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Abstract

The U.S. equity markets are currently conducting a pilot study of the effects of a larger tick size on market quality and on the rewards for liquidity provision. We show that the larger tick size causes quoted and effective spreads, but also depth, to increase. This raises the cost for retail-sized liquidity demanding orders by almost fifty percent. However, average trade size increases, suggesting that institutions may benefit from the deeper quotes. The larger tick size translates into forty percent higher profits to liquidity providers despite larger price impacts. We attribute these changes mainly to the changes in tick size for displayed quotes, while there are modest or no effects of requiring all trades to execute on a coarser price grid. Moreover, the bulk of the effects occur for tick-constrained stocks which trading costs more than double. By contrast, trading costs for unconstrained stocks decline by more than ten percent. Finally, we document significant spillovers to stocks with unchanged tick size. Our evidence suggests that some market makers left stocks trading in decimals for the more lucrative pilot stocks, and that the reduced competition causes quoted spreads and rewards for liquidity provision to increase also for stocks trading in decimals.

JEL Classification: G12, G14.
Key words: *U.S. Tick Size Pilot, JOBS Act, tick size, market quality, trading activity, liquidity provision*

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1. Introduction

Concerns about the paucity of initial public offerings, the dwindling number of publicly traded companies, and the perceived lack of sufficient liquidity for smaller capitalization stocks motivated Congress to direct the Securities & Exchange Commission (SEC) to study the effect of a larger tick size on market quality and on the rewards for liquidity provision.[2] In the 2012 Jumpstart Our Business Startups (JOBS) Act, legislators argue that decimalization has led to a lack of market maker support for smaller capitalization stocks, and that a larger tick size is needed to provide sufficient incentives for liquidity provision. In response, the SEC in conjunction with market participants developed a tick size pilot program which phased in five cent tick size for about 1,200 smaller capitalization ($3 billion or less) test securities during the month of October, 2016, and defined a control sample of roughly 1,400 securities that continued trading at a one cent (penny) tick. We use intraday transactions and quote data from the period surrounding the tick size pilot phase-in to study the effects of the increase in the tick size from one penny to a nickel on quote quality, trading activity, the rewards for liquidity provision, and price discovery.

Quintupling the tick size in a limit order book market has some obvious effects, but many that are more subtle. To see this, consider a stock with a penny best bid-offer (BBO) spread and an order book that is populated with limit orders at five or more price levels on each side of the BBO. When the tick size increases, there is a mechanical increase in the BBO from a penny to five cents. This means that traders who were willing to post more aggressive limit orders at the penny tick size now have to join the queue at the new minimum five cent BBO and the execution probability of limit orders therefore declines. On the other hand, to undercut resting limit orders, traders now have to give up at least five cents and this increases the execution probability of limit orders. Finally, traders who were demanding liquidity via market orders at the penny BBO now face a wider spread and may switch to limit orders. Traders optimally trade off these factors when determining their optimal order submission strategies, and the effects of the tick size increase on quote quality, trading activity, rewards for liquidity provision, and price discovery will depend on which factors prevail.

Several authors have developed models of limit order markets to analyze how these factors interact when the tick size increases. Goettler, Parlour and Rajan (2005) model a dynamic limit order book and find that following an increase in the tick size limit orders' execution probabilities increase because the reduced cost of undercutting outweighs the increased costs of queuing. Furthermore, traders switch from the more expensive market orders to limit orders. As a result, depth increases and volume declines. However, the

[2] For a recent survey of the state of the U.S. public corporations, including time series of the number of listed companies, see Kahle and Stulz (2017).

wider minimum spread imposed by the larger tick size overwhelms the natural improvement in spread that a switch from market to limit orders would typically generate, and the spread therefore widens.

Werner et al. (2015) model a dynamic limit order book to study a change in tick size and show that the effects on market quality depend on the liquidity of the stock. Consider a liquid stock that is trading at a penny spread prior to the tick size increase. Traders will be reluctant to post limit orders at the new five cent spread because the reduction in limit orders' execution probability due to long queues prevails both over the reduced cost of undercutting, and over the increased costs of market orders. In equilibrium traders therefore switch from limit to market orders resulting in an increase in spread, BBO depth and volume. Now, consider a less liquid stock that is trading at a spread that is wider than five cents prior to the tick size increase. Following a tick size increase there is no mechanical increase in spread for this stock, and there are no longer queues at the new price levels. However, traders switch from market orders to limit orders because of the reduced probability of undercutting. The result is an increase in depth and a decrease in volume. Furthermore, the wider was the initial spread, the greater will be the probability that spread is smaller following the tick size increase. In other words, the case studied by Goettler et al (2005) falls in-between the two cases of highly liquid (tick-constrained) stocks and less liquid (unconstrained) stocks.

A number of authors have also studied tick size increases in intermediated markets. Cordella and Foucault (1999) show that in a dealership market where a larger tick size translates into higher potential profits for liquidity suppliers, an increased tick size may induce dealers to post more aggressive limit orders thus increasing the speed of convergence to the competitive quotes and hence price discovery. Focusing on the profitability of liquidity providers, Anshuman and Kalay (1998) point out that a wider tick size is synonymous to a higher rewards for liquidity provision and therefore it may increase liquidity providers' ability to stay in business, while Kadan (2006) argues that the effect of a tick size increase on the profitability of liquidity providers depends on how competitive is the market for liquidity provision prior to the change. Finally, Seppi (1997) shows that in a specialist market populated by both institutional and retail traders a larger tick size may enable institutional traders to reduce their order splitting and hence lead to an increase in the average trade size.

We use the U.S. tick size pilot to test these theoretical predictions formally. To do so, we use intraday quotation and transaction data drawn from Thomson Reuters Tick History (TRTH) database. The period we examine is the eight week pre-pilot period August 1 – September 23, 2016, and the eight week post-pilot period defined as October 31 - December 23, 2016. We first calculate daily measures of quote condition, trading activity, rewards for liquidity provision, and price discovery for test stocks as well as control stocks. Based on these daily stock-level numbers, we test for univariate changes between the pre-

and the post-pilot periods. We also examine the daily average levels for each test group and the control group graphically to verify that difference-in-difference analysis is appropriate. Our main analysis relies on difference-in-difference panel regression analyses to test for differences in changes for stocks in each test group relative to control stocks. We control for VIX as a proxy for market-wide changes in fundamental variables. We complement this analysis with more conservative collapsed panel regressions. Furthermore, as suggested by Boehmer, Jones, and Zhang (2015), we estimate the changes also for control stocks to evaluate potential spillover effects from the tick pilot on stocks for which there was no change in tick size.

The pilot defines a control group of roughly 1,400 securities and three test groups each consisting of about 400 securities. The three test groups successively introduce the five cent tick size for: quotes (G1); for quotes and trades (G2); and finally in addition to the five cent tick for quotes and trades also imposed displayed order priority (G3). The last rule is commonly referred to as the trade-at rule, and requires market participants to route orders to transparent venues, unless they execute the trades at a meaningfully better price than what is available in transparent venues. Note that the rules overlap, so that the quote rule applies to all test stocks, the trade rule applies to G2 and G3, while the displayed order priority only applies to G3. In order to examine the effect of the different rules, we estimate the effects of each rule separately: the quote rule; the trade rule; and the trade-at rule.

Goettler et al. (2005) and Werner et al. (2015) predict that a tick-size increase on average will cause a widening of spreads, an increase in depth, and a reduction in volume while Seppi (1997) predicts an increase in average trade size. Our results show that the quote rule on average causes a widening of quoted spreads by 1.45 cents per share (17%) and effective spreads by 1.75 cents per share (46%), an increase in depth by 2,176 shares (275%), and an increase in midquote volatility by 0.29 percentage points (10%) where we use the pre-pilot averages for stocks in G2 as a benchmark. The economic magnitudes are very similar for the other test groups. Furthermore, the trade and trade-at rules have by comparison modest effects on quote quality. In terms of trading activity, we find an increase in average trade size by 11.8 shares (9%) also relative to pre-period averages for G2 stocks. While consolidated volume increases market-wide, volume does not change significantly for stocks in the test groups relative to control stocks. Hence, with the exception of volume, the overall results confirm the predictions. Overall, our results therefore suggest that trading costs facing liquidity-demanding retail investors increased dramatically as a result of increasing the tick size from one penny to five cents. However, the significant increase in average trade size suggests that the increase in depth may have been beneficial for institutional traders seeking liquidity by reducing their need to engage in order-splitting.

Werner et al. (2015) also predict that while quoted depth should increase both for tick-constrained and unconstrained stocks, tick-constrained stocks should experience a widening of quoted spreads and an increase in volume while unconstrained stocks may experience a decrease in quoted spread and a decline in volume. We create subsamples of stocks based on their pre-event average quoted spread, and define tick-constrained stocks to be those with a pre-event tick size of five cents and below and unconstrained stocks as those with a pre-event ticks size of ten cents or above. Roughly half the test stocks are tick-constrained, while 25 percent are unconstrained, using this definition. Tick-constrained stocks are larger, trade at lower prices, have higher depth, lower volatility, higher share volume, and larger trade size. Confirming the predictions, we find that quoted spreads increase 3.19 cents (112%) for tick constrained and decline by 2.60 cents (12%) for unconstrained stocks. Similarly, effective spreads increase by 2.31 cents (128%) for tick-constrained stocks but hardly change for unconstrained stocks. Depth increases by 3,450 shares (326%) for tick-constrained and by 456 shares (82%) for unconstrained stocks. However, volume declines for both subsamples based on panel regressions, but for neither subsample does volume change significantly in the more robust collapsed panel version of the tests. It is possible that volume does not decline because the tick size pilot generates migration of order flow between the lit and dark markets, and therefore causes trade creation. This would be an additional element to take into account when predicting the effects of a change in tick size on market quality.[3]

Finally, Cordella and Foucault (1999), Anshuman and Kalay (1998), and Kadan (2006) predict that a larger tick size will improve the profitability of liquidity provision and speed up price discovery. We use realized spreads as a proxy for the potential rewards to liquidity provision. Following Conrad and Wahal (2017), we study the term structure of liquidity provision and price impact for horizons ranging from 30 seconds to five minutes. Our results show that the quote rule on average causes realized spreads to increase by 0.78 cents (39%) at 30 seconds and 0.70 cents (42%) at a five-minute horizon where the percentages use the pre-pilot averages for G2 as a benchmark. The economic magnitudes are very similar for the other test groups. The trade-rule further significantly adds to the rewards for liquidity providers but the economic magnitudes of these changes are small. By contrast, the trade-at rule significantly *reduces* realized spreads by -0.38 cents (19%) at the 30-second horizon and -0.28 cents (17%) at the five-minute horizon. This suggests that trade-at rule, which encourage traders to move from the dark to the lit venues, produces an inflow of limit orders to the lit markets, and results in a tighter spread. Furthermore, we find that the bulk of the increases in the potential rewards for liquidity provision and price impacts arise from tick-constrained stocks. In fact, the quote rule does not cause a significant increase in realized spreads for unconstrained

[3] Neither Goettler et al. (2005) nor Werner et al. (2015) take this feature into account as their models are single market frameworks. For a discussion on the effects of competition from a dark pool on a lit market see Buti, Rindi, and Werner (2017).

stocks at any horizon and is associated with a significant price impact only out to the three-minute horizon. Hence, the increases in profits we document for the overall sample arise from the 50 percent of test stocks that are tick-constrained at the new five cent tick size. By contrast, there is no increase in the potential rewards for liquidity provision for the roughly 25 percent of test stocks that are unconstrained at the new five cent tick size.

We consider price impact based on changes in midquotes as a proxy for improved price discovery, and find that the quote rule is associated with a significantly larger price impact at all horizons ranging from 0.46 cents (52%) at the 30-second horizon to 0.49 cents (47%) at the five-minute horizon. The trade rule is associated with a significant, albeit small, further increase in price impact and there is no significant effect of the trade-at rule on price impacts at any horizon. Hence, while the speed of price discovery may have increased, this change did not offset the wider spreads and hence the potential rewards for liquidity provision increased tremendously. Therefore, we conclude that our overall results confirm the main predictions from theory focusing on the rewards for liquidity provision, and therefore the U.S. tick size pilot appears to have delivered the effect sought by Congress as expressed in the JOBS Act.

The eligible securities for the tick size pilot were selected because of having relatively low liquidity, and some of them trade infrequently. It is unclear whether market makers and other liquidity providers are able to capitalize on the increases in potential rewards for liquidity provision that we calculate as they would have to exit the position at the within five minutes. We therefore supplement our data with regulatory data on market maker profits. Unfortunately, these data are aggregated across stocks and market makers, making it difficult to conduct formal testing. We can only compare the average market maker profits across all eligible stocks during the pre-pilot period to the average market maker profits for stocks in each group during the post-pilot period. We find that compared to the pre-pilot period average market maker profits, profits for test stocks increased significantly more than profits for control stocks following the phase-in of the tick size pilot. This supplemental evidence suggests that market makers were indeed capable of capitalizing on the wider spreads.

Boehmer et al. (2015) emphasize that caution is warranted when studying regulatory experiments. In the ideal experimental setting, the treatment affects only the treated sample while there are no significant changes for the control sample. However, as documented by Boehmer et al. (2015), control stocks may be significantly affected by spillovers from the treatment. Indeed, we document significant changes to quote quality, trading activity, the rewards for liquidity provision, and price discovery also for control stocks following the phase-in of the tick size pilot. Moreover, these changes are in the same direction as the changes for treated stocks and they are particularly large for spreads, depth, volatility and consolidated

volume. Quoted spreads increase by 1.77 cents (21%), effective spreads increase by 0.53 cents (13%), depth increases by 163 shares (20%), volatility increases by 0.51 percentage points (17%), and consolidated volume increases by almost 70,000 shares (32%). By contrast, the changes in average trade size, realized spreads and price impact are, while significant, small relative to those we document for test stocks. The changes we observe for control stocks could in principle either be the result of a change to a fundamental factor or the result of spillovers from the treatment. We conjecture that spreads widen for control stocks because of spillovers from the treatment. Specifically, our results are consistent with market makers leaving control stocks, reducing the competitiveness of control stock quotes, and intensifying their market making activity for the more lucrative test stocks. It follows that test stock quoted spreads may widen less, and depth increase more, than they would if the increase in tick size was imposed market-wide.

We are aware of three contemporaneous studies that use data from the tick size pilot. The paper that is closest to ours is Griffith and Roseman (2017) who rely on order level data to show that tick-constrained test stocks experience an increase in quoted and effective spreads and volatility, but that cumulative depth remain unchanged or decreases and that trading volumes decline. Comerton-Forde, Grégoire, and Zhong (2017) and Lin, Swan, and Mollica (2017) focus on intermarket competition and show that the tick size pilot is associated with significant shift in volume across venues, and link these shifts in order flow to changes in venue-specific market quality. Our main contributions relative to these papers is that we: complement panel regressions with both graphical and collapsed panel regressions to show that volume does not change significantly for test stocks; formally test for the effects of the specific rules and show that the changes in market quality are virtually exclusively caused by the quote rule; show that the average trade size increases significantly for test stocks suggesting that institutions may benefit from the increase in depth; compare the results for smaller capitalization (Nasdaq-listed) to those for larger capitalization (NYSE-listed) firms; document a significant increase in reported market maker profits for test stocks relative to control stocks following the phase-in of the pilot; and document significant spillover effects from the tick size pilot to control stocks which are consistent with market makers switching away from control stocks to more lucrative test stocks.

The paper proceeds as follows. We discuss the tick size pilot in Section 2, and develop our hypotheses in Section 3. Section 4 is devoted to the data an empirical methodology, while Sections 5 and 6 report the results on the effects of the tick size pilot on market quality and trading activity overall and for tick-constrained and unconstrained subsamples respectively. We address the effect of the tick size pilot on liquidity provision and price discovery in Section 7. Robustness tests are discussed in Section 8 and Section 9 concludes.

2. U.S. Tick Size Pilot Program

On April 5, 2012, the JOBS Act was signed into law. Section 106(b) of the JOBS Act requires the SEC to conduct a study and report to Congress on how decimalization has affected the number of initial public offerings and the liquidity and trading of smaller capitalization company - so call Emerging Growth Company (EGC) - securities. The SEC responded by releasing a report on decimalization on July 20, 2012. In June 2014, the SEC ordered the national securities exchanges and the Financial Industry Regulatory Association (FINRA) to develop and file a proposal for a tick size pilot program.[4]

On August 26, 2014, the SEC announced that the national securities exchanges together with FINRA had filed a proposal to establish a national market system (NMS) plan to implement a targeted tick size pilot program.[5] The purpose of the NMS plan and the tick size pilot program was to "assist the Commission, market participants, and the public in studying and assessing the impact of increment conventions on the liquidity and trading of stocks of small capitalization companies."

The NMS plan and tick size pilot program proposal was approved by the SEC on May 6, 2015. The tick size pilot program defines eligible securities as "stocks of companies with $3 billion or less in market capitalization, an average daily trading volume of one million shares or less, and a volume weighted average price of at least $2.00 for every trading day."[6] The pilot was designed to include a control group of 1,400 securities and three test groups each consisting of 400 securities. The three test groups are:

- Test Group 1 (G1 - Quote Rule) which will be quoted in $0.05 increments, but will continue trading at their current price increment;
- Test Group 2 (G2 - Quote and Trade Rule) which will be both quoted and traded in $0.05 increments, but with exemptions for midpoint executions, and negotiated and retail trades; and
- Test Group 3 (G3 - Quote, Trade, and Trade-At Rule) that in addition to the rules applying to G2 will be subject to a trade-at requirement meaning non-displayed orders cannot trade at the bid or offer until after the displayed liquidity at the same price in all lit venues have been filled, but retail orders executed with at least $0.0005 price improvement and block size orders defined as greater than 5,000 shares or $100,000 are exempted from the trade-at prohibition.

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[4] Order Directing the Exchanges and the Financial Industry Regulatory Authority to Submit a Tick Size Pilot Plan, Exchange Act Release No. 72460 (June 24, 2014), available at http://www.sec.gov/rules/other/2014/34-72460.pdf

[5] Plan to Implement a Tick Size Pilot Program Submitted to the Securities and Exchange Commission Pursuant to Rule 608 of Regulation NMS Under the Securities Exchange Act of 1934 (Aug. 25, 2014), available at http://www.sec.gov/divisions/marketreg/tick-size-pilot-plan-final.pdf

[6] SEC Release No. 34-74892; File No. 4-657 and https://www.sec.gov/news/pressrelease/2015-82.html

The tick size pilot program was intended to start on May 6, 2016, but the start date was delayed based on requests from the national securities exchanges and market participants who argued they needed more time to do the necessary system adjustments. The tick size pilot program began on October 3, 2016, and is set to continue for two years. Based on recommendations by industry participants, the tick size pilot program was phased in gradually during the month of October 2016, with the last batch of test securities (G3) added on October 31, 2016.[7]

3. Hypotheses

There is a sizable literature discussing the trade-offs involved in setting the minimum price increment, the tick size. The early literature was largely motivated by the gradual reduction in the tick size for U.S. stocks from $1/8^{th}$ to $1/16^{th}$ in 1997, and the ultimate decimalization in 2001. Harris (1994), using a numerical example, makes the point that if the tick size exceeds the spread that would otherwise be quoted, i.e., the tick size is binding, spreads will be wide, the number of shares offered would be large, and volume low. Specifically, he argues that a reduction of the tick size from $1/8^{th}$ to $1/16^{th}$ would reduce spreads by 38 percent, reduce quotation sizes by 16 percent, and that daily volume would rise by 34 percent. By and large, these predictions were borne out by subsequent empirical work studying the reduction in tick sizes in the U.S. and elsewhere (e.g. Ahn et al., 1996; Ronen and Weaver, 2001; Bacidore, 1997; Griffith et al., 1998; Goldstein and Kavajecz, 2000; Bessembinder, 2003; and Jones and Lipson, 2001.).

In the U.S., exchange-listed stocks trade almost exclusively on electronic limit order books and we therefore draw our main predictions from models of limit order books. Goettler et al (2005) and Werner et al. (2015) model dynamic limit order book markets with strict price and time priority populated by rational liquidity traders who choose optimal order submission strategies. Each trader comes to the market with a private valuation of the security, observes the current state of the order book, and forms her trading strategy by weighing the price opportunity cost associated with a market order (a worse price since she has to cross the spread but immediate execution) against the non-execution cost associated with a limit order (a better price but with uncertain future execution). The execution probability of a limit order is affected both by the arrival of future market orders, and by the arrival of future limit orders that may undercut the resting order in the book by offering a more attractive limit price. The decision to trade is endogenous both with respect to participation, trade direction, and order type.

Goettler et al. (2005) solve the model with infinite horizon and characterize a stationary equilibrium in this market, whereas Werner et al. (2015) solve a four-period model by backward induction and show how

[7] The implementation schedule is reproduced in the Appendix A.

order liquidity evolves over the course of a trading day. Both models compare the equilibrium with a small tick size to one with a large tick size. For a stock of average liquidity, when the tick size is wider, the spread increases mechanically. As a result, market orders become less attractive as liquidity demanders have to cross a wider spread and volume therefore decreases. The lower incentive to submit market orders implies a higher non-execution probability of limit orders. However, at the same time limit orders are more attractive because the risk of being undercut is reduced. It is simply more expensive for another trader to gain priority by improving the limit price when the tick size is large. Traders optimally trade-off these costs, and overall liquidity supply increases with a larger tick size causing BBO depth to increase. At the same time, the spread increases due to the overwhelming effect of the mechanical increase in the tick size.

In a setting which includes a specialist competing with a limit order book, Seppi (1997) analyzes how trading strategies of different trader types (institutions and retail traders) are affected by the tick size. He shows that institutions trading large blocks prefer a larger tick than retail traders. The reason is that while spreads are wider in a large tick market, displayed depth is also higher which benefits institutions trading in size.

Werner et al. (2015) also show that in equilibrium the response to a change in the tick size depends on the nature of the liquidity of the stock. Consider first a stock for which the equilibrium spread with a small tick size is narrower than the minimum spread dictated by the larger tick size, i.e., the stock would be tick-constrained at the larger tick size. If the tick size increases for this stock, limit orders that were initially posted at prices that fall inside the new wider minimum spread have to move and queue up at the wider minimum spread imposed by the new tick size regime. This increases both the spread and BBO depth and makes the stock even more tick-constrained. The longer the queue, the smaller the execution probability of limit orders posted at the new BBO, the higher the incentive for traders to switch from limit to market orders, thus increasing volume.

Now consider a stock that has an equilibrium spread that is wider than the minimum spread implied by the new larger tick size, i.e., the stock is unconstrained at the larger tick size. In an unconstrained stock, there is room for undercutting and therefore traders' strategies crucially depend on the cost of undercutting.. If the tick size increases, the cost of undercutting rises and hence the risk of undercutting decreases. As a result, traders switch from market to limit orders with the result that in equilibrium the quoted spread narrows, the BBO depth increases, and volume declines. A similar prediction is made by Foucault, Kadan and Kandel (2005), who model a limit order market with strict price and time priority. They show that increasing the minimum tick size can reduce the expected spread if it makes the market more resilient in that limit order traders improve prices more generating the ("spread improvement effect").

This gives rise to the following hypotheses for quote quality and trading activity on average:

H1: *The U.S. tick size pilot will on average cause a widening of the quoted spread, an increase in BBO depth, and a decrease in volume.*

H2: *The U.S. tick size pilot causes an increase in average trade size as institutions engage less in order splitting.*

Furthermore, the following predictions apply for tick-constrained and unconstrained stocks, respectively:

H3a: *For tick-constrained stocks, the U.S. tick size pilot will cause a widening of the quoted spread, an increase in BBO depth and an increase in volume.*

H3b: *For unconstrained stocks, the U.S. tick size pilot may produce a narrowing of quoted spread, and will cause an increase in BBO depth and a decrease in volume.*

The benefits and costs of a smaller tick size has also been studied in theoretical models of intermediated markets. Anshuman and Kalay (1998) models a competitive dealer market to show that a large tick size may be needed to allow dealers to make sufficient profits to stay in business reducing the risk of market failure. Cordella and Foucault (1999) study price competition between dealers when bidding is sequential and show that a large tick size may actually speed up price discovery because dealers compete more aggressively. Kadan (2006) investigates the relationship between the tick size and the number of dealers and shows that when the number of dealers is large (small), an increase in the tick size benefits (hurts) dealers and hurts (benefits) investors. The reason is that a positive tick size curtails profits in a concentrated market, while it is the only source of profit in a competitive market. These theories motivate our final hypotheses regarding liquidity provision and price discovery:

H4a: *The U.S. tick size pilot may improve the profitability of liquidity provision.*

H4b: *The U.S. tick size pilot may speed up price discovery.*

H4c: *If the number of competing liquidity providers is large (small), the U.S. tick size pilot may improve (impair) the profitability of liquidity provision.*

We test these predictions based on data from the U.S. tick size pilot in the remainder of this paper.

4. Data and Methodology

To evaluate the effects of the tick size pilot program on market quality, we need to define a pre-pilot and a post-pilot period. The pilot officially started on October 3, 2016, but it was not until October 31st that all

test securities were subject to the new rules. There was considerable anticipation of the pilot and the transition period could have led to confusion among traders about which securities were subject to the new rules at what time. Therefore, we eliminate the week immediately prior to the pilot program's start through the transition period from our sample period, and define the pre-pilot period as the eight weeks leading up to the pilot, August 1 – September 23, 2016, and the post-pilot period as the eight weeks following the full implementation of the pilot, October 31 – December 23, 2016.[8]

The lists of control group and test group sample stocks are drawn from FINRA's website[9] and we include all the stocks identified on the lists that are either Nasdaq or NYSE-listed. We use TRTH data to calculate our market quality and trading activity metrics, and complement this data with firm characteristics from CRSP. We match the symbols provided on FINRA's website for the screened sample to the identifiers in TRTH and security identifiers in CRSP.

We apply the following additional screens: we exclude the test symbols, stocks that changed group during our sample period, stocks that were added after the beginning of, or eliminated before the end of, our sample period; preferred stocks; stocks with symbols that we are unable to match, stocks that trade fewer than 20 trades per day for more than half of the trading days in our sample period; and stocks that changed primary listing. The number of firms lost because of sample screening procedure is summarized in Appendix B.

The TRTH database is not commonly used to study U.S. equity markets, and a number of additional steps have to be taken to make the database comparable to the more commonly used TAQ data.[10] The file we use for each stock includes all updates to the official National Best Bid Offer (NBBO) as well as each trade, time-stamped to the microsecond with separate sequence numbers for quotes and trades (to settle ties). The NBBO is assigned to an exchange based on price, size, and time priority and each trade record indicates the executing venue (an exchange or one of the Trade Reporting Facilities (TRFs)). The TRTH data include a very large number of qualifiers for quotes and for trades, and because the raw data comes from the Security Information Processor (SIP), which is different for Nasdaq (UTP) and for the NYSE (CTA), securities listed on different exchanges have different qualifiers. We describe the procedures we use to screen the TRTH data in Appendix B.

[8] We exclude the week preceding the pilot, September 26-30 and the following holidays and partial trading days: September 5 (Labor Day); November 24 (Thanksgiving); and November 25 (markets closed at 1pm).
[9] http://www.finra.org/industry/oats/tick-size-pilot-data-collection-securities-files
[10] See also Hagströmer (2017) for suggested TRTH data matching and screening procedures for U.S. stocks.

We compute a battery of daily quote quality, trading activity, and liquidity provision and price impact measures for each stock. A list of our variables and their definitions can be found in Appendix C. Quote quality measures include:

- time-weighted quoted spread (ask –bid) in cents and in percent of the midquote (defined as (ask + bid)/2)
- share-weighted effective spread (2*(price – midquote)*Buy) in cents and in percent of the midquote (defined as (ask + bid)/2)
- time-weighted depth (asksize + bidsize) in shares and dollars
- standard deviation of mid-quote updates and midquotes sampled at five minute intervals

where price refers to a trade price, quote information (ask, bid, midquote, asksize, and bidsize) refers to the NBBO records, time-weighted refers to each observation being weighted by the time difference between NBBO quote updates in microseconds as a fraction of the total number of microseconds in the trading day, share-weighted refers to the size of the trade in shares relative to daily share volume, and Buy is an indicator for the trade direction that takes on the value of +1 for trades that from the viewpoint of the marketable order are classified as buys and -1 for sells. Trades are classified following the Lee and Ready (1991) algorithm as modified by Ellis, Michaely, and O'Hara (2000). Note that we match trades to the quotes in effect at the end of the preceding microsecond when calculating effective spreads (see Hagströmer, 2017). We also compute the following daily trading activity measures:

- Volume defined as consolidated volume including open and close volume measured in shares and dollars
- Average trade size defined as consolidated volume during continuous trading divided by the number of trades measured in shares and dollars
- Share-weighted average dollar trade price

Because depth, volume, and average trade size are highly skewed which could unduly influence our empirical analysis, we also calculate the logarithm of each of these variables:

- Log depth in shares and dollars
- Log volume in shares and dollars
- Log average trade size in shares and dollars

Finally, to evaluate changes in the profitability of liquidity provision, we calculate average realized spreads and price impacts at different horizons τ for a trade executed at time t.

- realized spread at horizon τ (2*(price$_t$ – midquote$_{t+\tau}$)*Buy) in cents and in percent of the midquote at the time of the trade
- price impact at horizon τ ((midquote$_{t+\tau}$ – midquote$_t$)*Buy) in cents and in percent of the midquote at the time of the trade

Buy is an indicator for the trade direction that takes on the value of +1 for trades that, from the viewpoint of the marketable order, are classified as buys and -1 for sells. A significant price impact will erode the returns for a liquidity provider whose limit order was filled. We calculate these measures at the following horizons, τ: 30 seconds, one, two, three, four, and five minutes.

[Insert Table 1 here]

Table 1 reports the descriptive statistics for our sample of stocks. Panel A reports the firm characteristics as of June 30, 2016, while Panels B and C report the measures of quote quality and trading activity for the pre-pilot period, August 1-September 23, 2016. Control firms and test groups are well matched based on market capitalization (size) and price also after our data screens. The average size ranges from 743.9 to 758.3 million dollars. Similarly, the average stock price ranges from $22.26 to $23.67. Furthermore, quote quality is well matched for stocks in control and test groups. The average quoted spread ranges from 8.26 to 8.96 cents and the average effective spread ranges 3.88 to 4.24 cents. The average NBBO depth ranges from 792 to 893 shares, and midquote volatility ranges from 2.87% to 2.92% based on mid-quote updates. Trading activity for the pre-period ranges from a share volume of 221,222 shares to 234,280 shares per day across the sample groups, while average trade size ranges from 128 to 137 shares.

To analyze our market quality data we first test for differences in means for each group of securities (C, G1, G2, and G3) using both a standard t-test and a non-parametric Wilcoxon test. We next examine the market quality data for parallel trends leading up to the tick size pilot program, and a shift in market quality for test stocks following the increase in tick size. Subsequently, we conduct a panel regression difference-in-difference analysis. We use two specifications for the panel difference-in-difference analysis. The first specification is:

$$MQ_{i,t} = \beta_0 + \beta_1 \cdot G1 + \beta_2 \cdot G2 + \beta_3 \cdot G3 + \beta_4 \cdot Event + \beta_5 \cdot G1 \cdot Event + \beta_6 \cdot G2 \cdot Event + \beta_7 \cdot G3 \cdot Event + \beta_8 \cdot X_t + \varepsilon_{i,t}, \quad (1)$$

where $MQ_{i,t}$ is a market quality measure (quote quality, trading activity) for stock i on day t, *G1*, *G2* and *G3* are dummies that take on a value of one for stocks belonging to the respective test groups, *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We cluster standard errors by firm and day.

As emphasized by Boehmer, Jones, and Zhang (2015), the total effect of the tick pilot for test stocks in, for example *G1*, is $\beta_4 + \beta_5$, which is composed of the direct effect β_5 and the indirect effect $\beta_4.\beta_4$ captures changes in market quality that coincide with the tick size pilot for stocks in group C. In an ideal setting, market quality for stocks in C should not change. However, such changes could either occur for reasons unrelated to the pilot, or because of spillovers related to the tick size pilot. The problem is that we cannot separate the two. The best we can do is to control for market-wide variables such as VIX that could affect market quality independently of the pilot.[11]

Another way to study the tick size pilot is to focus on the actual details of the rule changes. Specifically, all test stocks (G1, G2, and G3) are subject to the quote rule (Q), stocks in G2 and G3 are subject to the trade Rule (T), and stocks in G3 are subject to the trade-at rule (TA). This observation motivates the following specification:

$$MQ_{i,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{i,t}, \quad (2)$$

where $MQ_{i,t}$ is a market quality measure for stock *i* on day *t*, *Q*, *T* and *TA* are dummies that take on a value of one for stocks that are subject to the specific rule, *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is a market-wide control variable (VIX). Again, the total effect of the tick pilot for test stocks due to the quote rule (*Q*) is $\beta_4 + \beta_5$, which is composed of the direct effect β_5 and the indirect effect β_4 , where the latter captures changes in market quality for stocks in group C that coincide with the tick size pilot. Finally, we cluster standard errors by firm and day also for specification (2).

Even with double-clustered standard errors, it is possible that the results are overstated in a panel regression difference-in-difference analysis. To check the robustness of our finding, we therefore complement the analysis with a collapsed time series difference-in-difference analysis. For each day, we compute the cross-sectional average market quality measure for each group: C, G1, G2, and G3 (C, Q, T, and TA), and then run the following collapsed panel regression:

$$MQ_{g,t} = \beta_0 + \beta_1 \cdot G1 + \beta_2 \cdot G2 + \beta_3 \cdot G3 + \beta_4 \cdot Event + \beta_5 \cdot G1 \cdot Event + \beta_6 \cdot G2 \cdot Event + \beta_7 \cdot G3 \cdot Event + \beta_8 \cdot X_t + \varepsilon_{g,t}, \quad (3)$$

Where $MQ_{g,t}$ is the average market quality measure for stocks in group g on day *t*, and the dummies are defined as above. Similarly, with the alternative specification focusing on the rules that apply we have:

[11] Our results are virtually identical if we omit the market-wide control variable VIX. We have also conducted all analyses using firm and day fixed effects, dropping the G1, G2, and G3 dummies, and the results for the interaction coefficients are virtually indistinguishable from those reported in the empirical results section.

$$MQ_{g,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{g,t}. \quad (4)$$

For our collapsed panel difference-in-difference analysis, we use Newey-West standard errors with five lags.

5. Empirical Results Quote Quality and Trading Activity (H1 and H2)

We first examine how our market quality variables change between the pre and the post period for each of our subsamples: control stocks, G1, G2, and G3 stocks. Table 2 reports the mean for a subset of our market quality metrics in the pre and post-event period respectively, as well at the *t*-statistic for a test of differences in mean and the z-value for a two-sample Wilcoxon rank-sum (Mann-Whitney) test.

The first set of columns in Table 2 report the results for control stocks for which there were no changes in tick size. Nevertheless, we see significant changes both in the quote quality and trading activity. Specifically, quoted and effective spreads widen, depth, volatility, volume, trade size, and price all increase significantly based on the *t*-tests for differences in mean and this is true also for the Wilcoxon test with only one exception (average trade size in shares). For example, quoted (effective) spreads increase by 1.57 (0.49) cents, depth by 142 shares, volatility based on midquote updates by 0.55%, volume by 70,666 shares, average trade size by 3.35 shares, and price by $1.10 on average.

[Insert Table 2 here]

The statistics for the treated stocks for each test group are in the remaining columns of Table 2. All three groups show a significant increase in quoted and effective spreads, depth, volatility, volume, average trade size, and price based on the *t*-tests for differences in mean and this is true also for the Wilcoxon test. The changes in the quote quality (Panel A) is generally larger for stocks in the test groups than for stocks in the control group, but that is not universally the case for trading activity (Panel B). For example, quoted (effective) spreads for G1 stocks increases by 3.11 (2.27) cents, depth by 2,319 shares, volatility based on mid-quote updates by 0.83%, volume by 66,090 shares, average trade size by 15.15 shares, and price by $1.67 on average. While the changes in spreads are comparable across test groups, that is not the case for depth and trading activity. These variables increase much more modestly for G2 and G3 compared for G1 (and also compared to control stocks).

5.1 Graphical Analysis

To verify that a difference-in-difference analysis is appropriate, we compare the average daily market quality statistics for control stocks and the three groups of test stocks before and after the phase-in of the

tick size pilot in Figure 1. The Figure includes four panels, each plotting one daily market quality measure for control stocks (C) and the three test groups (G1, G2, and G3). The vertical red lines represent the start of the pilot (October 3, 2016) and the end of the phase-in (October 28, 2016) respectively. We exclude the phase in period, October 3 to October 28, 2016, from our main analysis as it is clearly a period of adjustment and stocks were gradually added to the test groups. We also exclude the week immediately preceding the phase in, September 26 - 30, 2016, to avoid any contamination due to anticipation of the tick size change.

For all four measures (quoted spread, effective spread, depth, and volume), the control and test samples exhibit parallel trends during the pre-period. Moreover, there is a gradual increase in quoted spread, effective spread and depth for test groups G1 and G2 relative to the control group during the phase-in period (between the red vertical lines). G3 was not fully phased in until October 31, and hence the changes in market quality for this group are delayed. Quoted spreads, effective spreads, and depth are clearly higher for the test groups than for the control group after the full implementation of the pilot (second vertical red line). By contrast, there is no visually detectible difference in volume for any test group compared to the control group following the implementation of the tick size pilot.

[Insert Figure 1 here]

It is also worth pointing out that there is a period of noticeably elevated quoted spreads and volume for all stocks during the days of November 9 - 15, 2016. These days coincide with market turbulence associated with the unexpected outcome of the U.S. Presidential election on November 8, 2016. It is important for our analysis that all groups of stocks appear to be similarly affected by this event. Moreover, we include VIX as a market-wide measure as a control variable in our analysis. Therefore, we see no a priori reason to exclude these days from our main analysis.[12]

5.2 Panel Difference-in-Difference Analysis: Test Groups

The tick size pilot was explicitly designed to allow for a difference-in-difference analysis to enable researchers to show how the quote rule, trade rule, and the trade-at rule affect market quality. In other words, the changes in market quality measures for stocks in the three test groups were meant to be compared to the changes for control stocks. Table 2 above illustrates how important it is to conduct a difference-in-difference analysis - stocks in the control group experience significant changes in market quality between the pre- and the post-event period despite not being subject to any change in tick size.

[12] We verify that our conclusions are robust to excluding these days in the robustness section.

We report the results from the panel difference-in-difference analysis based on equation (1) in Table 3. To deal with the highly skewed distributions of several market quality measures, we add the logarithm of depth in shares and dollars for the quote quality measures in Panel A, and the logarithm of volume and average trade size in shares and dollars for the trading activity measures in Panel B. First, note that the coefficient on the Event dummy, β_4, is significant for all market quality measures. Hence, the results show that there is a significant change in all market quality measures for control stocks following the implementation of the tick size pilot. For example, quoted (effective) spread increases by 1.77 (0.52) cents, depth increases by 163 shares, mid-quote volatility increases by 0.51%, volume increases by 69,902 shares, and average trade size increases by 3 shares. These changes are economically sizable compared to the pre-pilot averages (Table 1): a 21% (13%) increase in quoted (effective) spread; a 20% increase in depth; a 17% increase in volatility; and a 32% increase in volume. By contrast, the increase in trade size is only 2%. It is of course possible that the significant changes in market quality for control stocks are due to market-wide factors that are not captured by using VIX as a control variable. However, as mentioned above, it is also possible that these changes are the result of spillover from the tick size pilot stocks to control stocks.

[Insert Table 3 here]

The coefficients on the interaction terms reported in Table 3 are also all significant with one exception, G1*Event for volume. The results show that quoted (effective) spreads increase by 1.45 to 1.50 (1.65 to 1.93) cents, depths increase by 2,135 to 2,321 shares, midquote volatility increases by 0.23 to 0.86%, and average trade size increases by 5.07 to 12.28 shares. These changes are again economically significant. Consider G2 stocks for example. These stocks experience a 16% (46%) increase in quoted (effective) spread, almost a tripling of depth, an 8% increase in mid-quote volatility, and an 8% increase in trade size. By contrast, the pattern for volume across test groups is more mixed. There is no significant change in volume for G1 stocks but a significant decline in volume of -31,910 shares (-14%) for G2 stocks and -25,363 shares (-11%) for G3 stocks relative to control stocks.

Table 3 also illustrates that while the panel regressions for the logarithm of the skewed variables (depth, volume, and average trade size) have higher *R*-squares (within) and Wald statistics, the general conclusion is the same as for the level variables. Furthermore, the conclusions hold whether we estimate market quality measures such as depth, volume, and average trade size in shares or dollars, and whether we estimate spreads in dollars or in basis points.

5.3 Panel Difference-in-Difference Analysis: Rules

The tick size pilot was actually three pilots in one. It changed the quote rule for all test stocks (G1, G2, and G3), the trade rule for G2 and G3 stocks, and the trade-at rule for G3 stocks. To disentangle the potential

different effects of these three rules, we estimate the panel difference-in-difference regressions detailed in equation (2) with dummies for the different rules: quote rule (Q), trade rule (T), and trade-at rule (TA). The results are reported in Table 4 below.

[Insert Table 4 here]

The main cause for the changes in market quality we discussed above is clearly the quote rule. The Q*Event dummy is significant for all market quality measures with the exception of volume. The effects on market quality are identical to the ones estimated for G1*Event in Table 3. Hence, the economic magnitudes of the effects of the quote rule on market quality are large. The trade rule (T*Event dummy) has no additional effect on quoted spreads, share depth and average trade size, but causes effective spreads to widen (0.17 cents), dollar depth to increase ($123.42), and volume to decline (-26,653 shares or -$556,614). Aside from the decline in volume, which we discuss in the next section, these changes are modest compared to the effect of the quote rule. Finally, the trade-at rule (TA*Event dummy) is associated with no significant change in quoted spreads, a significant decline in effective spreads (-.28 cents), a decrease in dollar depth (-$94.96) but no significant change in share depth, a further increase in volatility (0.63%), and a decrease in average trade size (-5.14 shares). Again, with the exception of the average trade size change, these effects are minor compared to the effects of the quote rule.

To economize on space, we will use the dummy specification for the different rules (Q, T, and TA) as opposed to the test groups (G1, G2, and G) for the remainder of the paper.

5.4 Collapsed Panel Difference-in-Difference Analysis: Rules

Despite our efforts at screening the data, and using two-way clustered standard errors, it is possible that our inference is influenced by outliers. Daily data is quite noisy as evidenced by Figure 1. To check the robustness of our findings, we therefore estimate the difference-in-difference regressions based on a collapsed panel as described in equation (3). Each day, we calculate the simple arithmetic average for each variable for each group of stocks. The collapsed panel thus consists of a time series of four daily observations. The results of this estimation are in Table 5, and standard errors are computed following Newey-West with five lags.

[Insert Table 5 here]

The results show that the estimated coefficients on the Event dummy are very similar to those we reported in Table 4 for the panel difference-in-difference estimation. Recall that this implies that the tick size pilot potentially had significant spillover effects on control stocks, particularly in terms of the quoted

and effective spreads. The estimated coefficients on the Q*Event dummy which captures the changes associated with the quote rule are also similar. However, note that unlike the results reported in Table 4, there is no significant difference in volume between control and test stocks regardless of which rule they are subject to.

Furthermore, the more conservative estimation technique summarized in Table 5 shows that the trade and trade-at rules do not significantly affect spreads or share depth. While these rules appear to affect dollar depth in opposite directions, the more consistent estimates based on logarithms of the depth measures suggest that outliers may be responsible for the contradictory dollar depth pattern. Moreover, the trade-at rule is associated with a further increase in the logarithm of depth, but the magnitude is small compared to the effect of the quote rule. The trade-at rule continues to be associated with an increase in volatility, and a further decline in average trade size regardless of how we measure this variable.

5.5 Discussion

The overall results confirm hypothesis **H1** (Goettler et al., 2005; Werner et al., 2015), which predicts that a tick size increase causes a widening of spreads, an increase in depth, and a decrease in consolidated volume as traders switch from market to limit orders. In independent contemporaneous work, Griffith and Roseman (2017) also find results consistent with this hypothesis, including a decrease in consolidated volume. However, we show that the volume reduction result is weak and inconsistent across specifications and disappears entirely when we estimate the effect of the tick size pilot based on a collapsed panel regression. This is also what we would have predicted based on Figure 1, and illustrates that panel regressions may be misleading when data are noisy. A potential explanation for the insignificant average volume result is the opposing volume predictions related to tick constraints in **H3a** and **H3b** and we will compare the results for tick constrained versus unconstrained stocks in the next section.

The vast majority of the changes in quote quality caused by the tick size pilot can be attributed to the quote rule. By comparison, the changes caused by the trade-rule and the trade-at-rule are small in magnitude and often not significant. This does not mean that the trade-rule and the trade-at rule have no consequences. However, it appears these rules cause changes primarily to the market share of different venues as highlighted by Comerton-Forde et al. (2017) and Lin et al. (2017) as opposed to changes in the market-wide quote quality and trading activity that we capture in our analysis.

Our results are also consistent with hypothesis **H2** (Seppi, 1997), which predicts that a tick size increase causes an increase in average trade size as the higher depth reduces the need for institutional traders to split up larger orders. This is intriguing as it suggests that while quoted and effective spreads increased for test

stocks following the implementation of the tick size pilot, it is possible that institutional trading costs did not deteriorate, and may even have fallen. Recall that while spreads declined following the U.S. tick-size reductions in 1997 and 2001, researchers found that institutional trading costs increased particularly for large liquidity-demanding orders (e.g., Jones and Lipson, 2001; Chakravarty et al., 2005; and Bollen and Busse, 2006). Unfortunately, we do not at this time have access to the institutional order data that would be required to determine whether the reduced need for order splitting also results in lower trading costs facing institutions following the tick size pilot.

The results in Tables 3, 4, and 5 for share and dollar measures for depth, volume, and average trade size appear to be quite noisy. This is to be expected since the distributions of these variables are highly skewed. As a result, we put more weight on the estimation results based on the logarithm of this set of variables. In the remainder of this paper, we will only tabulate the regression results for the logarithms of depth, volume, and average trade size. However, we will at times discuss the magnitude of the coefficients from the un-logged share and dollar estimates as well.[13] Furthermore, because the average prices increase significantly between the pre- and the post-event period, we henceforth report only the dollar spreads.

6. Tick-Constrained vs. Unconstrained Stocks (H3)

In order to examine whether test stocks that were tick constrained prior to the implementation of the tick size pilot were affected differently compared to those that were unconstrained, we first have to determine what it means to be tick constrained. The five cent tick size that was imposed on all test groups (G1, G2, and G3) implies a five cent minimum quoted spread. We therefore classify any stock that was traded at an average quoted spread of five cents and below as tick constrained under the new quote rule. Furthermore, we classify any stock that was traded at an average quoted spread of ten cents and above as unconstrained. The reason is that the quoted spread could narrow by one full tick, from ten to five cents, for these stocks even with the new coarser five cent pricing grid.[14]

[Insert Table 6 here]

We report descriptive statistics for tick-constrained and unconstrained stocks in each sample group (C, G1, G2, and G3) in Table 6. Roughly half the stocks in the overall sample are tick-constrained based on our definition (976/2,028), while the group of unconstrained stocks comprise about a quarter of the sample (555/2,028). It is important for our analysis that the sample groups remain well-matched within tick-constrained and unconstrained subsamples, and the descriptive statistics suggest that this is indeed the case.

[13] The share and dollar estimates are available from the authors on request.
[14] We examine an alternative classification based on the pre-event quoted spread quartiles in the robustness section.

The numbers show that firms whose stocks are tick-constrained are slightly larger than unconstrained firms, and as expected the stock prices for tick-constrained firms are much lower than those for unconstrained firms. By design, the spreads are much wider for unconstrained stocks. Depth for tick-constrained stocks are about double the depth for unconstrained stocks on average. Tick-constrained firms are also much more actively traded, with four to five times the share volume of unconstrained stocks. Finally, trade size is about forty percent larger for tick-constrained stocks.

6.1 Graphical Analysis

We again verify that a difference-in-difference analysis is appropriate by first comparing the average daily market quality statistics for control stocks and the three groups of test stocks before and after the phase-in of the tick size pilot in Figures 2 and 3 for tick-constrained and unconstrained stocks respectively. The Figures include four panels, each graphing one daily market quality measure for control stocks (C) and the three test groups (G1, G2, and G3). Recall that the vertical red lines represent the start of the pilot (October 3, 2016) and the end of the phase-in (October 31, 2016).

[Insert Figure 2 here]

[Insert Figure 3 here]

Both tick-constrained and unconstrained stocks exhibit parallel trends during the pre-period, for all four measures (quoted spread, effective spread, depth, and volume). After the full implementation (second vertical red line), quoted spreads, effective spreads, and depth are clearly higher for tick-constrained test groups than for the tick-constrained control group. There is again no visually detectable difference in the change in volume for tick-constrained test groups relative to the control group. By comparison, for unconstrained stocks, there is no visually detectable difference in the change in quoted or effective spreads and a more complex development of depth and volume. Thus, while it appears that the impact of the tick size pilot on the quote quality was significant for tick-constrained stocks, we need to proceed with caution when evaluating the impact for unconstrained stocks.

6.2 Panel Difference-in-Difference Analysis: Rules

We formally test for differences-in-differences between treated samples and the control sample for tick-constrained and unconstrained stocks based on equation (2) in Table 7. With only one exception, the coefficients on the Event dummy, β_4, are positive and significant both for tick-constrained and unconstrained stocks. Hence, there is a significant change in market quality for both tick-constrained and unconstrained control stocks following the implementation of the tick size pilot. The economic magnitudes

of the changes we pick up with the Event dummy are particularly large for quoted spreads in the case of unconstrained stocks, 5.00 cents, and for volume both for tick-constrained and unconstrained stocks of 0.255 (98,037) and 0.331 (33,658) log shares (shares) respectively.[15] As mentioned previously, we are unable to distinguish whether these changes are the result of spillover from the tick size pilot to control stocks, of if they represent a market-wide change in market quality.

[Insert Table 7 here]

The estimated coefficients in Table 7 Panel A show that the quote rule causes a 3.19 cent increase in quoted spreads for tick-constrained stocks relative to controls while it is associated with a 2.60 cent *decrease* in quoted spreads for unconstrained stocks relative to controls. In terms of economic magnitudes, this change corresponds to a 112% (3.19/2.85) increase of the quoted spread compared to the pre-period spread for tick-constrained G2 stocks, and a 12% (-2.60/20.82) decrease in spreads compared to the pre-period spread for unconstrained G2 stocks. Effective spreads also increase by 2.31 cents for tick-constrained test stocks relative to control stocks, an increase of 128% (2.31/1.80) compared to the pre-period for G2 stocks. There is also a small increase in effective spreads of 0.7% (0.59/8.88) cents relative to controls compared to the pre-period level for unconstrained G2 stocks. We find that the quote rule causes a statistically and economically significant increase in depth for both tick-constrained and unconstrained test stocks relative to controls of 1.081 (3,450) and 0.306 (456) logshares (shares) respectively. Thus, share depth increases by 326% (3,450/1,059) for tick-constrained G2 stocks and by 82% (456/557) for unconstrained G2 stocks. The last set of columns in Table 7 Panel A show that the quote rule is associated with a significant increase in midquote volatility for tick-constrained test stocks relative to controls, but unconstrained test stocks instead experience a significant *decline* in midquote volatility.

In terms of trading activity, Table 7 Panel B shows that the quote rule is associated with a significant decline in trading volume both for tick-constrained and unconstrained test stocks relative to controls of 0.055 (9,744) logshares (shares) 0.041 (4,428) logshares (shares) respectively. While statistically significant, these changes are small both relative to the overall change in the market-wide volume (Event dummy), and the pre-event levels of trading activity reported in Table 6. The estimated coefficient also show that the quote rule is associated with a significant increase in logshare average trade size both for tick-constrained (0.101) and unconstrained (0.031) test stocks relative to controls. These figures correspond to an increase in average trade size by 12% (17.88/147.29) and 6% (6.42/104.83) compared to the pre-event levels for tick-constrained and unconstrained G2 test stocks respectively.

[15] The share estimates in this section come from the untabulated panel regressions based on the raw share volume numbers.

The estimates in Table 7 show that the effects of the trade rule and the trade-at rule, while often statistically significant, are generally of a smaller economic magnitude compared to the effects of the quote rule. Panel A shows that the trade (trade-at) rule is associated with a further widening (narrowing) of the quoted and effective spreads for tick-constrained firms, but no significant change for unconstrained stocks. Depth for tick-constrained test stocks is not affected by the trade rule, but increases significantly for test stocks subject to the trade-at rule by 0.108 (1,134) logshares (shares). By contrast, the trade rule is associated with a significant decline in depth by 0.38 (402) logshares (shares) while the trade-at rule does not affect depth for unconstrained stocks. The trade rule does not significantly affect volatility for tick-constrained stocks, but is associated with a further reduction in volatility for unconstrained stocks. The last columns show that while the trade-at rule is associated with a further increase in volatility both for tick-constrained and unconstrained stocks.

Table 7 Panel B shows that the trade rule is associated with a further volume reduction of 0.038 (37,467) logshares (shares) but no change in average trade size for tick-constrained stocks, but volume increases significantly by 0.055 (24,147) logshares (shares) for tick-constrained stocks subject to the trade-at rule. For unconstrained test stocks, the trade rule is associated with no significant change in either volume or trade size, while the trade-at rule is causes a significant further reduction both in volume and average trade size of 0.107 (19,505) and 0.062 (73) logshares (shares), respectively.

6.3 Collapsed Panel Difference-in-Difference Analysis: Rules

Our examination of the time-series for our core market quality variables in Figures 2 and 3 suggest that some of the results presented in the previous subsection, particularly those for volume, may not be robust. We therefore now turn to the collapsed panel regressions to validate our results. The results based on equation (3) are reported in Table 8.

[Insert Table 8 here]

The results based on the more conservative estimation method shows that there is no significant change in volume for test stocks relative to controls regardless of what trading rules they are subject to (Q, T, or TA) and regardless of whether or not they are tick-constrained. The results also show that the estimated coefficients and economic magnitudes of the effects of the quote rule from Table 7 are robust.

The trade-at rule is associated with a significant narrowing of quoted and effective spreads and a further increase in depth and volatility for tick-constrained test stocks while the trade-at rule has no effect on these measures for unconstrained test stocks. Furthermore, the trade-at rule is associated with a reduction is depth

both for tick-constrained and unconstrained stocks. By contrast, there is no statistically significant effect of the trade rule for any of our measures either for tick-constrained or unconstrained stocks.

6.4 Discussion

The theoretical models describe what happens to displayed orders, and hence speak to the quote rule. The overall results about the effect of the quote rule for quoted spreads and depth confirm hypotheses **H3a** and **H3b** (Foucault, Kadan and Kandel, 2005; Werner et al., 2015). Specifically, quoted spreads widen for tick-constrained test stocks while quoted spreads narrows for unconstrained test stocks relative to control stocks. The spread by definition widens when a coarser price grid is imposed for stocks that had a narrower quoted spread than the new minimum tick size, i.e., these stocks are tick-constrained at the new five cent tick size. Limit orders that would otherwise have been placed at ticks inside the new wider minimum spread now form a queue at the new wider minimum quoted spread, and hence depth increases.[16] For stocks that had an average spread of ten cents or more prior to the implementation of the pilot, the lower risk of undercutting encourages some liquidity providers to become more aggressive and the spreads fall and depth increases significantly as a result. Volume declines for both tick-constrained and unconstrained stocks based on the panel regressions but volume for tick-constrained stocks should increase according to **H3a**. However, as there is no significant change in volume for either subsample in the more conservative collapsed panel analysis, we conclude that the volume prediction for the quote rule is not borne out for either subsample. This is in contrast to the findings by Lin et al. (2017), who argue that consolidated volume declines for the tick constrained firms.

Furthermore, our results show that the trade rule, the fact that orders may execute in dark venues at a finer price grid, does not significantly affect the quote quality or trading activity measures while the trade-at rule is associated with a narrowing of spreads, a further increase in depth and volatility for tick-constrained stocks, but a reduction in average trade size for both subsamples. These results are consistent with Comerton-Forde et al. (2017) who show that the trade-at rule causes a shift away from dark venues to inverted venues for tick-constrained firms while the trade rule has no effect. When subject to the trade-at rule, traders are no longer able to trade through the displayed quotes in dark venues. As a result, limit orders migrate to the lit markets increasing the competitiveness of the displayed quotes.

[16] Note that we measure NBBO depth only. Griffith and Roseman (2017) use order-level data to show that cumulative depth remains unchanged or decreases.

7. Liquidity Provision and Price Discovery (H4)

One of the main reasons for Congress to direct the S.E.C. to conduct the pilot was the argument put forth in the JOBS Act that the penny tick size was too small to generate sufficient potential profits to attract market makers to EGCs. To evaluate the effects of the tick size pilot on the rewards for liquidity provision, we follow Conrad and Wahal (2017) and study the term structure of liquidity provision measured by realized spreads at different horizons (30 seconds, one, two, three, four, and five minutes). Significantly higher realized spreads present potential rewards available for liquidity providers. Furthermore, according to Cordella and Foucault (1999), an increase in the tick size may speed up the convergence of prices to the efficient price. The reason is that liquidity providers compete more aggressively in order to capture the wider minimum quoted spread. If the speed of price discovery increases following an increase in the tick size, then the information incorporated in future prices should increase and so should the price impact. We therefore study price impact measured as the change in the NBBO midquote at different horizons (30 seconds, one, two, three, four, and five minutes), and consider an increase in the price impact for test stocks relative to control stocks as evidence that the tick size pilot results in faster price discovery.

In Table 9, we report descriptive statistics for realized spreads and price impact for control stocks and for each test group in the pre-event period. Panel I includes the results for all stocks and all horizons, while panels II and III report the abbreviated results (30 second and five minute horizons) for tick-constrained and unconstrained stocks respectively. Panel I shows that realized spreads and price impacts are well-matched across groups. Realized spreads range from 1.73 to 1.99 cents at the 30 second horizon and decay by about 0.25 cents over the five-minute horizon. Price impact ranges from 0.82 cents to 0.88 cents at the 30 second horizon, and attenuate by about 0.15 cents over the five-minute horizon. The term structures of liquidity provision and price impacts are also well-matched across groups for the subsamples, and we note that realized spreads for unconstrained stocks are almost ten times larger at the five-minute horizon than realized spreads for constrained stocks.

[Insert Table 9 here]

7.1 Panel Difference-in-Difference Analysis: Rules

We report the overall results from panel regressions based on equation (2) in Table 10. Panel A displays the term structure of liquidity provision from a 30-second to a five-minute horizon. The quote rule raises the rewards for liquidity providers significantly. The estimated coefficient on the Q*Event interaction term is positive ranging from 0.78 cents at 30 seconds to 0.70 cents at a five-minute horizon. These changes for test stocks relative to controls are also economically significant, corresponding to an increase compared to

the pre-event realized spreads ranging from 39% (0.78/1.99) to 42% (0.70/1.68) for G2 stocks (Table 9 Panel IA). The trade-rule further significantly adds to the rewards for liquidity providers. However, the magnitudes of these changes are economically small (0.13 cents or less). By contrast, the trade-at rule significantly *reduces* realized spreads by 19% (-0.33/1.99) at the 30-second horizon to 17% (-0.28/1.68) at the five-minute horizon. Finally, the positive and significant coefficients on the Event dummy show that the rewards for liquidity provision increase significantly also for control stocks following the implementation of the pilot, but the magnitude of the coefficients are small by comparison: 0.12 cents declining to 0.07 cents translating to an increase in potential profits by 7 to 5 percent.

[Insert Table 10 here]

Panel B reports the results for price impact at the same set of horizons, and show that the quote rule is associated with a significantly larger price impact at all horizons ranging from 0.46 at the 30-second horizon to 0.49 cents at the five-minute horizon. Compared to the pre-event price impacts for G2 stocks (Table 9 Panel IB), these numbers correspond to an increase of 52% (0.46/0.88) to 47% (0.49/1.04). The trade rule is associated with a significant further increase in price impact, but the magnitude is small by comparison ranging from 0.06 to 0.08 cents as we move out the term structure. There is no significant effect of the trade-at rule on price impacts at any horizon. Again, the positive and significant coefficients on the Event dummy show that price impacts increase significantly also for control stocks following the pilot, and the effect is about one-third of the one for stocks subject to the quote rule.

For completeness, in Table 11 we examine the relationship between the rewards for liquidity provision for tick-constrained and unconstrained, respectively. Panel A shows that the bulk of the increase in the rewards from liquidity provision arises from trading tick-constrained stocks. For example, the coefficient on the Q*Event interaction term at the 30-second (five-minute) horizon is 1.11 (0.93) cents for tick-constrained stocks while the coefficients are insignificant for unconstrained stocks. This makes sense as it is for tick constrained stocks that quoted and effective spreads increase significantly. It also means that the increase in the potential rewards for liquidity providers for tick-constrained stocks is economically even more sizable, corresponding to 1.95 (1.11/0.57) and 1.86 (0.93/0.50) times the pre-event realized spreads for G2 stocks (Table 9 Panel IIA) at the 30-second and five-minute horizon, respectively. The trade rule does not significantly affect realized spreads for tick-constrained stocks or unconstrained stocks at any horizon. By contrast, the trade-at rule is associated with a significant *decline* in the potential rewards for

liquidity provision for tick constrained stocks at all horizons, and the magnitude ranges from -53% (-0.30/0.57) to -42% (0.21/0.50).[17]

[Insert Table 11 here]

Table 11 Panel B reports the results for panel regressions analyzing price impact at various horizons. The quote rule is associated with significantly higher price impacts at all horizons for tick-constrained stocks, and for unconstrained test stocks up to and including the three-minute horizon. Again, the bulk of the effect is for tick-constrained stocks. Compared to the pre-event level, the price impacts for tick-constrained stocks in test group two more than double, e.g., an increase of 121% (0.58/0.48) to 131% (0.67/0.51) for the 30-second and the five-minute horizons respectively. By comparison, the quote rule induced changes in price impacts for unconstrained stocks are very small in economic terms, e.g., 0.21/1.57 or 13% for G2 stocks at the 30-second and declines thereafter (the coefficients remain significant up to and including the three-minute horizon). The trade rule causes a further increase in price impacts for tick-constrained stocks, but it is small in economic magnitude (about 0.07 cents). Finally, there is a significant increase in price impacts caused by the trade-at rule for unconstrained stocks up to and including the three-minute horizon, but instead a *reduction* price impacts for tick-constrained stocks. In both cases, the economic magnitude is small relative to the levels of pre-event price impacts.[18]

7.2 Market Maker Profits

While commonly used as a proxy for market maker profits, short-term realized spreads only capture the potential for hhigher rewards for liquidity provision. Moreover, we are only calculating these rewards at horizons up to five minutes, and it is an open question whether liquidity providers in these relatively illiquid stocks are able to capture the realized spread at such short horizons. We therefore turn to the daily consolidated market maker profit data that is collected by FINRA as part of the tick size pilot to provide additional information regarding rewards for liquidity provision. The data is reported monthly on FINRAs website starting with the month of April, 2016.[19] We download the monthly data sets for April 2016 through

[17] Untabulated results from the collapsed panel regressions (equation 3) show that the effect of the trade rule on the rewards to liquidity provision is insignificant at all horizons (both for tick-constrained and unconstrained firms) while the effect of the trade-at rule is significant and negative but only for tick-constrained firms and only up to and including the two-minute horizon.

[18] Untabulated results based on the collapsed panel regressions (equation (3)) show that there is no significant effect of the trade rule on price impacts at any horizon either for tick-constrained or unconstrained firms. However, the trade-at rule is associated with a significant but economically small reduction in price impact at three-, four-, and five-minute horizons for tick-constrained stocks.

[19] http://www.finra.org/industry/appendix-c-data-publication.

May 2017. The data is available for control stocks for the pre-pilot period and this includes all eligible securities. The data for the post-pilot period is reported for control stocks and for each test group separately.

We first illustrate profitability graphically in Figure 5 based on the daily variables Total Market Maker Realized Profits (Panel A) and Total Market Maker Unrealized Profits (Panel B). For comparison purposes, we divide the total profit number by the number of securities in each sample group. The number of securities changes daily due to mergers and acquisitions, delistings, the roll-in of pilot stocks, etc. The series starts with 3,148 control stocks on March 8, 2016, and in line with the rest of our analysis, we define the end of the pre-pilot period as September 23, 2016. We take the post-period to start after the phase-in is completed, October 31, 2016, and the sample then has 1,189 control stocks, 397 G1 stocks, 394 G2 stocks, and 395 G3 stocks. The dashed vertical lines in each Panel represent September 23, and October 31, 2016, respectively. At the end of the plotted period, May 31, 2016, the sample has 1,154 control stocks, 377 G1 stocks, 373 G2 stocks, and 376 G3 stocks.

Daily average profits per stock in the pre-event period are $206 with a standard deviation of $215. Daily average profit across market makers per control stock in the post-event period is $403 with a standard deviation of $246. In other words, average control stock profit increases by $197 per stock (p-value < 0.0001 based on a two-tailed t-test with unequal variances). Daily average (standard deviation of) profits across market makers for test groups one through three in the post-event period are: $494 ($260) for G1; $575 ($329) for G2; and $565 ($288) for G3. These post-event profits are not only higher than average market maker profit in the pre-pilot period they are also higher than for the average control stock in the post-period by $91 (G1), $172 (G2), and $162 (G3). The differences between post-event profits for test and control stocks are all significant (p-values are 0.0024 (G1), < 0.0001 (G2), and < 0.0001 (G3) based on a two-tailed t-test with unequal variances). Hence, the increase in profits for test stocks is significantly higher than the increase in profits for control stocks. These results are robust to using the sample period to match that used in the rest of the paper, August 1-September 23, October 31-December 23.[20]

[Insert Figure 5 here]

Unrealized profits in Panel B are much more variable. The daily average unrealized profit for control stocks in the pre-period is $15 with a standard deviation of $348. By comparison, daily average unrealized profits for control stocks in the post-period is $98 with a standard deviation of $806. Unrealized average (standard deviation of) profits for test groups one through three in the post-event period are: $69 ($953);

[20] The differences in per stock market maker profits for test groups relative to control stocks are $99 (G1), $156 (G2), and $160 (G3) with p-values 0.1167, 0.0448, and 0.0393 respectively.

$122 ($917); and -$30 ($734), and these are not significantly different from unrealized profits for control stocks in the post-event period.

7.3 Discussion

Our result that realized spreads increase overall following the phase-in of the tick pilot is consistent with hypothesis **H4a** (Anshuman and Kalay, 1998). Thus, in principle liquidity providers should be able to turn the wider effective spreads into higher rewards for liquidity provision as anticipated when Congress adopted the JOBS Act and instructed the SEC to study the effects of a larger tick size for EGCs.[21] Griffith and Roseman (2017) and Lin et al (2017) also document larger realized spreads following the phase-in of the tick pilot for all test groups. We complement their findings by formally testing the impact of each specific rule, and our results clearly show that the increase in realized spreads is entirely caused by the quote rule. Hence, it is the fact that the price grid for the displayed quotes changes that produces larger profit opportunities for liquidity providers. In contrast, the trade rule which eliminates the opportunity for dark venues to execute trades inside the minimum five cent spread has no significant effect on realized spreads. Moreover, we show that the trade-at rule which eliminates trade-throughs in dark venues causes a significant *reduction* in profit opportunities for liquidity providers. Hence, the trade-at rule undermines the objective of the JOBS Act to improve the profit opportunities for market makers and other liquidity providers.

Our overall results that price impacts increase significantly following the implementation of the tick size pilot are also consistent with the hypothesis **H4b** (Cordella and Foucault, 1999), which predicts that a tick size increase may speed up price discovery. Furthermore, we showed in Section 6 that midquote volatility increased significantly for test stocks relative to control stocks, which is also consistent with faster price discovery. Lin et al (2017) document that variance ratios decline significantly, providing further evidence supporting the hypothesis that test stocks experience faster price discovery. Again, we show that virtually the entire effect is due to the quote rule, while the trade rule has only a modest effect and the trade-at rule no significant effect on price impacts for the overall sample. Thus, the more aggressive competition between liquidity providers at the wider minimum quoted spread means that quotes more rapidly move to incorporate trade-based information. Despite the higher price impact of trades, the increase in quoted spreads is sufficient to generate significantly larger realized spreads, and hence potential profits for liquidity providers.

[21] While quoted spreads for unconstrained stocks decline significantly as shown in Tables 7 and 8, effective spread for unconstrained stocks widen significantly.

We also contribute to the literature by studying the term structure of liquidity provision and price impacts following Conrad and Wahal (2017). We show that while price impacts increase over the hypothetical holding periods ranging from 30 seconds to five minutes, the increase is relatively slow and does not wipe out the increase in effective spreads resulting in significantly higher realized spreads for all horizons on average.

Furthermore, we show that the effects on the potential rewards for liquidity provision as well as the effects on price impacts arise virtually entirely from tick-constrained stocks. These stocks experience almost a doubling of realized spreads on average as a result of imposing the larger tick size for displayed quotes. By contrast, increasing the tick size for displayed quotes is an ineffective policy for improving the rewards for liquidity provision for stocks that are not tick constrained.

Although we do not have a measure of the number of liquidity providers per se, our realized spread results suggest that there is sufficient number of competing liquidity providers even for the stocks comprising the tick size pilot for the tick size increase to generate an improvement in profitability of liquidity provision as predicted by hypothesis **H4c** (Kadan, 2006).

Finally, we test for a difference in the changes in market maker profits for test stocks relative to control stocks based on the FINRA data on market maker profits. The data shows that market maker profits after the tick size pilot was implemented are higher for test than for control stocks compared to the pre-pilot market maker profits. Hence, at least one group of liquidity providers – market makers – are able to capitalize on the wider spreads induced by the tick size pilot. Recall that we find that spreads widen significantly for control stocks in the post-period despite the absence of tick size changes. As we mentioned earlier, it is unclear whether this is a result of market-wide changes in liquidity provision or is a result of spillover from the tick size pilot. However, we conjecture that the wider spreads for control stocks is a result of a reduction in competition as market makers attracted by the increasing rewards for liquidity provision in test stocks reduce their market making activities in control stocks. Hence, we conclude that the effects we observe for control stocks are indeed spillovers from the pilot.

8. Robustness Tests

We conduct a number of tests to check that our results are robust to the choice of sample period and methodology.[22] The pilot was implemented in the midst of a contentious 2016 U.S. Presidential election, and as we noted above, the outcome of the election had repercussions that are clearly noticeable in Figures 1, 2, and 3. Hence, we re-examine our results excluding Presidential election week November 9-15, 2016

[22] The robustness analyses are available from the authors on request.

and find that our results are qualitatively unchanged. Similarly, to avoid the anticipation effect and to keep the sample balanced at eight weeks pre- and eight weeks post-pilot, we exclude the week prior to the pilot, September 26-30, 2016, for our main analysis. However, our results are robust to including the week immediately preceding the start of the pilot.

Our main analysis uses difference-in-difference panel regressions without firm fixed effects as we wanted to verify that the coefficients for our group (G1, G2, and G3) and rule dummies (Q, T, and TA) were indeed insignificant after our sample screens. To validate the robustness of our results, we also re-estimate all our panel regressions using firm fixed effects, again clustering standard errors by firm and date. The results are virtually identical to those we present in the paper with this alternative specification.

Another potential concern is that while the definition of tick-constrained stocks as those with a pre-event quoted spread of five cents or below may be uncontroversial, to define unconstrained stocks as those with a pre-event quoted spread of ten cents of above may seem ad hoc. We re-estimate all our analyses defining tick-constrained (unconstrained) stocks as those with pre-event quoted spreads in the lowest quartile (highest quartile), and find that our results are again robust. Furthermore, we repeat the analysis defining unconstrained stocks as those with a pre-event quoted spread above five cents (in the second, third, and fourth quartiles). The only notable difference is that with this definition we no longer find quoted and effective spreads to decline significantly for unconstrained stocks.

Finally, in the Appendix D we repeat the main analysis using subsamples based on market of primary listing: Nasdaq or NYSE. While NYSE-listed pilot firms have significantly larger market capitalization, and their stocks have narrower spreads, lower volatility, and larger consolidated volume than Nasdaq-listed pilot stocks, the average stock price in each subsample is similar. Hence, this cut provides an alternative way of comparing stocks along the liquidity dimension while keeping the tick size relative to the stock price constant. The effects of the quote rule and the trade-at rules are qualitatively the same as the ones we find for the overall sample regardless of market of primary listing. However, while we found no significant effects of the trade rule in the overall sample, the trade rule is associated with a decline in depth and trade size for Nasdaq-listed stocks and an increase in depth and trade size for NYSE-listed stocks. Hence, the trade rule appears more effective in attracting limit orders away from the dark to the lit market for larger capitalization (more liquid) stocks than for stocks of lower capitalization (less liquid) stocks. However, graphical analysis suggests that caution is warranted in interpreting this finding. While the effect on depth for Nasdaq-listed stocks in G2 (those subject to the quote and trade rules) actually increases over time, the effect on depth for G2 stocks disappears by late December. This motivates future longer-term studies of the effect of the tick size pilot on market quality.

9. Conclusions

In this paper, we use intraday transactions and quote data from the period surrounding the tick size pilot phase-in to study the effects of the increase in the tick size from one penny to a nickel for quote quality, trading activity, the rewards to liquidity provision, and price discovery.

The results show that the larger tick size causes quoted and effective spreads, but also inside depth, to increase. While consolidated volume declines based on a panel regression difference-in-difference analysis, the more conservative regression and graphical analyses show that consolidated volume does not change significantly. By contrast, average trade size increases significantly. Hence, while the five cent tick size significantly raises the cost for retail-sized, liquidity-demanding orders, the deeper quotes may benefit institutions by reducing the need for order splitting. This is an intriguing possibility, and future research into the effects of the tick size pilot on institutional trading costs is clearly warranted.

We also find that the larger tick size translates into higher potential profits to liquidity providers (realized spreads) despite faster price discovery (price impacts) at horizons from 30 seconds to five minutes. Moreover, we document that aggregate market maker profits per stock increases significantly for test stocks relative to control stocks after the pilot. This was the effect that Congress sought to achieve when directing the SEC to undertake the tick size pilot, and in this sense the pilot has been successful.

The tick pilot introduces three different changes related to the tick size: the quote rule which applies to all test stocks; the trade rule which applies to test stocks in groups two and three; and the trade-at rule which applies only to stocks in test group three. We attribute the changes in quote quality, trading activity, potential rewards to liquidity provision, and price discovery mainly to the changes in tick size for displayed quotes (quote rule), while there are modest or no effects of requiring all trades to execute on a coarser price grid (trade and trade-at rules).

Moreover, the bulk of the effects of the larger tick size occur for stocks that traded at an average quoted spread of a five cents or lower prior to the pilot. The results for unconstrained stocks, those that traded at an average spread of ten cents or more prior to the pilot, the results are quite different. Unconstrained stocks are issued by smaller firms, and trade at higher prices and wider spreads. For these stocks, quoted spreads decline significantly and depth increases, which is beneficial for liquidity-demanding traders. There is also no economically significant change in the potential rewards for liquidity provision for unconstrained stocks. Hence, the five cent tick size is ineffective for delivering the desired increase in potential profits for market makers in unconstrained stocks.

Finally, we document significant spillovers from the tick size pilot to quote quality, trading activity, the rewards for liquidity provision, and price discovery for control stocks. Quoted and effective spreads, depth, volatility, volume and average trade size all increase significantly also for control stocks even though there was no change of the tick size for these stocks. This could in principle be caused by a market-wide increase in adverse selection. Consistent with this explanation, price impacts do increase significantly for control stocks at all horizons. However, potential rewards for liquidity provision also increase at all horizons after the tick size was changed for test stocks. Hence, quoted spreads for control stocks widen more than enough to compensate for the increased adverse selection risk. Our evidence therefore suggests that the pilot attracts liquidity providers away from control stocks, and that the reduced competition causes spreads and profits to increase also for stocks that continue trading in decimals.

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Appendix A: US Tick Size Pilot Program Implementation Schedule

Date	Action	Additional Details
Oct. 3	5 Symbols – Test Group 1 JAKK ISCA FET CFI SGA 5 Symbols – Test Group 2 GBT TTS HUBS RATE ERN	All other symbols assigned to Test Group1, Test Group 2, or Test Group 3 will be placed into the Control Group until they are activated in their respective group.
Oct. 10	100 Symbols - Test Group 1 100 Symbols - Test Group 2	
Oct. 17	400 Symbols – Test Group 1 400 Symbols – Test Group 2 5 Symbols – Test Group 3 CACQ CLFD ATTO PRTY DIT	All Test Group 1 and 2 symbols are live.
Oct. 24	100 Symbols – Test Group 3	
Oct. 31	400 Symbols – Test Group 3	All Test Group 3 symbols are live.

Appendix B: Data Processing

1. Sample Selection

We consider all common stocks involved in the pilot for NASDAQ and NYSE between August 1, 2016 and December 23, 2016 (our sample period) according to the U.S. tick size pilot list published on the FINRA website. We exclude securities consistently with the following rules:

I. Stocks that changed group during the Pilot; stocks which left the Pilot before the end of our sample period; and stocks that did not enter the Pilot at the beginning of the sample period (but later on).

II. Stocks that during the Pilot changed exchange listing.

III. Stocks (test stocks) initially used to test the Pilot.

IV. Stocks with too little trading volume for market quality to be reliably estimated: For each stock, we dropped the entire day if there were less than 20 trades on that day (including the opening trade). If for 1 stock we dropped more than 50% of the days of our sample period, we then dropped the stock from the sample.

V. Stocks for which data are not available from TRTH or CRSP.

Stocks	Nasdaq	NYSE	Total	Percent
Eligible common stocks*	1,591	681	2,272	100.00%
Rule I	30	17	47	2.07%
Rule II	0	1	1	0.04%
Rule III	4	4	8	0.35%
Rule IV	166	5	171	7.53%
Rule V	9	2	11	0.48%
Final Sample	1,382	652	2,034	89.52%

*Stocks in the pilot including those that entered between October 3, 2016 and December 23, 2016.

2. Sample Cleaning

The file from TRTH we use includes all updates to the official National Best Bid Offer (NBBO) as well as each trade, time-stamped to the microsecond with separate sequence numbers for quotes and trades (to settle ties). The NBBO is assigned to an exchange based on price, size, and time priority and each trade record indicates the executing venue (an exchange or one of the Trade Reporting Facilities (TRFs)). When processing the raw data we exclude some observations according to the following criteria:

a) Time stamp: time stamp missing.

b) Qualifiers: The TRTH data include a very large number of qualifiers for quotes and for trades, and because the raw data comes from the Security Information Processor (SIP), which is different for

Nasdaq (UTP) and for the NYSE (CTA), securities listed on different exchanges have different qualifiers. We use the following rules:

1. Trades marked as regular, odd lots, opening trades, closing trades, agency crosses, derivatively priced, or due to intermarket sweep orders are retained.
2. Trades flagged as corrected are excluded, and so are the corrections themselves.
3. Quotes marked as regular, opening, closing, or coinciding with changes in the limit up-limit down (LULD) price bands are retained.

c) Illiquidity: days with less than 20 trades.

d) Trading phase: we drop observations before 9.30 a.m. and after 16.00 pm.

e) Opening and Closing time: if a stock had the opening trade after 9.30 a.m., we drop all the observations before the opening trade. For example, if a stock had the opening trade at 9.51 a.m., we drop all the observations before 9.51 am.

f) Negative ask size or bid size.

g) Bid price or ask price or bid size or ask size equal to 0.

We also adjusted the data according to the following rules:

h) We Winsorize ask price, bid price, ask size and bid size, at 98%: all data below the 1st percentile were set equal to the 1st percentile and all data above the 99th percentile were set equal to the 99th percentile.

i) We sign trade direction with the Lee and Ready (1991) rule modified by Ellis et al. (2000).

2. Special Cases

NASDAQ & NYSE samples:

- For the econometric analysis we dropped the following days around the introduction of the pilot: September 26, 2016 – October 28, 2016.
- We dropped Labor Day, September 5, 2016, and Thanksgiving Day November 24, 2016, and November 25, 2016 as the day after Thanksgiving the market closed at 1pm.

NASDAQ sample:

- We dropped November 28, 2016 for symbols NRCIA and PBIP.
- We dropped December 19, 20, and 21, 2016 for symbol DTLK.

NYSE sample:

- August 4, 2016 is missing for symbol HUBS.
- October 28, 2016 is missing symbol VCRA.

Appendix C: Variable Definitions

Variable Name	Units	Definition	Weighting
Midquote	Dollars	(NBBO Ask + NBBO bid)/2	
Buy	+1/-1	Lee and Ready (1991) & Ellis et al (2000)	
Quoted spread	Dollars & percent of midquote	(NBBO ask – NBBO bid)	time-weighted
Effective spread	Dollars & percent of midquote	2*(price – midquote)*Buy	share-weighted
Depth	shares & dollars	(NBBO asksize + NBBO bidsize)	
Log Depth	Log(shares) & Log(dollars)	Log(Depth)	
Volatility	Percent	Standard deviation of returns based on midquote updates	
Volatility	Percent	Standard deviation of returns based on midquotes sampled every five minutes.	
Volume	shares and dollars	Consolidated volume including open and close	
Log Volume	Log(shares) & Log(dollars)	Log(Volume)	
Average Trade Size	shares & dollars	Volume/number of trades	
Log Average Trade Size	Log(shares) & Log(dollars)	Log(Average Trade Size)	
Price	Dollars		share-weighted
Realized Spread	dollars & percent of midquote	$2*(price_t - midquote_{t+\tau})*Buy$	
Price Impact	dollars & percent of midquote	$(mid\text{-}quote_{t+\tau} - midquote_t)*Buy$	

Appendix D: NYSE-listed versus Nasdaq-listed stocks

We repeat the main analysis using subsamples based on market of primary listing: Nasdaq or NYSE. The descriptive statistics for these subsamples are in Table D1. There are 1,380 Nasdaq-listed and 649 NYSE-listed stocks in our sample. While NYSE-listed pilot firms on average have significantly larger market capitalization (slightly over $1 billion compared to roughly $600 million), and their stocks have narrower spreads (6-7 cents compared to 9-10 cents), lower volatility roughly 2% compared to 3%), and larger consolidated volume (close to 300,000 shares compared to less than 200,000 shares) than Nasdaq-listed pilot stocks, the average stock price in each subsample is similar ($23.52 compared to $23.61). Hence, in addition to subsampling on exchange listing, this cut provides an alternative way of comparing stocks along the liquidity dimension while keeping the tick size relative to the stock price constant.

[Insert Table D1 here]

We report the results for changes in market quality based on difference-in-difference panel regressions for each subsample in Tables D2 and the results for changes in market quality based on difference-in-difference collapsed panel regressions in Table D3. The effects of the quote rule and the trade-at rules are qualitatively the same as the ones we find for the overall sample regardless of market of primary listing. Specifically, the quote rule causes quoted spreads to widen, depth to increase, average trade size to increase, but volume is unchanged.

[Insert Table D2 here]

[Insert Table D3 here]

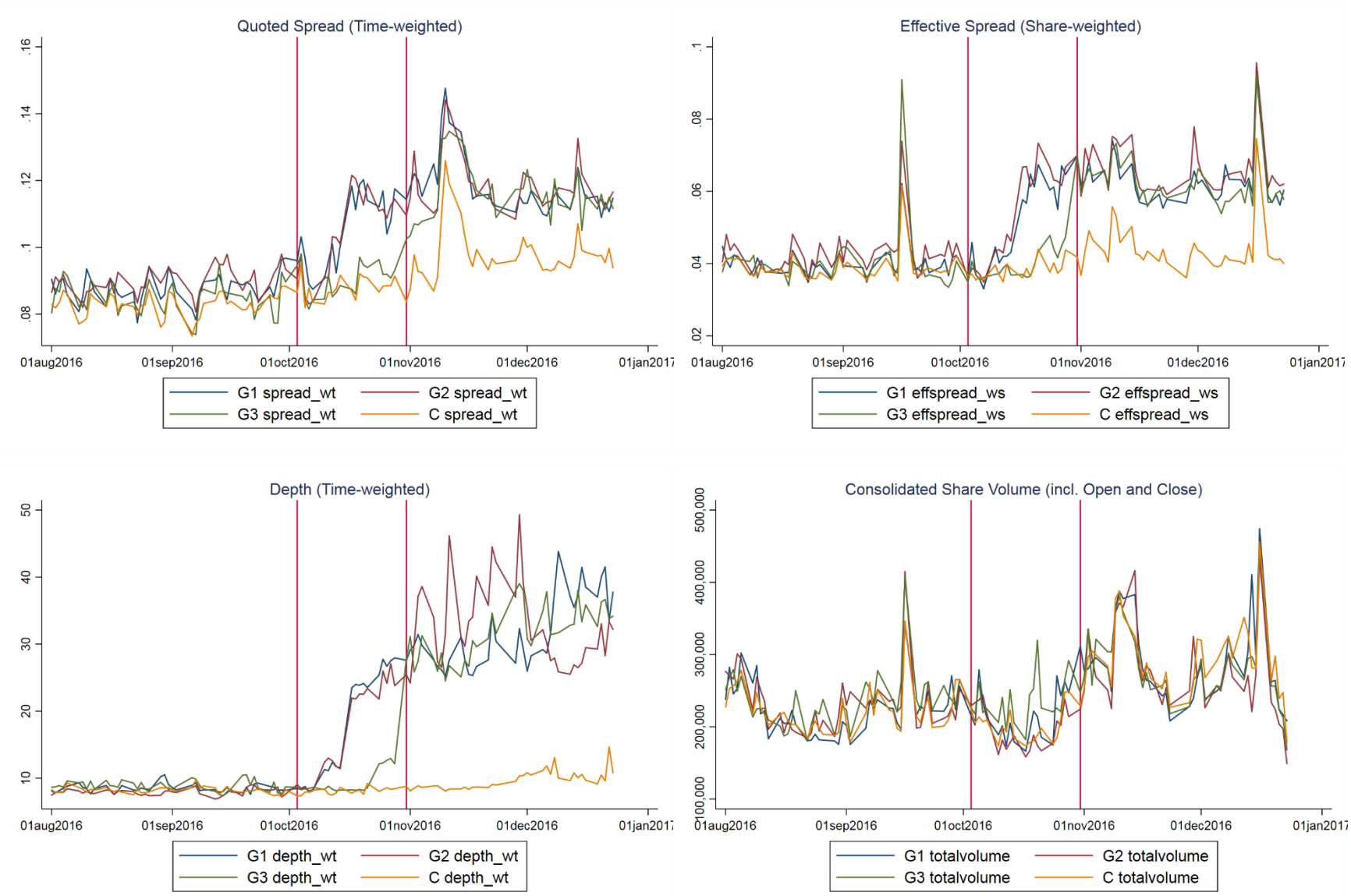
The results in Table D3 also show that there are notable differences between the subsamples. First, quoted spreads widen more for NYSE-listed stocks (2.22 cents) than for Nasdaq-listed stocks (1.36 cents). Second, there is no spillover effect of the pilot on quoted spreads and a small effect on logdepth (0.028) for NYSE-listed control stocks while Nasdaq-listed control stocks experience a significant widening of quoted spreads (1.99 cents) and a larger effect on logdepth (0.075). Third, the trade rule is associated with a significant decline in logdepth (-0.046) for Nasdaq-listed stocks and a significant increase in logdepth (0.086) for NYSE-listed stocks. Similarly, the trade rule is associated with a decline (albeit not significant) in the logarithm of average trade size for Nasdaq-listed stocks, but a significant increase in the logarithm of average trade size for NYSE-listed stocks. Hence, the trade rule appears more effective in attracting limit orders away from the dark to the lit market for larger capitalization (more liquid) stocks than for stocks of lower capitalization (less liquid) stocks.

We graph the daily averages for each group of stocks (C, G1, G2, and G3) of quoted spreads, effective spreads, depth, and consolidated volume for Nasdaq-listed stocks in Figure D1 and for NYSE listed stocks in Figure D2. The figures show that quoted spreads, effective spreads, and depth changes significantly while volume does not show a clear pattern of a change between the pre- and the post-pilot periods both for Nasdaq and NYSE stocks. Furthermore, they suggest that caution is warranted in interpreting the differences between Nasdaq and NYSE stocks when it comes to depth and average trade size. While the effect on depth for Nasdaq-listed stocks in G2 (those subject to the quote and trade rules) actually increases over time, the effect on depth for G2 stocks disappears by late December. This motivates future longer-term studies of the effect of the tick size pilot on market quality.

[Insert Figure D1 here]

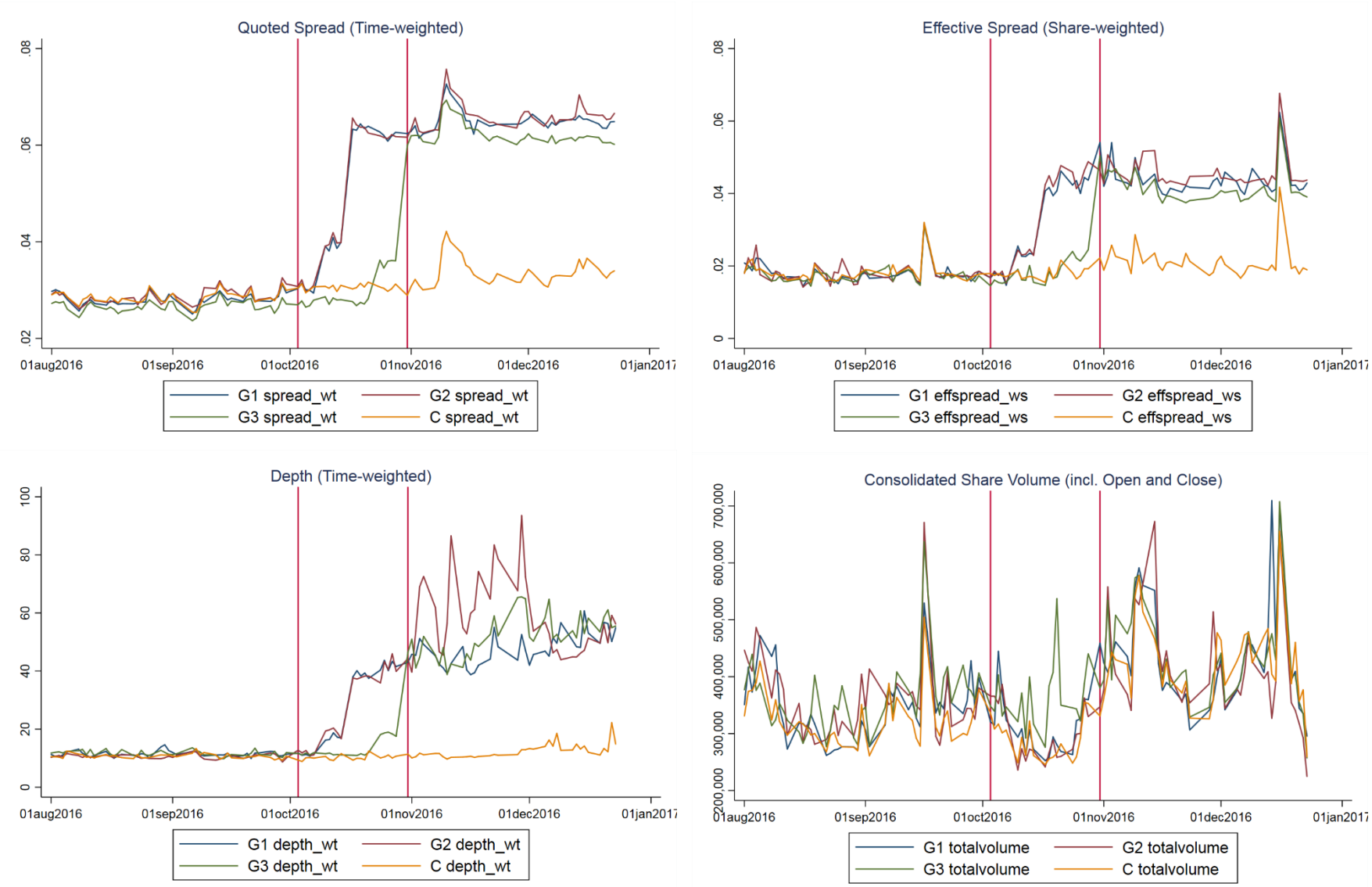
[Insert Figure D2 here]

Figure 1. U.S. Tick Size Pilot Market Quality



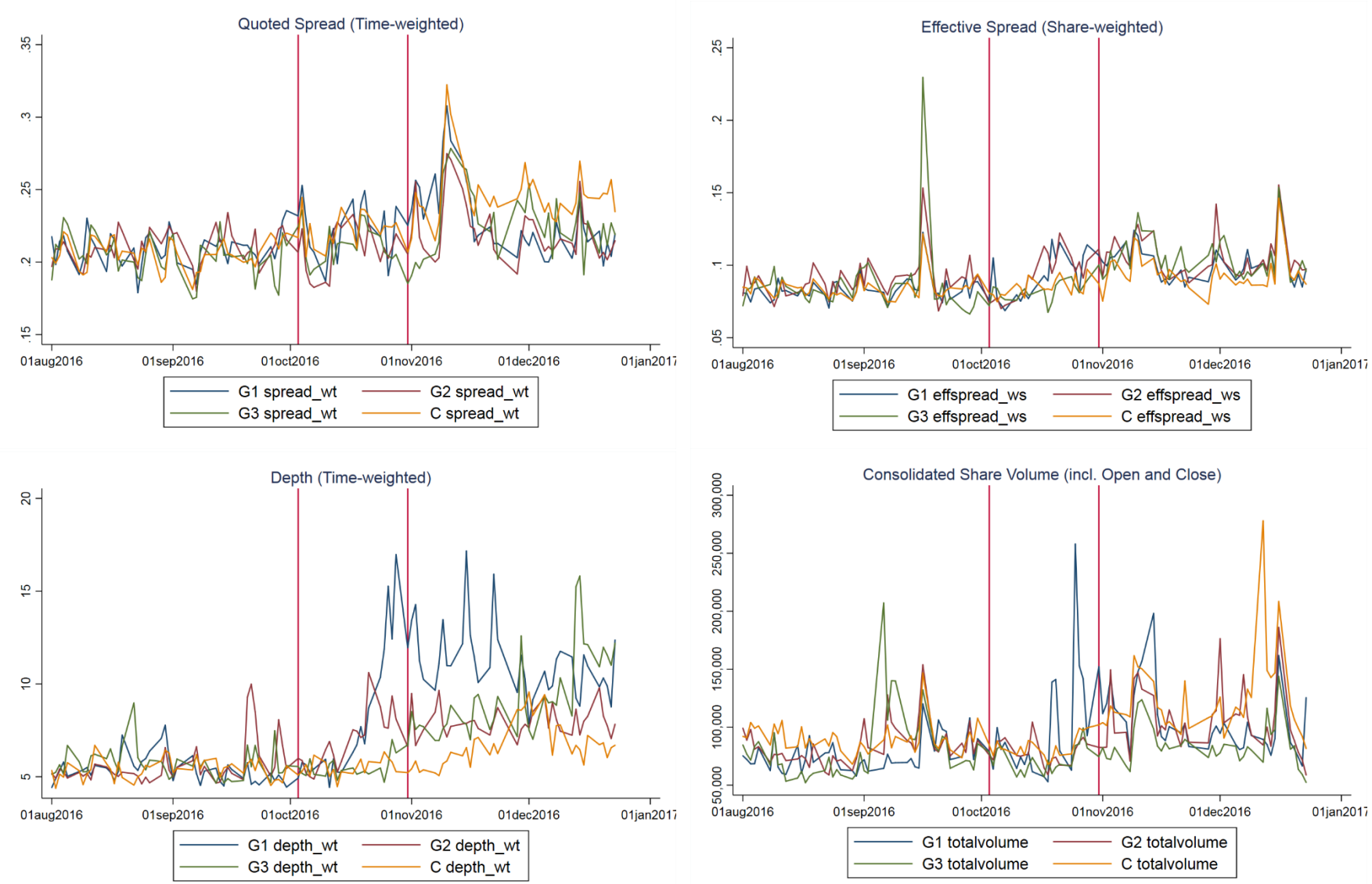
This figure plots the daily average market quality measures clock-wise from the upper left hand corner: time-weighted quoted spread, share-weighted effective spread, depth, and consolidated share volume including open and close for control stocks C and for test groups G1, G2, and G3 respectively. The vertical lines indicate the beginning and the end of the phase-in period, October 3, trough October 31st, 2016. Measures are calculated based on TRTH intraday trade and quote data.

Figure 2. Market Quality for Tick-Constrained Stocks (Pre-event quoted spread ≤ $0.05)



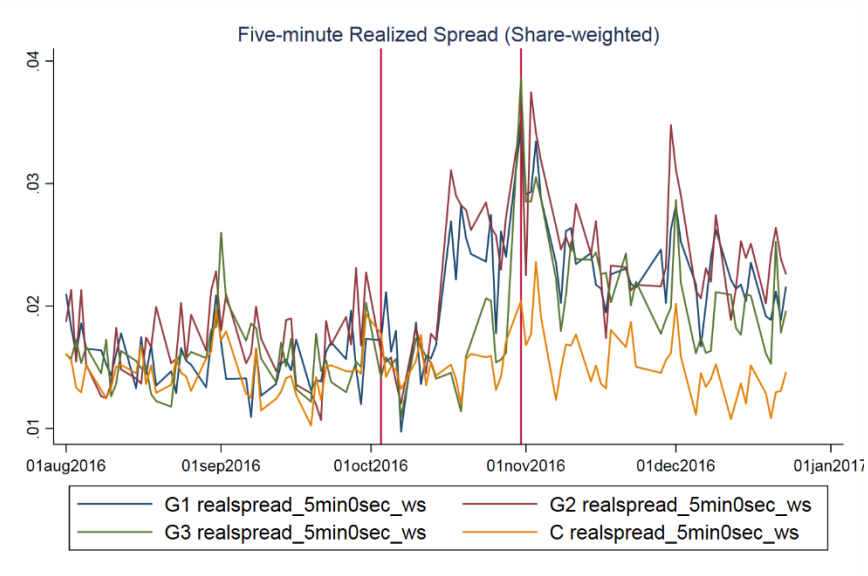
This figure plots the daily average market quality measures for tick-constrained stocks clock-wise from the upper left hand corner: time-weighted quoted spread, share-weighted effective spread, depth, and consolidated share volume including open and close for control stocks C and for test groups G1, G2, and G3 respectively. The vertical lines indicate the beginning and the end of the phase-in period, October 3, trough October 31st 2016. Measures are calculated based on TRTH intraday trade and quote data.

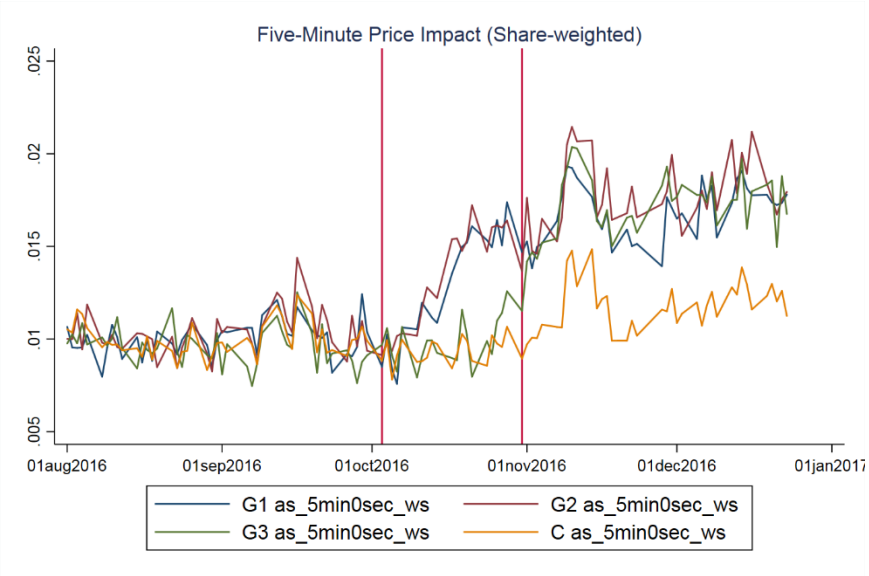
Figure 3. Market Quality for Unconstrained Stocks (Pre-event quoted spread ≥ $0.10)



This figure plots the daily average market quality measures for unconstrained stocks clock-wise from the upper left hand corner: time-weighted quoted spread, share-weighted effective spread, depth, and consolidated share volume including open and close for control stocks C and for test groups G1, G2, and G3 respectively. The vertical lines indicate the beginning and the end of the phase-in period, October 3, trough October 31st, 2016. Measures are calculated using TRTH intraday trade and quote data.

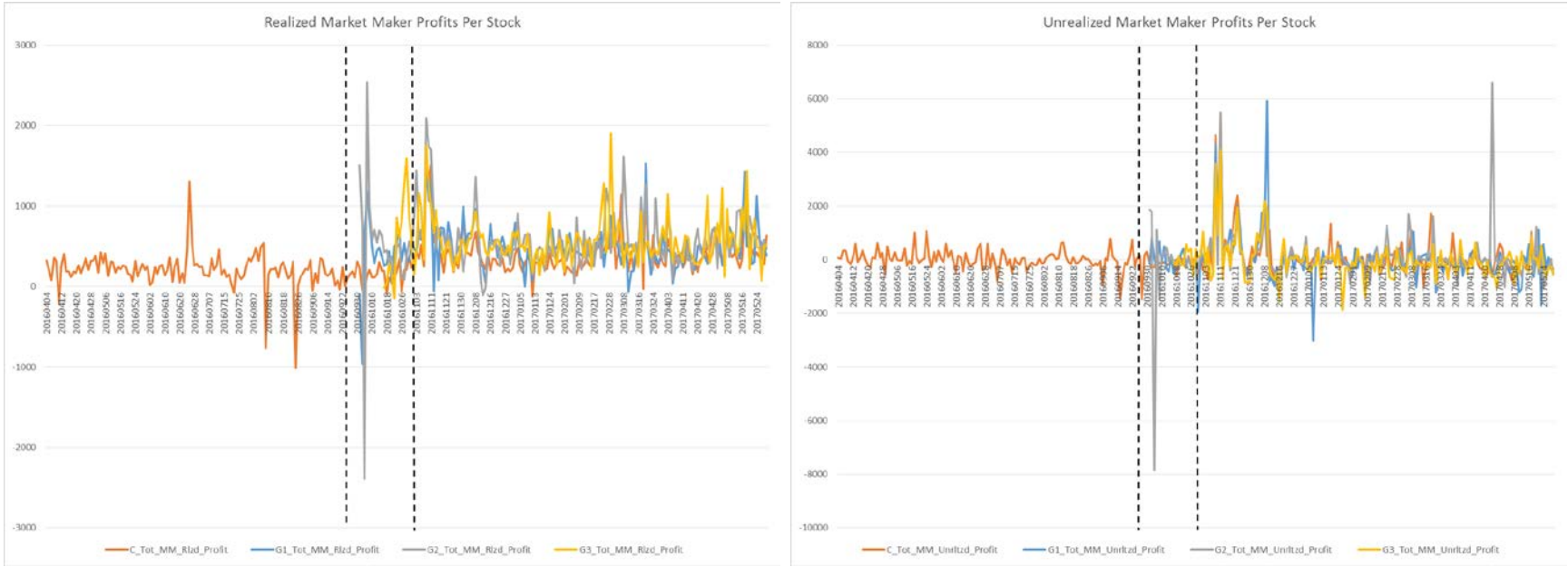
Figure 4. Realized Spreads and Price Impacts





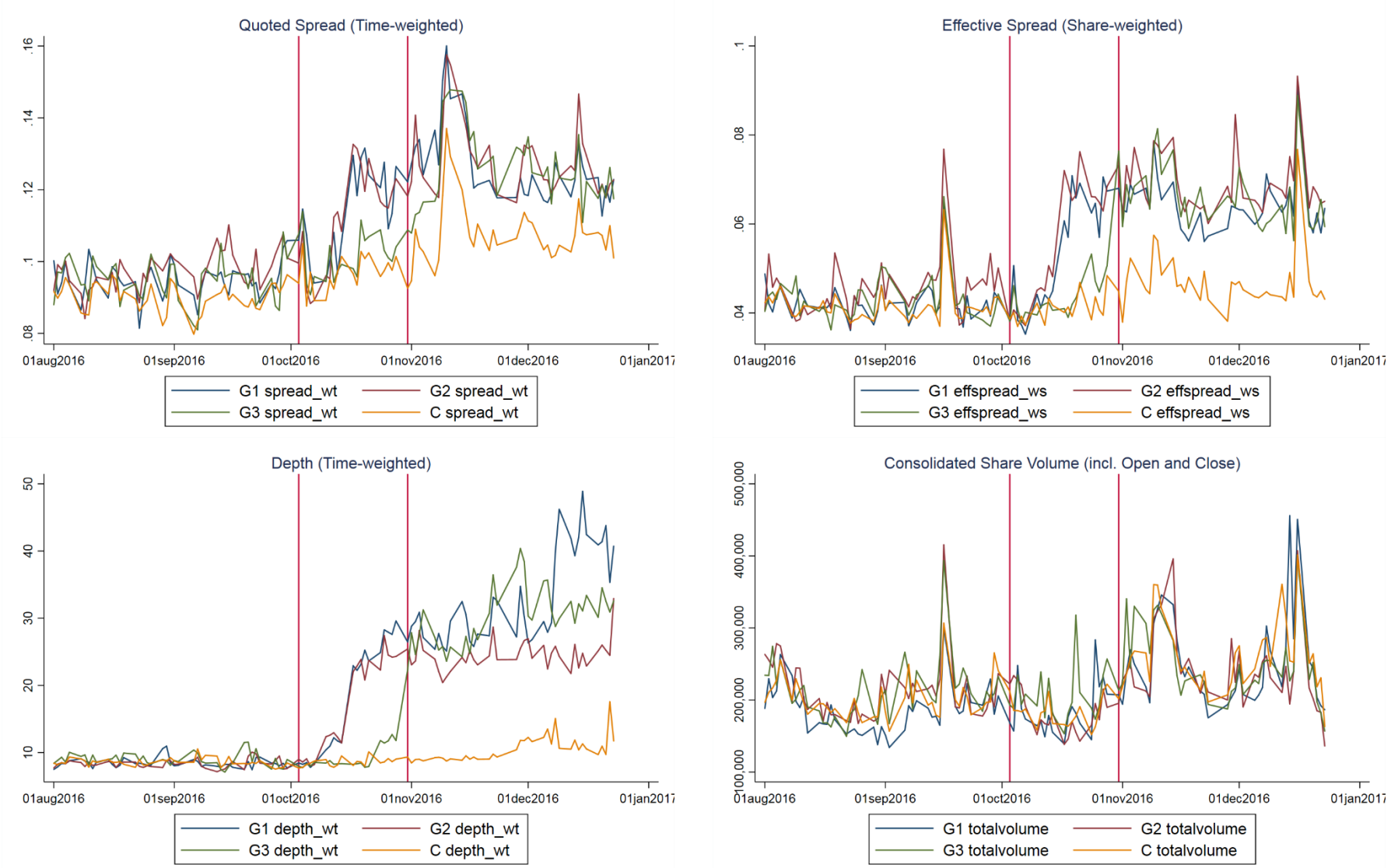
This figure plots the daily average measures for rewards for liquidity provision and price discovery: five-minute realized spread, and five-minute price impact for control stocks C and for test groups G1, G2, and G3 respectively. The vertical lines indicate the beginning and the end of the phase-in period, October 3, trough October 31st, 2016. Measures are calculated based on TRTH intraday trade and quote data.

Figure 5. Market Maker Profits Per Stock



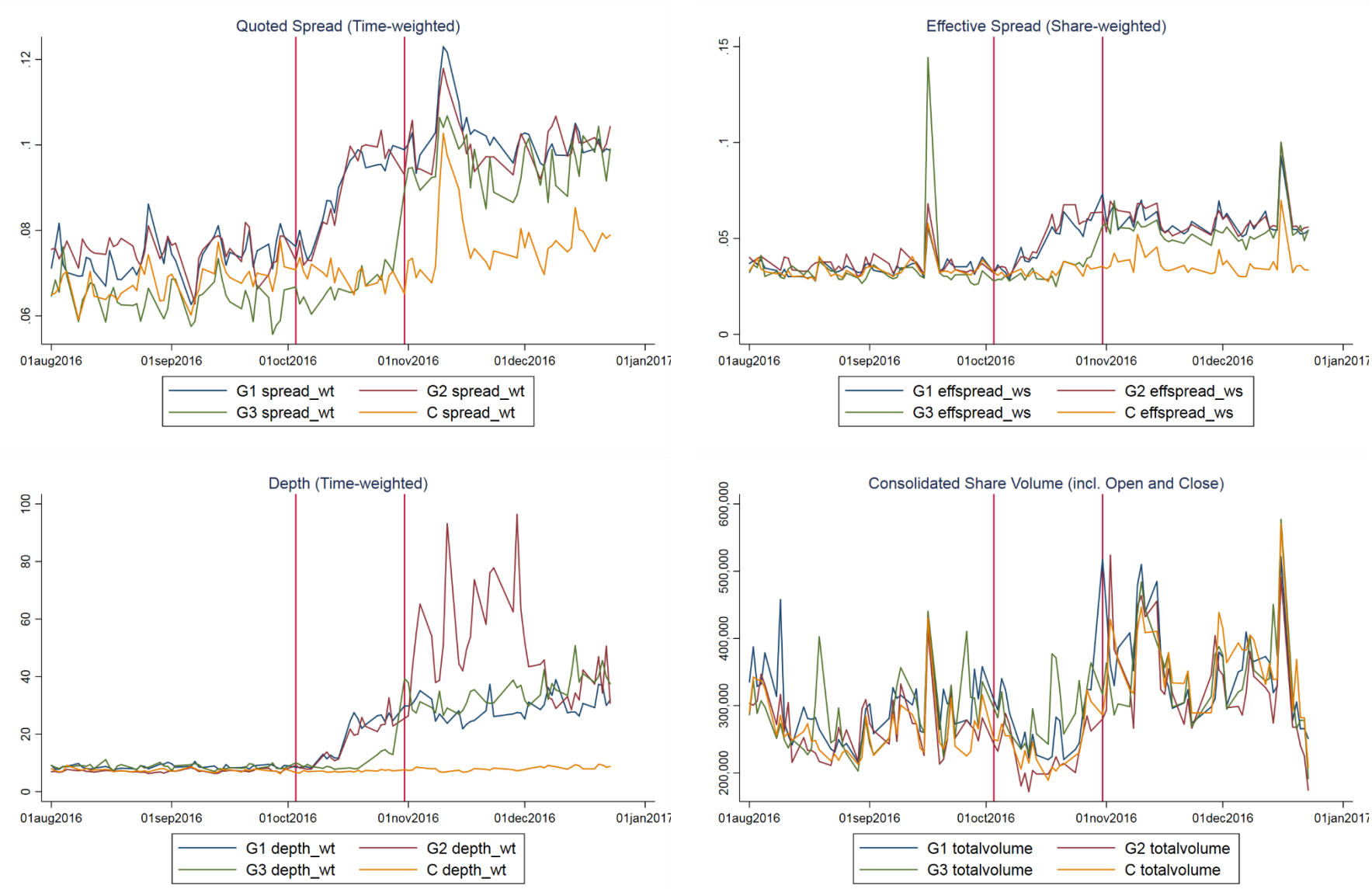
This figure plots the daily average realized market maker profits per stock (left panel) and average unrealized market maker profits per stock (right panel) for control stocks C and for test groups G1, G2, and G3 respectively. The vertical lines indicate the beginning and the end of the phase-in period, October 3, trough October 31st, 2016. Note that all stocks were designated as control stocks prior to October 3, 2016. Hence, there is only on line representing the average profit for eligible securities prior to that date. Furthermore, as described in Appendix A, the pilot was phased over the month of October 2016. Measures are calculated based on FINRA U.S. tick size pilot data on market maker profits.

Figure D1. Market Quality for Nasdaq-Listed Stocks



This figure plots the daily average market quality measures for Nasdaq-listed stocks clock-wise from the upper left hand corner: time-weighted quoted spread, share-weighted effective spread, depth, and consolidated share volume including open and close for control stocks C and for test groups G1, G2, and G3 respectively. The vertical lines indicate the beginning and the end of the phase-in period, October 3, trough October 31st 2016.

Figure D2. Market Quality for NYSE-Listed Stocks



This figure plots the daily average market quality measures for NYSE-listed stocks clock-wise from the upper left hand corner: time-weighted quoted spread, share-weighted effective spread, depth, and consolidated share volume including open and close for control stocks C and for test groups G1, G2, and G3 respectively. The vertical lines indicate the beginning and the end of the phase-in period, October 3, trough October 31st, 2016.

Table 1. Descriptive Statistics

	Control Stocks		G1 Stocks		G2 Stocks		G3 Stocks	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A. Firm Characteristics								
Market Capitalization	758,261	735,121	752,658	731,290	743,937	688,549	755,001	721,046
Price	22.55	20.85	23.67	23.25	23.52	21.65	22.26	20.29
Nfirms	1,012		341		336		339	
B. Quote Quality								
Quoted Spread	0.0826	0.1096	0.0875	0.1128	0.0896	0.1175	0.0849	0.1100
Effective Spread	0.0388	0.0494	0.0398	0.0478	0.0424	0.0586	0.0407	0.1016
Depth	8.28	14.72	8.50	11.79	7.92	10.59	8.93	15.60
Volatility	0.0292	0.0223	0.0290	0.0221	0.0291	0.0255	0.0287	0.0223
C. Trading Activity								
Volume	221,510	367,893	221,222	361,604	233,469	411,487	234,280	438,212
Average Trade Size	133.66	259.04	130.71	82.40	128.40	117.60	136.51	128.08
Nobs	38,499		12,997		12,741		12,868	

This table summarizes descriptive statistics for the U.S. tick size pilot sample based on data from the period August 1 – September 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, G1 stocks will be subject to the quote rule, G2 stocks to the quote and the trade rules, and G3 stocks to the quote, trade, and trade-at rules. Data was drawn from Thomson Reuters Tick History (TRTH) and CRSP data bases. Market capitalization as of June 20, 2016, is measured in $1,000 dollars and Price is the stock price in dollars, both variables from CRSP. Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars, Depth denotes the time-weighted NBBO depth, and is reported in round lots of 100 shares and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only.

Table 2. Changes in Average Market Quality

	Control Stocks					G1 Stocks					G2 Stocks					G3 Stocks				
	Pre	Post	Difference in Mean			Pre	Post	Difference in Mean			Pre	Post	Difference in Mean			Pre	Post	Difference in Mean		
	Mean	Mean	Pre-Post	*t*-stat	Z-value	Mean	Mean	Pre-Post	*t*-stat	Z-value	Mean	Mean	Pre-Post	*t*-stat	Z-value	Mean	Mean	Pre-Post	*t*-stat	Z-value
A. Quote Quality																				
Quoted Spread	0.0826	0.0983	-0.0157	-17.44	-15.29	0.0875	0.1185	-0.0311	-21.13	-54.69	0.0896	0.1189	-0.0293	-19.64	-54.61	0.0849	0.1165	-0.0316	-21.96	-54.92
Effective Spread	0.0388	0.0437	-0.0049	-12.29	-13.79	0.0398	0.0625	-0.0227	-35.43	-69.72	0.0424	0.0661	-0.0238	-31.41	-73.24	0.0407	0.0623	-0.0216	-20.69	-67.59
Depth	8.28	9.70	-1.42	-6.55	-11.02	8.50	31.69	-23.19	-26.26	-71.05	7.92	32.57	-24.65	-16.42	-73.31	8.93	31.68	-22.7518	-34.52	-71.07
Volatility	0.0292	0.0347	-0.0055	-29.27	-36.15	0.0290	0.0373	-0.0083	-23.93	-36.53	0.0291	0.0369	-0.0078	-23.98	-37.36	0.0287	0.0427	-0.0141	-42.95	-55.72
B. Trading Activity																				
Volume	221,510	292,175	-70,666	-17.87	-27.45	221,222	287,312	-66,090	-9.83	-13.53	233,469	272,476	-39,007	-6.68	-12.01	234,280	280,006	-45,726	-7.62	-11.36
Average Trade Size	133.66	137.02	-3.35	-2.20	0.72	130.71	145.86	-15.15	-13.16	-14.42	128.40	142.51	-14.10	-9.52	-15.24	136.51	144.73	-8.22	-4.80	-6.93
Price	22.82	23.92	-1.10	-6.99	-4.36	23.87	25.55	-1.67	-5.44	-4.40	23.87	25.31	-1.45	-5.04	-4.06	22.54	24.03	-1.49	-5.46	-3.41
Nobs	38,499	37,614				12,997	12,656				12,741	12,438				12,868	12,545			

This table reports changes in average quote quality and trading activity for the U.S. tick size pilot sample between the pre- and the post-pilot periods. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, G1 stocks will be subject to the quote rule, G2 stocks to the quote and the trade rules, and G3 stocks to the quote, trade, and trade-at rules. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars, Depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares, and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only. Price is the average daily share-weighted stock price in dollars. We report the results from two tests for significance of the observed changes: a *t*-test for differences in means (unequal variances); and a two-sample Wilcoxon rank-sum (Mann-Whitney) test.

Table 3. Changes in Market Quality: Panel Regressions (Groups)

A. Quote Quality	Quoted Spread		Effective Spread		Depth		log Depth		Volatility	
	(dollar)	(%)	(dollar)	(%)	(shares)	(dollar)	(shares)	(dollar)	quote upd.	5min
Intercept	0.0920 ***	0.0046 ***	0.0363 ***	0.0020 ***	11.91 ***	173.71 ***	1.888 ***	4.789 ***	0.0244 ***	0.0183 ***
	0.0043	0.0002	0.0014	0.0001	1.07	14.72	0.020	0.018	0.0005	0.0004
Event	0.0177 ***	0.0006 ***	0.0052 ***	0.0002 ***	1.63 ***	21.13 ***	0.056 ***	0.084 ***	0.0051 ***	0.0049 ***
	0.0004	0.0000	0.0003	0.0000	0.22	2.38	0.003	0.003	0.0002	0.0001
G1*Event	0.0145 ***	0.0022 ***	0.0175 ***	0.0018 ***	21.76 ***	182.68 ***	0.762 ***	0.776 ***	0.0029 ***	0.0007 **
	0.0009	0.0001	0.0006	0.0001	0.79	6.16	0.007	0.006	0.0003	0.0003
G2*Event	0.0148 ***	0.0019 ***	0.0193 ***	0.0018 ***	23.21 ***	306.10 ***	0.755 ***	0.776 ***	0.0023 ***	0.0002
	0.0009	0.0001	0.0007	0.0000	1.27	21.33	0.007	0.007	0.0003	0.0002
G3*Event	0.0150 ***	0.0022 ***	0.0165 ***	0.0018 ***	21.35 ***	211.14 ***	0.809 ***	0.824 ***	0.0086 ***	0.0019 ***
	0.0009	0.0001	0.0010	0.0001	0.59	5.76	0.007	0.007	0.0003	0.0002
VIX	-0.0001 *	0.0007 ***	0.0004 ***	0.0001 ***	-0.27 ***	-3.92 ***	-0.007 ***	-0.018 ***	0.0004 ***	0.0004 ***
	0.0001	0.0000	0.0001	0.0000	0.06	0.98	0.001	0.000	0.0000	0.0000
Nobs	152,358	152,358	152,358	152,358	152,359	152,358	152,358	152,358	152,358	152,358
R2 within	0.0459	0.0561	0.0302	0.044	0.0238	0.0148	0.2985	0.3336	0.0376	0.0338
Wald Chi2(8)	7,163.9	8,417.6	5,681.4	5,717.4	4,901.9	4,897.1	54,722.9	65,450.4	5,677.5	5,228.0

B. Trading Activity	Volume		log Volume		Average Trade Size		Log Average Trade Size		Price
	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(dollar)
Intercept	192,582 ***	5,211,466 ***	11.519 ***	14.418 ***	138.55 ***	2,753.04 ***	4.779 ***	7.678 ***	27.19 ***
	11,375	311,634	0.042	0.054	3.57	62.01	0.013	0.022	0.80
Event	69,902 ***	1,506,035 ***	0.292 ***	0.321 ***	2.97 **	65.88 ***	0.013 ***	0.041 ***	1.58 ***
	3,578	69,274	0.005	0.005	1.37	8.75	0.002	0.002	0.02
G1*Event	-5,256	234,049 *	-0.051 **	-0.034 **	12.28 ***	252.22 ***	0.073 ***	0.089 ***	0.40 ***
	6,829	127,552	0.009	0.009	1.63	14.56	0.004	0.004	0.05
G2*Event	-31,910 ***	-322,564 **	-0.069 ***	-0.046 ***	10.28 ***	250.07 ***	0.070 ***	0.092 ***	0.32 ***
	5,942	126,510	0.009	0.009	1.85	16.15	0.004	0.004	0.04
G3*Event	-25,363 ***	-532,875 ***	-0.088 ***	-0.071 ***	5.07 **	157.55 ***	0.029 ***	0.045 ***	0.26 ***
	6,131	121,748	0.009	0.009	2.04	17.54	0.004	0.004	0.04
VIX	1,797 ***	-246	-0.004 ***	-0.016 ***	-0.28 **	-27.83 ***	-0.001 ***	-0.012 ***	-0.30 ***
	529	9,966	0.001	0.001	0.11	1.07	0.000	0.000	0.00
Nobs	152,358	152,358	152,358	152,358	152,358	152,358	152,358	152,358	152,358
R2 within	0.005	0.0065	0.0402	0.0493	0.0009	0.0103	0.0086	0.0282	0.1012
Wald Chi2(8)	773.0	1,021.7	6,315.7	7,845.5	455.5	2,103.8	1,315.8	4,447.8	15,271.9

This table reports the results from difference-in-difference panel regressions that test for changes in average quote quality and trading activity for the U.S. tick size pilot sample stocks between the pre- and the post-pilot periods based on the following specification:

$$MQ_{i,t} = \beta_0 + \beta_1 \cdot G1 + \beta_2 \cdot G2 + \beta_3 \cdot G3 + \beta_4 \cdot Event + \beta_5 \cdot G1 \cdot Event + \beta_6 \cdot G2 \cdot Event + \beta_7 \cdot G3 \cdot Event + \beta_8 \cdot X_t + \varepsilon_{i,t}, \qquad (1)$$

where $MQ_{i,t}$ is a market quality measure (quote quality, trading activity) for stock *i* on day *t*, *G1*, *G2* and *G3* are dummies that take on a value of one for stocks belonging to the respective test groups, *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We cluster standard errors by firm and day. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, G1 stocks will be subject to the quote rule, G2 stocks to the quote and the trade rules, and G3 stocks to the quote, trade, and trade-at rules. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars, Depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares, and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only. Price is the average daily share-weighted stock price in dollars. We report results for Quoted and Effective Spreads in percent of the midquote, and Depth, Volume, and Average Trade Size in shares as well as in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. Standard errors are reported below the estimated coefficients, and *** designates significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

Table 4. Changes in Market Quality: Panel Regressions (Rules)

A. Quote Quality	Quoted Spread		Effective Spread		Depth		log Depth		Volatility	
	(dollar)	(%)	(dollar)	(%)	(shares)	(dollar)	(shares)	(dollar)	Midquote	5min
Intercept	0.0920 ***	0.0046 ***	0.0363 ***	0.0020 ***	11.91 ***	173.71 ***	1.888 ***	4.789 ***	0.0244 ***	0.0183 ***
	0.0043	0.0002	0.0014	0.0001	1.07	14.72	0.020	0.018	0.0005	0.0004
Event	0.0177 ***	0.0006 ***	0.0052 ***	0.0002 ***	1.63 ***	21.13 ***	0.056 ***	0.084 ***	0.0051 ***	0.0049 ***
	0.0004	0.0000	0.0003	0.0002	0.22	2.38	0.003	0.003	0.0002	0.0001
Q*Event	0.0145 ***	0.0022 ***	0.0175 ***	0.0018 ***	21.76 ***	182.68 ***	0.762 ***	0.776 ***	0.0029 **	0.0007 **
	0.0009	0.0001	0.0006	0.0001	0.79	6.16	0.007	0.006	0.0003	0.0003
T*Event	0.0003	-0.0004 ***	0.0017 **	0.0000	1.45	123.42 ***	-0.006	0.000	-0.0006	-0.0006 *
	0.0011	0.0001	0.0008	0.0001	1.47	22.00	0.009	0.008	0.0004	0.0003
TA*Event	0.0002	0.0004 ***	-0.0028 **	0.0000	-1.86	-94.96 ***	0.054 ***	0.048 ***	0.0063 ***	0.0017 ***
	0.0011	0.0001	0.0010	0.0001	1.37	21.89	0.009	0.009	0.0004	0.0002
VIX	-0.0001 *	0.0001 ***	0.0004 ***	0.0001 ***	-0.27 ***	-3.92 ***	-0.007 ***	-0.018 ***	0.0004 ***	0.0004 ***
	0.0001	0.0000	0.0001	0.0000	0.06	0.98	0.001	0.000	0.0000	0.0000
Nobs	142,358	152,358	152,358	152,358	152,358	152,358	152,358	152,358	152,358	152,358
R2 within	0.0459	0.0561	0.0302	0.0440	0.0238	0.0148	0.2985	0.3336	0.0376	0.0338
Wald Chi2(8)	7,163.9	8,417.6	5,681.4	5,717.4	4,901.9	4,897.1	54,722.9	65,450.4	5,677.5	5,228.0

B. Trading Activity	Volume		log Volume		Average Trade Size		Log Average Trade Size		Price
	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(dollar)
Intercept	192,582 ***	5,211,466 ***	11.519 ***	14.418 ***	138.55 ***	2,753.04 ***	4.779 ***	7.678 ***	27.19 ***
	11,375	311,634	0.042	0.054	3.57	62.01	0.013	0.022	0.80
Event	69,902 ***	1,506,035 ***	0.292 ***	0.321 ***	2.97 **	65.88 ***	0.013 ***	0.041 ***	1.58 ***
	3,578	69,274	0.005	0.005	1.37	8.75	0.002	0.002	0.02
Q*Event	-5,256	234,049 *	-0.051 ***	-0.034 ***	12.28 ***	252.22 ***	0.073 ***	0.089 ***	0.40 ***
	6,829	127,552	0.009	0.009	1.63	14.56	0.004	0.004	0.05
T*Event	-26,653 ***	-556,614 ***	-0.018	-0.013	-2.07	-2.15	-0.003	0.003	-0.08
	7,585	151,392	0.011	0.012	1.52	17.94	0.005	0.005	0.04
TA*Event	6,547	-210,310	-0.019 *	-0.025 **	-5.14 ***	-92.52 ***	-0.041 ***	-0.047 ***	-0.05
	6,963	146,530	0.011	0.012	1.96	20.43	0.005	0.005	0.05
VIX	1,797 ***	-246	-0.004 ***	-0.016 ***	-0.28 **	-27.83 ***	-0.001 ***	-0.012 ***	-0.30 ***
	529	9,966	0.001	0.001	0.11	1.07	0.000	0.000	0.00
Nobs	152,358	152,358	152,358	152,358	152,358	152,358	152,358	152,358	152,358
R2 within	0.0050	0.0065	0.0402	0.0493	0.0009	0.0103	0.0086	0.0282	0.1012
Wald Chi2(8)	773.0	1,021.7	6,315.7	7,845.5	455.5	2,103.8	1,315.8	4,447.8	15,271.9

This table reports the results from difference-in-difference panel regressions that test for changes in average quote quality and trading activity for the U.S. tick size pilot sample stocks between the pre- and the post-pilot periods based on the following specification:

$$MQ_{i,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{i,t}, \qquad (2)$$

where $MQ_{i,t}$ is a market quality measure (quote quality, trading activity) for stock *i* on day *t*, *Q*, *T* and *TA* are dummies that take on a value of one for stocks subject to the quote rule (Q), the trade rule (T), and the trade-at rule (TA), *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We cluster standard errors by firm and day. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, the quote rule applies to G1, G2, and G3, the trade rule applies to G2 and G3, and the trade-at rule applies to G3. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars, Depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares, and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only. Price is the average daily share-weighted stock price in dollars. We report results for Quoted and Effective Spreads in percent of the midquote, and Depth, Volume, and Average Trade Size in shares as well as in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. Standard errors are reported below the estimated coefficients, and *** designates significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

Table 5. Changes in Market Quality: Collapsed Panel Regressions (Rules)

A. Quote Quality	Quoted Spread		Effective Spread		Depth		log Depth		Volatility	
	(dollar)	(%)	(dollar)	(%)	(shares)	(dollar)	(shares)	(dollar)	quote upd.	5min
Intercept	0.0808 ***	0.0044 ***	0.0321 ***	0.0018 ***	12.51 ***	175.15 ***	1.894 ***	4.785 ***	0.0240 ***	0.0181 ***
	0.0032	0.0002	0.0016	0.0001	1.32	18.67	0.022	0.017	0.0019	0.0011
Event	0.0155 ***	0.0006 ***	0.0045 ***	0.0002 ***	1.68 ***	20.35 ***	0.059 ***	0.078 ***	0.0052 ***	0.0049 ***
	0.0019	0.0001	0.0012	0.0001	0.36	3.48	0.008	0.010	0.0012	0.0010
Q*Event	0.0154 ***	0.0022 ***	0.0178 ***	0.0018 ***	21.75 ***	183.24 ***	0.759 ***	0.780 ***	0.0028	0.0007
	0.0032	0.0002	0.0017	0.0001	1.46	9.88	0.013	0.016	0.0020	0.0015
T*Event	-0.0018	-0.0003	0.0010	0.0000	1.49	122.87 ***	-0.001	-0.004	-0.0005	-0.0005
	0.0031	0.0002	0.0019	0.0001	2.02	25.78	0.015	0.017	0.0024	0.0016
TA*Event	0.0023	0.0005	-0.0022	0.0000	-1.93	-94.72 ***	0.049 **	0.051 **	0.0063 ***	0.0016
	0.0031	0.0002	0.0022	0.0001	1.74	26.81	0.019	0.021	0.0024	0.0016
VIX	0.0001	0.0001 ***	0.0005 ***	0.0001 ***	-0.32 ***	-4.14 ***	-0.008 ***	-0.018	0.0004 ***	0.0004 ***
	0.0002	0.0000	0.0001	0.0000	0.10	1.41	0.002	0.001	0.0001	0.0001
Nobs	308	308	308	308	308	308	308	308	308	308
F-value	99.6	128.8	209.0	295.1	156.2	130.4	2,269.9	1,743.9	17.2	16.6

B. Trading Activity	Volume		log Volume		Average Trade Size		Log Average Trade Size		Price
	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(dollar)
Intercept	188,125 ***	5,221,246 ***	11.563 ***	14.452 ***	138.21 **	2,743.43 ***	4.782 ***	7.671 ***	26.66 ***
	15,808	424,073	0.060	0.067	2.27	30.37	0.010	0.011	0.35
Event	68,586 ***	1,472,594 ***	0.287 ***	0.306 ***	3.62 **	55.18 ***	0.017 ***	0.037 ***	1.34 ***
	12,467	311,703	0.045	0.046	1.41	16.57	0.006	0.007	0.21
Q*Event	-4,486	258,955	-0.044	-0.021	11.80 ***	259.80 ***	0.069 ***	0.092 ***	0.56 *
	20,275	439,736	0.064	0.065	1.81	28.52	0.009	0.011	0.32
T*Event	-27,048	-566,305	-0.019	-0.023	-1.06	0.14	0.004	0.000	-0.22
	21,727	461,843	0.068	0.068	2.05	34.91	0.001	0.013	0.36
TA*Event	6,643	-208,354	-0.021	-0.029	-5.90 **	-94.44 ***	-0.046 ***	-0.045 ***	0.04
	20,005	486,612	0.068	0.068	2.40	33.18	0.012	0.012	0.36
VIX	2,518 ***	9,145	-0.003	0.013 ***	-0.34 **	-27.99 ***	-0.002 **	-0.012 ***	-0.29 ***
	1,066	29,492	0.004	0.005	0.15	2.12	0.001	0.001	0.03
Nobs	308	308	308	308	308	308	308	308	308
F-value	11.8	10.8	14.3	16.6	52.4	114.8	56.2	139.4	45.8

This table reports the results from difference-in-difference collapsed panel regressions that test for changes in average quote quality and trading activity for the U.S. tick size pilot sample stocks between the pre- and the post-pilot periods. For each day, we compute the cross-sectional average market quality measure for control stocks (C) and for stocks subject to each rule: the quote rule (Q), the trade rule (T), and trade-at-rule (TA), and then run the following collapsed panel regression:

$$MQ_{g,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{g,t}, \qquad (3)$$

where $MQ_{g,t}$ is the average market quality measure (quote quality, trading activity) for stocks in group g on day *t*, *Q*, T and *TA* are dummies that take on a value of one for stocks subject to each rule, *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We use Newey-West standard errors with five lags. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, the quote rule applies to G1, G2, and G3, the trade rule applies to G2 and G3, and the trade-at rule applies to G3. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars, depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares, and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only. Price is the average daily share-weighted stock price in dollars. We report results for Quoted and Effective Spreads in percent of the midquote, and Depth, Volume, and Average Trade Size in shares as well as in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. Standard errors are reported below the estimated coefficients, and *** designates significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

Table 6. Descriptive Statistics: Tick-Constrained and Unconstrained Stocks

I. Tick-Constrained		Control Stocks		G1 Stocks		G2 Stocks		G3 Stocks	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A. Firm Characteristics									
Market Capitalization	('000 dollar)	766,790	708,221	747,420	693,838	779,340	653,986	812,581	742,118
Price	(dollar)	14.50	10.46	14.12	9.94	14.79	9.74	14.54	10.75
Nfirms		492		163		152		169	
B. Quote Quality									
Quoted Spread	(dollar)	0.0284	0.0133	0.0280	0.0133	0.0285	0.0138	0.0267	0.0126
Effective Spread	(dollar)	0.0182	0.0181	0.0178	0.0151	0.0180	0.0202	0.0176	0.0178
Depth	(100 shares)	10.79	19.22	11.44	14.57	10.59	10.21	14.64	10.79
Volatility	(midquote)	0.0261	0.0173	0.0261	0.0186	0.0257	0.0168	0.0254	0.0186
C. Trading Activity									
Volume	(shares)	323,525	449,236	342,190	446,124	362,881	565,390	356,698	531,910
Average Trade Size	(shares)	149.44	352.55	145.54	84.58	147.29	150.72	153.58	84.48
Nobs		19,134		6,342		5,915		6,574	

II. Unconstrained		Control Stocks		G1 Stocks		G2 Stocks		G3 Stocks	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A. Firm Characteristics									
Market Capitalization	('000 dollar)	694,105	706,580	705,482	682,921	692,759	706,137	628,476	592,810
Price	(dollar)	37.05	29.47	39.51	32.32	37.77	30.26	35.95	28.07
Nfirms		260		98		100		97	
B. Quote Quality									
Quoted Spread	(dollar)	0.2054	0.1634	0.2082	0.1555	0.2099	0.1642	0.2048	0.1495
Effective Spread	(dollar)	0.0836	0.0751	0.0831	0.0672	0.0888	0.0875	0.0877	0.1821
Depth	(100 shares)	5.46	7.50	5.44	6.65	5.57	12.81	5.71	7.54
Volatility	(midquote)	0.0322	0.0246	0.0326	0.0258	0.0331	0.0328	0.0344	0.0290
C. Trading Activity									
Volume	(shares)	90,024	183,758	74,733	147,087	84,300	189,126	82,174	284,920
Average Trade Size	(shares)	105.19	87.58	108.97	77.42	104.83	77.88	109.12	92.38
Nobs		9,439		3,579		3,599		3,539	

This table summarizes descriptive statistics for the U.S. tick size pilot sample based on data from the period August 1 – September 23, 2016, for tick-constrained stocks in Panel I and unconstrained stocks in Panel II. Tick-constrained stocks are those that have an average quoted spread of $0.05 or less and unconstrained stocks are those that have an average quoted spread of $0.10 or more during the pre-pilot period. Control stocks are those that will continue being quoted and traded in decimals, G1 stocks will be subject to the quote rule, G2 stocks to the quote and the trade rules, and G3 stocks to the quote, trade, and trade-at rules. Data was drawn from Thomson Reuters Tick History (TRTH) and CRSP data bases. Market capitalization as of June 20, 2016, is measured in $1,000 dollars and Price is the stock price in dollars, both variables from CRSP. Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars, Depth denotes the time-weighted NBBO depth, and is reported in round lots of 100 shares and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only.

Table 7. Changes in Market Quality for Tick-Constrained and Unconstrained Stocks: Panel Regressions (Rules)

A. Quote Quality	Quoted Spread		Effective Spread		log Depth				Volatility	
	Tick Constrained	Unconstrained	Tick Constrained	Unconstrained	Tick Constrained		Unconstrained		Tick Constrained	Unconstrained
	(dollar)	(dollar)	(dollar)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	Midquote	Midquote
Intercept	0.0286 ***	0.2287 ***	0.0143 ***	0.0813 ***	2.139 ***	4.716 ***	1.606 ***	5.053 ***	0.0215 ***	0.0284 ***
	0.0061	0.0110	0.0006	0.0037	0.029	0.025	0.028	0.040	0.0006	0.0012
Event	0.0051 ***	0.0500 ***	0.0026 ***	0.0121 ***	0.011 ***	0.028 ***	0.099 ***	0.017 ***	0.0043 ***	0.0069 ***
	0.0001	0.0017	0.0002	0.0010	0.004	0.004	0.006	0.006	0.0002	0.0004
Q*Event	0.0319 ***	-0.0260 ***	0.0231 ***	0.0059 ***	1.081 ***	1.106 ***	0.306 ***	0.282 ***	0.0082 ***	-0.0032 ***
	0.0002	0.0032	0.0004	0.0018	0.009	0.009	0.013	0.012	0.0004	0.0009
T*Event	0.0005 **	-0.0013	0.0015 **	0.0017	0.015	0.017	-0.038 **	-0.022	0.0003	-0.0021 **
	0.0002	0.0038	0.0005	0.0023	0.012	0.012	0.015	0.015	0.0005	0.0010
TA*Event	-0.0020 ***	0.0045	-0.0036 ***	-0.0021	0.106 ***	0.085 ***	0.006	0.010	0.0083 ***	0.0034 ***
	0.0002	0.0037	0.0005	0.0038	0.012	0.012	0.015	0.015	0.0005	0.0009
VIX	0.0000	-0.0004 *	0.0003	0.0005 ***	-0.006 ***	-0.018 ***	-0.008 ***	-0.019 ***	0.0004 ***	0.0003 ***
	0.0000	0.0002	0.0000	0.0002	0.001	0.001	0.001	0.001	0.0000	0.0001
Nobs	74,984	39,762	74,984	39,762	74,984	74,984	39,762	39,762	74,984	39,762
R2 within	0.6410	0.0292	0.1649	0.0095	0.4533	0.4851	0.0949	0.1347	0.1138	0.0115
Wald Chi2(8)	154,604.7	1,124.5	17,484.4	531.4	53,612.0	61,979.1	3,945.3	5,955.0	7,774.0	516.4

B. Trading Activity	log Volume				log Average Trade Size				Price	
	Tick Constrained		Unconstrained		Tick Constrained		Unconstrained		Tick Constrained	Unconstrained
	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(dollar)	(dollar)
Intercept	12.174 ***	14.752 ***	10.534 ***	13.975 ***	4.891 ***	7.469 ***	4.582 ***	8.023 ***	17.26 ***	44.35 ***
	0.042	0.064	0.075	0.113	0.016	0.027	0.025	0.043	0.05	2.31
Event	0.255 ***	0.272 ***	0.331 ***	0.400 ***	-0.002	0.016 ***	0.021 ***	0.090 ***	0.86 ***	3.31 ***
	0.006	0.007	0.009	0.010	0.003	0.003	0.005	0.005	0.02	0.07
Q*Event	-0.055 ***	-0.028 **	-0.041 **	-0.065 ***	0.101 ***	0.128 ***	0.031 ***	0.007	0.20 ***	0.19
	0.013	0.013	0.018	0.018	0.005	0.006	0.009	0.009	0.04	0.16
T*Event	-0.038 **	-0.037 **	0.027	0.045 **	0.001	0.002	0.007	0.025 **	0.30 ***	-0.62 ***
	0.016	0.016	0.022	0.023	0.007	0.007	0.010	0.011	0.05	0.17
TA*Event	0.055 ***	0.033 **	-0.107 ***	-0.105 ***	-0.010 ***	-0.062 ***	-0.040 ***	-0.037 ***	-0.48 ***	0.65 ***
	0.015	0.016	0.023	0.023	0.007	0.007	0.011	0.011	0.05	0.14
VIX	-0.001	-0.013 ***	-0.010 ***	-0.020 ***	-0.001 ***	-0.012 ***	-0.003 ***	-0.013 ***	-0.20 ***	-0.47 ***
	0.001	0.001	0.001	0.001	0.000	0.000	0.001	0.001	0.00	0.01
Nobs	74,984	74,984	39,762	39,762	74,984	74,984	39,762	39,762	74,984	39,762
R2 within	0.0341	0.0389	0.0502	0.0700	0.0147	0.0339	0.0035	0.0268	0.1040	0.1363
Wald Chi2(8)	2,614.1	3,021.2	2,117.5	3,000.9	1,107.8	2667.83	145.9	1,106.0	8,038.6	5,722.4

This table reports the results from difference-in-difference panel regressions that test for changes in average quote quality and trading activity for tick-constrained and unconstrained U.S. tick size pilot sample stocks between the pre- and the post-pilot periods. Tick-constrained stocks are those with an average quoted spread of $0.05 or less and unconstrained stocks are those with an average quoted spread of $0.10 or more in the pre-pilot period. We use the following specification:

$$MQ_{i,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{i,t}, \qquad (2)$$

where $MQ_{i,t}$ is a market quality measure (quote quality, trading activity) for stock *i* on day *t*, *Q*, *T* and *TA* are dummies that take on a value of one for stocks subject to the quote rule (Q), the trade rule (T), and the trade-at rule (TA), *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We cluster standard errors by firm and day. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, the quote rule applies to G1, G2, and G3, the trade rule applies to G2 and G3, and the trade-at rule applies to G3. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars, depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares, and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only. Price is the average daily share-weighted stock price in dollars. We report results for Quoted and Effective Spreads in percent of the midquote, and Depth, Volume, and Average Trade Size in shares as well as in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. Standard errors are reported below the estimated coefficients, and *** designates significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

Table 8. Changes in Market Quality for Tick-Constrained and Unconstrained Stocks: Collapsed Panel Regressions (Rules)

A. Quote Quality	Quoted Spread		Effective Spread		log Depth				Volatility	
	Tick Constrained	Unconstrained	Tick Constrained	Unconstrained	Tick Constrained		Unconstrained		Tick Constrained	Unconstrained
	(dollar)	(dollar)	(dollar)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	midquote	midquote
Intercept	0.0283 ***	0.1995 ***	0.0139 ***	0.0714 ***	2.143 ***	4.720 ***	1.599 ***	5.022 ***	0.0214 ***	0.0275 ***
	0.0011	0.0093	0.0010	0.0041	0.035	0.274	0.022	0.024	0.0018	0.0025
Event	0.0051 ***	0.0416 ***	0.0026 ***	0.0098 ***	0.011	0.028 **	0.105 ***	0.154 ***	0.0043 ***	0.0070 ***
	0.0007	0.0049	0.0007	0.0025	0.012	0.012	0.011	0.014	0.0011	0.0015
Q*Event	0.0319 ***	-0.0206 **	0.0231 ***	0.0073 **	1.081 ***	1.106 ***	0.299 ***	0.293 ***	0.0082 ***	-0.0033
	0.0010	0.0089	0.0011	0.0036	0.019	0.022	0.018	0.021	0.0021	0.0023
T*Event	0.0005	-0.0096	0.0015	-0.0011	0.016	0.015	-0.018	-0.027	0.0004	-0.0023
	0.0009	0.0087	0.0011	0.0042	0.023	0.023	0.019	0.020	0.0025	0.0024
TA*Event	-0.0020 **	0.0116	-0.0036 ***	0.0002	0.104 ***	0.087 ***	-0.003	0.016	0.0082 ***	0.0036
	0.0009	0.0083	0.0011	0.0056	0.028	0.027	0.021	0.021	0.0025	0.0026
VIX	0.0000	0.0004	0.0003 ***	0.0009 ***	-0.007 **	-0.018 ***	-0.009 ***	-0.017 ***	0.0004 ***	0.0004 *
	0.0001	0.0007	0.0001	0.0003	0.003	0.002	0.001	0.002	0.0001	0.0002
Nobs	308	308	308	308	308	308	308	308	308	308
F-value	1,320.6	13.3	473.0	23.7	2,115.4	1,946.3	298.7	437.5	33.9	6.1

B. Trading Activity	log Volume				log Average Trade Size				Price	
	Tick Constrained		Unconstrained		Tick Constrained		Unconstrained		Tick Constrained	Unconstrained
	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(dollar)	(dollar)
Intercept	12.162 ***	12.741 ***	10.624 ***	14.042 ***	4.887 ***	7.465 ***	4.591 ***	8.009 ***	17.29 ***	43.02 ***
	0.056	0.061	0.084	0.091	0.014	0.010	0.018	0.020	0.24	0.52
Event	0.253 ***	0.269 ***	0.335 ***	0.383 ***	-0.001	0.015 **	0.032 ***	0.081 ***	0.85 ***	2.53 ***
	0.044	0.045	0.051	0.052	0.007	0.008	0.009	0.011	0.15	0.42
Q*Event	-0.058	-0.032	-0.035	-0.042	0.101 ***	0.127 ***	0.022	0.016	0.20	0.80
	0.067	0.068	0.072	0.074	0.012	0.012	0.018	0.021	0.21	0.56
T*Event	-0.039	-0.040	0.032	0.027	0.002	0.000	0.028	0.022	0.29	-1.12 *
	0.072	0.072	0.076	0.077	0.013	0.013	0.021	0.021	0.25	0.59
TA*Event	0.060	0.043	-0.118	-0.100	-0.042 ***	-0.059 ***	-0.056 **	-0.038 **	-0.45 *	0.93 *
	0.069	0.068	0.082	0.080	0.012	0.012	0.022	0.019	0.25	0.51
VIX	0.001	-0.011 **	-0.009	-0.016 **	0.000	-0.012 ***	-0.004 ***	0.011 ***	-0.20 ***	-0.42 ***
	0.004	0.004	0.006	0.007	0.001	0.001	0.001	0.001	0.02	0.04
Nobs	308	308	308	308	308	308	308	308	308	308
F-value	14.2	15.2	16.3	22.5	97.1	137.7	11.1	54.2	41.3	75.4

This table reports the results from difference-in-difference collapsed panel regressions that test for changes in average quote quality and trading activity for tick-constrained and unconstrained U.S. tick size pilot sample stocks between the pre- and the post-pilot periods. Tick-constrained stocks are those with an average quoted spread of $0.05 or less and unconstrained stocks are those with an average quoted spread of $0.10 or more in the pre-pilot period. For each day, we compute the cross-sectional average market quality measure for control stocks (C) and for stocks subject to each rule: the quote rule (Q), the trade rule (T), and trade-at-rule (TA), and then run the following collapsed panel regression:

$$MQ_{g,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{g,t}, \qquad (3)$$

where $MQ_{g,t}$ is the average market quality measure (quote quality, trading activity) for stocks in group g on day *t*, *Q*, T and *TA* are dummies that take on a value of one for stocks subject to each rule, *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We use Newey-West standard errors with five lags. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, the quote rule applies to G1, G2, and G3, the trade rule applies to G2 and G3, and the trade-at rule applies to G3. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars, depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares, and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only. Price is the average daily share-weighted stock price in dollars. We report results for Quoted and Effective Spreads in percent of the midquote, and Depth, Volume, and Average Trade Size in shares as well as in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. Standard errors are reported below the estimated coefficients, and *** designates significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

Table 9. The Term Structure of Liquidity Provision and Price Impacts

I. All Stocks	Control Stocks		G1 Stocks		G2 Stocks		G3 Stocks	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A. Realized Spreads								
30 second horizon	0.0173	0.0380	0.0184	0.0375	0.0199	0.0470	0.0188	0.0409
1 minute horizon	0.0159	0.0377	0.0171	0.0376	0.0185	0.0473	0.0176	0.0408
2 minute horizon	0.0149	0.0387	0.0160	0.0379	0.0174	0.0487	0.0167	0.0419
3 minute horizon	0.0146	0.0395	0.0156	0.0385	0.0170	0.0490	0.0163	0.0425
4 minute horizon	0.0145	0.0401	0.0156	0.0393	0.0169	0.0491	0.0160	0.0433
5 minute horizon	0.0144	0.0407	0.0156	0.0400	0.0168	0.0497	0.0159	0.0440
B. Price Impact								
30 second horizon	0.0085	0.0112	0.0086	0.0109	0.0088	0.0120	0.0082	0.0107
1 minute horizon	0.0092	0.0125	0.0093	0.0121	0.0095	0.0131	0.0088	0.0117
2 minute horizon	0.0097	0.0137	0.0098	0.0136	0.0100	0.0147	0.0093	0.0130
3 minute horizon	0.0099	0.0146	0.0100	0.0147	0.0102	0.0155	0.0095	0.0140
4 minute horizon	0.0099	0.0154	0.0100	0.0155	0.0103	0.0162	0.0096	0.0148
5 minute horizon	0.0099	0.0159	0.0100	0.0161	0.0104	0.0168	0.0097	0.0155
Nobs	38,499		12,997		12,741		12,868	

II.Tick-constrained	Control Stocks		G1 Stocks		G2 Stocks		G3 Stocks	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A. Realized Spreads								
30 second horizon	0.0056	0.0132	0.0058	0.0128	0.0057	0.0146	0.0054	0.0140
5 minute horizon	0.0047	0.0157	0.0049	0.0162	0.0050	0.0192	0.0048	0.0203
B. Price Impact								
30 second horizon	0.0049	0.0041	0.0047	0.0037	0.0048	0.0041	0.0047	0.0040
5 minute horizon	0.0053	0.0066	0.0052	0.0059	0.0051	0.0064	0.0050	0.0064
Nobs	19,134		6,342		5,915		6,574	

II.Unconstrained	Control Stocks		G1 Stocks		G2 Stocks		G3 Stocks	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A. Realized Spreads								
30 second horizon	0.0457	0.0651	0.0449	0.0577	0.0488	0.0767	0.0467	0.0646
5 minute horizon	0.0382	0.0703	0.0376	0.0630	0.0410	0.0816	0.0393	0.0701
B. Price Impact								
30 second horizon	0.0156	0.0181	0.0157	0.0172	0.0157	0.0190	0.0150	0.0165
5 minute horizon	0.0194	0.0257	0.0194	0.0258	0.0198	0.0265	0.0187	0.0240
Nobs	9,439		3,579		3,599		3,539	

This table summarizes descriptive statistics on the term structure of liquidity provision and price discovery for the U.S. tick size pilot sample based on data from the period August 1 – September 23, 2016. Panel I reports the statistics overall, and Panels II and III report a subset of the statistics for tick-constrained and unconstrained stocks respectively. Tick-constrained stocks are those with an average quoted spread of $0.05 or less and unconstrained stocks are those with an average quoted spread of $0.10 or more in the pre-pilot period. Control stocks are those that will continue being quoted and traded in decimals, G1 stocks will be subject to the quote rule, G2 stocks to the quote and the trade rules, and G3 stocks to the quote, trade, and trade-at rules. Data was drawn from Thomson Reuters Tick History

(TRTH). Realized Spreads and Price Impacts are share-weighted and measured in dollars. We compute each measure at the 30 second, and the one, two, three, four, and five-minute horizons.

Table 10. Changes in the Term Structure of Liquidity Provision and Price Discovery: Panel Regressions (Rules)

A. Realized Spread	30 second horizon	1 minute horizon	2 minute horizon	3 minute horizon	4 minute horizon	5 minute horizon
Intercept	0.0130 ***	0.0116 ***	0.0105 ***	0.0098 ***	0.0095 ***	0.0093 ***
	0.0011	0.0010	0.0010	0.0010	0.0010	0.0010
Event	0.0012 ***	0.0011 ***	0.0008 ***	0.0007 ***	0.0006 **	0.0007 **
	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003
Q*Event	0.0078 ***	0.0075 ***	0.0075 ***	0.0073 ***	0.0072 ***	0.0070 ***
	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006
T*Event	0.0013 **	0.0012 *	0.0010	0.0010	0.0009	0.0010
	0.0007	0.0007	0.0007	0.0007	0.0007	0.0008
TA*Event	-0.0033 ***	-0.0031 ***	-0.0031 ***	-0.0031 ***	-0.0028 ***	-0.0028 ***
	0.0007	0.0007	0.0007	0.0008	0.0008	0.0008
VIX	0.0004 ***	0.0004 ***	0.0004 ***	0.0004 ***	0.0005 ***	0.0005 ***
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nobs	152,357	152,357	152,357	152,357	152,357	152,357
R2 within	0.0093	0.0084	0.0070	0.0063	0.0058	0.0055
Wald Chi2 (8)	1,234.5	1,113.3	923.4	844.6	778.5	736.0

B. Price Impact	30 second horizon	1 minute horizon	2 minute horizon	3 minute horizon	4 minute horizon	5 minute horizon
Intercept	0.0098 ***	0.0105 ***	0.0111 ***	0.0114 ***	0.0116 ***	0.0116 ***
	0.0003	0.0004	0.0004	0.0004	0.0004	0.0004
Event	0.0018 ***	0.0018 ***	0.0019 ***	0.0020 ***	0.0020 ***	0.0020 ***
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Q*Event	0.0046 ***	0.0047 ***	0.0047 ***	0.0048 ***	0.0048 ***	0.0049 ***
	0.0002	0.0002	0.0002	0.0002	0.0002	0.0023
T*Event	0.0006 ***	0.0006 ***	0.0007 ***	0.0007 ***	0.0008 ***	0.0007 **
	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003
TA*Event	0.0002	0.0000	0.0001	0.0000	-0.0001	-0.0001
	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003
VIX	-0.0001 ***	-0.0001 ***	-0.0001 ***	-0.0001 ***	-0.0001 ***	-0.0001 ***
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nobs	152,357	152,357	152,357	152,357	152,357	152,357
R2 within	0.0465	0.0394	0.0346	0.0314	0.0288	0.0265
Wald Chi2 (8)	6,757.9	5,767.3	4,940.7	4,504.8	413,585.0	3,800.8

This table reports the results from difference-in-difference panel regressions that test for changes in the term structure of liquidity provision and price discovery for U.S. tick size pilot sample stocks between the pre- and the post-pilot periods. We use the following specification:

$$MQ_{i,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{i,t}, \qquad (2)$$

where $MQ_{i,t}$ is a market quality measure (realized spread, price impact) for stock *i* on day *t*, *Q*, *T* and *TA* are dummies that take on a value of one for stocks subject to the quote rule (Q), the trade rule (T), and the trade-at rule (TA), *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We cluster standard errors by firm and day. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, the quote rule applies to G1, G2, and G3, the trade rule applies to G2 and G3, and the trade-at rule applies to G3. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Realized Spreads and Price Impacts are share-weighted and measured in dollars. We compute each measure at the 30 second, and the one, two, three, four, and five-minute horizons. Standard errors are reported below the estimated coefficients, and *** designates significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

Table 11. Changes in the Term Structure of Liquidity Provision and Price Discovery for Tick-Constrained and Unconstrained Stocks: Panel Regressions (Rules)

A. Realized Spread	30 second horizon		1 minute horizon		2 minute horizon		3 minute horizon		4 minute horizon		5 minute horizon	
	Tick constrained	Unconstrained	Tick constrained	Unconstrained	Tick constrained	Unconstrained	Tick constrained	Unconstrained	Tick constrained	Unconstrained	Tick constrained	Unconstrained
Intercept	0.0015 ***	0.0390 ***	0.0009 *	0.0354 ***	0.0010 *	0.0317 ***	0.0010 ***	0.0294 ***	0.0012 **	0.0278 ***	0.0013 ***	0.0268 ***
	0.0005	0.0030	0.0005	0.0030	0.0005	0.0030	0.0005	0.0030	0.0005	0.0030	0.0005	0.0030
Event	0.0011 ***	0.0018 **	0.0011 ***	0.0016 *	0.0010 ***	0.0007	0.0010 ***	0.0004	0.0011 ***	0.0000	0.0011 ***	0.0003
	0.0002	0.0008	0.0002	0.0009	0.0002	0.0009	0.0002	0.0009	0.0002	0.0009	0.0002	0.0010
Q*Event	0.0111 ***	0.0006	0.0107 ***	0.0006	0.0103 ***	0.0015	0.0098 ***	0.0020	0.0095 ***	0.0026	0.0093 ***	0.0019
	0.0004	0.0015	0.0004	0.0016	0.0004	0.0016	0.0004	0.0017	0.0004	0.0017	0.0004	0.0018
T*Event	0.0006	0.0022	0.0004	0.0023	0.0002	0.0018	0.0003	0.0014	0.0004	0.0006	0.0005	0.0010
	0.0004	0.0021	0.0005	0.0021	0.0005	0.0022	0.0005	0.0022	0.0005	0.0023	0.0005	0.0023
TA*Event	-0.0030 ***	-0.0042 *	-0.0027 ***	-0.0043 *	-0.0023 ***	-0.0050 **	-0.0021 ***	-0.0054 **	-0.0021 ***	-0.0047 *	-0.0021 ***	-0.0048 *
	0.0004	0.0022	0.0005	0.0023	0.0005	0.0023	0.0005	0.0024	0.0005	0.0024	0.0006	0.0025
VIX	0.0003 ***	0.0006 ***	0.0003 ***	0.0007 ***	0.0003 ***	0.0008 ***	0.0003 ***	0.0009 ***	0.0003 ***	0.0009 ***	0.0003 ***	0.0009 ***
	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001
Nobs	74,984	39,761	74,984	39,761	74,984	39,761	74,984	39,761	74,984	39,761	74,984	39,761
R2 within	0.0575	0.0013	0.0490	0.0013	0.0408	0.0013	0.0357	0.0014	0.0328	0.0014	0.0302	0.0014
Wald Chi2 (8)	4,779.9	43.6	3,915.9	43.8	3,248.3	44.1	2,836.8	49.9	2,616.7	50.9	2,386.8	51.4

B. Price Impact	30 second horizon		1 minute horizon		2 minute horizon		3 minute horizon		4 minute horizon		5 minute horizon	
	Tick constrained	Unconstrained	Tick constrained	Unconstrained	Tick constrained	Unconstrained	Tick constrained	Unconstrained	Tick constrained	Unconstrained	Tick constrained	Unconstrained
Intercept	0.0053 ***	0.0183 ***	0.0056 ***	0.0200 ***	0.0056 ***	0.0219 ***	0.0055 ***	0.0231 ***	0.0055 ***	0.0238 ***	0.0054 ***	0.0243 ***
	0.0001	0.0009	0.0001	0.0010	0.0002	0.0010	0.0002	0.0011	0.0002	0.0011	0.0002	0.0012
Event	0.0006 ***	0.0046 ***	0.0006 ***	0.0047 ***	0.0006 ***	0.0052 ***	0.0006 ***	0.0053 ***	0.0006 ***	0.0055 ***	0.0006 ***	0.0054 ***
	0.0000	0.0003	0.0001	0.0003	0.0001	0.0003	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Q*Event	0.0058 ***	0.0021 ***	0.0060 ***	0.0021 ***	0.0062 ***	0.0016 **	0.0064 ***	0.0014 **	0.0066 ***	0.0011	0.0067 ***	0.0014 *
	0.0001	0.0005	0.0001	0.0006	0.0001	0.0006	0.0001	0.0007	0.0001	0.0007	0.0002	0.0007
T*Event	0.0006 ***	0.0008	0.0007 ***	0.0007	0.0008 ***	0.0009	0.0007 ***	0.0011	0.0007 ***	0.0015	0.0006 ***	0.0013
	0.0001	0.0007	0.0001	0.0007	0.0002	0.0008	0.0002	0.0009	0.0002	0.0009	0.0002	0.0010
TA*Event	-0.0004 ***	0.0016 **	-0.0006 ***	0.0016 **	-0.0008 ***	0.0020 **	-0.0009 ***	0.0022 **	-0.0009 ***	0.0018 *	-0.0009 ***	0.0019 *
	0.0001	0.0007	0.0001	0.0008	0.0002	0.0009	0.0002	0.0006	0.0002	0.0010	0.0002	0.0010
VIX	0.0000 ***	-0.0001 ***	0.0000 ***	-0.0002 ***	0.0000 ***	-0.0002 ***	0.0000	-0.0003 ***	0.0000	-0.0003 ***	0.0000	-0.0003 ***
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0001	0.0000	0.0001
Nobs	74,984	39,761	74,984	39,761	74,987	39,761	74,984	39,761	74,984	39,761	74,984	39,761
R2 within	0.2041	0.027	0.1811	0.0224	0.162	0.0202	0.1457	0.0185	0.1314	0.0173	0.117	0.0159
Wald Chi2 (8)	16,369.4	1,043.9	14,658.5	868.6	12,296.9	774.0	10,944.3	700.6	9,875.9	651.7	8,637.4	593.0

This table reports the results from difference-in-difference panel regressions that test for changes in the term structure of liquidity provision and price impacts for U.S. tick size pilot sample stocks between the pre- and the post-pilot periods. Tick-constrained stocks are those with an average quoted spread of $0.05 or less and unconstrained stocks are those with an average quoted spread of $0.10 or more in the pre-pilot period. We use the following specification:

$$MQ_{i,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{i,t}, \qquad (2)$$

where $MQ_{i,t}$ is a market quality measure (realized spread, price impact) for stock *i* on day *t*, *Q*, *T* and *TA* are dummies that take on a value of one for stocks subject to the quote rule (Q), the trade rule (T), and the trade-at rule (TA), *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We cluster standard errors by firm and day. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, the quote rule applies to G1, G2, and G3, the trade rule applies to G2 and G3, and the trade-at rule applies to G3. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Realized Spreads and Price Impacts are share-weighted and measured in dollars. We compute each measure at the 30 second, and the one, two, three, four, and five-minute horizons. Standard errors are reported below the estimated coefficients, and *** designates significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

Table D1. Descriptive Statistics for Nasdaq-Listed and NYSE-Listed Stocks

I. Nasdaq-Listed Stocks		Control Stocks		G1 Stocks		G2 Stocks		G3 Stocks	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A. Firm Characteristics									
Market Capitalization	('000 dollar)	627,746	667,522	599,621	624,247	623,818	651,323	628,280	658,569
Price	(dollar)	20.93	20.26	20.93	19.76	21.48	20.63	21.52	21.37
Nfirms		693		230		225		232	
B. Quote Quality									
Quoted Spread	(dollar)	0.0917	0.1275	0.0964	0.1305	0.0990	0.1329	0.0956	0.1243
Effective Spread	(dollar)	0.0421	0.0577	0.0430	0.0564	0.0459	0.0695	0.0438	0.0582
Depth	(100 shares)	8.65	16.68	8.44	11.56	8.32	11.76	9.04	15.91
Volatility	(midquote)	0.0320	0.0024	0.0317	0.0239	0.0318	0.0285	0.0309	0.0244
C. Trading Activity									
Volume	(shares)	200,112	371,066	183,897	352,151	214,521	456,905	213,172	447,555
Average Trade Size	(shares)	135.58	295.39	133.23	89.29	130.55	131.83	136.59	145.75
Nobs		26,122		8,690		8,471		8,726	

II. NYSE-Listed Stocks		Control Stocks		G1 Stocks		G2 Stocks		G3 Stocks	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A. Firm Characteristics									
Market Capitalization	('000 dollar)	1,029,713	792,315	1,056,433	827,370	982,634	701,815	1,024,722	773,120
Price	(dollar)	25.85	21.41	28.97	27.73	27.21	22.31	23.61	17.55
Nfirms		320		111		111		107	
B. Quote Quality									
Quoted Spread	(dollar)	0.0645	0.0748	0.0715	0.0837	0.0718	0.0749	0.0606	0.0672
Effective Spread	(dollar)	0.0325	0.0368	0.0339	0.0356	0.0362	0.0449	0.0336	0.1594
Depth	(100 shares)	7.50	9.26	8.64	12.23	7.15	7.72	8.72	14.47
Volatility	(midquote)	0.0233	0.0161	0.0237	0.0172	0.0239	0.0172	0.0240	0.0161
C. Trading Activity									
Volume	(shares)	266,747	357,110	296,172	368,758	271,381	378,234	280,005	415,002
Average Trade Size	(shares)	129.58	156.78	125.59	66.14	124.27	82.30	136.75	78.83
Nobs		12,365		4,309		4,260		4,122	

This table summarizes descriptive statistics for the U.S. tick size pilot sample based on data from the period August 1 – September 23, 2016, for Nasdaq-listed stocks in Panel I and NYSE-listed stocks in Panel II. Control stocks are those that will continue being quoted and traded in decimals, G1 stocks will be subject to the quote rule, G2 stocks to the quote and the trade rules, and G3 stocks to the quote, trade, and trade-at rules. Data was drawn from Thomson Reuters Tick History (TRTH) and CRSP data bases. Market capitalization as of June 20, 2016, is measured in $1,000 dollars and Price is the stock price in dollars, both variables from CRSP. Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars, Depth denotes the time-weighted NBBO depth, and is reported in round lots of 100 shares and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only.

Table D2. Changes in Market Quality for Nasdaq-Listed and NYSE-Listed Stocks: Panel Regressions (Rules)

A. Quote Quality	Quoted Spread				log Depth				Volatility	
	Nasdaq		NYSE		Nasdaq		NYSE		Nasdaq	NYSE
	(dollar)	(%)	(dollar)	(%)	(shares)	(dollar)	(shares)	(dollar)	Midquote	Midquote
Intercept	0.1074 ***	0.0056 ***	0.0659 ***	0.0026 ***	1.930 ***	4.736 ***	1.797 ***	4.907 ***	0.0270 ***	0.0189 ***
	0.0062	0.0003	0.0040	0.0002	0.024	0.023	0.034	0.028	0.0007	0.0006
Event	0.0226 ***	0.0008 ***	0.0090 ***	0.0001 ***	0.070 ***	0.093 ***	0.026 ***	0.064 ***	0.0070 ***	0.0015 ***
	0.0007	0.0000	0.0004	0.0000	0.004	0.004	0.004	0.004	0.0002	0.0002
Q*Event	0.0124 ***	0.0022 ***	0.0203 ***	0.0023 ***	0.770 ***	0.774 ***	0.741 ***	0.779 ***	0.0011 **	0.0065 **
	0.0013	0.0001	0.0008	0.0001	0.009	0.008	0.010	0.010	0.0047	0.0004
T*Event	0.0043 **	-0.0002 *	-0.0029 ***	-0.0006 ***	-0.054 ***	-0.043 ***	0.089 ***	0.085 ***	-0.0004	-0.0003
	0.0017	0.0001	0.0009	0.0001	0.011	0.011	0.014	0.014	0.0006	0.0005
TA*Event	-0.0061 **	0.0003 **	0.0042 ***	0.0005 ***	0.041 ***	0.046 ***	0.091 ***	0.062 ***	0.0064 ***	0.0058 ***
	0.0017	0.0001	0.0009	0.0001	0.011	0.011	0.014	0.014	0.0005	0.0005
VIX	-0.0003 ***	0.0000 ***	0.0000	0.0000 ***	-0.009 ***	-0.019 ***	-0.004 ***	-0.017 ***	0.0004 ***	0.0003 ***
	0.0001	0.0000	0.0001	0.0000	0.001	0.001	0.001	0.001	0.0000	0.0000
Nobs	102,907	102,907	49,450	49,450	102,907	102,907	49,450	49,450	102,907	49,450
R2 within	0.0383	0.0491	0.1230	0.1543	0.2693	0.3004	0.3757	0.4163	0.0343	0.0676
Wald Chi2(8)	3,938.4	5,012.3	7,344.6	6,674.1	32,996.9	39,518.6	23,265.4	27,526.0	3,568.3	2,745.1

B. Trading Activity	log Volume				log Average Trade Size				Price	
	Nasdaq		NYSE		Nasdaq		NYSE		Nasdaq	NYSE
	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(dollar)	(dollar)
Intercept	11.353 ***	14.157 ***	11.877 ***	14.985 ***	4.788 ***	7.592 ***	4.758 ***	7.865 ***	25.45 ***	30.75 ***
	0.052	0.067	0.060	0.080	0.016	0.026	0.019	0.036	0.86	1.25
Event	0.296 ***	0.320 ***	0.289 ***	0.325 ***	0.021 ***	0.046 ***	-0.005 **	0.031 ***	1.63 ***	1.47 ***
	0.006	0.006	0.007	0.007	0.003	0.003	0.003	0.003	0.03	0.04
Q*Event	-0.026 **	-0.021 *	-0.102 ***	-0.061 ***	0.077 ***	0.082 ***	0.063 ***	0.104 ***	0.24 ***	0.83 ***
	0.012	0.012	0.014	0.014	0.005	0.005	0.006	0.006	0.05	0.11
T*Event	-0.056 ***	-0.044 ***	0.061 ***	0.054 ***	-0.020 ***	-0.008	0.034 ***	0.027 ***	0.14 **	0.32 ***
	0.015	0.015	0.017	0.017	0.007	0.007	0.007	0.008	0.07	0.07
TA*Event	0.005	0.008	-0.068 ***	-0.095 ***	-0.043 ***	-0.040 ***	-0.035 ***	-0.063 ***	0.03	-0.18 **
	0.014	0.015	0.018	0.018	0.007	0.007	0.007	0.008	0.07	0.08
VIX	-0.007 ***	-0.017 ***	0.000	-0.012 ***	-0.002 ***	-0.013 ***	0.001 **	-0.012 ***	-0.28 ***	-0.34 ***
	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.00	0.01
Nobs	102,907	102,907	49,450	49,450	102,907	102,907	49,450	49,450	102,907	49,450
R2 within	0.0382	0.0453	0.0481	0.0629	0.0084	0.0240	0.0121	0.0436	0.1124	0.0916
Wald Chi2(8)	4,041.8	4,834.2	2,462.4	3,311.0	874.0	2,533.9	581.3	2,284.0	11,315.2	4,802.5

This table reports the results from difference-in-difference panel regressions that test for changes in average quote quality and trading activity for Nasdaq-listed and NYSE-listed U.S. tick size pilot sample stocks between the pre- and the post-pilot periods. We use the following specification:

$$MQ_{i,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{i,t}, \qquad (2)$$

where $MQ_{i,t}$ is a market quality measure (quote quality, trading activity) for stock *i* on day *t*, *Q*, *T* and *TA* are dummies that take on a value of one for stocks subject to the quote rule (Q), the trade rule (T), and the trade-at rule (TA), *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We cluster standard errors by firm and day. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, the quote rule applies to G1, G2, and G3, the trade rule applies to G2 and G3, and the trade-at rule applies to G3. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Quoted spreads are time-weighted, and effective spreads are share-weighted and both are measured in dollars, depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares, and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only. Price is the average daily share-weighted stock price in dollars. We report results for Quoted and Effective Spreads in percent of the midquote, and Depth, Volume, and Average Trade Size in shares as well as in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. Standard errors are reported below the estimated coefficients, and *** designates significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.

Panel D3. Changes in Market Quality for Nasdaq-Listed and NYSE-Listed Stocks: Collapsed Panel Regressions (Rules)

A. Quote Quality	Quoted Spread				log Depth				Volatility	
	Nasdaq		NYSE		Nasdaq		NYSE		Nasdaq	NYSE
	(dollar)	(%)	(dollar)	(%)	(shares)	(dollar)	(shares)	(dollar)	midquote	midquote
Intercept	0.0912 ***	0.0053 ***	0.0642 ***	0.0025 ***	1.937 ***	4.724 ***	1.801 ***	4.915 ***	0.0264 ***	0.0191 ***
	0.0044	0.0002	0.0022	0.0001	0.021	0.016	0.030	0.026	0.0021	0.0016
Event	0.0199 **	0.0009 **	0.0078 ***	0.0000	0.075 ***	0.087 ***	0.028 **	0.062 ***	0.0070 ***	0.0015
	0.0021	0.0002	0.0015	0.0001	0.006	0.009	0.012	0.015	0.0013	0.0010
Q*Event	0.0136 ***	0.0021 ***	0.0222 ***	0.0024 ***	0.767 ***	0.780 ***	0.737 ***	0.783 ***	0.0010	0.0065 ***
	0.0038	0.0003	0.0025	0.0001	0.011	0.015	0.021	0.023	0.0023	0.0016
T*Event	0.0017	-0.0001	-0.0019	-0.0006 ***	-0.046 ***	-0.049 ***	0.086 ***	0.085 ***	-0.0004	-0.0004
	0.0046	0.0003	0.0025	0.0001	0.015	0.017	0.022	0.022	0.0027	0.0019
TA*Event	-0.0018	0.0002	0.0015	0.0005 ***	0.031 *	0.049 ***	0.100 ***	0.062 *	0.0063 **	0.0059 ***
	0.0048	0.0003	0.0020	0.0001	0.018	0.018	0.027	0.032	0.0027	0.0021
VIX	0.0000	0.0001 ***	0.0000	0.0001 ***	-0.010 ***	-0.019 ***	-0.004 *	-0.017 ***	0.0004 ***	0.0003 ***
	0.0003	0.0002	0.0002	0.0000	0.002	0.001	0.002	0.002	0.0002	0.0001
Nobs	308	308	308	308	308	308	308	308	308	308
F-value	62.2	92.4	186.8	261.8	2,719.2	1,828.6	1,239.8	1,224.6	16.3	22.4

B. Trading Activity	log Volume				log Average Trade Size				Price	
	Nasdaq		NYSE		Nasdaq		NYSE		Nasdaq	NYSE
	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(shares)	(dollar)	(dollar)	(dollar)
Intercept	11.412 ***	14.197 ***	11.879 ***	14.985 ***	4.794 ***	7.579 ***	4.754 ***	7.866 ***	24.70 ***	30.82 ***
	0.058	0.066	0.068	0.074	0.011	0.012	0.012	0.016	0.04	0.43
Event	0.286 ***	0.299 ***	0.291 ***	0.324 ***	0.088 ***	0.070 ***	-0.004	0.029 ***	1.31 ***	1.30 ***
	0.047	0.048	0.047	0.017	0.007	0.008	0.006	0.008	0.21	0.25
Q*Event	-0.016	-0.001	-0.108	-0.058	0.072 ***	0.087 ***	0.060 ***	0.110 ***	0.48	1.25 ***
	0.065	0.066	0.069	0.069	0.010	0.013	0.011	0.010	0.30	0.40
T*Event	-0.062	-0.063	0.048	0.044	-0.012	-0.013	0.033 **	0.030 **	-0.09	-0.28
	0.067	0.068	0.074	0.074	0.012	0.015	0.013	0.014	0.39	0.47
TA*Event	-0.004	0.012	-0.039	-0.075	-0.051 ***	-0.034 **	-0.032 ***	-0.069 ***	0.26	-1.03 ***
	0.067	0.068	0.072	0.074	0.015	0.015	0.012	0.016	0.70	0.39
VIX	-0.006	-0.015 ***	0.002	-0.011 **	-0.003 ***	-0.012 ***	0.001	-0.012 ***	-0.27 ***	-0.35 ***
	0.004	0.005	0.005	0.005	0.001	0.001	0.001	0.001	0.03	0.03
Nobs	308	308	308	308	308	308	308	308	308	308
F-value	15.3	16.7	14.2	19.5	62.4	82.5	60.6	142.8	32.0	230.8

This table reports the results from difference-in-difference collapsed panel regressions that test for changes in average quote quality and trading activity for Nasdaq-listed and NYSE-listed U.S. tick size pilot sample stocks between the pre- and the post-pilot periods. For each day, we compute the cross-sectional average market quality measure for control stocks (C) and for stocks subject to each rule: the quote rule (Q), the trade rule (T), and trade-at-rule (TA), and then run the following collapsed panel regression:

$$MQ_{g,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{g,t}, \qquad (3)$$

where $MQ_{g,t}$ is the average market quality measure (quote quality, trading activity) for stocks in group g on day *t*, *Q*, T and *TA* are dummies that take on a value of one for stocks subject to each rule, *Event* is a dummy that takes on a value of one for days in the post-period, and X_t is the VIX index which we use as a market-wide control variable. We use Newey-West standard errors with five lags. The pre-period is August 1 – September 23, 2016, and the post-period is October 31-December 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, the quote rule applies to G1, G2, and G3, the trade rule applies to G2 and G3, and the trade-at rule applies to G3. Measures are calculated based on data from Thomson Reuters Tick History (TRTH). Quoted spreads are time-weighted, and effective spreads are share-weighted and both are measured in dollars, depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares, and Volatility is measured as the standard deviation of midquote returns and is in percent. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only. Price is the average daily share-weighted stock price in dollars. We report results for Quoted and Effective Spreads in percent of the midquote, and Depth, Volume, and Average Trade Size in shares as well as in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. Standard errors are reported below the estimated coefficients, and *** designates significant at the 1% level, ** significant at the 5% level, and * significant at the 10% level.