the NASDAQ pilot to show that HFTs do shift from the make to the take market when informed traders migrated away from the NASDAQ market. It would thus appear that HFT is best suited to facing the market-making challenges of LOB markets when more sophisticated informed traders are placing market orders. During the pilot, this challenge disappeared and, as a consequence, HFT switched from one side of the market to the other. Our findings concerning endogenous information content in the order flow therefore cast new light on the motivations for HFT–namely, that this distinct trader-type, neither informed nor uninformed, occupies instead a substantial and flexible niche regardless of the tax-subsidy scheme.

4. The NASDAQ Fee Pilot

NASDAQ has adopted a maker-taker fee model that charges a take fee for removing liquidity by submitting marketable orders, and provides a make rebate for adding liquidity by submitting non-marketable orders (i.e., limit orders that cannot be executed immediately). On February 2, 2015, NASDAQ implemented a maker-taker fee pilot for 14 traded stocks on NASDAQ where the take fee was lowered to 5 cents per 100 shares (CPS) from 30 CPS to remove displayed liquidity; the make rebate for adding displayed liquidity was lowered to 4 CPS from an indicative 29 CPS[8]. The indicative rebate for the PilotOff period is summarized in Table 1. The pilot ended on May 31, 2015, when the fee reverted to its pre-pilot level.

<Insert Table 1 here>

Seven of these stocks were listed on the NYSE and seven on NASDAQ. The participating stocks were chosen, *albeit* non-randomly, by NASDAQ to improve the quality of the experiment from its perspective. To do so, stocks had to be very liquid with a high volume traded, especially in off-exchange and dark pools, as NASDAQ was primarily concerned about whether fees and rebates discouraged its lit market. For our test purposes, the high liquidity of the chosen stocks turns out to be beneficial in terms of observing significant changes to the trading pattern over the course of the experiment. It is not inconceivable, but seems unlikely to us, that NASDAQ's process induced some sort of bias to our procedures that affects the results. For example, since we are largely interested in testing the quotes, and off-exchange venues do not provide quotes, we chose not to match our control group in the DiD methodology on the exposure to off-market trading.

Table 2 identifies the 11 lit exchanges, and their indicative fee structures during our 2015 sample period. Eight are maker-taker markets, and three are taker-maker markets. These eleven venues in aggregate account for approximately 65% of the dollar volume in U.S. equities. BATS Exchange (BATS), BATS Y Exchange (BATS Y), Chicago Stock Exchange (CHX), EDGA Exchange (EDGA), EDGX Exchange (EDGX), NASDAQ BX (BX), NASDAQ PHLX (PSX), NASDAQ Stock Market (NASDAQ), New York Stock Exchange (NYSE), NYSE MKT (AMEX), and NYSE Arca (ARCA). Among these 11 lit exchanges, NASDAQ, BX, and PSX are within the NASDAQ group (and account for 18.2% market share); NYSE, ARCA, and AMEX are within the Intercontinental Exchange group (24.6%); and BATS, BATS Y, EDGA, and EDGX are within BATS Global Markets (21.6%) and Chicago Stock Exchange accounted for 0.6% of total market

[8] The maker rebate scheme is much more complicated (see http://nasdaqtrader.com/Trader.aspx?id=PriceListTrading2). Further, see ITG Takeaways from the NASDAQ Pilot Program report, available at http://www.itg.com/marketing/ITG_Pearson_WP_20150602.pdf.

share.[9] NASDAQ, NYSE and ARCA which have the largest exchange-level market shares follow the price, display type, and time execution priority model.

<Insert Table 2 here>

Off-exchange trades for NMS stocks, which account for approximately 35% of total volume, must be reported to either the NASDAQ or NYSE trade reporting facility (TRF) set up by FINRA for their members for which the Participant ID (Pid) is D in centralized SIP data. In the U.S., equities trade on execution venues that can be classified into three main categories: exchanges, and three types of alternative trading systems (ATSs) – namely, dark pools, non-dark off-exchange venues (which consists of voice-brokered trades), and broker-dealer internalization. The primary difference between an ATS (typically operated by broker-dealers) and an exchange is that the former includes less regulatory scrutiny, fewer reporting requirements, and restricted access.

5. Data, Sample Selection, and Methodology

5.1. Data sources

Our analysis is based on trader-level data and U.S. SIP data. Our HFT data are identified by NASDAQ based on the method described in Brogaard, Hendershott, and Riordan (2014). We analyze the effect of NASDAQ's fee pilot for an eight-month window (December 1, 2014 to July 31, 2015), two months before to two months after the introduction of the maker-taker fee pilot.

Our data include all information on order submission and trades, including price, volume, and a unique identifier for the trader that submitted the order, which allow us to construct the HFT data. We restrict our attention to transactions that occur in the LOB and trades during regular trading hours. For each LOB transaction, the data contain identifiers for buyer- or seller-initiated trade, adding or removing liquidity, and types of liquidity (such as displayed, non-displayed midpoint, and non-displayed non-midpoint). Our ATS data are provided via www.FINRA.org/ATS, copyrighted by FINRA 2015. ATS data is reported weekly. Our 38 dark pools list is taken from the SEC report on the "Regulation of NMS Stock Alternative Trading Systems."

5.2. Sample selection and Methodology

NASDAQ introduced a maker-taker fee reduction for 14 stocks that they split equally between their own listings and those of the NYSE (seven listed on NASDAQ—AAL, MU, FEYE, GPRO, GPRN, SIRI, and ZNGA—and seven listed on the NYSE—BAC, GE, KMI, RAD, RIG, S, and TWTR). We use the remaining

[9] NASDAQ Trader website in December 2015: http://nasdaqtrader.com/trader.aspx?id=FullVolumeSummary.

companies on each corresponding listing exchange to find a one-to-one control group without replacement to ensure that our results are not driven by market-wide, exchange-wide, or industry-wide fluctuations. Moreover, we exclude securities that had stock splits, switched listing exchange, or had days with a stock price below $1. In our sample, the minimum trade count per stock per day is 450.

Our control sample matches listing exchange, closing price, market capitalization, and average daily trading volume (ADV) based on one month prior to our sample period data. Davies and Kim (2009) argue that one-to-one matching without replacement based on closing price and market capitalization is the most appropriate method to test for differences in trade execution costs. O'Hara and Ye (2011) followed their approach and matched on closing price, market capitalization and listing exchange. We add ADV as a matching criterion since this study focuses not only on trade execution costs but also on trader behavior.

In addition, we randomize the matching order by sorting the stocks in the treatment group alphabetically by ticker symbol. The match for each treatment group security *i* is then defined to be the control group security *j* that minimizes the following matching error:

$$matcherror_{i,j} = \left|\frac{CP_i - CP_j}{CP_i + CP_j}\right| + \left|\frac{MC_i - MC_j}{MC_i + MC_j}\right| + \left|\frac{ADV_i - ADV_j}{ADV_i + ADV_j}\right|, \tag{16}$$

where CP, MC, and ADV denote the security's closing price, market capitalization as of the end of November 2014, and average November 2014 ADV on its corresponding listing exchange (i.e., NASDAQ or NYSE), respectively. Our panel regression analysis employs a DiD approach to account for market-wide fluctuations. Estimation is based on the following DiD specification:

$$Y_{i,t} = \alpha_0 + \alpha_1 Treat_i + \alpha_2 PilotOn_t + \beta_1 Treat_i \times PilotOn_t + \gamma VIX_t + \varphi X_i + \varepsilon_{i,t}, \tag{17}$$

where $Y_{i,t}$ is the dependent variable; α_0 is the intercept; $Treat_i$ is the dummy variable if security *i* is a pilot stock; $PilotOn_t$ is the dummy variable that is one if date t is during the pilot period and zero otherwise; VIX_t is the closing value of CBOE's volatility index for day *t*; and X_i is the vector of security-level control variables including the log of the average closing price during the sample period, the log of the average market capitalization during the sample period, and average volatility, measured by daily high price minus daily low price over closing price, during the sample period. Several stock-level control variables (log price, log market cap, and price volatility) are specified to control for idiosyncratic execution strategies. In addition, we reestimated the reported specification with stock-level fixed effects but the qualitative results were the same and are available upon request from the authors.

Table 3 reports the summary statistics across U.S. equity trading venues for our sample of 28 stocks with the sample period divided into two parts: (i) the pilot period between February 2, 2015 and May 31, 2015 and (ii) the two months before and after the pilot from December 1, 2014 to February 1, 2015 and June 1, 2015 to July 31, 2015.

<Insert Table 3 here>

The NASDAQ market share dropped by 1.45% on average during the pilot period, while the average price and market capitalization remained relatively stable. The NASDAQ depth at the NBBO and depth share declined, while the fill ratio and speed of fill improved due to the reduced queue of limit orders following the removal of the rebate. None of these changes should have occurred if fees and rebates wash out. The raw effective spread increased, while the realized spread decreased, and the price impact decreased. We found that HFT changed trading behavior from adding liquidity (dropped by 10.04%) to taking liquidity (increased by 9.94%) after the reduction of the make rebate and take fee. The decline in HFT adding liquidity mainly came from the displayed liquidity type. Non-HFT traders moved in the opposite direction.

6. Empirical Results

6.1. Market quality and the information content of trades

6.1.1. How does the NASDAQ percentage of time at the NBBO, market depth, NBBO quoted spread, fill rate and speed change when the maker rebate is removed?

Our initial inquiry concerns five market quality measures affecting the NBBO at the national market level. Recall our model predicts there should be no change in either the quoted or effective spread since the predicted decrease in information content should fully offset the rebate removal. With the flight of informed traders to the remaining high-rebate venues, limit order providers would also desert NASDAQ to chase these more informative orders, leaving their LOB much thinner and lower-rated in the NBBO. By contrast, the extant theoretical and empirical literature predicts that the quoted and effective spread will rise by the full amount of the rebate reduction to achieve a wash-out, with no alteration to the depth or the fill rate in the LOB as the rise in the spread should match the fall in the fee on market (take) orders.

Focusing on our estimate of the treatment effect when the pilot make-rebate was reduced, Table 4, row 4 shows that the NASDAQ percentage time and depth at the NBBO declined. Our model argues that this decline was due to the flight of both limit and (relatively informed) market orders to the remaining high-rebate venues. The NBBO quoted spread increased (coefficient of 0.285*** for 100 round-trip trades), but by far less than the drop in the rebate of 50 cents (0.500) for 100 round-trip trades that would be required for wash-out. Indeed,

our model predicts precisely such a mitigated rise in the equilibrium quoted spread attributable to the reduced information content of take order-flow.

Furthermore, in the last two columns of Table 4, we find that the fill rate and speed of fill increased with order flow in the LOB now clustered at the best bid and ask, matching the lower information content of orders. That is, after the make rebate was reduced, the queue of NASDAQ orders in the LOB declined, contrary to the extant literature predicting a wash-out with no effect on execution strategy.

<Insert Table 4 here>

6.1.2. How do the effective spread, realized spread, and price impact change?

The effective spread (*espread*) is twice the signed difference between the transaction price (either net, "cum-fee" or raw without the fee) and the midpoint of the bid and offer quotes at the time of the transaction. The realized spread (*rspread*) is twice the signed difference between that midpoint and a later one to measure the profit to market makers, given enough time for them to adjust their inventory. Many classic microstructure studies set this time interval, τ, as long as five minutes to assure that transitory effects dissipated and liquidity providers had sufficient time to close their positions. In today's ultra-high frequency execution environment, with upgraded trading systems accurate to mere nanoseconds, we follow Conrad, Wahal, and Xiang (2015) in calculating the realized spread at one second and five second intervals after the transaction. Specifically,

$$cum\ fee_espread_{i,t} = 2q_{i,t}\left(p_{i,t} - m_{i,t}\right) + 2f_{i,t}\ \text{, and} \tag{18}$$

$$cum\ rebate_rspread_{i,t} = 2q_{i,t}\left(m_{i,t+\tau} - m_{i,t}\right) + 2r_{i,t}\ , \tag{19}$$

where $f_{i,t}$ is the take fee for security *i* at time *t*, $r_{i,t}$ is the make rebate for security *i* at time *t*, $a_{i,t}$ is the ask price of the quote, $b_{i,t}$ is the bid price of the quote, $p_{i,t}$ is the transaction price for security *i* at time *t*, $m_{i,t}$ is the midpoint of the prevailing ($a_{i,t}$, $b_{i,t}$) quotes at the time of the trade, $m_{i,t+\tau}$ is the midpoint of the quotes at various intervals after the trade, and $q_{i,t}$ is an indicator variable that equals one if the trade is buyer-initiated and minus one if the trade is seller-initiated.[10]

Finally, price impact is defined as the signed change between the midpoint of the quotes prevailing one or five seconds after the trade and the midpoint of the quotes at the time of the trade:

$$price_impact_{i,t} = 2q_{i,t}\left(m_{i,t+\tau} - m_{i,t}\right). \tag{19}$$

The price impact is intended to capture the permanent information that is revealed by the trade such that a decline in the price impact indicates a decline in adverse selection costs.

[10] Our NASDAQ SIP data reporting the prevailing quotes also contains a marker that signs each trade as buyer- or seller-initiated.

When the NASDAQ fee pilot removed the make rebate, the effective spread should rise by the fall in the rebate but, as shown in our theoretical model (*Proposition 3*), this should be precisely offset by a fall in the market impact as the order flow becomes less informative. Hence, there should be no significant change in the raw effective spread. However, the raw realized spread should rise due to the removal of the make rebate and a reinforcing decline by the same amount in market impact due to the lowered information content of the taker order flow. On a cum-fee basis the effective spread should fall to the extent of the rebate reduction with both the realized spread and market impact declining by a significantly smaller amount.

<Insert Table 5a here>

Table 5a, our key table, shows that, as predicted by our model (*Proposition 3*), the raw effective spread remained the same (see row 4, $treatment \times PilotOn$). According to the extant literature, it should have risen by the full 50 cent rebate reduction per 100 round-trip trades. Table 5b shows the cum-fee effective spread decreased (coefficient of -0.438***), which corresponds to the rebate reduction, as predicted by our model. Note this result presents a stark contrast with the findings of Malinova and Park (2015) and the extant theoretical literature which says there should be no change in the cum-fee effective spread due to wash-out. The cum-fee effective spreads are adjusting to the removal of the take fee, while the cum-rebate realized spread adjusts upwards to the removal of the make rebate, consistent with Proposition 3.

Moreover, we find that the cum-fee price impact declined (-0.232***) for the one-second price impact and (-0.304***) for the five-second price impact per 100 round-trips after the maker-taker fee reduction. These declines in price impact are precisely as predicted by our model. They indicate the sizeable extent to which the NASDAQ taker order flow became less informative as both informed trade takers and their counterparty makers, departed to other competing venues.

<Insert Table 5b here>

6.1.3. How does market efficiency change?

To test the informational efficiency of prices, we use variance ratio tests of the random walk hypothesis (Lo and MacKinlay, 1988) and autocorrelation, which are identified by Chordia, Roll, and Subrahmanyam (2008) as the two information-associated measures in multiple time intervals:

$$Variance\ Ratio = \mathrm{var}\left(r_{i,t}\right) \times x \Big/ \mathrm{var}\left(r_{i,x\times t}\right), \tag{21}$$

$$Autocorrelation = Corr\left(r_{i,t}, r_{i,t-1}\right), \tag{22}$$

where $\mathrm{var}\left(r_{i,t}\right)$ refers to the variance of the return during the tth time interval for i, $\mathrm{var}\left(r_{i,x\times t}\right)$ refers to the variance of the return during the $x \times t$ time interval for i and $Corr\left(r_{i,t}, r_{i,t-1}\right)$ refers to the autocorrelation of the midpoint return during the tth time period for i. Specifically, when a stock's price follows a random walk, the

variance of its returns is a linear function of the measurement frequency, i.e., $\mathrm{var}\left(r_{i,x\times t}\right)$ is x times larger than $\mathrm{var}\left(r_{i,t}\right)$.

When the maker-taker fee is reduced, we find the evidence reported above that there is less information in the order flow, exactly as predicted by our model. Thus, we expect the informational efficiency of prices to decrease. The first two columns of Table 6, Panel A show that in response to the maker-taker fee reduction, the variance ratios of NASDAQ prices at 10, 60 and 100 seconds did increase. DiD modeling to control for possible omitted variables confirms evidence of our hypothesized reduction in information content at 99% at all three time-horizons. In contrast, In Table 6, Panel B, first-order return autocorrelations declined slightly when we would have expected them to increase.[11] This pattern suggests that the variance ratios rise because of increased mispricing, with less private information being reflected in prices following the maker-taker fee reduction. The autocorrelation of the two highest rebate-paying exchanges remaining after NASDAQ's unilateral reduction – namely, Arca and BATS-- also declined slightly but much less than NASDAQ. This is what we would expect as more informed order flow migrated to the higher rebate-paying venues.

<Insert Table 6 here>

6.2. Trading volume and market share

6.2.1. Does a reduced exchange access fee attract trading volume from off-exchange venues?

The NASDAQ access fee pilot aimed to test whether a lower exchange access fee can raise the market share of off-exchange venues. In this regard, the SEC (2014) filing states the following:

> "Off-exchange orders do not generate quotes on public markets, do not interact with orders on public markets and consequently do not promote or contribute to price discovery to the same extent as do orders posted and executed on exchanges. Economic studies from markets spanning the world conclude that as more orders migrate away from exchanges, the price discovery process weakens, trading spreads widen, and overall investor trading costs increase… NASDAQ believes that proposed changes may improve price discovery in the select securities."

Ours is not the first paper to address these venue competition empirical issues in a differential fee framework. An early study by Barclay, Kandel, and Marx (1998) finds that higher implicit transaction costs in spread components reduce trading volume. Barclay, Hendershot, and McCormick (2003) discovered that ECNs

[11] This inconsistency has been noted previously. Chordia, Roll and Subrahmanyam (2008) explain: "the higher variance ratios can be attributed either to an increase in mispricing or to an increase in privately informed trading that results in the incorporation of more information into prices……Regardless of the cause, if such mispricing were driving the increase in variance ratios across time, autocorrelations should have increased along with variance ratios as the tick size decrease; but there is no evidence of this increase. In fact, there is reliable evidence that the opposite transpired for smaller firms." (p. 266).

compete with lit markets by utilizing sub-penny tick sizes denied lit markets and thereby attract informed order flow. Dosanjh (2013) examines the introduction of make fee rebates to the Australian Stock Exchange (ASX) Exchange Traded Funds (ETFs) to show that rebates improve depth and liquidity. Clapham, Gomber, Lausen, and Panz (2017) examine the 2016 Xetra Liquidity Provider Program at Deutsche Bourse, which provides maker rebates, and find increased venue liquidity share.

Panayides, Rindi, and Werner (2016) study the effects of BATS Europe maker-taker fee reduction on market quality and market share in a fragmented market. In their model incorporating a binding minimum tick constraint, an increase in the take fee and make rebate reduces the spread and increases the depth but inter-venue competition leads to a migration of order flow away to other venues, worsening both market quality and venue share. By contrast, in our model, the increased make rebate does not reduce the spread or increase depth because both informed order flow and makers prepared to counterparty those orders are attracted from other venues. Hence, our prediction is that both market share and pricing efficiency improve.

<Insert Table 7 about here>

Table 7 shows that after the NASDAQ fee reduction, the NASDAQ market share declined on average (see also Hatheway, 2015a, 2015b), while the consolidated trading volume remained stable. The NASDAQ share loss was captured by the remaining two highest rebate-paying stock exchanges (ARCA and BATS Z).

As far as competition with off-exchange venues, Kwan, Masulis, and McInish (2015) find that the U.S. minimum tick constrains some stock spreads, causing large limit order queues, which dark pools allow traders to bypass with minimal price improvement. Moreover, Foley and Putniņš (2014) find that when Canada and Australia implemented minimum price improvement rules, the level of dark trading decreased. We expect no change in dark pools trading volume in the U.S. after the maker-taker fee reduction by NASDAQ since their ability to circumvent the time priority of displayed limit orders is not affected, and the U.S. dark pools are not required to provide price improvement.

Table 8, columns 3 and 4 show that when NASDAQ reduced the maker rebate and taker fee, there was no significant market share drop from the off-exchange trading venues of dark pools and other non-dark pools. Instead, we observe a redistribution of market share from NASDAQ in column 1 to other lit exchanges in column 2 (presumably, as we have shown above, to those with the highest liquidity provision rebate).

To summarize on venue competition with access fees, NASDAQ alone reduced the access fee unilaterally during the pilot in an otherwise competitive trading environment. Dark pools rely on sub-tick price improvement relative to midpoint prices of the lit exchanges to attract uninformed order flow and are protected by the inability of lit exchanges to reduce the minimum tick size because of the SEC's regulations. Instead, of volume migrating to the off-exchange venues, we observe a redistribution effect among lit exchanges. Even

with a uniform fee reduction across the entire lit market, a movement of trading volume toward the lit market would remain unlikely as dark pools could still undercut the 1-cent tick rule.

6.2.2. How does the lit exchange volume and market share change in response to the maker-taker fee reduction?

Our theoretical model predicts a decline in NASDAQ's market share during the pilot as the elimination of the rebate to limit orders destroys the Pareto-efficiency of the market by removing at least some of the profit earned by informed traders and does not improve the position of liquidity, (i.e., uninformed) traders. Since NASDAQ eliminated its rebate unilaterally, the harmed informed traders, together with the limit order providers who lost their counterparties, flee to the maker-taker venue with the next highest rebate relative to NASDAQ prior to the rebate. Consequently, we expect NASDAQ's market share to fall and its LOB to thin.

<Insert Table 9 here>

The DiD regression model in Table 9, row 4, columns 1, 2 and 3 shows that the NASDAQ market share did decreases in response to the maker-taker fee reduction, as our theory predicts. And this occurred despite no significant effect of the fee rebate reduction on consolidated volume. To verify whether this reduced market share is caused by a reduction in liquidity supply, recall in Table 4 that we compared the NASDAQ depth at the NBBO change with the NASDAQ trading volume change. We found that the NASDAQ depth at the NBBO (coefficient of -0.337*** in Table 4, column 2, row 4) dropped about three times more than the NASDAQ trading volume drop (coefficient of -0.131*** in Table 9, column 2, row 4). This finding indicates that the reduced NASDAQ market share is primarily associated with the drop in NASDAQ depth at the NBBO. Our framework of endogenous information content behavior in response to the fee rebate reduction provides a robust explanation; many now redundant limit order providers withdrew from NASDAQ during the fee pilot because of the departure of their informed trader counterparties to higher-rebate-paying venues.

Cardella, Hao, and Kalcheva (2015) find the opposite—namely, that reductions in relative take fees in U.S. equity markets are associated with increased market share, inconsistent with our findings and our theory. However, Malinova and Park (2015) argue that the change in the maker-taker fees in Cardella, Hao, and Kalcheva (2015) are accompanied by changes in the total access fee. Thus, the Cardella, Hao, and Kalcheva (2015) result is suspect and not congruent with the NASDAQ pilot fee experiment which held the total access fee relatively constant and instead varied the fee components.

6.2.3. How do the NASDAQ routing dynamics change?

Reg NMS Rule 611[12], also known as the "Order Protection Rule" or "Trade-through" rule, restricts trading, either as agent or principal, on one venue at prices inferior to the displayed quotations on another venue during regular trading hours (9:30 am to 4:00 pm ET). Thus, if one exchange does not have the NBBO when it receives incoming orders and if the order is eligible for immediate electronic execution, the focal venue is obligated to route the incoming order to another trading venue displaying the NBBO. After the NASDAQ rebate was reduced, the incentive to submit non-marketable orders on NASDAQ decreased, but our model clarifies this happened because of the flight of informed orders to competing venues. Without the possibility of being hit by a market order, there is no longer any point in adding depth to the NASDAQ market. Thus, we predict the NASDAQ percentage of time at the NBBO would decline, and outbound routing would increase.

Table 9, columns 4 and 5, row 4 shows that the NASDAQ incoming orders routed to NASDAQ declined and that the proportion routed away to other exchanges increased, consistent with our model's prediction. Moreover, recall from Table 8, columns 3 and 4, row 4 that the percentage of volume routed to off-exchange trading venues remained stable.

6.3. HFT vs. non-HFT trading behavior

6.3.1. HFT vs. non-HFT adding/taking liquidity-volume

HFT is distinguished by more efficient monitoring of the informed order flow dynamics. Any trader who sees a signal containing information before a slower trader will take liquidity before that information advantage is exploited by other traders. Nevertheless, as holding inventory is expensive, Rosu (2015) argues a risk-averse trader reverses part of his order to make money supplying liquidity to slower traders who receive a delayed signal. The fast trader could even post some of these reversed trades as limit orders. Hence, HFT traders are likely to have information and thus take liquidity but can also make liquidity. As both the make rebate and the take fee on liquidity makers fell during the NASDAQ fee pilot, HFT traders would likely shift from predominanntly making to taking liquidity.

<Insert Table 10 here>

Table 10, columns 1 and 2, row 4 shows that in response to the maker-taker fee reduction, HFT traders switched trading behavior on NASDAQ from posting liquidity (coefficient of -10.043***) to taking liquidity

[12] "Rule 611 does not affirmatively require the routing of orders to trading venues displaying the best prices. Rather, it only restricts trades at prices worse than a protected quotation. Any trading venue is free to execute trades at prices equal to or better than a protected quotation, regardless of whether such a trading center is currently quoting at that price or is a dark venue that never displays quotations." (SEC, 2015b).

(coefficient of 9.936***), while the overall NASDAQ HFT volume remained stable (coefficient of -0.054 in column 3, row 4 with no statistical significance).

6.3.2. HFT vs. non-HFT adding and taking liquidity: spreads and price impact

Carrion (2013) finds that spreads are wider (tighter) when HFT traders provide (take) liquidity, which suggests HFTs provide liquidity when it is scarce and consume liquidity when it is plentiful. Because of their effective real-time forecasting of the state of the market, HFT traders face lower adverse selection costs than non-HFT traders when supplying liquidity in larger trades, suggesting they have an informational advantage when demanding liquidity and avoid being the supplier of liquidity to informed traders. SEC (2010) has thus questioned whether "rebates generally benefit long-term investors by promoting narrower spreads and more immediately accessible liquidity?"

<Insert Table 11 here>

Focusing on the cum fee/rebate columns in Table 11, we analyze the net effect of the participation by the two trader types. After the NASDAQ fee/rebate reduction, the effective spread for HFT in row 1 is lower compared with non-HFT when placing market orders, with the spread sizably reduced for both types because of the removal of the 0.50 fee on market orders. This is because HFT market orders are less informed than non-HFT market orders as the price impact in rows 4 and 5 over both the one-second and five-second intervals falls by a larger amount than that for non-HFT, such that the fall in the realized spread in rows 2 and 3 is less for HFT market orders.

HFT is therefore more inclined to add to liquidity relative to non-HFT when the cum-fee effective spread is narrower because of its relatively less informed order flow, as shown by both the one-second and the five-second delay price impacts being relatively small. Therefore, the realized spread is higher when HFT traders provide liquidity relative to non-HFT traders. These findings imply that HFT is more likely to take liquidity when it is relatively plentiful (i.e., spreads are narrow), consistent with Carrion (2013)) and provide liquidity when it is relatively cheap (i.e., the effective spread is relatively narrow), as HFT then uses its informational advantage to supply liquidity to less informed counterparts.

Subsidized limit orders and taxed market orders benefit relatively informed short-term traders, as seen when NASDAQ's unilateral withdrawal of the subsidy and tax during the pilot led to the movement of such traders to exchange with higher subsidy/tax regimes. Insofar as long-term investors are also informed, high subsidy/tax regimes might also benefit such investors. However, if they are not informed, then they should be no worse off under the subsidy/tax regime. This is because they still trade on the same terms as other uninformed traders whose terms remain the same in the LOB market. Of course, if long-term traders are uninformed in the short-

term and persist in using taxed market orders in preference to subsidized limit orders, then they are worse off. On the other hand, to the extent that all market participants gain from improved price discovery and pricing efficiency, long-term traders benefit along with the entire market.

7. Robustness Tests

To explore the robustness of our strikingly different results to those presented by previous studies, we change the matching variables used to identify the control sample. An obvious alternative was to construct the control sample by using only the price and ADV selection criteria in line with the sample in the NASDAQ fee pilot report. All the results are qualitatively consistent.

<Insert Table 12 here>

A second robustness test involved normalizing our dependent variables. We compute the quoted spread, effective spread, realized spread, and price impact (both one second and five second) in bps rather than cents (see Table 12). Again, the results are qualitatively consistent.

8. Conclusions

This study provides a new and deliberately straight-forward and transparent theoretical model of maker-taker fees to show that the entire fee rebate must be consumed by an increase in the information content of informed trades in equilibrium, motivated by a *rise* in the trading profitability of informed market orders paying the taker fee. Uninformed traders neither benefit from the fee rebate nor suffer from it. Freedom of entry into uninformed market making also ensures that makers (dealers) neither gain nor lose from alterations to the fee structure. We then empirically investigate how a reduction in the maker-taker fee affects market competition, liquidity, and HFT/non-HFT make-or-take decisions during the NASDAQ pilot that was constructed as a natural experiment.

The current literature holds that only changes in the net exchange fee matter for optimal execution behavior, market quality and transaction cost efficiency. Our findings dispute that result and instead support our theoretical implications that, although the raw effective spreads are unaffected by the rebate reduction as our model predicts, the information content of the order flow falls substantially. Holding the net fee essentially constant, the change in component fees and rebates *does* matter. When NASDAQ's fee pilot reduced both the fee and the rebate, its market share declined to the benefit of other high rebate-paying lit exchanges.

O'Hara and Ye (2011) show that more fragmented stocks have lower execution costs and faster execution speeds. In this paper, we have shown that competition between venues differentiated by differences in maker-taker fee structures can lead to greater depth, higher trade volume, more informed trading, and better price

discovery, especially in venues with the highest permitted levels of LOB fee rebate. Hence, we question the capping of the rebate by the SEC at an extraordinarily low level relative to the SEC-mandated minimum tick.

We find that the equivalently-reduced fee and rebate lowers quote quality and routed volume to NASDAQ while enhancing the fill rate and speed of fill because of the reduced taker fee and a thinner market. With their relative routing position improved, adverse selection costs decline on NASDAQ and liquidity suppliers profit (the realized spread increases). Our evidence means that NASDAQ's existing strategy of providing the highest possible subsidy to liquidity makers funded by a tax on liquidity takers encourages better price discovery and higher market efficiency. Profits of informed trades are enhanced with liquidity suppliers no worse off and probably better off. Hence, and as shown by our simple model that brings the Glosten and Milgrom (1985) model to life in the maker-taker markets, fee rebates to liquidity makers can improve Pareto efficiency.

NASDAQ designed the access fee pilot as a natural experiment to address in part the question of whether high exchange access fees cause trading to shift from exchanges to dark pools. We find no evidence for such a shift, perhaps because only one exchange reduced its access fee unilaterally in a competitive trading environment. However, even if all exchanges had participated, the outcome may have remained the same, as the net fee did not substantially alter. Instead, something fundamental changed in the competition between lit exchanges (the informed equilibrium order flow decreased on NASDAQ) but nothing fundamental changed between exchange and off-exchange venues.

Finally, we have shown that as exchange access fees and rebates decrease, HFT traders tend to switch from adding to taking liquidity. While standard quality measures such as the effective spread, realized spread, and price impact all appear to improve on a cum-rebate basis, these apparent improvements reflect the lower information content in NASDAQ's order flow during the experiment as informed orders shifted to exchanges that maintained high rebates. Given their relative inability to monitor the now less informed order flow dynamics, non-HFT firms increased liquidity making and decreased their liquidity taking while HFT firms did just the reverse, *albeit* with a less informed equilibrium order flow.

We find notable that exchange venues have discovered by serendipity that a subsidy to LOB makers paid for by a levy on takers achieves a Pareto improvement in market making. Thus, opening-up of trading to promote the incorporation of more asymmetric information has resulted in greater pricing efficiency. This improved market design has been achieved by venue access fees that are far from neutral. Pioneers of asymmetric information bargaining such as Nobel Laureate William Vickery would be delighted to know that their insights into the critical role played by these third parties has been utilized to such practical effect.

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Table 1: Nasdaq Maker-Taker Fee Structure

This table reports the Nasdaq pricing measured in cents per 100 shares (CPS) traded during (PilotOn) and pre/post (PilotOff) the Nasdaq access fee pilot implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. Net fee is defined as the sum of the take fee and the make rebate, which is the exchange revenue per 100 shares traded. The take fee is the highest rate Nasdaq can charge and make rebate is the most indicative rate Nasdaq provides in the Nasdaq pricing table.

Fee/ Rebate	**PilotOn (C*PS*)**	**PilotOff (C*PS*)**	**Difference**
Take Fee to Remove Liquidity:	5	30	-25
Make Rebate to Add Liquidity:			
Displayed Liquidity	4	29	-25
Non-Displayed Midpoint	2	25	-23
Other Non-Displayed Liquidity	0	10	-10
Net Fee:			
Displayed Liquidity	1	1	0
Non-Displayed Midpoint	3	5	-2
Other Non-Displayed Liquidity	5	20	-15

Table 2: Indicative U.S. Exchange Fee Structure

This table reports the U.S. stock exchanges pricing, measured in cents per 100 shares (CPS) traded. Fee is the exchange charge (pay) in the maker-taker (taker-maker) market. Rebate is the exchange pay (charge) in the maker-taker (taker-maker) market. Net fee is defined as the sum of the take fee and the maker rebate, which is the exchange revenue per 100 shares traded. For simplicity, the fee is the highest rate the exchange can charge and rebate is the highest rate below the fee given its pre-determined fee structure in their pricing table.

Exchange	Fee Model	Fee (CPS)	Rebate (CPS)	Net Fee (CPS)
NASDAQ	Maker-Taker	30	-29	1
ARCA	Maker-Taker	30	-29	1
BATS Z	Maker-Taker	30	-29	1
NYSE	Maker-Taker	27.5	-26	1.5
AMEX	Maker-Taker	30	-25	5
PHLX	Maker-Taker	29	-23	6
EDGX	Maker-Taker	29	-20	9
CHX	Maker-Taker	30	-20	10
EDGA	Taker-Maker	-2	5	3
BATS Y	Taker-Maker	-15	18	3
BX	Taker-Maker	-17	19	2

Table 3: Summary Statistics

The table reports summary statistics for the selected variables for Nasdaq fee pilot stocks and its matching stocks. Nasdaq access fee pilot is implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. PilotOn is the period when Nasdaq implemented the fee pilot; and PilotOff refers to two months prior and post the fee pilot.

	Treatment						Control							
	PilotOn			PilotOff			PilotOn			PilotOff			Diff in Diffs	
Number of Daily Obs.		1,148			1,190		1,148			1,190				
	Mean	Median	Std	Mean	Median	Std	Mean	Median	Std	Mean	Median	Std	Diff	t-stats
Panel A: Trading Stats and Market Share														
Closing Price	24.21	22.78	17.28	23.78	18.79	17.93	31.08	33.99	18.66	30.11	33.01	18.7	-0.54	-0.44
Market Cap (millions)	47.63	20.7	73.32	46.78	18.78	74.4	43.56	18.44	63.5	42.84	18.46	62.93	0.13	0.03
Nasdaq Volume (millions)	2.27	1.57	2.29	2.62	1.97	2.11	1.71	1.33	1.36	1.86	1.57	1.56	-0.19	-1.77
Nasdaq MarketShare (%)	12.77	12.01	4.72	14.72	13.95	5.77	18.73	18.59	6.07	19.22	19.04	6.69	-1.46	-4.25
Panel B: Quote Quality, Fill Ratio and Speed														
Nasdaq Time at NBBO (%)	88.25	95.71	13.19	94	98.82	9.3	93.02	98	10.64	93.8	98.12	9.8	-4.98	-6.86
Nasdaq Depth at NBBO (millions)	1.69	0.38	3.51	2.33	0.72	5.26	0.41	0.26	0.47	0.41	0.26	0.46	-0.64	-3.67
Nasdaq Depth Share	15.68	15.57	5.88	19.31	18.5	7.29	21.64	19.27	6.58	21.25	19.66	7.58	-4.02	-10.15
Quoted Spread (cents)	1.35	1.01	0.83	1.59	1.02	1.28	1.63	1.01	1.86	2.15	1.03	3.23	0.28	2.33
Fill Rate (%)	3.91	3.59	1.46	3.65	3.5	1.48	2.99	2.91	1.27	2.96	2.83	1.14	0.24	3.02
Fill Time (seconds)	189	110	197	236	118	265	134	93	119	123	83	127	-58	-5.59
Panel C: Transaction Cost_cents														
Effective Spread (cents)	1.14	0.97	0.58	1.18	0.96	0.7	1.3	0.97	1.13	1.4	0.96	1.34	0.06	1.02
Realized Spread 1s (cents)	-0.12	-0.07	0.48	-0.38	-0.42	0.35	-0.39	-0.43	0.51	-0.36	-0.44	0.68	0.29	9.97
Realized Spread 5s (cents)	-0.3	-0.2	0.59	-0.62	-0.54	0.5	-0.56	-0.51	0.66	-0.51	-0.52	0.68	0.37	10.18
Price Impact 1s (cents)	1.26	1.06	0.74	1.56	1.42	0.7	1.69	1.45	1.09	1.77	1.46	1.13	-0.22	-3.95
Price Impact 5s (cents)	1.44	1.16	0.89	1.81	1.51	1.08	1.86	1.52	1.45	1.92	1.51	1.41	-0.31	-3.95
Panel D: HFT vs Non-HFT Trading Behavior														
HFT Volume (millions)	1.69	1.07	1.71	1.96	1.49	1.59	1.26	1.08	0.98	1.4	1.23	1.11	-0.13	-1.59
Non-HFT Volume (millions)	2.86	2.04	2.96	3.29	2.44	2.74	2.15	1.7	1.81	2.33	1.89	2.11	-0.25	-1.78
HFT Adding Liquidity (%)	22.91	23.2	7.67	33.59	33.18	10.15	33.15	32.63	13.12	33.8	33.08	12.18	-10.04	-13.6
HFT Taking Liquidity (%)	50.68	51.5	9.88	41.05	41.61	8.8	41.18	39.91	9.83	41.48	40.09	10.09	9.94	17.2
Non-HFT Adding Liquidity (%)	77.09	76.8	7.67	66.41	66.82	10.15	66.85	67.37	13.12	66.2	66.92	12.18	10.04	13.6
Non-HFT Taking Liquidity (%)	49.32	48.5	9.88	58.95	58.39	8.8	58.82	60.09	9.83	58.52	59.91	10.09	-9.94	-17.2
Panel E: Liquidity Adding Types and HFT														
Displayed Liquidity (%)	88.99	90.1	5.37	89.01	90.56	5.65	91.48	92.32	4.05	91.18	92.16	4.45	-0.32	-1.17
Non-displayed Midpoint Liquidity (%)	7.78	6.23	5.66	8.12	6.51	5.98	5.77	5.31	2.88	5.92	5.33	3.29	-0.19	-0.73
Non-displayed Non-Midpoint Liquidity (%)	3.23	2.12	3.3	2.78	1.56	3.36	2.65	1.47	3.63	2.81	1.69	3.64	0.61	2.81
HFT Displayed Liquidity (%)	18.37	18.31	6.14	28.43	28.57	9.27	29.35	29.15	12.07	30.05	29.37	11.71	-9.36	-13.79
HFT Non-displayed Midpoint Liquidity (%)	3.87	2.27	4.19	4.51	3.23	4.31	3.21	2.71	2.7	3.1	2.49	2.73	-0.76	-3.51
HFT Non-displayed Non-Midpoint Liquidity (%)	0.67	0.16	1.39	0.56	0.04	1.63	0.49	0.06	1.36	0.56	0.05	1.56	0.17	1.92

Table 4: Quote Quality, Fill Ratio and Speed Regression

The table tests the impact of trading fee change on the percentage of time and market depth when Nasdaq at national best bid or offer (NBBO), as well as the fill rate and speed. Time% NQ at NBBO is the average percentage time Nasdaq bid at NBB and Nasdaq ask at NBO. NQ Depth at NBBO is the average quote size when Nasdaq bid at NBB and Nasdaq ask at NBO. NQ Depth Share at NBBO is the average percentage of quote size when Nasdaq bid at NBB and Nasdaq ask at NBO. Fill rate is the ratio of volume of executed orders to the volume of resting orders. Quoted spread_raw is calculated as the time weighted difference between the bid and ask using NBBO quote data. Fill time represents the average time (measured in seconds) that it takes executed to receive their first (and perhaps only) execution. All the variables are measured on a daily basis per security. The control variables (Price, Mkt Cap and Volatility) are computed as the average value over the sample period. Nasdaq access fee pilot is implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. Standard errors (in parentheses) are adjusted for both heteroscedasticity and clustering within stocks. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Dependent Variable	**Time% NQ at NBBO**	**NQ Depth at NBBO**	**NQ Depth Share at NBBO**	**Quoted Spread raw**	**Fill Rate**	**Log (Fill Time)**
Intercept	70.375***	10.392***	107.689***	8.322***	7.352***	8.469***
	(2.907)	(0.226)	(2.929)	(0.794)	(0.603)	(0.239)
Treat	-3.064***	0.194***	-1.034***	-0.148**	0.843***	0.203***
	(0.261)	(0.020)	(0.263)	(0.071)	(0.054)	(0.022)
PilotOn	-0.962***	-0.047**	0.262	-0.407***	-0.002	0.038*
	(0.265)	(0.021)	(0.267)	(0.072)	(0.055)	(0.022)
Treat*PilotOn	-4.977***	-0.337***	-4.010***	0.285***	0.237***	-0.261***
	(0.365)	(0.028)	(0.368)	(0.100)	(0.076)	(0.030)
VIX	-0.115***	-0.032***	-0.077**	0.072***	-0.015**	-0.063***
	(0.038)	(0.003)	(0.038)	(0.010)	(0.008)	(0.003)
Log (Price)	-9.495***	-1.729***	0.206*	1.109***	0.373***	-0.822***
	(0.108)	(0.008)	(0.109)	(0.029)	(0.022)	(0.009)
Log (Mkt Cap)	2.656***	0.372***	-3.271***	-0.484***	-0.223***	-0.009
	(0.110)	(0.009)	(0.110)	(0.030)	(0.023)	(0.009)
Volatility	-249.743***	-31.073***	-311.181***	19.009***	-2.274	-7.885***
	(13.732)	(1.068)	(13.836)	(3.749)	(2.849)	(1.130)
Adjusted R^2	0.682	0.911	0.251	0.307	0.152	0.693
Observations	4,676	4,676	4,676	4,676	4,676	4,676

Table 5a: Raw Bid-Ask Spreads and Price Impact Regression_Cents

The table tests the impact of trading fee change on bid-ask spreads and price impact. Effective spread_raw is calculated as twice the volume weighted signed difference between the transaction price and the midpoint of the prevailing bid and ask quotes. Realized spread_raw is calculated as twice the volume weighted signed difference between the transaction price and the midpoint of the bid and ask quotes 1 and 5 seconds after the trade. Price impact_raw is twice the volume weighted signed difference between the quote midpoint and the quote midpoint 1 and 5 seconds after the trade. All spreads and price impact measures are measured in cents on a daily basis per security. The control variables (Price, Mkt Cap and Volatility) are computed as the average value over the sample period. Nasdaq access fee pilot is implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. Standard errors (in parentheses) are adjusted for both heteroscedasticity and clustering within stocks. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Dependent Variable	**Effective Spread_raw**	**Realized Spread 1s_raw**	**Realized Spread 5s_raw**	**Price Impact 1s_raw**	**Price Impact 5s_raw**
Intercept	4.639***	2.119***	0.750***	2.520***	3.889***
	(0.364)	(0.237)	(0.272)	(0.337)	(0.440)
Treat	-0.011	0.003	-0.152***	-0.014	0.141***
	(0.033)	(0.021)	(0.024)	(0.030)	(0.040)
PilotOn	-0.084**	-0.039*	-0.055**	-0.045	-0.029
	(0.033)	(0.022)	(0.025)	(0.031)	(0.040)
Treat*PilotOn	0.062	0.294***	0.366***	-0.232***	-0.304***
	(0.046)	(0.030)	(0.034)	(0.042)	(0.055)
VIX	0.012**	-0.006*	-0.006*	0.017***	0.018***
	(0.005)	(0.003)	(0.004)	(0.004)	(0.006)
Log (Price)	0.597***	0.0001	-0.182***	0.597***	0.780***
	(0.013)	(0.009)	(0.010)	(0.012)	(0.016)
Log (Mkt Cap)	-0.246***	-0.092***	-0.009	-0.154***	-0.237***
	(0.014)	(0.009)	(0.010)	(0.013)	(0.017)
Volatility	16.565***	-8.139***	-13.501***	24.704***	30.066***
	(1.718)	(1.122)	(1.283)	(1.592)	(2.081)
Adjusted R^2	0.385	0.068	0.128	0.429	0.423
Observations	4,676	4,676	4,676	4,676	4,676

Table 5b: Cum Fee Bid-Ask Spreads and Price Impact Regression_Cents

The table tests the impact of trading fee change on bid-ask spreads and price impact. Effective spread_cum is calculated as twice the volume weighted signed difference between the transaction price and the midpoint of the prevailing bid and ask quotes. Realized spread_cum is calculated as twice the volume weighted signed difference between the transaction price and the midpoint of the bid and ask quotes 1 and 5 seconds after the trade. Price impact_cum is twice the volume weighted signed difference between the quote midpoint and the quote midpoint 1 and 5 seconds after the trade. All spreads and price impact measures are measured in cents on a daily basis per security. The control variables (Price, Mkt Cap and Volatility) are computed as the average value over the sample period. Nasdaq access fee pilot is implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. Standard errors (in parentheses) are adjusted for both heteroscedasticity and clustering within stocks. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Dependent Variable	**Effective Spread_cum**	**Realized Spread 1s_cum**	**Realized Spread 5s_cum**	**Price Impact 1s_cum**	**Price Impact 5s_cum**
Intercept	5.239***	2.699***	1.330***	2.520***	3.889***
	(0.364)	(0.237)	(0.272)	(0.337)	(0.440)
Treat	-0.011	0.003	-0.152***	-0.014	0.141***
	(0.033)	(0.021)	(0.024)	(0.030)	(0.040)
PilotOn	-0.084**	-0.039*	-0.055**	-0.045	-0.029
	(0.033)	(0.022)	(0.025)	(0.031)	(0.040)
Treat*PilotOn	-0.438***	-0.206***	-0.134***	-0.232***	-0.304***
	(0.046)	(0.030)	(0.034)	(0.042)	(0.055)
VIX	0.012**	-0.006*	-0.006*	0.017***	0.018***
	(0.005)	(0.003)	(0.004)	(0.004)	(0.006)
Log (Price)	0.597***	0.0001	-0.182***	0.597***	0.780***
	(0.013)	(0.009)	(0.010)	(0.012)	(0.016)
Log (Mkt Cap)	-0.246***	-0.092***	-0.009	-0.154***	-0.237***
	(0.014)	(0.009)	(0.010)	(0.013)	(0.017)
Volatility	16.565***	-8.139***	-13.501***	24.704***	30.066***
	(1.718)	(1.122)	(1.283)	(1.592)	(2.081)
Adjusted R^2	0.428	0.061	0.123	0.429	0.423
Observations	4,676	4,676	4,676	4,676	4,676

Table 6: Market Efficiency Univariate Analysis

This table reports variance ratio (panel A) and autocorrelation (panel B) univariate analysis for Nasdaq fee pilot stocks and its matching stocks. Nasdaq access fee pilot is implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. PilotOn is the period when Nasdaq implemented the fee pilot; and PilotOff refers to two months prior and post the fee pilot. Variance ratio are computed in 1 to 10 second, 10 to 60 second, and 1 to 300 second time intervals; and autocorrelation are computed in 1 seconds, 10 seconds and 300 seconds. Chicago Stock Exchange and NYSE Amex are not reported in this table due to small market share which both are smaller than 0.5%.

	Treatment						**Control**											
	PilotOn			**PilotOff**			**PilotOn**			**PilotOff**			**DiD**			**t-Stats**		
Panel A: Variance Ratio																		
Exchange	1t10s	10t60s	1t300s	1t10s	10t60s	1t300s	1t10s	10t60s	1t300s	1t10s	10t60s	1t300s	1t10s	10t60s	1t300s	1t10s	10t60s	1t300s
NASDAQ	1.083	1.146	1.509	1.003	1.044	1.221	1.108	1.099	1.466	1.117	1.091	1.413	0.089	0.094	0.234	8.590	6.763	5.819
ARCA	1.125	1.169	1.585	1.087	1.109	1.425	1.175	1.153	1.701	1.195	1.167	1.732	0.058	0.075	0.190	5.687	6.204	4.214
BATS Z	1.214	1.236	1.933	1.172	1.172	1.723	1.226	1.188	1.912	1.235	1.187	1.865	0.051	0.063	0.163	3.959	4.260	2.327
NYSE	1.128	1.153	1.521	1.092	1.108	1.401	1.101	1.086	1.389	1.128	1.120	1.558	0.063	0.080	0.290	6.830	4.772	3.497
PHLX	3.375	3.098	40.301	2.647	2.358	22.506	3.453	3.214	53.811	3.189	2.904	40.701	0.465	0.431	4.684	3.493	4.478	1.436
EDGX	1.167	1.192	1.699	1.152	1.162	1.705	1.268	1.263	2.379	1.353	1.358	3.076	0.100	0.125	0.692	6.168	6.282	4.802
EDGA	1.796	1.575	5.772	1.753	1.550	5.522	1.928	1.660	6.781	2.048	1.775	8.464	0.163	0.141	1.934	2.350	3.351	2.532
BATS Y	1.790	1.551	5.604	1.786	1.543	5.934	1.942	1.663	8.752	1.895	1.643	7.722	-0.044	-0.011	-1.361	-0.691	-0.260	-1.519
BX	2.478	2.055	19.667	2.711	2.187	30.773	2.452	2.095	20.437	2.956	2.459	34.489	0.271	0.231	2.946	2.130	2.875	0.975
Consolidated	1.057	1.128	1.416	1.605	1.302	5.290	1.044	1.059	1.294	1.764	1.386	9.881	0.172	0.152	4.713	3.155	4.300	4.455
Panel B: Autocorrelation																		
Exchange	ac1s	ac10s	ac300s	ac1s	ac10s	ac300s	ac1s	ac10s	ac300s	ac1s	ac10s	ac300s	ac1s	ac10s	ac300s	ac1s	ac10s	ac300s
NASDAQ	-0.016	0.892	0.995	-0.002	0.900	0.996	-0.024	0.890	0.995	-0.028	0.889	0.996	-0.017	-0.009	-0.001	-6.538	-8.800	-6.108
ARCA	-0.029	0.888	0.995	-0.021	0.892	0.996	-0.038	0.884	0.995	-0.040	0.882	0.995	-0.011	-0.006	-0.001	-4.996	-6.147	-4.286
BATS Z	-0.045	0.879	0.994	-0.037	0.884	0.995	-0.047	0.879	0.994	-0.048	0.878	0.994	-0.009	-0.005	0.000	-3.485	-4.163	-2.204
NYSE	-0.029	0.887	0.995	-0.023	0.891	0.996	-0.029	0.890	0.996	-0.029	0.888	0.995	-0.005	-0.007	-0.001	-2.563	-7.031	-3.418
PHLX	-0.234	0.675	0.890	-0.174	0.754	0.940	-0.206	0.676	0.869	-0.193	0.703	0.904	-0.047	-0.051	-0.015	-5.589	-4.460	-1.987
EDGX	-0.041	0.884	0.995	-0.035	0.885	0.995	-0.053	0.875	0.993	-0.064	0.867	0.991	-0.017	-0.010	-0.002	-6.070	-6.329	-5.223
EDGA	-0.112	0.827	0.982	-0.110	0.831	0.984	-0.117	0.817	0.980	-0.120	0.810	0.978	-0.004	-0.010	-0.003	-0.703	-1.826	-1.505
BATS Y	-0.119	0.827	0.983	-0.128	0.824	0.981	-0.125	0.816	0.972	-0.130	0.815	0.976	0.003	0.002	0.005	0.493	0.325	1.610
BX	-0.127	0.771	0.952	-0.150	0.739	0.922	-0.120	0.774	0.950	-0.169	0.719	0.917	-0.026	-0.023	-0.002	-3.538	-2.083	-0.311
Consolidated	-0.009	0.894	0.995	-0.061	0.840	0.983	-0.010	0.896	0.996	-0.080	0.825	0.970	-0.018	-0.017	-0.013	-4.026	-3.145	-4.203

Table 7: Trading Volume and Market Share across each Trading Venue

This table reports the daily average trading volume and market share in each U.S. trading venue before, during and after the Nasdaq access fee pilot implemented on February 2, 2015 and ended on May 31, 2015. During the sample period, there are 11 lit exchanges in the U.S. equity markets, and TRF captures all the off-exchange trades including Dark Pools, ECNs, voice-brokered trades and Broder/Dealer Internalization. The sample period is from December 1, 2014 to July 31, 2015.

	Treatment		Control			
Trading Venue (Pid)	**PilotOn**	**PilotOff**	**PilotOn**	**PilotOff**	**Diff in Diffs**	**t-stats**
Panel A: Market Share Per Trading Venue						
NASDAQ (Q/T)	12.77	14.72	18.73	19.22	-1.46	-4.25
ARCA (P)	9.91	8.73	10.58	10.59	1.19	6.75
BATS Z (Z)	8.05	6.82	10.10	10.02	1.15	5.54
NYSE (N)	8.81	8.31	9.50	9.82	0.81	1.55
EDGX (K)	8.71	8.09	7.06	6.79	0.35	2.13
AMEX (A)	0.32	0.26	0.28	0.22	0.01	0.16
CHX (M)	0.58	0.52	0.65	0.56	-0.02	-0.17
EDGA (J)	2.74	2.92	3.14	3.11	-0.21	-2.83
PHLX (X)	1.14	1.20	1.32	1.14	-0.24	-5.26
BX (B)	1.68	2.16	2.15	2.29	-0.34	-6.01
BATS Y (Y)	4.39	4.49	4.99	4.67	-0.41	-3.40
TRF (D)	40.89	41.78	31.51	31.57	-0.83	-2.09
Panel B: Trading Volume Per Trading Venue						
Consolidated Volume	20,349,535	21,114,357	11,012,865	11,585,448	-192,240	-0.72
NASDAQ (Q/T)	2,272,872	2,622,836	1,705,936	1,862,962	-192,937	-1.77
ARCA (P)	1,958,653	1,812,350	1,076,705	1,125,105	194,704	2.00
BATS Z (Z)	1,568,537	1,468,514	975,009	1,070,096	195,110	2.69
NYSE (N)	2,518,804	2,488,645	1,395,893	1,577,664	211,930	0.94
EDGX (K)	1,514,448	1,557,424	682,305	690,438	-34,843	-0.49
AMEX (A)	64,420	51,374	23,448	19,026	8,624	1.20
CHX (M)	126,856	125,932	124,190	103,060	-20,206	-0.73
EDGA (J)	619,019	689,642	350,232	355,551	-65,303	-1.79
PHLX (X)	250,213	297,040	151,272	138,851	-59,247	-3.77
BX (B)	386,755	524,416	239,178	270,556	-106,284	-3.91
BATS Y (Y)	946,024	1,038,663	574,679	533,566	-133,752	-2.53
TRF (D)	8,122,933	8,437,522	3,714,019	3,838,572	-190,035	-0.49

Table 8: Market Share (weekly) across Types of Trading Venue

The table tests the impact of trading fee change on the market share for Nasdaq, other lit exchange, dark pools and non-dark pools (other off exchange trades other than the dark pools). The NQ_MktShare_weekly is the percentage weekly total Nasdaq trading volume over the weekly total trading volume on all the U.S. markets. The OtherExch_MktShare_weekly is the percentage of weekly other 10 lit exchanges total trading volume over the weekly total trading volume on all the U.S. markets. The DarkPools_MktShare_weekly is the percentage of weekly dark pools trading volume over the weekly total trading volume on all the U.S. markets. The NonDarkPools_MktShare_weekly is the percentage of weekly non-dark pools off exchange trading volume over the weekly total trading volume on all the U.S. markets. The control variables (Price, Mkt Cap and Volatility) are computed as the average value over the sample period. Nasdaq access fee pilot is implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. Standard errors (in parentheses) are adjusted for both heteroscedasticity and clustering within stocks. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Dependent Variable	**NQ_MktShare_weekly**	**OtherExch_MktShare_weekly**	**DarkPools_MktShare_weekly**	**NonDarkPools_MktShare_weekly**
Intercept	136.286***	-106.988***	47.669***	23.033***
	(5.255)	(6.697)	(3.335)	(5.466)
Treat	-1.611***	-7.646***	0.116	9.141***
	(0.468)	(0.597)	(0.297)	(0.487)
PilotOn	-0.057	0.374	-0.053	-0.264
	(0.476)	(0.607)	(0.302)	(0.496)
Treat*PilotOn	-1.451**	1.809**	0.17	-0.528
	(0.657)	(0.837)	(0.417)	(0.683)
VIX	0.304***	0.059	-0.125***	-0.238***
	(0.074)	(0.094)	(0.047)	(0.077)
Log (Price)	3.905***	-3.635***	-1.695***	1.425***
	(0.194)	(0.247)	(0.123)	(0.202)
Log (Mkt Cap)	-5.203***	6.507***	-0.804***	-0.500**
	(0.197)	(0.251)	(0.125)	(0.205)
Volatility	-385.575***	454.371***	-226.512***	157.716***
	(24.709)	(31.491)	(15.681)	(25.705)
Adjusted R^2	0.543	0.478	0.306	0.458
Observations	980	980	980	980

Table 9: Trading Volume, Market Share and Routing Dynamics Regression

The table tests the impact of trading fee change on the trading volume, market share, as well as the Nasdaq routing dynamics. Consolidated_Volume is the consolidated daily trading volume, and NQ_Volume is the Nasdaq daily trading volume. The NQ_MktShare is the percentage of daily total Nasdaq trading volume over the daily total trading volume on all the U.S. markets. Routing to NQ% is the percentage of orders routed to Nasdaq, and Routing to OtherExch% is the percentage of orders routed to other U.S. markets. The control variables (Price, Mkt Cap and Volatility) are computed as the average value over the sample period. Nasdaq access fee pilot is implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. Standard errors (in parentheses) are adjusted for both heteroscedasticity and clustering within stocks. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Dependent Variable	**Log (Consolidated _Volume)**	**Log (NQ_Volume)**	**NQ_MktShare**	**Routing to NQ%**	**Routing to OtherExch%**
Intercept	0.745***	3.723***	98.210***	131.561***	-31.561***
	(0.264)	(0.284)	(1.913)	(1.631)	(1.631)
Treat	0.454***	0.308***	-2.368***	-1.659***	1.659***
	(0.024)	(0.026)	(0.172)	(0.147)	(0.147)
PilotOn	0.011	0.034	0.134	-0.637***	0.637***
	(0.024)	(0.026)	(0.174)	(0.149)	(0.149)
Treat*PilotOn	-0.024	-0.131***	-1.463***	-0.381*	0.381*
	(0.033)	(0.036)	(0.240)	(0.205)	(0.205)
VIX	0.031***	0.058***	0.388***	0.02	-0.02
	(0.003)	(0.004)	(0.025)	(0.021)	(0.021)
Log (Price)	-0.466***	-0.227***	3.710***	-0.214***	0.214***
	(0.010)	(0.011)	(0.071)	(0.060)	(0.060)
Log (Mkt Cap)	0.660***	0.422***	-3.824***	-1.318***	1.318***
	(0.010)	(0.011)	(0.072)	(0.062)	(0.062)
Volatility	20.708***	8.572***	-243.160***	-90.175***	90.175***
	(1.247)	(1.342)	(9.038)	(7.705)	(7.705)
Adjusted R^2	0.679	0.453	0.595	0.195	0.195
Observations	4,676	4,676	4,676	4,676	4,676

Table 10: HFT vs non-HFT Add or Take Liquidity Regression

The table tests the impact of trading fee change on the HFT vs Non-HFT trading behavior. HFT is identified using Nasdaq proprietary data. HFT% is the ratio of HFT trading volume over total trading volume, while non-HFT% is the ratio of non-HFT trading volume over total trading volume. HFT Add (Take)_Liquidity% is the ratio of HFT adding (taking) liquidity volume over total trading volume. Non-HFT Add (Take)_Liquidity% is the ratio of non-HFT adding (taking) liquidity volume over total trading volume. All the variables are measured on a daily basis per security. Nasdaq access fee pilot is implemented on February 2, 2015 and ended on May 31, 2015. The control variables (Price, Mkt Cap and Volatility) are computed as the average value over the sample period. The sample period is from December 1, 2014 to July 31, 2015. Standard errors (in parentheses) are adjusted for both heteroscedasticity and clustering within stocks. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Dependent Variable	**HFT Add_Liquidity%**	**HFT Take_Liquidity%**	**HFT Volume%**	**non-HFT Add_Liquidity%**	**non-HFT Take_Liquidity%**	**non-HFT Volume%**
Intercept	-48.685***	-36.667***	-42.676***	148.685***	136.667***	142.676***
	(3.287)	(4.172)	(2.675)	(3.287)	(4.172)	(2.675)
Treat	-4.757***	-1.350***	-3.053***	4.757***	1.350***	3.053***
	(0.296)	(0.375)	(0.241)	(0.296)	(0.375)	(0.241)
PilotOn	-0.366	0.272	-0.047	0.366	-0.272	0.047
	(0.300)	(0.380)	(0.244)	(0.300)	(0.380)	(0.244)
Treat*PilotOn	-10.043***	9.936***	-0.054	10.043***	-9.936***	0.054
	(0.413)	(0.524)	(0.336)	(0.413)	(0.524)	(0.336)
VIX	0.171***	0.359***	0.265***	-0.171***	-0.359***	-0.265***
	(0.042)	(0.054)	(0.035)	(0.042)	(0.054)	(0.035)
Log (Price)	-9.714***	0.587***	-4.564***	9.714***	-0.587***	4.564***
	(0.122)	(0.155)	(0.099)	(0.122)	(0.155)	(0.099)
Log (Mkt Cap)	4.299***	2.383***	3.341***	-4.299***	-2.383***	-3.341***
	(0.124)	(0.157)	(0.101)	(0.124)	(0.157)	(0.101)
Volatility	324.353***	504.703***	414.528***	-324.353***	-504.703***	-414.528***
	(15.525)	(19.708)	(12.635)	(15.525)	(19.708)	(12.635)
Adjusted R^2	0.649	0.27	0.402	0.649	0.27	0.402
Observations	4,676	4,676	4,676	4,676	4,676	4,676

Table 11: Coefficient of HFT vs Non-HFT Bid-Ask Spread and Price Impact (cents) Regression

This table reports the regression coefficient of Treat*PilotOn from the Equation (17) in the paper for non-stock fixed effect. HFT is identified using Nasdaq proprietary data. HFT Take (Add) is when HFT is the liquidity taker (maker) in the trade. Non-HFT Take (Add) is when non-HFT is the liquidity taker (maker) in the trade.

	Cents				Cum Fee/Rebate Cents			
Regression Coefficient	**HFT Take**	**HFT Add**	**Non-HFT Take**	**Non-HFT Add**	**HFT Take**	**HFT Add**	**Non-HFT Take**	**Non-HFT Add**
Effective Spread	0.041	0.450***	0.071	0.628***	-0.459***	-0.05	-0.429***	0.128
Realised Spread 1s	0.425***	0.111**	0.255***	-0.018	-0.075**	-0.389***	-0.245***	-0.518***
Realised Spread 5s	0.530***	0.067	0.328***	-0.131**	0.03	-0.433***	-0.172***	-0.631***
Price Impact 1s	-0.384***	0.339***	-0.184***	0.647***	-0.384***	0.339***	-0.184***	0.647***
Price Impact 5s	-0.489***	0.383***	-0.257***	0.760***	-0.489***	0.383***	-0.257***	0.760***

Table 12: Relative Bid-Ask Spread and Price Impact Regression_bps

The table tests the impact of trading fee change on bid-ask spreads and price impact. Quoted spread_rel is calculated as the time weighted difference between the bid and ask over the quote midpoint using NBBO (Nasdaq) quote data. Effective spread_rel is calculated as twice the volume weighted signed difference between the transaction price and the midpoint of the prevailing bid and ask quotes. Realized spread_rel is calculated as twice the volume weighted signed difference between the transaction price and the midpoint of the bid and ask quotes 1 and 5 seconds after the trade. Price impact is twice the volume weighted signed difference between the quote midpoint and the quote midpoint 1 and 5 seconds after the trade. All spreads and price impact measures are expressed in basis points (bps) of the prevailing midpoint, and measured on a daily basis per security. The control variables (Price, Mkt Cap and Volatility) are computed as the average value over the sample period. Nasdaq access fee pilot is implemented on February 2, 2015 and ended on May 31, 2015. The sample period is from December 1, 2014 to July 31, 2015. Standard errors (in Parentheses) are adjusted for both heteroscedasticity and clustering within stocks. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Dependent Variable	**Quoted Spread_rel**	**Effective Spread_rel**	**Realized Spread 1s_rel**	**Realized Spread 5s_rel**	**Price Impact 1s_rel**	**Price Impact 5s_rel**
Intercept	73.713***	58.871***	25.913***	12.830***	32.958***	46.041***
	(2.273)	(1.625)	(1.566)	(1.574)	(2.117)	(2.304)
Treat	1.280***	1.025***	0.682***	-0.075	0.342*	1.099***
	(0.204)	(0.146)	(0.141)	(0.142)	(0.190)	(0.207)
PilotOn	-1.138***	-0.260*	0.038	0.005	-0.298	-0.264
	(0.207)	(0.148)	(0.143)	(0.144)	(0.193)	(0.210)
Treat*PilotOn	0.284	-0.003	3.615***	3.644***	-3.618***	-3.647***
	(0.285)	(0.204)	(0.197)	(0.198)	(0.266)	(0.289)
VIX	0.193***	0.050**	-0.118***	-0.113***	0.168***	0.163***
	(0.029)	(0.021)	(0.020)	(0.020)	(0.027)	(0.030)
Log (Price)	-6.603***	-6.535***	1.437***	2.021***	-7.972***	-8.556***
	(0.084)	(0.060)	(0.058)	(0.058)	(0.078)	(0.085)
Log (Mkt Cap)	-1.948***	-1.338***	-1.083***	-0.671***	-0.255***	-0.667***
	(0.086)	(0.061)	(0.059)	(0.059)	(0.080)	(0.087)
Volatility	-54.200***	-31.272***	-207.134***	-174.469***	175.863***	143.197***
	(10.737)	(7.675)	(7.396)	(7.436)	(9.998)	(10.885)
Adjusted R^2	0.699	0.796	0.355	0.399	0.771	0.77
Observations	4,676	4,676	4,676	4,676	4,676	4,676