Inverted Fee Venues and Market Quality

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ABSTRACT

Stock exchanges incentivize the demand and supply of liquidity through their fee models. A traditional model pays a rebate to the liquidity supplier and an inverted model pays a rebate to liquidity demanders. We examine the impact of inverted fee models on market quality using an exogenous shock to inverted venue market share created by a regulatory intervention – the 2016 Tick Size Pilot. We show higher inverted venue share improves pricing efficiency, increases liquidity and decreases volatility. Our findings suggest that the finer pricing grid provided by inverted venues encourages competition between liquidity providers and improves market quality.

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I. Introduction

Stock exchanges compete to attract suppliers and demanders of liquidity to their market. The fee models used by exchanges to price trading services have evolved over time as the regulatory landscape has changed. Historically, exchanges imposed a fee on both liquidity suppliers and demanders. However, in the late 1990s, Island ECN introduced the concept of a liquidity provider rebate in an attempt to incentivize liquidity provision on its new trading venue. Under this fee model, liquidity demanders (takers) are charged a fee, but liquidity providers (makers) receive a rebate. This fee model is now common place, with 8 of the 13 US exchanges offering a traditional make-take fee model. More recently three exchanges, BATS-Y, NASDAQ BX and EDGA, have adopted an inverted fee model, offering rebates to liquidity demanders and charging fees to liquidity providers.

Theoretically traders should choose to be demanders or suppliers of liquidity based on spreads, net of fees. In a competitive equilibrium spreads should narrow to adjust for the rebates on offer (Cohen, Maier, Schwartz, and Whitcomb, 1981). Colliard and Foucault (2012) provide theoretical evidence that the allocation of fees between makers and takers is unimportant, and that only the total fee matters. However, in practice, discrete tick sizes prevent prices from being adjusted in a manner to neutralize the impact of rebates (Foucault, Kadan, and Kandel, 2013). Exchange fee models, therefore, impact trading decisions.

Although fees and rebates are not reflected in quoted prices, fees and rebates alter the economics of liquidity supply and demand. The compensation paid to liquidity suppliers via the spread is supplemented with a rebate on a traditional make-take venue, while the cost of crossing the spread is reduced by a rebate on an inverted venue. These fee/rebate differences influence where traders route their orders, and alter the probability of execution of displayed orders. Limit orders displayed on inverted venues will likely execute before limit orders displayed at the same price on traditional make-take venues due to the rebate paid to liquidity takers. However, inverted venues are also less likely to attract liquidity suppliers. Traders need to evaluate the costs and benefits of these alternatives when making routing decisions. The inverted fee model offers another unique feature – it creates a finer pricing grid within the spread – allowing traders to obtain price improvement relative to the National Best Bid and Offer (NBBO).

Inverted fee models, and make-take fees more generally, have been a controversial feature of the US market. They increase the complexity of the market, and encourage fragmentation because each exchange operator has created multiple trading venues. Inverted venues operate with different fee models to attract different customers and to create additional order book queues, which provides more opportunities for traders to be at the front of the queue at any given price point. They distort prices because they are quoted without adjusting for fees (Harris, 2013). They can also exacerbate agency conflicts between brokers and clients where brokers charge a flat commission to their clients rather than passing on the fees/rebate (Battalio, Corwin, and Jennings, 2016). Despite these negatives, alternative fee models are an important competitive tool for exchanges. The inverted fee model is particularly important because it enables exchanges to create a finer pricing grid within the spread. This allows exchanges to more directly compete with non-exchange venues that are allowed to trade in sub-pennies.

In this paper we examine whether competition based on these different fee models is positive or negative for market quality. More specifically, we ask whether competition on a finer pricing grid on a lit venue is better or worse for market quality than competition on a finer pricing grid on a dark venue. We are able to examine these questions using changes in market design resulting from a regulatory experiment implemented by the Financial Industry Regulatory Authority (FINRA) and the Securities and Exchange Commission (SEC). The purpose of this experiment, known as the Tick Size Pilot, is "to assist in evaluating the impact of widening the tick size on the securities of smaller capitalization companies." The pilot increased the minimum tick size from \$0.01 to \$0.05 for three groups of pilot stocks.

Controversially, one of the groups of pilot stocks (group 3) is also subject to a "trade-at" rule. This rule prohibits price matching by trading venues that are not already displaying a quotation at that price, unless an exception applies, effectively shutting down the opportunity to trade in sub-pennies in the dark, therefore making the finer pricing grid offered by the inverted fee venues more attractive to liquidity demanders and suppliers. The average lit market share of inverted venues rose from 15% to 28% for stocks subject to the trade-at rule, providing us with an effective instrument to study the impact of inverted fee models and the finer pricing grid that they create. This effect is most pronounced for stocks that are tick constrained. The staggered implementation of the trade-at rule also assists with identification. The experimental design enables us to assess the impact of the increase in inverted venue share, and the impact of the finer pricing grid in the lit market on market quality.

We find that the net impact of inverted fee models on market quality is positive. Price efficiency and liquidity increase with inverted venue market share, while short-term volatility decreases. In contrast, increasing the overall level of lit trading offers trade-offs as it improves liquidity but reduces price efficiency. Different stocks are affected differently. The effects of inverted trading on price efficiency are stronger for stocks that are tick constrained while the effects of lit trading are stronger for those that are not.

We then investigate increased competition for liquidity provision as a potential channel for this improvement in market quality. Theory suggests that a finer pricing grid encourages such competition (e.g. Foucault and Menkveld (2008), and Werner, Wen, Rindi, Consonni, and Buti (2015)), while more liquidity provision is associated with better price discovery and less volatile prices (Hagströmer and Norden, 2013). Our results show that the trade-at prohibition leads to more order activity on inverted venues. When the rule is implemented, cancellation rates on inverted venues decrease and execution rates increase. This change is economically significant. The execution rate on inverted venues increases by approximately

1/3rd of its pre-pilot level. Among the three inverted venues, BATS-Y, NASDAQ BX, and EDGA, we find that NASDAQ BX has the most pronounced changes in cancellation rate and execution rate. For example, the impact of the trade-at prohibition on the cancellation rate on NASDAQ BX is more than three times the impact on BATS-Y. We do not find any significant change in order activity on traditional venues.

We next dig deeper, looking at order-level data from the main NASDAQ venue and NASDAQ BX. In the order-level analysis, we study the change to algorithmic trading activity, and changes to a limit order's hazard rate of time-to-cancellation and time-to-execution. We find that the trade-at prohibition significantly increases the hazard rate of time-to-execution. In other words, orders are executed faster on NASDAQ BX following the implementation of the trade-at prohibition. The faster execution does not seem to be caused by more algorithmic trading. We find that the prohibition significantly decreases algorithmic trading activity.

Our findings indicate a significant increase in popularity of inverted venues followed by the enforcement of the trade-at prohibition. More orders are submitted to inverted venues, less are canceled, and more are executed. This is consistent with the view that the finer pricing grid on inverted venue encourages competition in liquidity provision. It is most pronounced after the prohibition becomes effective, as traders can no long conduct sub-penny trading on dark venues. More importantly, we find the migration of order activity and trades to inverted venues is beneficial to market quality.

Our paper relates most closely to the literature on sub-penny trading in dark pools and its impact on market quality. Sub-penny trading enables traders to undercut the limit order book by less than a penny, effectively creating a finer pricing grid. Buti, Consonni, Rindi, Wen, and Werner (2015) and Kwan, Masulis, and McInish (2015) find that sub-penny trading is higher in liquid stocks and stocks with a high tick to price ratio (i.e. low priced), suggesting that sub-penny trading is driven, at least in part by sub-optimal tick sizes. Buti, Consonni, Rindi, Wen, and Werner (2015) also show that sub-penny trading improves market quality for liquid, high priced stocks, but reduces it for illiquid, low priced stocks. They also illustrate that its effects are dampened when the relative tick size is reduced in the lit market. Our contribution to this literature is to examine whether the impact of a finer pricing grid on inverted lit markets has more or less impact than a finer pricing grid in a dark market.

We also build on the existing empirical work on exchange fees. Cardella, Hao and Kalcheva (2015) show empirically that fees are an important determinant of market share. They report that the total exchange fee relative to competitors is what matters and that the impact of take fees is stronger than make fees. Using an exogenous fee change, Malinova and Park (2015) show that make-take fees impact bid ask spreads, the ratio of market to limit orders and execution rates. Skjeltorp, Sojli, and Tham (2013) empirically identify the cross-sided externality between liquidity demand and supply using exogenous changes in fees and tick size. They show that the externality is on average positive, although it declines with adverse selection. Our contribution is to consider the impact of inverted fee models rather than traditional make-take fee models.

II. Institutional Details

Trading in US-listed equities is governed by Regulation National Market System (Reg NMS). Competition for trading services is intense, with activity split across 13 exchanges, approximately 40 Alternative Trading Systems (ATS) and over 200 broker-dealer internalizers. Exchanges account for approximately 62% of consolidated volume, with no single exchange venue accounting for more than 15% of consolidated volume. ATS, mainly in the form of dark pools, account for approximately 15% of consolidated volume. Broker-dealer internalizers account for the residual 23% of consolidated volume.

The market design choices made by regulators in the implementation of Reg NMS fundamentally changed the trading landscape in the US equities market. Two elements of Reg NMS are particularly relevant for our paper: the order protection rule and the minimum price increment rule (minimum tick), as they constrained the way in which exchanges could compete against each other, and against non-exchange trading venues.

Rule 610, the Order Protection Rule (OPR), requires exchanges to ensure that orders at the top-of-book at each exchange are filled before execution can occur at inferior prices on another exchange. This rule requires participants to connect to all exchanges and has promoted a proliferation of exchanges, as exchanges seek to create more limit order queues in order to give traders more opportunities to be at the front of the queue at any given price point. It also encourages order splitting across venues (Spatt, 2016). The OPR does not extend to orders away from the top of book. Traders use smart order routers (SORs) to direct order flow to both exchange and non-exchange venues to achieve best execution.

Rule 612, requires that the minimum tick size is \$0.01 for all stocks priced above \$1, and \$0.0001 for stocks priced below \$1. This rule encourages competition between traders based on speed, especially for stocks where the minimum tick size is binding (Yao and Ye, 2014). Although Rule 612 applies to both exchanges and non-exchange venues, the rule only prohibits venues from displaying, ranking or accepting orders or indications of interests in sub-pennies. It does not prohibit sub-penny trading. As a result, non-exchange venues, namely dark pools and wholesale internalizers of retail order flow, have been very successful at attracting order flow by offering price improvement within the National Best Bid and Offer (NBBO). Sub-penny trading is particularly high in stocks that are constrained by the minimum tick size. Kwan, Masulis, and McInish (2015) argue that this rule also places exchanges at a competitive disadvantage relative to non-exchange venues. However, inverted fee models enable exchanges to compete with non-exchange venues on this dimension as the finer pricing grid within the spread allows them to offer limited price improvement. We explore whether competition on this dimension is positive or negative for market quality.

Two other elements of market structure that are critical for our paper are the exchange fee models and the tick size pilot. Therefore we also explain these institutional details.

A. Exchange Fee Models

There are currently three exchange fee models offered by US equities exchanges. These are (i) a traditional make-take fee model where liquidity providers are paid a rebate and liquidity suppliers are charged a fee, (ii) an inverted fee model where liquidity demanders are paid a rebate and liquidity suppliers are charged a fee, and (iii) a fee-only model where no rebates are paid. Eight of the 13 exchanges offer a traditional make-take fee model; three offer an inverted fee model and two offer a fee-only model. Figure 1 provides details of the fee model offered by each exchange for Tape C securities. The fee models are similar for the other tapes.

Rule 610 imposes an access fee cap of \$0.003. Given that exchanges typically use fees collected for trading to pay trading rebates, the access fee cap perversely sets the maximum amount payable for rebates (Securities and Exchange Commission, 2015a). It is clear from Figure 1 that exchanges offering a traditional make-take fee model set the take fee at or close to the access fee cap. Some market participants argue that the exchange access fee creates an unlevel playing field between exchange and non-exchange venues as it encourages traders to shift their activity to non-exchange venues.

Figure 1 also shows that the magnitude of the fees/rebates used by the inverted venues is substantially lower. There is also considerably more variation in take rebate than the take fee charged by the traditional fee venues.

An important feature of the inverted venues is their ability to offer a finer pricing grid within the spread. To understand this feature, consider, for example, a stock listed on NASDAQ that currently has a best bid and ask of \$16.00 and \$16.05, respectively. Using the fees/rebates reported in Figure 1 we observe that a liquidity provider that buys one share on NASDAQ, which uses a traditional make-take fee model, will pay the bid of \$16.00 and receive a rebate of \$0.0015, for a net purchase price of \$15.9985 which is outside the quoted spread. Similarly, a liquidity demander that buys one share at the ask of \$16.05 will pay a fee of \$0.003, for a net purchase price of \$16.053 which is also outside the quoted spread. In contrast, consider the two same trades being executed on NASDAQ BX, an inverted fee venue. The liquidity provider would pay a fee of \$0.002 for a net purchase price of \$16.002, while the liquidity taker would receive a rebate of \$0.0006 for a net purchase price of \$16.0494. Both net purchase prices fall within the quoted spread, and this result holds true for sells as well. The inverted fee model therefore enables traders to obtain price improvement relative to the current National Best Bid and Offer (NBBO).

B. Tick Size Pilot Program

On August 24, 2014, the Securities & Exchange Commission (SEC) announced a joint proposal with the Financial Industry Regulatory Authority (FINRA) to hold a tick size pilot program. The program, which was approved on May 6, 2015, aims to "to study the effect of tick size on liquidity and trading of small capitalization stocks." The pilot program rules progressively came in effect over a transition period spanning the month of October 2016.

For the duration of the Tick Size Pilot Program, each eligible stock is assigned to one of three pilot test groups or to the control group following a stratified sampling procedure. Each pilot test group consists of 400 stocks, and stocks within each group are subject to different rules. Pilot stocks in the control group may be quoted and traded at any trading increment currently allowed, and serve as a baseline for the experiment. Pilot stocks in test group one are subject to a quoting requirement (quote rule) such that investors can only submit orders in \$0.05 increments, with the exception of orders priced to trade at the NBBO midpoint or entered in a retail liquidity program. Pilot stocks in test group two are subject to the same quoting requirement as test group one, but are also subject to a trading requirement (trade rule) that prohibits trades at price increments other than \$0.05, with the exception of trades at the NBBO midpoint, retail investor orders with a price improvement of at least \$0.005 and negotiated trades.[1] Finally, pilot stocks in test group three are subject to a "trade-at"

[1] This rule is directed at broker internalization systems and dark venues. In the absence of this trading requirement,

prohibition (trade-at rule) in addition to the quoting and trading requirements. Under this trade-at prohibition, trading centers cannot execute orders at a protected price level for a quantity larger than their displayed liquidity. In effect, this rule, combined with the quoting and trading requirements, prohibits dark venues from executing orders at prices other than the NBBO midpoint or with full-tick price improvement.[2]

The pilot program came into effect following a staggered implementation schedule. The pilot began on October 3 with the first five stocks of test groups one and two. An additional 100 stocks were added to pilot groups one and two on October 10. The remaining stocks for groups one and two were activated on October 17. On the same date the first five securities were added to pilot group three. An additional 100 stocks were added on October 24, and all remaining group three stocks were added on October 31.

Eligible stocks are those listed on NYSE, NYSE MKT or NASDAQ that have a market capitalization of $3 billions or less, a stock price of at least $2.00 and an average daily volume of 1 million shares or less.[3] Each stock is assigned to one of the test groups or the control group following a stratified sampling procedure.

III. Data Description and Sample Statistics

Our sample starts with the 2,399 eligible pilot and control stocks included in the tick size pilot program. For each of these pilot stocks, we obtain intraday trade and quote data for the consolidated tape and individual venue feeds from Thomson Reuters Tick History (TRTH) as provided by the Securities Industry Research Centre of Asia-Pacific (SIRCA), from September 1 to December 13, 2016. Our sample therefore begins one month before the pilot program began and ends the day before the Federal Open Market Committee announced

brokers are allowed to internalize client trades at a price improvement, and dark venues can accept quotes that offer price improvement as long as that price improvement is not guaranteed.

[2]There are 13 exceptions to the trade-at prohibition. The main ones are for block trades and retail trades that offer at least $0.005 of price improvement.

[3]See Securities and Exchange Commission (2015b) for a technical description of eligibility criteria and the stratified sampling procedure.

an increase of the Fed fund rate target range. We obtain market capitalization, share price and industry classification as of end of August 2016 from CRSP, and ETF holdings from the iShares website as of end of August 2016 which we use as a proxy for index membership. We exclude stocks that are delisted or excluded from the pilot program before the end of our sample, and exclude November 25 because it is not a full trading day. Our final sample contains 375 stocks in group one, 373 in group two, 373 in group three and 1,132 in the control group, for a total of 2,253 stocks, or 47,471 stock-day observations.

Sample statistics for our variables of interest are presented in Table 1. For the typical (median) stock in our sample, approximately 61.1% of consolidated volume during the pre-pilot period is executed on lit exchanges, and about 13.6% of that volume is executed on inverted venues. 4.9% is executed executed off-exchange at the mid point of the NBBO, and a further 31.2% is executed off-exchange at the quote or price improving (i.e. executed at or within the NBBO spread, but not at mid point). The median stock has a market capitalization of $409 million, daily trade volume of $1 million and quoted spread of $0.05. Approximately 66% of stocks are NASDAQ-listed, 30% are NYSE-listed and 5% are NYSE MKT-listed. Approximately 66% of the stocks are included in the Russell 2000 index, and 2% are included in the Russell 1000.

We next assess the factors associated with the cross-sectional dispersion in the market shares of lit venues and inverted venues during the pre-pilot period. Table 2 presents coefficient estimates from OLS regressions of the average daily lit market share and inverted venues market share of lit trading during the pre-pilot period of September 2016 on a set of variables know to affect dark trading (see, e.g. O'Hara and Ye (2011) and Buti, Consonni, Rindi, Wen, and Werner (2015)). We control for the average daily Amihud illiquidity ratio and the log of the average daily dollar trading volume in different regressions since the two variables are highly negatively correlated. We also control for the inverse of the stock price and the log market capitalization at the close on the last trading day of August 2016, and for index membership and industry fixed effects. We find that larger stocks, those that trade at a higher price per share and those that trade more have a larger share of their trades executed on lit venues. The same characteristics also increase the share of lit trading that goes to inverted venues, with the notable exception of the stock price. While stocks that have a low stock price and are thus more likely to be tick constrained trade more on dark venues, they are also more likely to trade on inverted venues.

IV. Distribution of Trade Volume Across Venues

We begin our analysis by examining how the distribution of trading volume across venues is affected when the Tick Size Pilot program is enacted. Figure 2 presents the average daily dollar volume for each tick pilot group and the control group. While the overall trade volume fluctuates through time, no across-group difference emerges during the pilot program. The pilot program does not appear to affect volume.

Figure 3 presents, for each tick pilot group and the control group, the daily mean share of trading volume for some metrics of interest from September 1 to December 13, 2016. Horizontal lines indicate dates when additional stocks are added to the pilot groups. We refer to observations before those dates as the pre-pilot period and refer to observations after as the pilot period.

Panel A presents the daily mean lit market share, which we define as the total dollar trading volume across lit venues during continuous trading (excluding opening and closing crosses) divided by total volume across all venues including all trades reported to trade reporting facilities. Clearly, the pilot groups diverge from the control group in the pilot period. Groups one and two see a reduction in their lit market share of less than 5%. This is consistent with Kwan, Masulis, and McInish (2015) and Buti, Consonni, Rindi, Wen, and Werner (2015), since an increase in the tick size pushes liquidity demanders looking for better execution prices to dark venues. Interestingly, when the tick size increases, we also find more trading occurs on inverted venues. In Panel B, which presents the daily mean share of lit trading that occurs on inverted venues, we observe a big shift in lit trading towards inverted venues. Given the large increase in tick size, traders that post liquidity may be more willing to pay a fee to post, rather than cross the spread which is at least 5 cents after the pilot implementation. Further, traders that are willing to cross the spread will try to reduce their spread by earning a rebate whenever possible. Evidence from Panels C and D suggest that the volume of price improving trades on dark venues does not significantly increase following the change in tick size. Focusing on group one, the share of dark trading occurring at the NBBO mid-quote barely increases, while the share of dark trading at NBBO (including with price improvement other than at NBBO mid-quote) decreases slightly.

In contrast to groups one and two, the lit market share for group three increases significantly by almost 10% relative to the control group. This is a direct result of the trade-at prohibition which prevents executions of undisplayed liquidity that does not improve a full tick over the NBBO, except for midpoint crosses. Consequently, the share of dark trading at the mid-quote increases by almost 20% while the share of dark trading at NBBO decreases by 20%. The share of dark trading at NBBO does not go down completely to zero because exceptions are allowed for retail orders and for block trades.[4] We also observe an even larger increase in inverted venue share of trading than for groups one and two.

We next test formally the insights from Figure 3. Table 3 presents coefficient estimates

[4]This could also be due in part to measurement noise. We classify trades as NBBO, price improving or mid-quote based on the transaction price and the NBBO from the consolidated tape at the time of the transaction. Events for which quotes are updated before the trade is reported can result in misclassification.

of the following OLS regressions:

$$\begin{aligned}\text{Lit Share}_{i,\tau} = {}& \alpha + \beta_1 \mathbf{1}_{[\text{trade-at}]_{i,\tau}} + \beta_2 \mathbf{1}_{[\text{trade}]_{i,\tau}} + \beta_3 \mathbf{1}_{[\text{quote}]_{i,\tau}} \\ & + \beta_4 \text{Lit Share}_{i,\tau-1} + \beta_5 \text{Inverted Share}_{i,\tau-1} + \gamma X_{i,\tau} + \epsilon_{i,\tau}, \qquad \text{(1a)} \\ \text{Inverted Share}_{i,\tau} = {}& \alpha + \beta_1 \mathbf{1}_{[\text{trade-at}]_{i,\tau}} + \beta_2 \mathbf{1}_{[\text{trade}]_{i,\tau}} + \beta_3 \mathbf{1}_{[\text{quote}]_{i,\tau}} \\ & + \beta_4 \text{Lit Share}_{i,\tau-1} + \beta_5 \text{Inverted Share}_{i,\tau-1} + \gamma X_{i,\tau} + \epsilon_{i,\tau} \qquad \text{(1b)}\end{aligned}$$

where $\mathbf{1}_{[\text{trade-at}]}$, $\mathbf{1}_{[\text{trade}]}$, and $\mathbf{1}_{[\text{quote}]}$ are dummy variables for the Tick Size Pilot rules. Dummies are equal to one if the rule is in effect and zero otherwise. X are controls. The trade-at rule applies to group three only, the trade rule applies to groups two and three, and the quote rule applies to all pilot tests groups. Controls include the daily VIX level, the log of the stock issue market cap (Log(Size)), index membership fixed effects, and industry fixed effects.[5] t-stastistics from robust standard errors clustered by date and stock are presented in parenthesis.

Table 3 first presents results for the full sample, which confirms the findings in Figure 3. The trade-at prohibition increases the lit share by 8.51%, and the inverted venue share by 1.28%. The larger tick size decreases the lit share by 4.06% and increases the inverted share by 7.37%. Estimates also indicate that both lit share and inverted venues share are positively related to stock size. Lit share increases with stock price, while inverted share decreases with stock price. All of those estimates are statistically and economically significant. The increase of inverted share due to the trade-at prohibition alone is 10% of its average level in the pre-pilot period, while the combined effect on inverted share due to the quote policy and the trade-at prohibition is roughly (7.37% + 1.27%≈) 8.6%, which is 63% of the pre-pilot level.

If this shift in trading towards inverted venues is driven by liquidity takers' desire to receive price improvement, we would expect to see a stronger effect for stocks that usually

[5] Our controls include control variables used in prior studies. O'Hara and Ye (2011) consider size as an important determinant in market fragmentation. Menkveld, Yueshen, and Zhu (2016) use the VIX as an important determinant of lit and dark trading.

trade at a tighter spread. To validate this hypothesis, we split our sample stocks in two subsamples based on their level of tick constraint during the pre-pilot period. We classify as high tick constraint the sample stocks that have a time-weighted average quoted spread below the median of $0.05 and classify the other sample stocks as low tick constraint.

Results from this subsample analysis paint a clearer picture of the dynamics at play. The effect of the trade-at prohibition on the inverted share is only significant in high tick constraint stocks. Liquidity providers use inverted venues as a substitute to sub-penny trading dark venues to offer price improvement within the tick. This is most pronounced among stocks that are likely to be tick constrained and when liquidity providers are prohibited from doing so on dark venues. In contrast, the effect of the quote rule on the inverted share is quite similar in both samples, suggesting that the mechanical increase in inverted trading due to the rule change does not depend on the spread of the stock. The coefficient estimate on the quote rule is significant in both subsamples but larger in high tick constraint stocks, which is not surprising as those stocks are now constrained most of the time under the larger tick size. The effect of stock price on inverted share is likely due to the mechanical link between relative tick size and stock price, and the estimate becomes insignificant in the split sample .

We only observe equilibrium outcomes that arise from the interaction of liquidity suppliers with liquidity takers. Figure 4 shows how the liquidity supply varies over time on the three inverted fee venues. Panels A to C present the daily average relative depth at the NBBO for each tick pilot group and the control group on BATS-Y, NASDAQ BX and EDGA respectively. We define the relative depth as the time-weighted average quantity posted at the NBBO, divided by the aggregate quantity posted at the NBBO across all lit venues. While there does not appear to be significant differences among the pilot groups, the average depth decreases for BATS-Y and EDGA while it increases for NASDAQ BX for all pilot groups relative to the control group. Nonetheless, those changes are small in magnitude. Panels D to E present the daily average fraction of time that each exchange is quoting at the NBBO. These measures change in a similar way for all pilot groups, while it remains constant for the control group. BATS-Y and NASDAQ BX go from quoting at NBBO around 20% of the time to above 50% of the time, while EDGA goes from 10% to over 30%. This shift is quite significant considering that these venues are offering effective price improvement when at NBBO, due to the rebate being paid to liquidity demanders.

Figure 5 shows how the routing decisions of liquidity takers varies over time. Panels A to C show for each group the likelihood that a given lit trade is executed on an inverted venue unconditionally, conditional on having at least one inverted venue at NBBO and conditional on having all three inverted venues at NBBO, respectively. Conditional probabilities are estimated at the group level for each pilot group and the control group. Clearly, these venues do attract liquidity takers as they receive over 45% of trades when at least one of them is at NBBO, and over 50% of trades when they all are at NBBO. These fractions increase for all pilot groups after the pilot is enacted, and much more so for group three which is subject to the trade-at prohibition and which has more lit trading and a larger share of lit trading going to inverted venues.

Panels D to F decompose the contribution of each inverted fee venue to the conditional probability of Panel C. This decomposition presents two interesting patterns. First, the pilot increases the probability of execution for all group on BATS-Y and NASDAQ BX, but decreases it slightly on EDGA. This effect is consistent with there being more liquidity on BATS-Y and NASDAQ BX. Given that BATS-Y and NASDAQ BX offer larger rebates, they should attract more trades when the quantity on offer is large enough to satisfy the order volume. Second, the increase in probability of execution in group three that we observe in Panels A to C appears to come exclusively from NASDAQ BX. One possible explanation is that the trade-at prohibition affects the type of traders that are sending marketable orders to inverted venues. According to the base fee structure presented in Figure 1, rebates offered by BATS-Y are larger than those offered by NASDAQ BX. However, fee structures are quite complex, and this generalization does not hold when taking into account tier pricing. When taking into account the tier pricing for liquidity takers on NASDAQ BX, the rebate offered to very large traders is larger on that venue than on BATS-Y.[6]

V. Inverted Venues and Market Quality

Having established that the trade-at prohibition imposed by the Tick Size Pilot Program affects both the lit market and the inverted venue market share, we now turn our attention to changes in market quality around the initiation of the program. We study market quality along three dimensions: price efficiency, liquidity and volatility.

In order to disentangle the effects of the increase in lit trading from those due to the increase in inverted venues trading, we adopt an instrumented variables approach to identify this causal relation.

Specifically, we run the following IV-2SLS regression:

$$\begin{aligned} Y_{i,\tau} = \alpha &+ \beta_1 \widehat{\text{Lit Share}}_{i,\tau} + \beta_2 \widehat{\text{Inverted Share}}_{i,\tau} + \delta_1 \mathbf{1}_{[\text{trade}]_{i,\tau}} \\ &+ \delta_2 \mathbf{1}_{[\text{quote}]_{i,\tau}} + \gamma X_{i,\tau} + \eta_{i,\tau}, \end{aligned} \tag{2}$$

where $Y_{i,\tau}$ is a market quality measure. $\widehat{\text{Lit Share}}_{i,\tau}$ and $\widehat{\text{Inverted Share}}_{i,\tau}$ are the fitted market shares of lit trading and inverted venue trading from the first stage regressions, which use the specifications defined in Equations 1a and 1b. Although the change in minimum tick size may mechanically affect our market quality measures, the trade-at prohibition should not. The prohibition is a pre-determined market wide exogenous shock that redistributes market share across trading venues. Importantly, the carefully designed experimental nature of this event guarantees that this shock is unrelated to the fundamental information environment

[6] Both BATS-Y and NASDAQ BX offer tier pricing for fees and rebates based on total monthly trade volume. The rebate per share on BATS-Y varies between \$0.0010 and \$0.0015, while it varies between \$0.0006 and \$0.0016 on NASDAQ BX. Since the actual rebate affects the effective price improvement, tier pricing can affect the ranking of preferences for a venue over another by different traders.

of a stock. Therefore, the prohibition should only affect market quality through a shift in trading activity between various venues.

We argue that because of these characteristics, the imposition of the trade-at prohibition is an ideal instrument to study the causal relation between inverted venue trading and market quality. The instrumental variables approach allows us to tackle the problem of endogeneity in trading allocation regarding market conditions (see Buti, Rindi, and Werner (2011), and Comerton-Forde and Putniņš (2015)). We also include lagged lit market share and market share of inverted venues as additional instrument variables. Adding lagged variables is an established practice in the literature (e.g. Sarkar and Schwartz (2009) and Foley and Putniņš (2016)) and in our case allows us to instrument both the change in lit trading and in inverted venue trading using the rule change.

A. Price efficiency

We begin our analysis of market quality by looking at market efficiency. Following O'Hara and Ye (2011), we use the absolute difference between one and the variance ratio to proxy for information efficiency:

$$\text{Price efficiency}_{i,\tau} = \left| 1 - \frac{\sigma^2_{1min;i,\tau}}{4\sigma^2_{15sec;i,\tau}} \right|$$

where $\sigma^2_{15sec;i,\tau}$ and $\sigma^2_{1min;i,\tau}$ are the daily variances of NBBO mid-quote returns for stock i on day τ sampled at 15 seconds and one minute intervals respectively.

Table 4 presents coefficient estimates of our IV-2SLS regression of price efficiency. t-stastistics from robust standard errors clustered by date and stock are presented in parenthesis. We first test the validity of our instrument variables. The Kleibergen-Paap rank LM test rejects the null hypothesis that instruments are under-identified in the full sample and in both sub samples, while Hansen J's statistic is not significant in any sample, alleviating concerns that our instrumented variables are over-identified. Taken together, these tests suggest that our instruments are valid.

Coefficient estimates on lit share are all positive and statistically significantly different for zero, suggesting that an increase in lit trading is harmful for price efficiency. The effect is about 72% larger for stocks that are less tick constrained. This result is consistent with Buti, Rindi, and Werner (2011) and Foley and Putniņš (2016), who find that dark trading can improve market efficiency.

Turning our attention to inverted venues share of lit trading, the coefficient in the full sample is negative and significant, indicating that trading on inverted venues increases price efficiency. From the subsample analysis, we see that this result is driven by stocks that are more tick constrained. This is consistent with our interpretation that inverted venues are used for competing in liquidity provision, since they allow price improvement when the NBBO is tick constrained.

The coefficients on the quote rule dummy also warrant some discussion. Looking at the full sample, it is barely significant, which suggests that increasing the minimum price increment has almost no effect on price efficiency. However, looking at the subsample analysis, we see that it does, but the effect depends on the spread of the stock. For stocks that are not tick constrained, increasing the tick size improves price efficiency. This is consistent with O'Hara, Saar, and Zhong (2016), who find that depth increases when the spread of a stock is tick constrained. However, for stocks that are tick constrained, coarsening the pricing grid reduces price efficiency. Finally, consistent with prior literature, controls also confirm that larger stocks offer better price efficiency.

B. Liquidity

We now shift our focus to liquidity. Theory suggests that a finer pricing grid encourages competition among liquidity providers (e.g., Foucault and Menkveld (2008), and Werner, Wen, Rindi, Consonni, and Buti (2015)). Since rebates incentivize liquidity takers to route their market orders to inverted venues, liquidity providers' limit orders on those venues are more likely to get executed. This means liquidity providers can expect a better execution rate by paying a small fee. When the tick size increases, routing orders to inverted venues becomes more attractive, as price improving by a full tick on a traditional venue becomes more costly. If the increasing market share of inverted venues reflects increased competition in liquidity supply, we should observe changes in liquidity measures.

We repeat the previous exercise, using the IV-2SLS specification described in Equation 2 to assess the effect of lit trading and inverted venue trading on liquidity. We use the log of the daily Amihud illiquidity ratio as our main measure of liquidity. Estimation results are presented in Table 5.

Our results indicate that increases in the inverted share increases liquidity as the coefficient is negative and statistically significant. On the other hand, the coefficient on the quote rule dummy suggests that increasing the minimum tick size is harmful to liquidity. Lit share does not appear to affect liquidity significantly. The adjusted R^2 indicates that our specification explains about 63% of the variation in liquidity. Controls confirm our expectation that larger stocks are more liquid, and that stocks with lower share price are less liquid.

We diverge from the usual practice of using the Amihud ratio in levels for two reasons. First, our sample is composed of small illiquid stocks, and the distribution of Amihud ratio observations is highly skewed, as is apparent from summary statistics presented in Table 1. Using the Amihud ratio in levels would raise the concern that results are driven by extreme values, while using the log alleviates such concerns. Second, since our sample stocks are very illiquid, we expect rule changes to affect their liquidity measure by some orders of magnitude, which the log transformation is better able to capture. For robustness and consistency with prior literature, we also do our analysis with the Amihud ratio in levels, and results are consistent with those in logs, however the R^2 is much smaller, and the coefficient lit share is significant, indicating a potential improvement in liquidity.

C. Volatility

Our results on liquidity support the notion the the tick pilot program affected competition for liquidity provision. More liquidity provision is associated with better price discovery and more stable prices, leading towards a less volatile market (see Hagströmer and Norden (2013)). However, some traders may use the finer pricing grid offered by inverted venues to step ahead of queues on other venues at a small cost. Traders becomes reluctant to provide liquidity in the presence of stepping-ahead risk (see Buti, Consonni, Rindi, Wen, and Werner (2015)), or increasingly randomize their order placement strategies (see Yang and Zhu (2016)). This slows down the price discovery, adding noise to the pricing process.

We next test empirically which effect dominates by looking at intraday volatility estimated from high frequency returns. Table 6 presents coefficient estimates of regressions of volatility estimated from 15-seconds and 1-minute mid-quote returns using the IV-2SLS specification described in Equation 2 . While estimates for lit market share are not significant, estimates for inverted venues share are negative and significant, indicating that more inverted trading reduces noise in the price discovery process. In contrast, both the quote rule and the trade rule significantly increase volatility. Controls confirm our expectation that larger stocks are less volatile, and that aggregate market volatility is positively related to stock-specific volatility.

Taken together, our results suggest that market quality increases with inverted venues share in market efficiency, liquidity and volatility. Lit trading is harmful to price efficiency, which is consistent with findings from Comerton-Forde and Putniņš (2015) who find that low levels of dark trading are beneficial for price efficiency. In the next section, we investigate competition for liquidity provision as one possible channel to explain the positive effects of trading on inverted venues.

VI. Liquidity Competition on Inverted Venues

Results presented in the last section indicate that trading on inverted venues is beneficial for market quality along many dimensions. In this section, we use SEC Rule 605 data from all lit venues and order-level data from two NASDAQ exchanges to investigate competition for liquidity provision as a potential channel for this improvement in market quality.

A. Rule 605

The SEC Rule 605, adopted in 2000, requires market centers to publicly disclose a basket of market execution quality metrics, per stock, on a monthly basis. This data has been used in the literature to assess the impact of the Rule 605 (Zhao and Chung (2007)) and to study some aspects of market quality (e.g. Goyenko, Holden, and Trzcinka (2009) and O'Hara and Ye (2011)).

We obtain the Rule 605 data for all lit venues from September to November 2016. Since Rule 605 data is published monthly and the Tick Size Pilot Program was phased in progressively over the course of October 2016, we focus our analysis on changes between September and November along four key metrics: the cancellation rate and the execution rate, measured for top-of-book quotes (at-the-quote orders), and the effective and realized spreads for market orders.

We use the following regression to disentangle the effect of each pilot policy on the change of order activities:

$$\Delta_{i,e} = \alpha + \delta_1 \mathbf{1}_{[\text{trade-at}]_{i,e}} + \delta_2 \mathbf{1}_{[\text{trade}]_{i,e}} + \delta_3 \mathbf{1}_{[\text{quote}]_{i,e}} + \epsilon_{i,e}, \tag{3}$$

where $\Delta_{i,e}$ represents the change in the order activity (e.g., the cancellation rate, execution rate or spread) after the pilot implementation for stock i on venue e. Changes in monthly market quality measures are defined as the difference between the November and September 2016 observations. To compare the pilot impact on different types of venues, we run the above regression for inverted and traditional venues separately. Furthermore, we also conduct the above regression on each of the three inverted venues: BATS-Y, NASDAQ BX, and EDGA.

Table 7 presents the results of the analysis of the Rule 605 data. We first look at the cancellation rate and execution rate on inverted venues. The first two columns of Panel A present coefficient estimates for regressions of changes in cancellation rate and execution rate, respectively, for all inverted venues. We find that the pilot significantly affects order activity on inverted venues. The increase in the minimum tick increment lowers the cancellation rate by 1.31%, while the trade-at prohibition lowers it by a further 1.75%. These effects are statistically significant, and economically large given that in the pre-pilot period only 6.67% went uncanceled on average. The trade rule has the opposite effect: it increases the cancellation rate by 0.89%, but the estimate is barely statistically significant despite the large sample size. Since an order is either canceled or executed, we expect the execution rate to be strongly negatively correlated with the cancellation rate, and the results are consistent with this. The quote rule increases the execution rate on inverted venues by 0.68%, the trade-at rule by a further 1.46% while the trade rule lowers it by 0.67%. These effects are all economically large with respect to the pre-pilot average execution rate of 4.57%.

The next six columns of Panel A present results for regressions estimated on each inverted venue separately. We find that the adoption of a larger tick size universally reduces the cancellation rate (by 0.97% to 1.65%). Interestingly, the impact of the trade-at prohibition varies across venues. The most pronounced impact is on NASDAQ BX with a significant 3.52% drop in cancellation rate, more than three times the impact on BATS-Y. Furthermore, the prohibition has almost no measurable impact on EDGA. Looking at the execution rate, we also find that NASDAQ BX is most affected by the quote policy and the trade-at prohibition. After the implementation of the quote policy, the execution rate on NASDAQ BX significantly increases by 1.63%, about 1.5 times more than on BATS-Y. As for the trade-at prohibition, the execution rate on NASDAQ BX increases by 3.18%, about three times more than on BATS-

Y. Neither the quote policy nor the trade-at prohibition affects the execution rate on EDGA. This breakdown of the order activity among inverted venues is consistent with our previous observation that the pilot program disproportionately impacts NASDAQ BX (see Figures 4 and 5).

In addition to order activity, Rule 605 data also allows us to study trading costs. Panel B presents regression results of changes in the effective spread and the realized spread (for marketable orders) on pilot policies. Results are first presented for all inverted venues and then for each inverted venue separately. Effective spread is calculated as double the difference between the execution price and the NBBO midpoint the time of order receipt. Realized spread is calculated as double the difference between the execution price and the NBBO midpoint five minutes after the execution. We find that an increase in tick size increases the effective spread and the realized spread for inverted venues in aggregate. This effect if driven by NASDAQ BX and is not observed on BATS-Y or EDGA. The increase in realized spread implies that the profit margin for providing liquidity on NASDAQ BX increases after the quote policy is implemented. This suggests that either informed traders are increasingly using limit orders on NASDAQ BX or that uninformed marketable orders are increasingly routed there, or both.

Finally, Panel C presents the analysis of changes in the four metrics from the Rule 605 data on the traditional venues. For completeness, we also present results for NASDAQ separately as this exchange is the focus of more analysis in the next section. Looking at the first five columns, we see that the tick pilot program has little impact on traditional venues. The only statistically significant effect is an increase in the effective spread due to the trade rule. Looking at NASDAQ specifically, we notice a large and statistically significant reduction in the cancellation rate. In contrast to inverted venues, this decrease in the cancellation rate is not accompanied by a significant increase in the execution rate.

Results from our Rule 605 analysis indicate that traders become more aggressive in liquidity provision on inverted venues after the pilot implementation. Their orders are canceled less and executed more. The aggressiveness is mostly concentrated on NASDAQ BX. We do not find similar patterns for orders submitted to traditional venues.

B. Order-level data

Having established that competition for liquidity provision appears to increase on inverted venues after the implementation of trading rules that increase their market share, we now take a closer look at changes to high-frequency activities on lit venues following the pilot. Since the pilot has the most impact on NASDAQ BX, we now focus on NASDAQ BX and its traditional counterpart, the main NASDAQ exchange, for this more granular analysis.[7] We use order-level data for both venues from NASDAQ TotalView-ITCH, which contains order-level messages with nanosecond timestamps. We obtain the daily ITCH feeds from September 1 to December 13, 2016.

We first study the message traffic, which is the daily number of messages disseminated in the ITCH feed regarding each stock. Following Hendershott, Jones, and Menkveld (2011), we also use a trade-adjusted measure of message traffic. The two measures we use are the logarithm of daily number of message plus one ($Log(Messages)$) and the number of messages per \$100 of trading value ($Messages/TradeValue$). Using trade-adjusted measures causes issues of missing observations in our sample since we have many stock/day observations for which there are no trades, and very few messages, if any. Since these are more likely to occur on NASDAQ BX and during the pre-pilot period or within control group stocks, using these measures at a daily level would cause a selection bias. We therefore estimate these measures for each stock during the pre-pilot period of September 2016 and during the pilot period of November 1 to December 13, 2016. We estimate $Log(Messages)$ using the average daily number of messages for each stock during each period. We estimates $Messages/TradeValue$ using the total number of messages and the total trade value for

[7] In addition, the NASDAQ venues are the only ones for which we are able to obtain order-level data.

each stock during each period. We only keep messages and trades that occur during regular trading hours, excluding the opening and closing crosses. To mitigate the impact of outliers, we winsorize the top and bottom 1% of changes for each measure and each venue.

Using the same approach as in the previous section with Rule 605 data, we regress changes in these measures on rule dummies. Coefficient estimates for both venues are presented in the first two columns of Table 8. Looking first at NASDAQ BX (Panel A), we find that the quote rule increases Log(Messages) by about $0.816/6.01 \approx 14\%$ over the pre-pilot mean. This effect is statistically significant and economically large considering that the overall market share of inverted venues (relative to total trading, including dark) increases by only $(1 - .03900) \times (1 + .07241) - 1 \approx 3.06\%$ according to Table 3. In contrast, following the trade-at prohibition which increases the overall market share of inverted venues by 9.81%, we observe no significant change in $Log(Messages)$. This is quite surprising given the increase in the level of trading on the venue. Indeed, we document significant decreases in $Messages/TradeValue$ due to the trade-at prohibition, but a significant increase due to the increase in tick size. Following the interpretation that Hendershott, Jones, and Menkveld (2011) makes of these measures, this indicates that the quote rule increases the proportion of algorithmic trading activity, while the trade-at prohibition reduces it.

Looking next at the main NASDAQ venue (Panel B), we find conflicting effects related to the trade-at prohibition, which increases $Log(Messages)$, but decreases $Messages/TradeValue$. This is consistent with an increase in total activity on NASDAQ, but trade activity increases even more. We find a statistically significant decrease in Log(Messages) associated with the quote rule. This is consistent with the notion that trading on lit venues decreases with the increase in tick size.

The increased traffic to NASDAQ BX, an inverted venue, is consistent with our Rule 605 analysis. There is more order activity on inverted venues after the pilot program is enacted. The lower cancellation rate and higher execution rate on inverted venues suggests that those orders are competing for liquidity provision. Given we do not observe a similar pattern on traditional venues, or in some instances we even observe the opposite pattern, we attribute this change to traders increasingly competing for liquidity provision.

We next apply survival (or duration) analysis to study the changes in time-to-cancellation and time-to-execution for a limit order. More specifically, we use the Cox model with the following specification:

$$\log h_{i,t} = const + \theta_i \mathbf{1}_{[\text{After}]_i} + BookStatus_{i,t} + \epsilon_{i,t}, \tag{4}$$

where $h_{i,t}$ is the hazard rate for cancellation and execution events for stock i in period t, and $\mathbf{1}_{[\text{After}]_i}$ is a dummy variable that is equal to one for post-event observations and zero otherwise. In addition, we control for the distance between the order price and the prevailing quote (on the corresponding venue) normalized by the mid-quote, and the same side and opposite side depth in $BookStatus_{i,t}$. For cancellation estimates, the execution event is assumed to be an exogenous censoring event, while for execution, the cancellation event is the censoring event.

After the above step, we collect the estimated θ_i, winsorize the top and bottom 1% to mitigate the effect of outliers, then estimate the following regression to disentangle the pilot impact on cancellation and execution hazard rates.

$$\exp(\theta_i) - 1 = \alpha + \delta_1 \mathbf{1}_{[\text{trade-at}]_i} + \delta_2 \mathbf{1}_{[\text{trade}]_i} + \delta_3 \mathbf{1}_{[\text{quote}]_i} + \epsilon_i. \tag{5}$$

The transformation $\exp(\theta_i) - 1$ provides the percentage change in expected cancellation or execution hazard rate between the pre- and post-event periods.

The last two columns of Table 8 includes the results of this analysis. We find that the increase in the minimum tick size significantly increases the cancellation hazard rate of orders on NASDAQ BX. This increase is about 21%. However, we do not find other pilot policies to have additional significant impact on the cancellation hazard rate. Despite the fact that orders become more "fleeting" following the quote rule change, we find that orders are executed faster. We show the quote policy increases the execution hazard rate by 44%, and the trade-at prohibition contributes to an additional increase of 66%. This increase is both statistically and economically significant. The joint effect of the quote policy and trade-at prohibition implies that orders on NASDAQ BX are executed over 100% faster than they were before the pilot.

On the traditional NASDAQ venue, we find that the implementation of the quote rule significantly decreases the cancellation hazard rate of an order by 22%, while the trade-at prohibition significantly increases the cancellation rate by 5%. As for the execution hazard rate, we find that both the quote and trade policies significantly increases the time-to-execution rate by 36% and 25% respectively. However, the trade-at prohibition does not have any impact on orders submitted to NASDAQ. Our findings are consistent with O'Hara, Saar, and Zhong (2016), who find that the cancellation hazard rate decreases and execution hazard rate increases for stocks with large relative tick sizes.

Together, the results from Rule 605 and order-level data suggest that the trade-at prohibition causes an increase in competition for liquidity provision on inverted venues in general and NASDAQ BX in particular.

VII. Policy implications

This paper presents evidence that trading on inverted fee venues is beneficial to market quality because it attracts competition for liquidity provision. The trade-at component of the Tick Size Pilot aimed to prevent trades from shifting to dark venues in the presence of a wider tick size. The shift to inverted venues is an unintended outcome, and highlights the importance for regulators to consider the interaction of different aspects of market structure when making policy changes. In this section, we study the effect on market quality of the combination of rule changes introduced by the Tick Size Pilot Program.

From Table 3 which we introduce in Section IV, we know that lit share and inverted share

are both affected by the increase in the minimum tick size and the trade-at prohibition, albeit differently. The increase in tick size reduces lit trading but increases the share of lit trading that occurs on inverted venues, and the latter is more important than the former (7.28% vs -3.8%). The imposition of the trade-at prohibition increases both the lit share of volume (8.38%) and inverted share of lit volume (1.34%).

To assess the impact of the different trading rules on market quality, Table 9 presents OLS regressions estimates of price efficiency, liquidity and volatility measures on rules dummies and controls. The net effect of the trade-at prohibition appears to be negative as price efficiency decreases. Consistent with results from Table 5 that show a positive effect on liquidity for inverted share, the coefficient on the trade-at dummy indicates an improvement in liquidity. However, the effect is not statistically significant, nor is the effect on volatility. The net effect of increasing the minimum quote increment is to improve price efficiency. On the flip side, liquidity decreases. All these effects are statistically significant. Finally, the imposition of the trading requirement does not exhibit any statistically significant impact on our market quality measures.

Results from this analysis suggest that rules have no effect on volatility, which goes against our results from Table 6. Taking a closer look, we see that while not statistically significant, coefficients on all rules dummies are positive, which is consistent with those previous results given that, for the trade-at dummy, the negative effect of lit share dominates the positive of inverted venues share. Nonetheless, we do not have a satisfying answer as to why this specification lacks statistical significance.

VIII. Conclusion

Inverted fee models, and make-take fees more generally, are controversial. Our results are timely, as the impact of these fee models are receiving increased market and regulatory attention. In December 2014, the NYSE proposed a 'grand bargain' which included a ban on make-take and inverted fee models. In response BATS proposed a significant reduction in access fees, but opposed a ban on rebates. NASDAQ conducted a limited pilot study to test the premise that high access fees discourage the use of displayed limit orders. Finally, the SEC Market Structure Advisory Committee recently recommended that the SEC undertake an Access Fee Pilot.

Careful evaluation of the benefits and costs of exchange fee models is warranted. On the positive side, traditional and inverted make-take fee models provide a significant competitive tool for exchanges to compete against each other. The inverted fee model also enables them to compete with non-exchange venues by enabling them to compete on a finer pricing grid within the spread and offering price improvement. This in turn should increase competition between liquidity providers, improving price efficiency and liquidity (Biais, Bisiere, and Spatt, 2010). Our results provide support for the view that inverted pricing models increase pricing efficiency through increased competition for liquidity provision. Make-take models also narrow the quoted spread as the rebate subsidizes the displayed spread. Our results suggest that this may only be due to sub-optimal tick sizes.

On the downside, make-take fee models significantly increase the complexity of the market. The market has become more fragmented because each exchange operator has created multiple trading venues with different fee models. New order types have also proliferated as exchanges seek to provide opportunities for traders to capture rebates and avoid fees. They also distort prices because they are quoted without adjusting for fees (Harris, 2013). We intend to explore the impact of these issues in future research.

Make-take fee models also exacerbate agency conflicts between brokers that charge a flat commission and their clients (for details, see Battalio, Corwin, and Jennings (2016)). While brokers are required to seek best execution for their clients, avoiding inverted venues for providing liquidity while favoring them for demanding it is preferable from the perspective of a broker who wants to maximize rebates and minimize fees. From the perspective of clients, providing liquidity on inverted venues would be optimal as it offers a higher execution probability.

This agency problem generates unequal access to inverted venues. On one side, sophisticated traders such as high frequency traders, who are able to send their orders directly to trading venues, enjoy the finer pricing grid offered by inverted venues. On the other side, unsophisticated traders are prevented from providing liquidity on those platforms. Sophisticated traders can take advantage of this unequal access and impose adverse selection risk on unsophisticated traders. They can step ahead of unsophisticated traders (with a small cost) by posting orders on the inverted venue when they find it is favorable to provide liquidity while leaving unsophisticated traders to provide liquidity when it is not. As this increases the adverse selection cost to unsophisticated traders, they will only be willing to provide liquidity with larger spreads. As a consequence, liquidity and market efficiency is reduced. This is also an issue we intend to explore as we extend our analysis further.

The finer pricing grid offered by inverted fee venues is a feature they share with many dark venues, and our results suggests that this finer pricing grid can partially account for the positive effects of dark trading documented by Buti, Consonni, Rindi, Wen, and Werner (2015). On the other hand, since the net effect of the trade-at prohibition is negative, something is lost by pushing dark volume into the light. Whether this is due to increased transparency or to order segmentation resulting from rule exceptions remains an open question.

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Figure 1. Fees and Rebates for Tape C Stocks

This figure presents the standard exchange fee and rebate schedule, in \$ per share, for Tape C stocks (NASDAQ-listed stocks) priced above \$1 as at 21 December 2016. Positive numbers (red solid bars) indicate a fee while negative numbers (green hatched bars) indicate a rebate. The three venues with an inverted fee structure are BATS-Y, NASDAQ BX and EDGA. Data is from each venue's respective website.

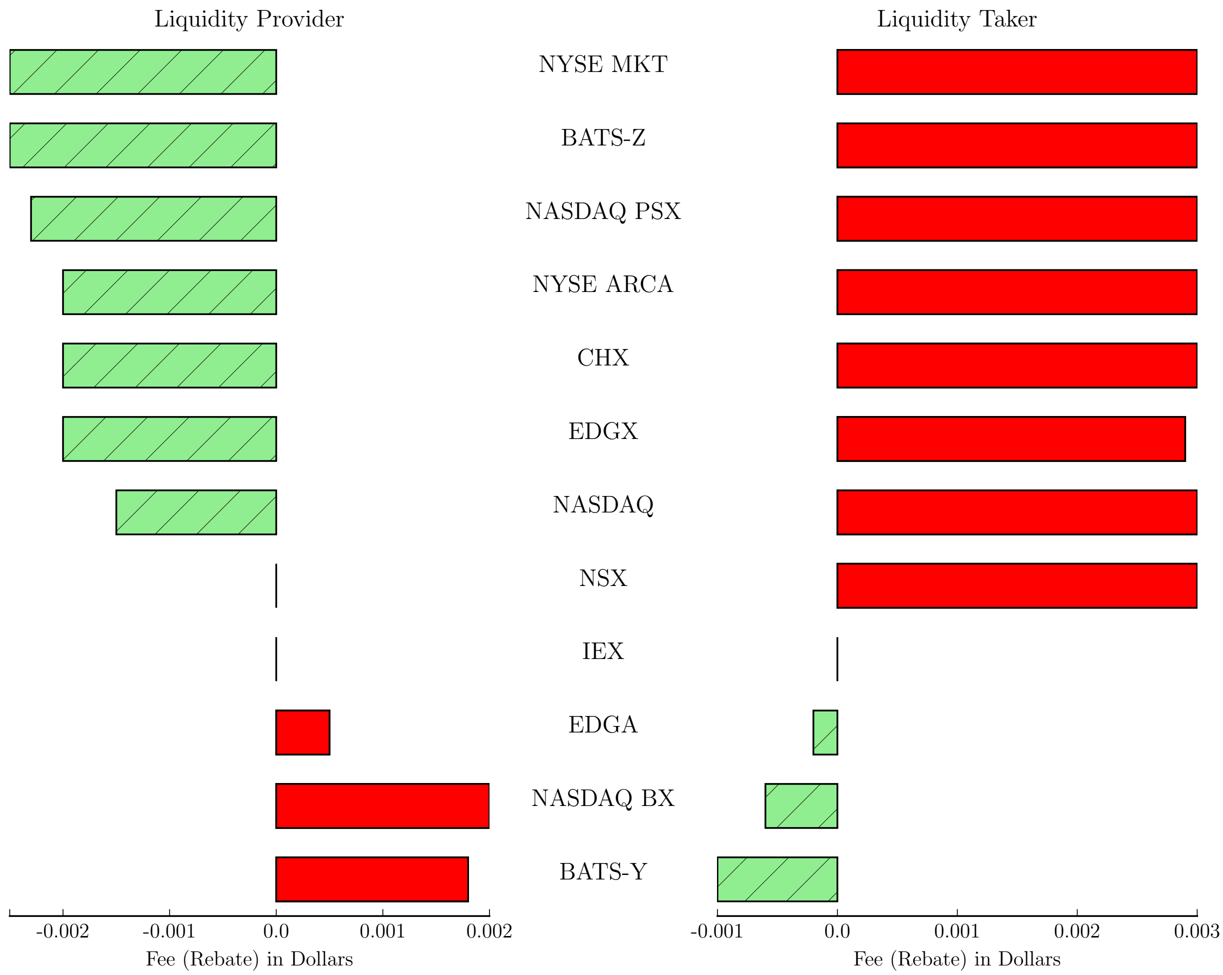

Figure 2. Daily Mean Dollar Volume

This figure shows the daily mean consolidated dollar volume from lit and dark venues. The means are presented separately for group one (green squares), group two (red triangles), group three (blue circles) and the control group (black crosses). The shaded areas are pointwise 95% confidence bands around the daily means. The horizontal lines indicate when stocks are added to the pilot groups. Five stocks were added to groups one and two at the first line, a further 100 stocks were added at the second line and all remaining group one and two stocks are added at the third line. Five group three stocks are also added at the third line, a further 100 group three stocks were added at the fourth line and the remaining group three stocks were added at the fifth line. The dark shaded band indicates the U.S. election week. The sample period is September 1 to December 13, 2016.

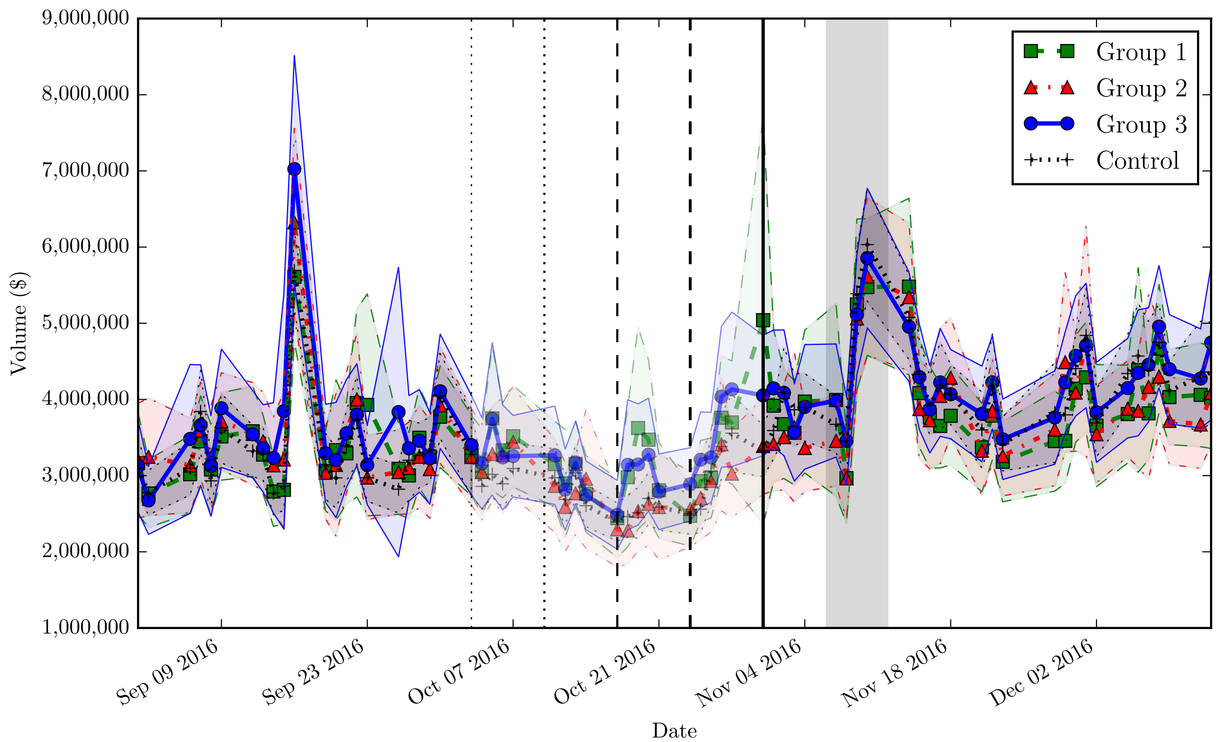

Figure 3. Daily Mean Trading Share

This figure shows the daily mean of the lit market share of continuous trading (Panel A), the inverted venues market share of lit trading (Panel B), the share of dark trading executed at the NBBO midquote (Panel C) and the share of non-midquote dark tading that is at or price improving over the NBBO (Panel D). All values are in percent. The means are presented separately for group one (green squares), group two (red triangles), group three (blue circles) and the control group (black crosses). The horizontal lines indicate when stocks are added to the pilot groups. Five stocks were added to groups one and two at the first line, a further 100 stocks were added at the second line and all remaining group one and two stocks are added at the third line. Five group three stocks are also added at the third line, a further 100 group three stocks were added at the fourth line and the remaining group three stocks were added at the fifth line. The dark shaded band indicates the U.S. election week. The sample period is September 1 to December 13, 2016.

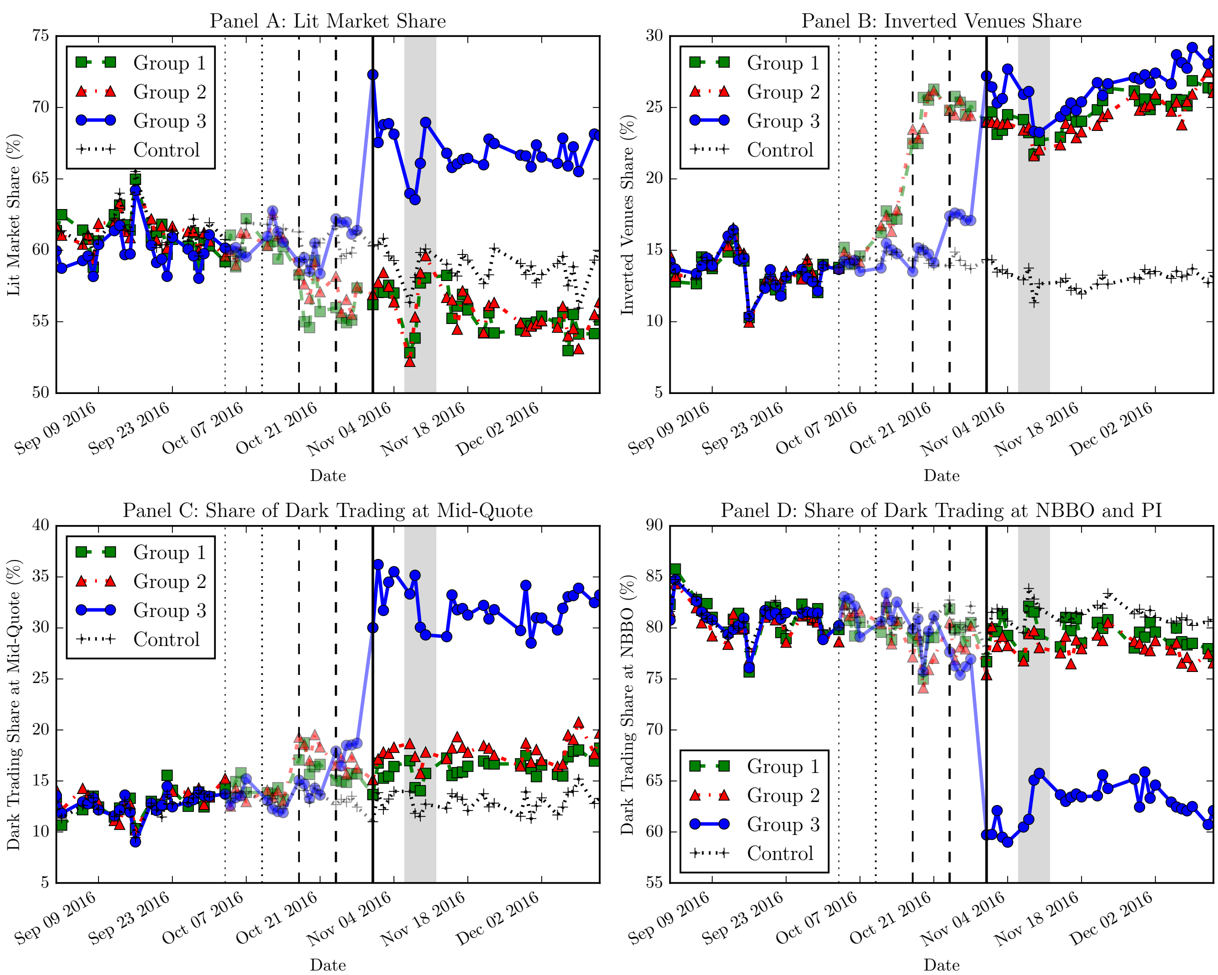

Figure 4. Inverted Venues Quotes at NBBO

This figure shows the daily mean relative depth at NBBO for BATS-Y, NASDAQ BX and EDGA (Panels A, B and C, respectively) and the daily mean fraction of time at NBBO for those venues (Panels D, E and F, respectively). The relative depth is defined as the time-weighted average of the quantity at NBBO on inverted venues, divided by the total quantity at NBBO on all lit venues. All values are in percent. The means are presented separately for group one (green squares), group two (red triangles), group three (blue circles) and the control group (black crosses). The horizontal lines indicate when stocks are added to the pilot groups. Five stocks were added to groups one and two at the first line, a further 100 stocks were added at the second line and all remaining group one and two stocks are added at the third line. Five group three stocks are also added at the third line, a further 100 group three stocks were added at the fourth line and the remaining group three stocks were added at the fifth line. The dark shaded band indicates the U.S. election week. The sample period is September 1 to December 13, 2016.

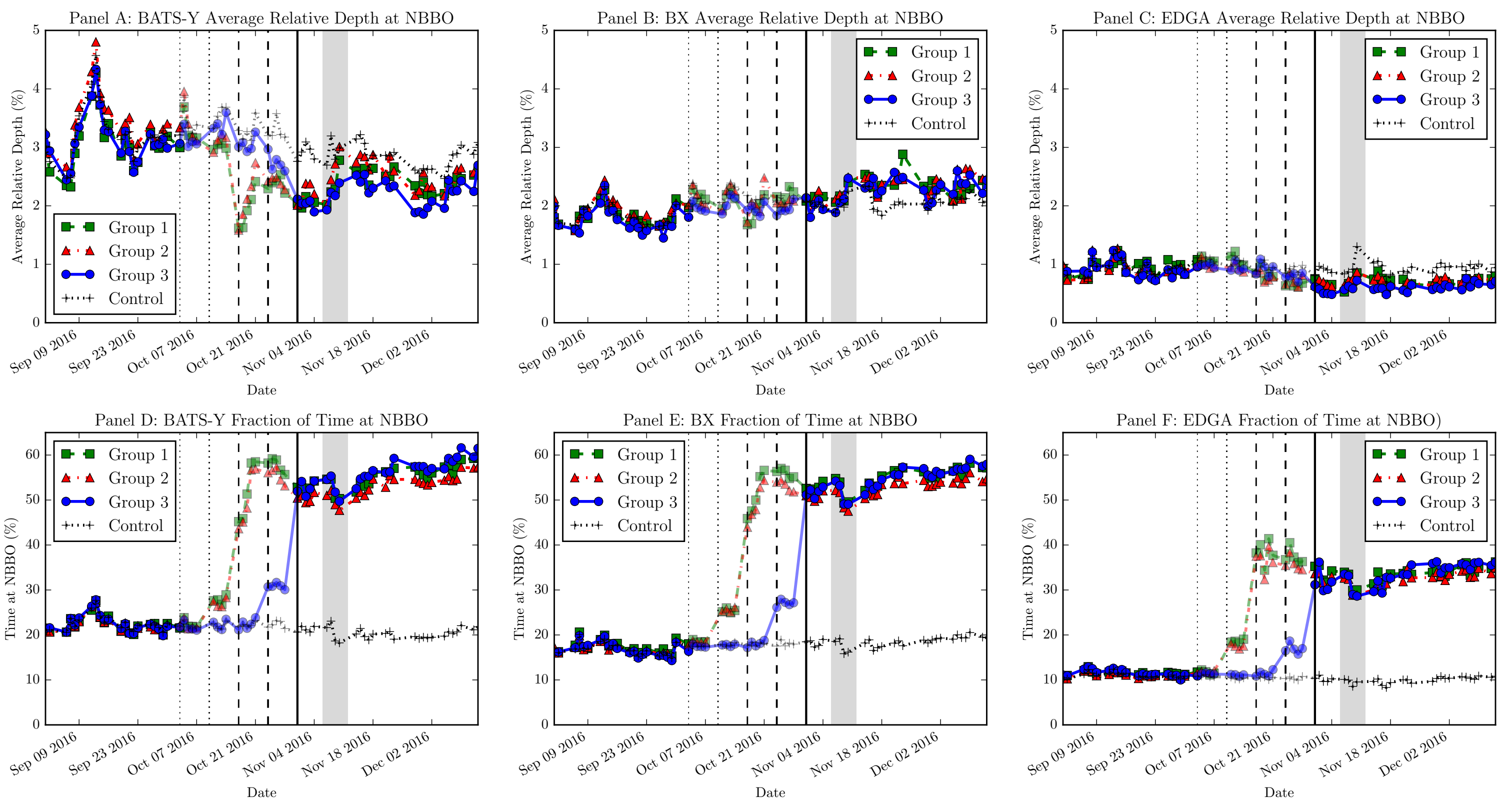

Figure 5. Inverted Venues Execution Probabilities

This figure shows the daily unconditional probability that a lit trade is executed on an inverted venue (Panel A), the probability that it is executed on an inverted venue conditional on at least one inverted venue being at NBBO (Panel B), the probability conditional on all inverted venues being at NBBO (Panel C), and the probabilities that a trade occurs on a specific inverted venue conditional on all inverted venues being at NBBO (Panels D, E and F). All values are in percent. The probabilities are presented separately for group one (green squares), group two (red triangles), group three (blue circles) and the control group (black crosses). The horizontal lines indicate when stocks are added to the pilot groups. Five stocks were added to groups one and two at the first line, a further 100 stocks were added at the second line and all remaining group one and two stocks are added at the third line. Five group three stocks are also added at the third line, a further 100 group three stocks were added at the fourth line and the remaining group three stocks were added at the fifth line. The dark shaded band indicates the U.S. election week. The sample period is September 1 to December 13, 2016.

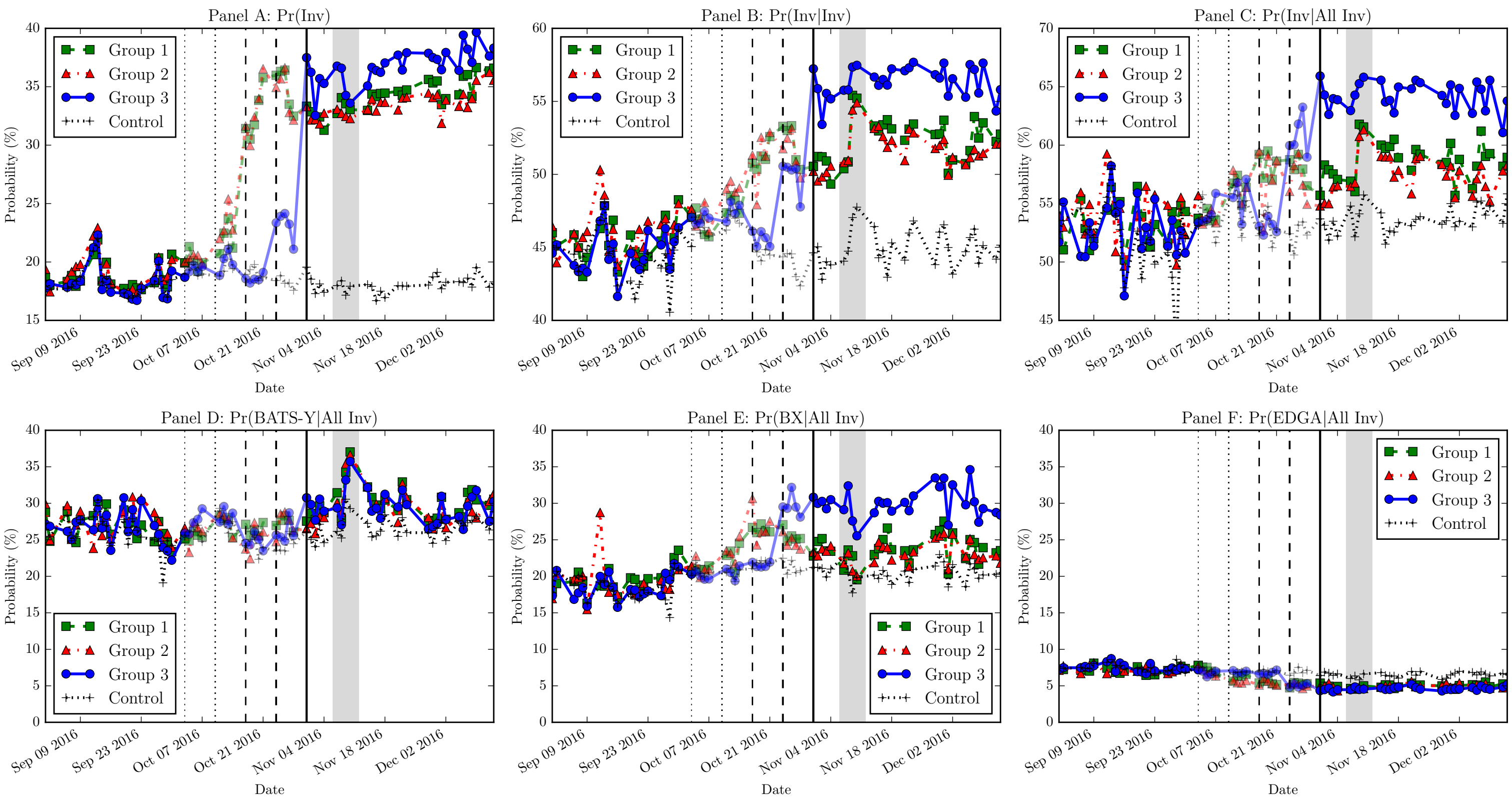

Table 1
Descriptive Statistics

The table presents descriptive statistics for variables of interest during the pre-pilot period of September 2016. All variables are daily stock-level observations, except for Rule 605 variables which are monthly exchange-stock-level observations, and ITCH trade ratios and static controls that are one observation per sample stock. The sample includes all stocks from tick pilot groups and the control group.

	N	Mean	Std	Min	25 Pct	Median	75 Pct	Max
Market Share								
Lit Market Share (%)	47,711	61.12	17.82	0.00	51.22	64.24	73.99	99.99
Inverted Venues Share of Lit Trading (%)	47,711	13.61	8.57	0.00	8.16	13.62	18.36	100.00
Share of Dark Trading at Mid-Quote (%)	47,711	12.61	12.72	0.00	3.17	9.51	17.95	100.00
Share of Dark Trading at NBBO and Price Improving (non-MQ) (%)	47,711	80.20	17.89	0.00	72.20	83.86	93.22	100.00
Stock Charateristics								
Trade Volume ($ 1000')	47,711	3,393.92	7,330.40	0.00	157.33	1,004.85	3,825.55	344,527.39
Lit Trade Count	47,711	268.82	363.47	0.00	28.00	146.00	366.00	6,101.00
Time-weighted Quoted Spread ($)	47,711	0.15	0.54	0.00	0.03	0.05	0.13	39.03
Log(Size)	2,253	19.72	1.27	15.30	18.81	19.84	20.77	21.97
Stock Price	2,253	23.18	27.60	2.00	7.74	16.10	29.50	490.35
Listing Exchange								
NYSE (%)	2,253	29.47						
NYSE MKT (%)	2,253	4.53						
NASDAQ (%)	2,253	66.00						
Index Membership								
Russell 1000 (%)	2,253	1.69						
Russell 2000 (%)	2,253	66.09						
S&P MidCap 400 (%)	2,253	3.82						
S&P SmallCap 600 (%)	2,253	22.41						
S&P Total Market (%)	2,253	85.31						
Price Efficiency								
$\|1 - \text{Variance Ratio}\|$ (1 minute/15 seconds)	47,711	0.14	0.13	0.00	0.05	0.11	0.20	1.65
Liquidity								
Log(Amihud Ratio)	47,462	-12.61	1.81	-20.46	-14.00	-12.80	-11.41	-4.76
Amihud Ratio ($\times 10^5$)	47,516	2.51	16.09	0.00	0.08	0.28	1.10	857.95
Volatility								
15 seconds Mid-Quote Standard Deviation (%)	47,711	0.07	0.29	0.00	0.04	0.05	0.07	23.52
1 minute Mid-Quote Standard Deviation (%)	47,711	0.13	0.57	0.00	0.07	0.10	0.14	43.18
Rule 605								
Cancellation Rate(%)	20,348	93.33	10.64	0.00	92.07	97.70	99.61	100.00
Execution Rate (%)	20,348	4.57	6.92	0.00	0.23	1.76	5.93	100.00
Effective Spread	20,568	0.07	0.18	-0.54	0.01	0.03	0.06	6.96
Realized Spread for Market Orders	20,568	0.02	0.13	-3.47	-0.01	0.00	0.02	5.67
Order Level ITCH								
NASDAQ BX Messages	47,711	2,301.34	3,295.28	0.00	78.00	1,170.00	3,241.00	56,863.00
Log(1 + NASDAQ BX Messages)	47,711	6.01	2.81	0.00	4.37	7.07	8.08	10.95
Messages per $100 of Trade Value on NASDAQ BX	2,213	0.02	0.11	0.00	0.01	0.01	0.02	3.96
NASDAQ Messages	47,711	15,794.94	19,653.20	86.00	2,971.00	10,164.00	22,323.00	1,348,898.00
Log(1 + NASDAQ Messages)	47,711	8.92	1.44	4.47	8.00	9.23	10.01	14.11
Messages per $100 of Trade Value on NASDAQ	2,327	0.13	3.41	0.00	0.01	0.02	0.03	162.69

Table 2
Determinants of Market Share

This table reports coefficients from OLS regressions of lit venue share and inverted venues market share of dollar-volume lit trading, both in %, on the Amihud illiquidity ratio (multiplied by a factor of 10^5), the log of the average daily dollar-volume (Log(Daily Volume)), the inverse of the share price (1/Price), the log of the stock issue market cap (Log(Size)), index membership fixed effects, and industry fixed effects. Both dependent variables, the Amihud illiquidity ratio and the daily volume are measured daily and averaged over the pre-pilot period of September 2016. The share price and market cap are measured using the last closing price of August 2016. t-statistics are presented in parenthesis and *, ** and, *** indicate statistical significance at the 10%, 5%, and 1% level respectively. The sample includes all stocks from tick pilot groups and the control group.

	Lit Share		Inv. Share	
	(1)	(2)	(3)	(4)
Intercept	-15.920***	-13.065***	-30.154***	-23.031***
	(-4.24)	(-3.30)	(-13.13)	(-9.68)
Amihud ($\times 10^5$)	0.002		-0.012***	
	(0.42)		(-3.43)	
Log(Daily Volume)		0.207*		0.649***
		(1.91)		(9.95)
1/Price	-9.895***	-10.152***	7.423***	6.353***
	(-5.47)	(-5.60)	(6.71)	(5.83)
Log(Size)	3.490***	3.211***	2.044***	1.257***
	(18.94)	(13.95)	(18.14)	(9.09)
Index F.E.	Yes	Yes	Yes	Yes
Industry F.E.	Yes	Yes	Yes	Yes
Adjusted R^2	0.657	0.658	0.420	0.441
N	2,329	2,329	2,329	2,329

Table 3
Market Share

This table reports coefficients from OLS regressions of lit dollar-volume market share and inverted venues dollar-volume market share of lit trading, both in %, on rule dummies ($\mathbf{1}_{[\text{trade-at}]}$, $\mathbf{1}_{[\text{trade}]}$, and $\mathbf{1}_{[\text{quote}]}$), lags of the dependent variables, and controls. The trade-at rule applies to group three only, the trade rule applies to groups two and three, and the quote rule applies to all pilot tests groups. Controls include the daily VIX level, the log of the stock issue market cap (Log(Size)), index membership fixed effects, and industry fixed effects. Results are presented for the full sample, and for two sub samples of stocks with below and above median tick constraint. The level of tick constraint is measured as the inverse of the time-weighted average spread during the pre-pilot period of September 2016. t-statistics from robust standard errors clustered by date and stock are presented in parenthesis and *, ** and, *** indicate statistical significance at the 10%, 5%, and 1% level respectively. The sample period is September 1, 2016 to December 13, 2016, and include stocks from the Tick Size Pilot Program groups and control group.

	Full Sample		Low Tick Constraint		High Tick Constraint	
	Lit Share (1)	Inv. Share (2)	Lit Share (3)	Inv. Share (4)	Lit Share (5)	Inv. Share (6)
Intercept	-4.700	-22.468***	-6.495	-24.409***	-6.660	-4.310**
	(-1.46)	(-12.43)	(-1.47)	(-10.31)	(-1.40)	(-2.09)
$\mathbf{1}_{[\text{trade-at}]}$	8.514***	1.267***	8.107***	0.324	8.537***	1.609***
	(19.01)	(3.48)	(12.79)	(0.80)	(16.88)	(3.38)
$\mathbf{1}_{[\text{trade}]}$	0.330	-0.340	0.248	-0.356	0.145	-0.192
	(0.96)	(-1.23)	(0.45)	(-0.89)	(0.42)	(-0.65)
$\mathbf{1}_{[\text{quote}]}$	-4.059***	7.373***	-3.088***	6.324***	-4.939***	8.388***
	(-11.94)	(27.09)	(-6.63)	(18.03)	(-13.07)	(26.11)
Lit Share $(t-1)$	0.247***	0.015***	0.196***	0.014***	0.333***	0.024***
	(39.27)	(6.18)	(26.31)	(4.76)	(39.43)	(6.95)
Inv. Share $(t-1)$	0.048***	0.362***	0.052***	0.269***	0.073***	0.424***
	(5.02)	(33.89)	(4.49)	(22.37)	(6.08)	(36.29)
VIX	0.114*	0.002	0.113	0.019	0.105	-0.005
	(1.70)	(0.05)	(1.50)	(0.50)	(1.66)	(-0.16)
Log(Size)	2.181***	1.409***	2.341***	1.565***	2.058***	0.516***
	(14.25)	(16.22)	(10.58)	(13.03)	(9.55)	(5.47)
1/Price	-10.769***	5.787***	-7.063***	0.694	-9.436***	0.756
	(-5.87)	(5.67)	(-3.32)	(0.57)	(-3.82)	(1.10)
Index F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Industry F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.333	0.429	0.294	0.304	0.413	0.568
N	152,300	152,300	73,884	73,884	78,416	78,416

Table 4
Price Efficiency

This table reports coefficients from IV-2SLS regressions of price efficiency, measured as the absolute difference between one and the variance ratio, on lit market share and inverted venues market share, both in decimals, rule dummies ($\mathbf{1}_{[\text{trade}]}$, and $\mathbf{1}_{[\text{quote}]}$), and controls. Instrumented variables lit market share and inverted venues market share are estimated in the first stage by regressing on the dependent variables of the second stage and the trade-at rule dummy ($\mathbf{1}_{[\text{trade-at}]}$), lag lit market share and lag inverted venues market share as instruments. The trade-at rule applies to group three only, the trade rule applies to groups two and three, and the quote rule applies to all pilot tests groups. Controls include the daily VIX level, the log of the stock issue market cap (Log(Size)), index membership fixed effects, and industry fixed effects. Results are presented for the full sample, and for two sub samples of stocks with below and above median tick constraint. The level of tick constraint is measured as the inverse of the time-weighted average spread during the pre-pilot period of September 2016. t-statistics from robust standard errors clustered by date and stock (date only in column 4) are presented in parenthesis and *, ** and, *** indicate statistical significance at the 10%, 5%, and 1% level respectively. The sample period is September 1, 2016 to December 13, 2016, and include stocks from the Tick Size Pilot Program groups and control group.

	Full Sample (1)	Low Tick Constraint (2)	High Tick Constraint (3)
Intercept	0.272***	0.190***	0.285***
	(12.19)	(5.24)	(10.73)
Lit Share	0.091***	0.115***	0.067***
	(7.69)	(5.85)	(5.26)
Inv. Share	-0.050***	-0.020	-0.104***
	(-2.68)	(-0.56)	(-5.18)
$\mathbf{1}_{[\text{trade}]}$	-0.002	-0.002	-0.001
	(-1.02)	(-0.68)	(-0.55)
$\mathbf{1}_{[\text{quote}]}$	-0.005*	-0.021***	0.015***
	(-1.87)	(-5.28)	(3.84)
VIX	0.000	0.000	0.000
	(0.37)	(0.18)	(0.34)
Log(Size)	-0.007***	-0.003	-0.008***
	(-6.24)	(-1.40)	(-6.28)
1/Price	-0.027***	0.017	-0.021**
	(-3.12)	(1.07)	(-2.42)
Index F.E.	Yes	Yes	Yes
Industry F.E.	Yes	Yes	Yes
Kleibergen-Paap rank LM	62.37***	57.76***	59.35***
Hansen J	0.022	0.307	1.395
Adjusted R^2	0.008	0.005	0.007
N	152,303	73,884	78,416

Table 5
Liquidity

This table reports coefficients from IV-2SLS regressions of liquidity on lit market share and inverted venues market share, both in decimals, rule dummies ($\mathbf{1}_{[\text{trade}]}$, and $\mathbf{1}_{[\text{quote}]}$), and controls. Instrumented variables lit market share and inverted venues market share are estimated in the first stage by regressing on the dependent variables of the second stage and the trade-at rule dummy ($\mathbf{1}_{[\text{trade-at}]}$), lag lit market share and lag inverted venues market share as instruments. The liquidity measures are the log Amihud illiquity ratio and the Amihud illiquidity ratio (multiplied by a factor of 10^5). The trade-at rule applies to group three only, the trade rule applies to groups two and three, and the quote rule applies to all pilot tests groups. Controls include the daily VIX level, the log of the stock issue market cap (Log(Size)), index membership fixed effects, and industry fixed effects. t-statistics from robust standard errors clustered by date and stock are presented in parenthesis and *, ** and, *** indicate statistical significance at the 10%, 5%, and 1% level respectively. The sample period is September 1, 2016 to December 13, 2016, and include stocks from the Tick Size Pilot Program groups and control group.

	Log(Amihud) (1)	Amihud ($\times 10^5$) (2)
Intercept	4.717***	34.810***
	(7.60)	(5.56)
Lit Share	-0.028	-4.324**
	(-0.14)	(-2.30)
Inv. Share	-1.307***	-20.548***
	(-4.24)	(-5.84)
$\mathbf{1}_{[\text{trade}]}$	0.003	0.887**
	(0.05)	(2.05)
$\mathbf{1}_{[\text{quote}]}$	0.421***	2.492***
	(7.47)	(4.55)
VIX	0.009	0.010
	(1.17)	(0.29)
Log(Size)	-0.888***	-1.461***
	(-29.58)	(-4.87)
1/Price	3.310***	19.041***
	(8.47)	(6.01)
Index F.E.	Yes	Yes
Industry F.E.	Yes	Yes
Kleibergen-Paap rank LM	62.53***	62.40***
Hansen J	1.414	1.353
Adjusted R^2	0.624	0.046
N	151,648	151,853

Table 6
Volatility

This table reports coefficients from IV-2SLS regressions of volatility on lit market share and inverted venues market share, both in decimals, rule dummies ($\mathbf{1}_{[\text{trade}]}$, and $\mathbf{1}_{[\text{quote}]}$), and controls. Instrumented variables lit market share and inverted venues market share are estimated in the first stage by regressing on the dependent variables of the second stage and the trade-at rule dummy ($\mathbf{1}_{[\text{trade-at}]}$), lag lit market share and lag inverted venues market share as instruments. Volatility is measured by the daily standard deviation of mid-quote returns sampled at 15-seconds or 1-minute intervals, in %. The trade-at rule applies to group three only, the trade rule applies to groups two and three, and the quote rule applies to all pilot tests groups. Controls include the daily VIX level, the log of the stock issue market cap (Log(Size)), index membership fixed effects, and industry fixed effects. t-statistics from robust standard errors clustered by date and stock are presented in parenthesis and *, ** and, *** indicate statistical significance at the 10%, 5%, and 1% level respectively. The sample period is September 1, 2016 to December 13, 2016, and include stocks from the Tick Size Pilot Program groups and control group.

	Std. Dev. MQ (15 sec) (1)	Std. Dev. MQ (1 min) (2)
Intercept	0.440***	0.818***
	(7.29)	(7.24)
Lit Share	-0.024	-0.064
	(-0.39)	(-0.49)
Inv. Share	-0.236***	-0.443***
	(-3.10)	(-3.03)
$\mathbf{1}_{[\text{trade}]}$	0.028**	0.054**
	(2.40)	(2.35)
$\mathbf{1}_{[\text{quote}]}$	0.029***	0.056***
	(3.30)	(3.21)
VIX	0.001**	0.002*
	(2.01)	(1.85)
Log(Size)	-0.016***	-0.029***
	(-4.41)	(-4.14)
Index F.E.	Yes	Yes
Industry F.E.	Yes	Yes
Kleibergen-Paap rank LM	62.53***	62.53***
Hansen J	0.519	0.513
Adjusted R^2	0.007	0.007
N	152,156	152,156

Table 7
Rule 605

This table reports coefficients from OLS regressions of changes in market quality measures on rule dummies ($\mathbf{1}_{[\text{trade-at}]}$, $\mathbf{1}_{[\text{trade}]}$, and $\mathbf{1}_{[\text{quote}]}$). Panel A shows results for changes in the cancellation rate and the execution rate at the best quote, in %, for all inverted venues (BATS-Y, EDGA, and NASDAQ BX) and for each inverted venue separately. Panel B shows results for changes in the effective spread and the realized spread for market orders, in %, for all inverted venues and for each inverted venue separately. Panel C shows results for changes in all variables for all traditional venues and for NASDAQ.Changes in monthly market quality measures are defined as the difference between the November and September 2016 observations. The quote rule applies to all pilot tests groups, the trade rule applies to groups two and three, and the trade-at rule applies to group three only. t-statistics from robust standard errors clustered by stock are presented in parenthesis and *, ** and, *** indicate statistical significance at the 10%, 5%, and 1% level respectively. The sample includes stocks from the Tick Size Pilot Program groups and control group, and lit market venues subject to the SEC Rule 605.

Panel A: Order Activity

	Inv. Venues		BATS-Y		NASDAQ BX		EDGA	
	Δ Cancel. Rate	Δ Exec. Rate	Δ Cancel. Rate	Δ Exec. Rate	Δ Cancel. Rate	Δ Exec. Rate	Δ Cancel. Rate	Δ Exec. Rate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	0.119	-0.174	0.355*	-0.474***	-0.361	0.055	0.345	-0.093
	(0.63)	(-1.14)	(1.76)	(-2.86)	(-0.90)	(0.16)	(1.38)	(-0.46)
$\mathbf{1}_{[\text{trade-at}]}$	-1.746***	1.459***	-1.147**	0.895**	-3.519***	3.185***	-0.615	0.336
	(-3.61)	(4.18)	(-2.15)	(2.13)	(-3.78)	(4.23)	(-0.85)	(0.77)
$\mathbf{1}_{[\text{trade}]}$	0.885*	-0.674*	0.430	-0.434	1.800*	-1.142	0.445	-0.448
	(1.83)	(-1.92)	(0.76)	(-1.00)	(1.77)	(-1.52)	(0.74)	(-0.96)
$\mathbf{1}_{[\text{quote}]}$	-1.311***	0.680**	-1.306***	0.990***	-1.652**	1.630***	-0.972**	-0.573
	(-3.43)	(2.32)	(-2.93)	(2.95)	(-2.00)	(2.64)	(-2.02)	(-1.41)
Adjusted R^2	0.006	0.005	0.011	0.009	0.009	0.015	0.002	0.003
N	6,582	6,582	2,226	2,226	2,148	2,148	2,208	2,208

Panel B: Trading Costs

	Inv. Venues		BATS-Y		NASDAQ BX		EDGA	
	Δ Eff. Spread	Δ Real. Spread	Δ Eff. Spread	Δ Real. Spread	Δ Eff. Spread	Δ Real. Spread	Δ Eff. Spread	Δ Real. Spread
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	0.012***	-0.001	0.014***	0.004	0.004	-0.002	0.019***	-0.004
	(3.76)	(-0.29)	(2.87)	(0.66)	(0.92)	(-0.50)	(2.65)	(-0.65)
$\mathbf{1}_{[\text{trade-at}]}$	0.012	0.005	0.028**	0.010	0.005	0.004	0.004	0.001
	(1.52)	(0.72)	(2.03)	(1.13)	(0.60)	(0.55)	(0.33)	(0.11)
$\mathbf{1}_{[\text{trade}]}$	0.003	0.006	0.020	0.016	-0.007	-0.001	-0.004	0.002
	(0.50)	(0.99)	(1.49)	(1.63)	(-0.94)	(-0.10)	(-0.32)	(0.21)
$\mathbf{1}_{[\text{quote}]}$	0.019***	0.009*	0.001	-0.006	0.038***	0.029***	0.019	0.004
	(3.56)	(1.78)	(0.07)	(-0.63)	(6.16)	(4.00)	(1.47)	(0.46)
Adjusted R^2	0.005	0.002	0.008	0.001	0.022	0.011	0.000	-0.001
N	6,582	6,582	2,226	2,226	2,148	2,148	2,208	2,208

Panel C: Traditional Venues

	Trad. Venues				NASDAQ			
	Δ Cancel. Rate	Δ Exec. Rate	Δ Eff. Spread	Δ Real. Spread	Δ Cancel. Rate	Δ Exec. Rate	Δ Eff. Spread	Δ Real. Spread
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intercept	-1.507***	1.247***	0.011***	-0.004*	-3.716***	3.045***	0.009**	0.001
	(-7.87)	(9.14)	(4.82)	(-1.65)	(-7.33)	(10.05)	(2.52)	(0.34)
$\mathbf{1}_{[\text{trade-at}]}$	-0.379	0.355	0.005	0.007	-0.424	0.335	0.012	0.016*
	(-0.81)	(1.09)	(0.78)	(1.51)	(-0.34)	(0.47)	(1.17)	(1.74)
$\mathbf{1}_{[\text{trade}]}$	-0.154	0.072	0.011**	0.005	-1.590	0.766	0.013	0.004
	(-0.33)	(0.22)	(2.05)	(0.97)	(-1.30)	(1.11)	(1.49)	(0.48)
$\mathbf{1}_{[\text{quote}]}$	-0.408	-0.384	0.007	-0.005	-2.054**	-0.338	0.007	-0.005
	(-1.06)	(-1.44)	(1.46)	(-0.97)	(-2.10)	(-0.59)	(0.79)	(-0.74)
Adjusted R^2	0.000	0.000	0.005	0.000	0.009	-0.000	0.008	0.001
N	9,540	9,540	9,540	9,540	2,224	2,224	2,224	2,224

Table 8
ITCH Messages

This table reports coefficients from OLS regressions of changes in total ITCH message activity, in logs, in the messages to trade value ratio, and in estimated hazard rates for cancellations and executions on rule dummies ($\mathbf{1}_{[\text{trade-at}]}$, $\mathbf{1}_{[\text{trade}]}$, and $\mathbf{1}_{[\text{quote}]}$). All message-based measures are estimated for each stock in the pre-pilot period of September 2016 and in the post-pilot period of November 1 to December 13, 2016, and we define changes as the difference between the two. ITCH message activity is defined as the log of one plus of the average total daily message count in the ITCH order-level feed. Messages to trade value is defined as the total message count per 100$ of trade value during the estimation period. Cancellation and execution hazard rates are estimated simultaneously in the pre- and post-period, and a dummy coefficient is used to capture the change between the two period. See the text for a detailed description of variable construction. Panel A presents results for NASDAQ BX, an inverted venue, while Panel B presents results for NASDAQ, a traditional venue. The trade-at rule applies to group three only, the trade rule applies to groups two and three, and the quote rule applies to all pilot tests groups. t-statistics are presented in parenthesis and *, ** and, *** indicate statistical significance at the 10%, 5%, and 1% level respectively. The sample includes stocks from the Tick Size Pilot Program groups and control group.

Panel A: NASDAQ BX

	Δ Log(Messages)	Δ Messages/Trade Value	Δ Cancel Rate	Δ Execution Rate
	(1)	(2)	(3)	(4)
Intercept	0.142***	-0.005***	-0.039*	0.549***
	(5.40)	(-5.75)	(-1.80)	(7.59)
$\mathbf{1}_{[\text{trade-at}]}$	0.028	-0.009***	-0.057	0.664***
	(0.44)	(-4.07)	(-1.10)	(3.56)
$\mathbf{1}_{[\text{trade}]}$	0.059	0.003	0.061	-0.361*
	(0.91)	(1.39)	(1.16)	(-1.93)
$\mathbf{1}_{[\text{quote}]}$	0.816***	0.004**	0.214***	0.441***
	(15.52)	(2.14)	(5.02)	(2.93)
Adjusted R^2	0.199	0.009	0.032	0.016
N	2,163	2,163	1,774	1,601

Panel B: NASDAQ

	Δ Log(Messages)	Δ Messages/Trade Value	Δ Cancel Rate	Δ Execution Rate
	(1)	(2)	(3)	(4)
Intercept	-0.093***	-0.014***	-0.058***	0.691***
	(-7.77)	(-20.43)	(-9.67)	(19.14)
$\mathbf{1}_{[\text{trade-at}]}$	0.106***	-0.004**	0.049***	0.072
	(3.61)	(-2.21)	(3.28)	(0.82)
$\mathbf{1}_{[\text{trade}]}$	-0.007	-0.000	0.002	0.250***
	(-0.24)	(-0.08)	(0.14)	(2.84)
$\mathbf{1}_{[\text{quote}]}$	-0.579***	-0.002	-0.218***	0.358***
	(-24.14)	(-1.20)	(-18.02)	(5.02)
Adjusted R^2	0.328	0.006	0.199	0.063
N	2,163	2,163	2,261	1,916

Table 9
Net Policy Effects

This table reports coefficients from OLS regressions of market quality metrics on rule dummies ($\mathbf{1}_{[\text{trade-at}]}$, $\mathbf{1}_{[\text{trade}]}$, and $\mathbf{1}_{[\text{quote}]}$), and controls. The trade-at rule applies to group three only, the trade rule applies to groups two and three, and the quote rule applies to all pilot tests groups. Controls include the daily VIX level, the log of the stock issue market cap (Log(Size)), index membership fixed effects, and industry fixed effects. See the text for a detailed description of market quality metrics. t-statistics from robust standard errors clustered by date and stock are presented in parenthesis and *, ** and, *** indicate statistical significance at the 10%, 5%, and 1% level respectively. The sample period is September 1, 2016 to December 13, 2016, and include stocks from the Tick Size Pilot Program groups and control group.

	$\|1 - VR\|$, MQ (1)	Log(Amihud) (2)	Std. Dev. MQ (15 sec) (3)	Std. Dev. MQ (1 min) (4)
Intercept	0.285***	5.236***	0.445***	0.821***
	(12.87)	(8.82)	(6.79)	(6.93)
$\mathbf{1}_{[\text{trade-at}]}$	0.008***	-0.081	0.011	0.020
	(3.58)	(-1.54)	(0.85)	(0.78)
$\mathbf{1}_{[\text{trade}]}$	-0.001	0.030	0.013	0.025
	(-0.42)	(0.56)	(1.52)	(1.51)
$\mathbf{1}_{[\text{quote}]}$	-0.015***	0.271***	0.006	0.014
	(-7.83)	(6.52)	(1.46)	(1.66)
VIX	0.000	0.008	0.001	0.002
	(0.75)	(1.09)	(1.55)	(1.65)
Log(Size)	-0.006***	-0.921***	-0.019***	-0.034***
	(-5.30)	(-32.90)	(-6.24)	(-6.41)
1/Price	-0.045***	3.192***	0.008	0.024
	(-4.79)	(8.91)	(0.36)	(0.55)
Index F.E.	Yes	Yes	Yes	Yes
Industry F.E.	Yes	Yes	Yes	Yes
Adjusted R^2	0.014	0.628	0.007	0.007
N	153,940	153,940	153,940	153,940