U.S. Tick Size Pilot[1]

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First Draft: May 30, 2017

This Draft: January 25, 2019

Abstract

The U.S. equity markets recently increased the tick size from one to five cents for smaller capitalization stocks. We show that the larger tick size raised the cost for retail-sized liquidity demanding orders by almost fifty percent, and raised profits to liquidity providers by forty percent. The bulk of the effects occurred for tick-constrained stocks for which trading costs more than doubled. Trading costs for unconstrained stocks declined by more than ten percent. Finally, we document significant changes in market quality for control stocks relative to similar stocks that were not part of the study.

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

[1] We thank Davide Cao, Minki Kim, and Andrea Lupi for excellent research assistance and the Baffi-Carefin Center for financial support. We are grateful for comments from seminar participants at ESSEC, Cornell University, University of Virginia's Darden School, and the University of Utah.

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 1,200 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 five cents on quote quality, trading activity, the rewards for liquidity provision, and price discovery.

Quintupling the tick size in a limit order book has three main possible effects. First, a mechanical increase of the best-bid offer (BBO) makes market orders more expensive and reduces traders' willingness to use market orders. Second, an increase of the number of limit orders queueing at the BBO may decrease the incentive to use limit orders. Third, an increase of the cost of undercutting resting limit orders may increase the execution probability of limit orders and hence increase traders' incentive to choose 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 on price discovery will depend on which factors prevail for any given stock.

Werner, Wen, Rindi and Buti (2019) study how a change in the tick size affects the equilibrium in a limit order book for stocks with different liquidity. They show that for stocks that before the tick size increase had a BBO of one penny, and hence were tick-constrained, both the mechanical increase in spread and the increase in the limit order queues are substantial, and as a result, both spread and depth at the BBO increase. The effect on volume is negligible as the mechanical increase in spread reduces the incentive for traders to use market orders, whereas the longer queue at the new BBO increases the incentive for traders to choose limit rather than market orders, and the two effects offset each other. For stocks that before the tick size increase had a BBO wider than one penny, and hence were unconstrained by the tick size, the increase in the cost of undercutting makes traders more willing to supply liquidity, and this outweighs 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).

effects both of the mechanical increase in spread and of the increase in length of the queue at the BBO. In fact, the stronger the increase in the willingness of traders to supply liquidity, the smaller will be the resulting spread and trading volume, and the greater will be the resulting depth at the new inside BBO. The forces at work are the same as, and results are consistent with, those obtained by Goettler, Parlour and Rajan (2005) who model a dynamic limit order book and find that following an increase in the tick size spread widens, depth increases and volume tends to decline for a stock with average liquidity.

A number of authors have also studied tick size increases in intermediated markets. Cordella and Foucault (1999) show that in a dealership market, 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 experiment 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.

The pilot defines a control group of roughly 1,200 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.

Consistent with Goettler et al. (2005) and Werner et al. (2019) predictions, 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%), and an increase in depth by 2,176 shares (275%) relative to control stocks where we gauge the economic magnitude of the changes based on pre-pilot averages for stocks in G2. 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, consolidated volume increases market-wide but volume does not change significantly for stocks in the test groups relative to control stocks. Seppi (1997) predicts an increase in average trade size, and we find that the quote rule causes an increase in average trade size by 11.8 shares (9%) relative to control stocks where we again compare the magnitude to pre-period averages for G2 stocks. Hence, the overall results confirm the predictions and show 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.

Boehmer, Jones and Zhang (2017) 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, 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 is, 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 one or more fundamental factor that affects both treated and control stocks or it could be the result of spillovers from the treatment. A fundamental factor could for example be an increase in adverse selection facing stocks in this segment, while a spillover could occur if market makers substitute away from control stocks toward more lucrative treated stocks, so that the quote competition for control stocks falls.

In an attempt to discriminate between these two explanations for changes in market quality for control stocks, we create two samples of stocks that are similar to control stocks but were not part of the tick size pilot program. We run difference-in-difference panel regressions to test if changes in market quality for these similar stocks are significantly different from changes for control stocks. Despite the fact that neither this group of similar stocks nor control stocks experienced a change in tick size, we find that market quality changes significantly for control stocks relative to similar stocks that were not part of the pilot program. Quoted and effective spreads, depth and volatility decrease significantly for similar stocks relative to control stocks in such a way that the total effect of the experiment is near zero. Furthermore, volume declines for similar stocks relative to control stocks, but the total effect is still significantly positive albeit less than half as large as for control stocks. Finally, average trade size actually increases for similar stocks relative to control stocks. We conclude that the changes in spreads, depth and volatility for control stocks are largely a "placebo effect" due to spillovers from the treatment, whereas the increase in volume and average trade size appear to be a dampened response to a segment-wide fundamental factor.

Werner et al. (2019) predict that while quoted depth should increase both for tick-constrained and unconstrained stocks, tick-constrained stocks should experience a widening of quoted spreads while unconstrained stocks may experience a decrease in quoted spread, while the effect on volume is negligible for tick-constrained stocks but negative and small for unconstrained stocks. 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 tick 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 the quote rule causes quoted spreads to increase 3.19 cents (112%) for tick constrained and to decline by 2.60 cents (12%) for unconstrained stocks relative to their respective control stocks. Similarly, it causes effective spreads to increase by 2.31 cents (128%) for tick-constrained stocks but hardly change for unconstrained stocks relative to control stocks. Depth increases by 3,450 shares (326%) for tick-constrained and by 456 shares (82%) for unconstrained stocks. Volume declines relative to control stocks for both subsamples based on panel regressions, but for neither subsample does volume change significantly relative to control stocks in the more robust collapsed panel version of the tests, confirming the theoretical predictions.

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, relative to control stocks, 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 relative to control stocks 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 relative to control stocks for unconstrained stocks at any horizon and is associated with a significant price impact only out to the three-minute horizon. Hence, the increases in profits relative to control stocks 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 relative to control stocks 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 relative to controls stocks, ranging from 0.46 cents (52%) at the 30-second horizon to 0.49 cents (47%) at the five-minute 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 they had relatively low liquidity, and some of them traded 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 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.

Our paper focuses on the direct effect of the tick size pilot on quote quality, trading activity, and the rewards for liquidity provision. It complements a number of recent empirical papers examining the tick size pilot, including Comerton-Forde et al. (2018), Griffith and Roseman (2018), and Lin et al. (2017). To our knowledge, ours is the only paper that documents significant changes in market quality and the rewards for liquidity provision for control stocks, even relative to similar stocks that were not part of the SEC pilot study, illustrating the methodological challenges we face when evaluating regulatory experiments. We also contribute to our understanding of the effect of an increase in tick size by documenting that the average trade size increases significantly for test stocks suggesting that institutions may benefit from the increase in BBO depth. Furthermore, we show that volume does not change significantly for test stocks compared to control stocks based on more conservative analyses. We also provide additional evidence that is to our knowledge unique to the literature: We document a significant increase in reported market maker profits for test stocks relative to control stocks. Finally, we provide more granular results by showing that the changes in market quality are virtually exclusively caused by the quote rule; and by comparing the results for smaller capitalization (Nasdaq-listed) to those for larger capitalization (NYSE-listed) firms. Several related empirical papers document indirect effects of the tick size pilot. For example, researchers have found that the tick size pilot is associated with a significant shift in volume across venues (Comerton-Forde et al., 2018, Hansen et al., 2017, and Lin et al., 2017), a reduction in hidden and algorithmic trading (Cox et al., 2017), a reduction in dark trading (Bartlett and McCrary, 2017, and Farley et al., 2018), and even a drop in stock prices (Albuquerque et al., 2017). These findings suggest that regulatory experiments often have a wide range of consequences, many of which were likely unforeseen.

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.[3]

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.[4] 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 and a closing price of $2 or less on the last day of the measurement period, and an average daily trading volume of one million shares or less over the measurement period, a volume-weighted average price of at least $2.00 for every trading day in the measurement period, and a closing price of not less than $1.50 on every day of the measurement period.[5] The measurement period was the three calendar months following April 4th, 206. The pilot was designed to include three stratified test groups each consisting of 400 securities, the remaining stocks constitute the control group. The three test groups are:[6]

- 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.

[3] 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
[4] 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 hiip://www.sec.gov/divisions/marketreg/tick-size-pilot-plan-final.pdf
[5] See FINRA (2018) for further details.
[6] See SEC Approves Pilot to Assess Tick Size Impact for Smaller Companies (May 6, 205), available at hiips://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 ended September 28, 2018.[7] 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.[8]

3. Predictions

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 1/8th to 1/16th in 1997, and the ultimate decimalization in 2001. Harris (1994), 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. 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. (2019) 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 in exchange for immediate execution) against the non-execution cost associated with a limit order (a better price at the cost of 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 orders 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. (2019) solve a three-period model by backward induction and show how order liquidity in a limit order book evolves over the course of a trading day. Werner et al. (2019) also discuss how migration of order flows to a competing crossing network that executes at the mid-quote of the primary market may affect the

[7] SEC Public Statement on the Expiration of the Tick Size Pilot hiips://www.sec.gov/news/public-statement/tm-dera-expiration-tick-size-pilot.
[8] The implementation schedule is reproduced in the Appendix A.

results. To derive our predictions, we focus on the version of the Werner et al. (2019) model that faces no competition from any trading venue as in Goettler et al. (2005). Both the Goettler et al. (2015) and Werner et al. (2019) models compare the equilibrium with a small tick size to one with a large tick size. The effects at work in the two models are the same but while Werner at al. (2019) present results both for liquid and for illiquid stocks, Goettler et al. (2015) present results for a stock of average liquidity.

There are three main effects following an increase of the tick size in a limit order book. First, due to the wider tick size, the inside spread of the new price grid may be mechanically wider. Hence, market orders that have to cross the spread to execute at the new quoted spread become more expensive. Second, the queue of limit orders sitting at the new quoted spread may increase, thus reducing the probability of execution of limit orders. Hence, the incentive for traders to choose limit as opposed to market orders decreases. Third, due to the coarser price grid, undercutting limit orders posted at the new quoted spread may become more expensive. To gain price priority traders now have to forgo a greater price improvement, and this in turn increases the execution probability of limit orders standing at the new quoted spread. Werner at al. (2019) show that which factor prevails determines the effects of a tick size increase on quote quality, trading activity and rewards for liquidity provision. For liquid stocks the effects of the mechanical increase of the spread and of the longer limit order queue at the new quoted spread are more pronounced; whereas for illiquid stocks the undercutting effect is stronger.

Consider first a stock for which the equilibrium spread with a small tick size was narrower than the minimum spread dictated by the larger tick size, i.e., the stock would become tick-constrained at the larger tick size. If the tick size increases for this stock, limit orders that were initially posted at prices that now 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 effect increases both the quoted spread and BBO depth and makes the stock even more tick-constrained. The effect on volume (market orders) is negligible because of two strong opposite forces: the new wider quoted spread makes the execution of market orders more expensive and reduces the incentive for traders to choose market orders; the longer queue at the new quoted spread reduces the execution probability of limit orders and decreases the incentive for traders to use limit orders. The stronger is the effect of the longer queue at the new quoted spread, the greater will be the incentive for traders to choose limit as opposed to market orders and the smaller volume will be.

Now consider a stock that had an equilibrium spread that was wider than the minimum spread implied by the new larger tick size, i.e., the stock was unconstrained before the tick size increase. 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 there is a small decrease in volume.

A similar prediction is made by Foucault, Kadan and Kandel (2005), who model a limit order market and 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."

For a stock of average liquidity Goettler, Parlour and Rajan (2005) find that following an increase in the tick size the execution probabilities of limit orders increase because the reduced cost of undercutting outweighs the increased costs of queueing and traders switch from the more expensive market orders to limit orders. As a result, depth increases and volume tends to decrease. However, the 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.

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.

Considering these results in conjunction we can now draw our empirical predictions on quote quality and trading activity both for a stock with average liquidity, and for liquid and illiquid stocks.

For stocks with average liquidity we draw the following predictions:

P1: *The U.S. tick size pilot will on average cause a widening of the quoted spread, an increase in BBO depth, and a small reduction in volume.*

P2: *The U.S. tick size pilot will cause an increase in average trade size as institutions engage less in order splitting.*

For tick-constrained and unconstrained stocks respectively, we draw the following predictions

P3a: *For tick-constrained stocks, the U.S. tick size pilot will cause a widening of the quoted spread, an increase in BBO depth, and a negligible effect on volume.*

P3b: *For unconstrained stocks, the U.S. tick size pilot may cause a narrowing of quoted spread, and will cause an increase in BBO depth, and a small reduction in volume.*

The benefits and costs of a smaller tick size have also been studied in theoretical models of intermediated markets. Anshuman and Kalay (1998) model 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 predictions regarding liquidity provision and price discovery:

P4a: *The U.S. tick size pilot may improve the profitability of liquidity provision.*

P4b: *The U.S. tick size pilot may speed up price discovery.*

P4c: *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 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.[9]

The lists of control group and test group sample stocks are drawn from FINRA's website[10] and we include all securities 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

[9] 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).
[10] hiip://www.finra.org/industry/oats/tick-size-pilot-data-collection-securities-files

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.[11] 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.

We compute a battery of daily quote quality, trading activity, and liquidity provision and price impact 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 in cents and in percent of the midquote
- share-weighted effective spread in cents and in percent of the midquote
- time-weighted depth in shares and dollars
- square root of realized volatility of returns based on midquote-updates and on midquotes sampled at five minute intervals

where quote information 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 marketable orders are classified as buys and -1 for sells following the Lee and

[11] See also Hagströmer (2017) for suggested TRTH data matching and screening procedures for U.S. stocks.

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 measured in shares and dollars
- average trade size defined as consolidated volume excluding open and close 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 inference, we also calculate the logarithm of each of these variables. 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 in cents and in percent of the midquote at the time of the trade
- price impact at horizon τ in cents and in percent of the midquote at the time of the trade

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. Furthermore, quote quality and trading activity are well matched for stocks in control and test groups..

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. [12] We cluster standard errors by firm and day.

As emphasized by Boehmer et al. (2017), 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 β_4. β_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.

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).

A significant β_4 in equations (1) or (2) motivates further investigation into whether the effect of the treatment on control stocks is likely the result of a change in fundamental factors that especially affects eligible stocks, or if it is likely the result of a spillover from the experiment itself. In an attempt to control for a change in unobserved fundamental factors, we define samples of stocks that are very similar to control stocks along the price, share volume, and size dimensions, and run the following difference-in-difference panel regression on the combined sample of boundary and control stocks (or holdout and control stocks):

$$MQ_{i,t} = \gamma_0 + \gamma_1 \cdot f_i + \gamma_2 \cdot Event + \gamma_3 \cdot S \cdot Event + \gamma_4 \cdot X_t + \mu_{i,t}, \quad (3)$$

[12] Our results are virtually identical if we omit the market-wide control variable VIX. Analyses based on a specification using firm fixed effects, dropping the G1, G2, and G3 dummies, are discussed in the robustness section.

where f_i are stock fixed effects and *S* designates similar stocks. γ_2 captures the indirect effect of the pilot experiment on control stocks. If similar stocks are affected the same way as control stocks, we expect to find that $\gamma_3 = 0$. By contrast, if the tick size pilot did not affect similar stocks at all, we expect to find that $\gamma_2 + \gamma_3 = 0$.

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:

$$MQ_{g,t} = \beta_0 + \beta_1 \cdot G1 + \beta_2 \cdot G2 + \beta_3 \cdot G3 + \beta_4 \cdot Event + \beta_5 \cdot G1 \cdot Event + \beta_6 \cdot G2 \cdot Event + \beta_7 \cdot G3 \cdot Event + \beta_8 \cdot X_t + \varepsilon_{g,t}, \quad (4)$$

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:

$$MQ_{g,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{g,t}. \quad (5)$$

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 (P1 and P2)

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 reports 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 31, 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.[13]

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.

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 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%. In subsection 5.5 below, we use two samples of similar stocks that were not part of the tick size pilot to test whether these observed changes in market quality are unique 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, depending on the test group, 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 relative to control stocks. These changes are again economically significant. Consider G2 stocks for example. These stocks experience a 16% (46%) increase in quoted (effective) spread, a 293% increase in depth, an 8% increase in mid-quote volatility, and an 8% increase in trade size relative to controls. 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

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

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 the panel regressions for the logarithm of the skewed variables (depth, volume, and average trade size) have higher *R*-squares (within) and Wald statistics, and that 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 percent.

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.

[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 dollar 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) relative to stocks subject only to the quote rule. 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 dollar quoted spreads, a significant decline in dollar effective spreads (-0.28 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) relative to stocks subject only to the quote rule. 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 to screen 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. 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 changes in volume between control and test stocks regardless of which rule(s) 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 Control Stock Effects: Fundamental Factors or Spillovers?

The changes we observe for control stocks could in principle either be the result of a change to one or several unobserved fundamental factors or the result of spillovers from the treatment. To discriminate between these two explanations, we create two samples of stocks that are similar to control stocks but that were not part of the tick size pilot program. These stocks should in principle have been affected by the same fundamental factors as control stocks. Therefore, if we observe that market quality changes significantly for control stocks relative to similar stocks, the effects we discussed above for control stocks are a likely the result of spillovers from the treatment.

The first group of similar stocks are defined as stocks in CRSP with share code 10 or 11 that are listed on either NYSE or Nasdaq and were never part of the U.S. tick size pilot, and have either: (BP) a stock price between $1.50 and $2.00 and market capitalization less than or equal to $3bn on August 31, 2016, and an average daily share volume less than or equal to 1mn shares for the month of August, 2016; (BS) a stock price of at least $2.00 and market capitalization between $3bn and $6bn on August 31, 2016, and an average daily share volume less than or equal to 1mn shares for the month of August, 2016; or (BV) a stock price of at least $2.00 and market capitalization less than or equal to $3bn on August 31, 2016, and an average daily share volume between 1mn and 2mn shares for the month of August, 2016. There are 33 stocks in the BP sample, 25 stocks in the BS sample, and 32 stocks in the BV sample, for a total of 90 stocks.[14] We call this group boundary stocks.

To improve the matching of boundary stock to control stocks, we define a subset of control stocks that are close to each boundary (price, share volume, and size), following the same procedure as we described above for boundary stocks. Specifically, starting from the matched CRSP-pilot stock sample, we select: (CP) the 100 control stocks with prices closest to $2.00 on August 31, 2016, (CS) the 100 control stocks with market capitalization closest to $3bn on August 31, 2016, and (CV) the 100 control stocks with average daily volume for the month of August, 2016, closest to 1mn shares. We then take all stocks in each group that pass our other sample screens described above, leaving us with 45 stocks in the CP, 50 stocks in the CS, and 42 stocks in the CV sample respectively for a total of 137 control stocks at the boundary.

The second group of similar stocks are defined as stocks that were originally on the SEC list of eligible securities (flagged as 'C'), that had a closing price of at least $2 and market capitalization of no more than $3bn as of August 31, 2016, and a daily average share volume for the month of August 2016 of no more than 1mn shares, but were dropped from the set of securities on September 6, 2016, as the SEC imposed its full set of eligibility criteria.[15] We call this group holdout stocks. We find 68 stocks in the holdout sample that are listed on NYSE or Nasdaq and that have CRSP share code 10 or 11.[16] Finally, we create a propensity-matched sample of control stocks that are matched to holdout stocks based on closing price and size as of August 31, 2016, and average daily share volume for the month of August, 2016.

Table 6 summarizes the descriptive statistics for control stocks, control stocks at the boundary, propensity-matched control stocks, boundary stocks and holdout stocks. As expected, boundary stocks are

[14] We lose four tickers, HMPR and SNTA from the boundary price sample, and LSXMA and LVNTA from boundary size sample because of mergers, and name/ticker changes.
[15] The SEC used additional criteria such as volume-weighted average price, and daily closing prices, and a three-month measurement period, to identify pilot program stocks.
[16] We lose three tickers, KELYB, DRII, and MIFI due to mergers and name/ticker changes.

larger and more liquid than the overall sample of control stocks. Firm characteristics, quote condition, and trading activity for the subsample of control stocks at the boundary are more similar to the boundary stocks. Finally, firm characteristics, quote conditions, and trading activity for holdout stocks match those for control stocks reasonably well, but as expected the match is improved using propensity-score matching.

[Insert Table 6 here]

We run panel difference-in-difference regressions based on equation (3) to evaluate changes in market quality and trading activity for boundary stocks relative to either the entire sample of control stocks (Table 7 Panel A) or a subsample of control stocks that are close to each boundary (Table 7 Panel B), and for holdout stocks relative to the entire sample of control stocks (Table 7 Panel C), and for holdout stocks relative to a propensity-matched sample of control stocks (Table 7 Panel D).

[Insert Tables 7 here]

As expected, the coefficients on the *Event* dummy in Table 7 Panel A are very close to those reported in Tables 3 and 4. The slight difference is the result of including firm fixed effects in Table 7. The coefficients on the interaction term *B*Event* are all negative and significant, showing that spreads and depth fell for boundary stocks relative to control stocks. The same is true for our volume measures and price. By contrast, boundary stocks experienced an even larger increase in average trade size than control stocks.

The negative interaction terms beg the question, did boundary stocks experienced a significant change in market quality? This is captured by the total effect, or the sum of the coefficients ($\gamma_2 + \gamma_3$). The total effect is positive for quoted spread, corresponding to an increase of 7% compared to the pre-event mean in Table 6, which is small compared to the increase in quoted spread for control stocks of 22%. The total effect on effective spread is essentially zero. The total effect is *negative* and economically small for log depth, and log dollar depth. By comparison, log depth and log dollar depth *increase* modestly for control stocks. The total effect on boundary stock log volume and log dollar volume and price is positive but the magnitude of the increase is less than half of the effect we observe for control stocks. Finally, the total effect on boundary stock trade size measures is positive, but again the economic magnitude is economically small.

We repeat the analysis in Table 7 Panel B using the subset of control stocks that are close to the boundary. The coefficients on the *Event* dummy are generally smaller for this sample, but relative to the pre-event means in Table 6, the economic magnitude of the changes is still large for several of the measures. The results show that quoted spread, effective spread, and log depth decreased significantly for boundary stocks relative to controls stocks at the boundary. Boundary stock log volume in shares declines significantly, while boundary stock log dollar average trade size and price increase significantly, relative to

control stocks at the boundary. The conclusions we draw from comparing the economic magnitude of total effect on market quality (the sum of the coefficients $(\gamma_2 + \gamma_3)$ in Table 7 Panel B) relative to pre-event means (Table 6) for boundary stocks compared to control stocks at the boundary are qualitatively unchanged compared to those discussed above for Table 7 Panel A.

We run panel difference-in-difference regressions combining control stocks and holdout stocks in Table 7 Panel C. The results show that quoted spread, effective spreads and depth declined significantly for holdout stocks relative to controls. The coefficients on the interaction term H**Event* is about twice as large as the coefficient on the *Event* dummy for the spread regressions, and unreported tests show that the total effect $(\gamma_2 + \gamma_3)$ is negative and significant for all quote quality measures. The results for trading activity are similar to those in the other panels, the increase in volume for holdout stocks is roughly half that for control stocks while trade size increases more for holdout stocks than for control stocks. Holdout stock prices decline significantly relative to control stocks, and the total effect is negative and significant.

The last panel of Table 7 (Panel D) repeats the analysis comparing holdout stocks to propensity matched control stocks. While the magnitude of the coefficients on the event dummy is smaller for the quote quality regressions in Panel D compared to Panel C, the general pattern is the same as in the previous panels. Specifically, spread and depth measures increase significantly for propensity-matched control stocks following the phase-in of the pilot, but holdout stocks instead experience a significant decline in quoted spread and depth measures. The trading activity regressions also confirm our previous findings: holdout stocks experience a dampened effect on volume whereas the effect on average trade size is amplified for holdout stocks compared to propensity-matched control stocks.

5.6 Discussion

The overall results confirm hypothesis **P1** (Goettler et al., 2005; Werner et al., 2019), which predicts that a tick size increase on average causes a widening of spreads, an increase in depth, and a small reduction in consolidated volume as traders switch from market to limit orders. In independent contemporaneous work, Griffith and Roseman (2018) 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 **P3a** and **P3b** 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. (2018), Hansen et al., (2017), and Lin et al. (2018) 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 **P2** (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. Our results suggest 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).

We document significant changes in market quality for control stocks, and use two samples of stocks which are very similar to control stocks (boundary stocks and holdout stocks) to evaluate if these changes are likely due to a shift in one or more fundamental factors or a spillover from the pilot experiment. The results suggest that the effects on the quote quality was largely caused by a spillover from the tick size experiment similar to a "placebo" effect. Boundary (holdout) stocks experience an economically small increase (large decrease) in quoted spread and significant decrease in depth, while effective spreads do not change significantly (decline significantly). By contrast, spreads widen and depth increases significantly for control stocks, suggesting that the displayed quotes became less competitive. Furthermore, our results suggest that about half the effect on volume for control stocks appears to be driven by one or more fundamental factors, while the average trade size increase is dampened for control stocks relative to boundary and holdout samples.

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.[17] 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 (P3)

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.[18]

[Insert Table 8 here]

We report descriptive statistics for tick-constrained and unconstrained stocks in each sample group (C, G1, G2, and G3) in Table 8. Roughly half the stocks in the overall sample are tick-constrained based on our definition, while the group of unconstrained stocks comprises about a quarter of the sample. 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. 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

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

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 9. 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 relative to controls 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.[19]

[Insert Table 9 here]

The estimated coefficients in Table 9 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, these changes correspond to a 112% increase in the quoted spread compared to the pre-period spread for tick-constrained G2 stocks, and a 12% decrease in spreads compared to the pre-period spread for

[19] Share estimates in this section come from the un-tabulated panel regressions based on the raw share volume numbers, and are available from the authors on request.

unconstrained G2 stocks. Effective spreads also increase by 2.31 cents for tick-constrained test stocks relative to control stocks, an increase of 128%compared to the pre-period for G2 stocks. There is also a small increase in effective spreads of 0.7% 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, tick-constrained G2 stocks experience an incremental increase in share depth of 326% while unconstrained G2 experience an incremental increase in share depth of 82%. The last set of columns in Table 9 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 relative to controls.

In terms of trading activity, Table 9 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 incremental increases in average trade size by 12% and 6% compared to the pre-event levels for tick-constrained and unconstrained G2 test stocks respectively.

The estimates in Table 9 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 an incremental 0.108 (1,134) logshares (shares). By contrast, the trade rule is associated with a significant incremental 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 the trade-at rule is associated with a further increase in volatility both for tick-constrained and unconstrained stocks.

Table 9 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, but volume increases significantly by 0.055 (24,147)

logshares (shares) for tick-constrained stocks subject to the trade-at rule relative to controls. For unconstrained test stocks relative to controls, the trade rule is associated with no significant change in either volume or trade size, while the trade-at rule 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 suggests 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 10.

[Insert Table 10 here]

The results based on the more conservative estimation method show 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 9 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 average trade size 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 **P3a** and **P3b** (Foucault, Kadan and Kandel, 2005; Werner et al., 2019). Specifically, quoted spreads widen for tick-constrained test stocks while quoted spreads narrow 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. 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 have a negligible effect according to **P3a**. 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 confirmed. This is in contrast to the findings by Griffith and Roseman (2018) and 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. (2018) 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.

7. Liquidity Provision and Price Discovery (P4)

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 11, 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 11 here]

7.1 Panel Difference-in-Difference Analysis: Rules

We report the overall results from panel regressions based on equation (2) in Table 12. 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% to 42% for G2 stocks (Table 11 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% at the 30-second horizon to 17% at the five-minute horizon.

[Insert Table 12 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 11 Panel IB), these numbers correspond to an increase of 52% to 47%. 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.

The coefficients on the *Event* dummy which captures the effect on control stocks both in Panels A and B of Table 12 are statistically significant, albeit economically small relative to the total effect for test stocks. Realized spreads increase by 0.12 cents declining to 0.07 cents, translating to an increase in potential profits by 7% to 5% relative to pre-event means. Price impacts also increase significantly for control stocks following the pilot, and the effect is about one-third of the one for stocks subject to the quote rule. We

evaluate whether these change in realized spreads and price impacts at the five minute horizon for boundary stocks relative to control stocks and relative to control stocks close to the boundary, and for holdout stocks relative to controls stocks and for holdout stocks relative to propensity-matched controls, respectively, in Table 13. The event dummy is positive while the coefficient on the interaction term in the realized spread regressions is insignificant for boundary stocks, suggesting that the rewards for liquidity provision increased also for boundary stocks. By contrast, there was a significant, albeit economically small, decrease in price impact for boundary stocks relative to control stocks. Realized spreads decline significantly for holdout stocks relative to control stocks whether or not we use propensity matching, while the results for price impact disappear if we use propensity matching.

[Insert Table 13 here]

For completeness, in Table 14 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 and 1.86 times the pre-event realized spreads for G2 stocks (Table 11 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% to -42%.[20]

[Insert Table 14 here]

Table 14 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% to 131% for the 30-second

[20] 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.

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* in price impacts for tick-constrained stocks. In both cases, the economic magnitude is small relative to the levels of pre-event price impacts.[21]

7.2 Market Maker Profits

While commonly used as a proxy for market maker profits, short-term realized spreads only capture the potential for higher 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.[22] We download the monthly data sets for April 2016 through 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, de-listings, 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.

[21] 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.

[22] hiip://www.finra.org/industry/appendix-c-data-publication.

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 but 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.[23]

[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); $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 **P4a** (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.[24] Griffith and Roseman (2018) 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

[23] 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.
[24] While quoted spreads for unconstrained stocks decline significantly as shown in Tables 7 and 8, effective spread for unconstrained stocks widen significantly.

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 **P4b** (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.

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 a 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 **P4c** (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 show 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.

8. Robustness Tests

We conduct a number of tests to check that our findings are robust to the choice of methodology, sample period, variable definitions, and definition of tick-constrained vs. unconstrained stocks. The detailed results for these robustness tests are reported in the Internet Appendix (IA), but we summarize the main findings in this section.

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 reported in the IA are virtually identical to those we present in the paper with this alternative specification.

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, from our main analysis. However, as shown in the IA, our results are robust to including the week immediately preceding the start of the pilot. Moreover, 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 the week of the Presidential election, November 9-15, 2016, in the IA and find that our results are qualitatively unchanged.

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 our analyses defining tick-constrained (unconstrained) stocks as those with pre-event quoted spreads in the lowest quartile (highest quartile), and the results in the IA show 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) in the IA. The only notable difference is that, with this definition, we no longer find quoted and effective spreads to decline significantly for unconstrained stocks. Finally, our tables

with tick-constrained and unconstrained stocks omit the group of stocks with a pre-event quoted spreads between 5 and 10 cents. For completeness, the IA reports the results for the omitted group.

For completeness, we report the results for our tests comparing each subsample of boundary stocks (price, size, trading volume) separately to control stocks and control stocks close to the boundary in the IA. The results are generally qualitatively the same for each subsample as those discussed above for the combined sample of boundary stocks. We also report the results for percent spreads, and measures for depth, volume, and average trade size without taking logs in the IA. Again, the results are noisier but qualitatively unchanged.

Finally, 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 results reported in the IA show that 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 primary listing. However, while we find 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 five cents 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.

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 when, in addition, all trades are required 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, 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 the most illiquid unconstrained stocks.

Finally, we document significant changes in quote quality, trading activity, the rewards for liquidity provision, and price discovery also for control stocks. Quoted and effective spreads, depth, volatility, volume and average trade size all increase significantly for control stocks even though there was no change in the tick size for these stocks. This could be caused either by a change in one or more unobservable fundamental factor, or by spillovers from the tick size pilot to control stocks. Such spillovers may occur if the pilot attracts liquidity providers away from control stocks, and if the resulting reduced competition causes spreads and profits to increase also for stocks that continue trading in decimals. Based on analyzing two samples of stocks that are similar to control stocks, but were not ultimately part of the tick size pilot program, we conclude that the changes in the spreads and depth for control stocks to a large extent can be explained by spillovers from the treatment, whereas the increase in volume and average trade size appear mainly to be a response to a segment-wide fundamental factor.

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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 were moved from a test group to the control group during the pilot due to low stock price.

II. Stocks that changed symbols during the pilot.

III. Stocks that during the Pilot changed exchange listing.

IV. Preferred stocks.

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

VI. 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.

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

Stocks	Nasdaq	NYSE	Total	Percent
Eligible common stocks*	1,567	679	2,246	100.00%
Rule I	2	0	2	0.09%
Rule II	11	3	14	0.62%
Rule III	2	2	4	0.18%
Rule IV	0	11	11	0.49%
Rule V	4	4	8	0.36%
Rule VI	166	5	171	7.61%
Rule VII	0	2	2	0.09%
Final Sample	1,382	652	2,034	90.56%

*Eligible stocks in the pilot on 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 below 1% and above 99%.

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 drop the following days around the introduction of the pilot: September 26, 2016 – October 28, 2016.
- We drop 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 drop November 28, 2016 for symbols NRCIA and PBIP.
- We drop December 19, 20, and 21, 2016 for symbol DTLK.

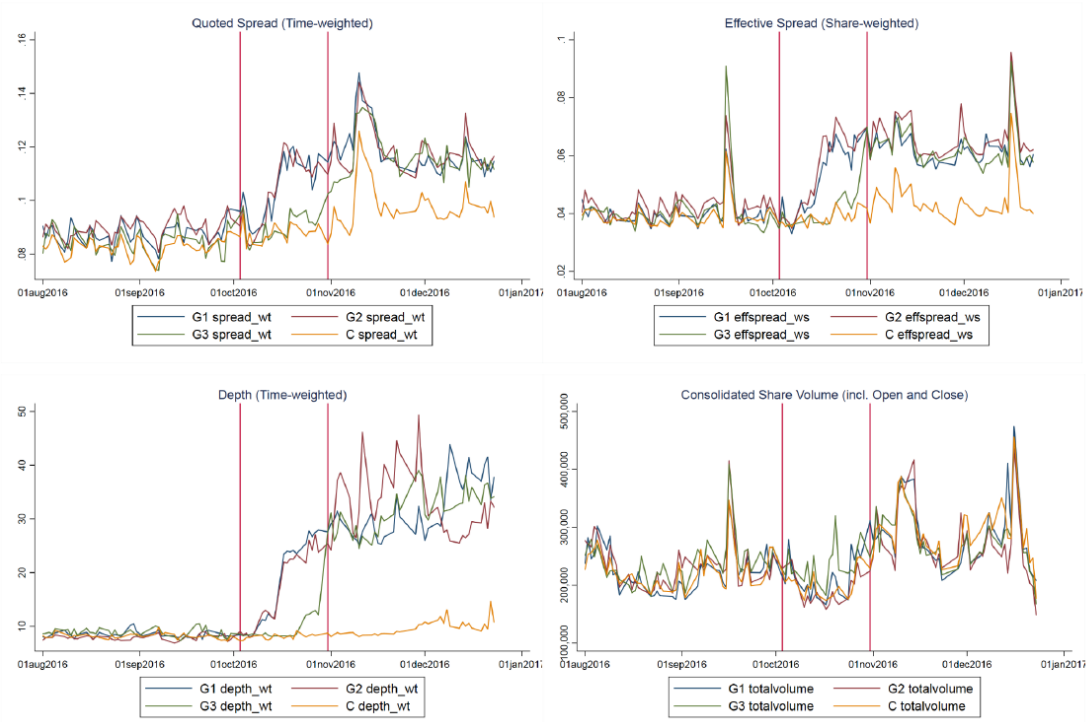
NYSE sample:

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

Appendix C: Variable Definitions

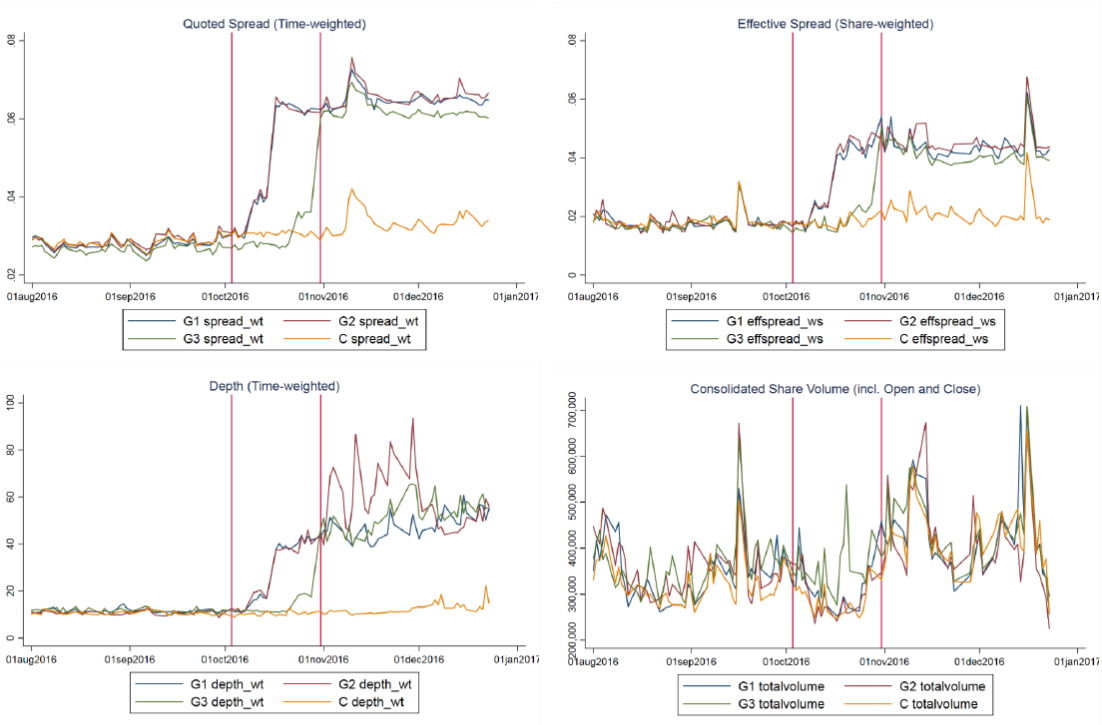
Variable Name	Units	Definition	Notes
Midquote$_t$	Dollars	$(ask_i + bid_i)/2$	i is either quote update time, clock time, or trade time
Buy	+1/-1	Buy indicator, for definition see Lee and Ready (1991) & Ellis et al. (2000)	
Quoted Spread	Dollars & percent of midquote	$\sum_{n=1}^{N} tw_n(ask_n - bid_n)$	time-weighted, N is quote updates
Effective Spread	Dollars & percent of midquote	$\sum_{t=1}^{T} sw_t \cdot 2 \cdot Buy_t \cdot (price_t - midquote_t)$	share-weighted, T is trades
Depth	shares & dollars	$\sum_{n=1}^{N} tw_n(asksize_n + bidsize_n)$	time-weighted, N is quote updates
Return	Percent	$R_{i,i+j} = \log(midquote_{i+j}) - \log(midquote_i)$	i is either quote update time or clock time
Volatility	Percent	$\sqrt{\sum_{n=1}^{N} (\mathrm{R}_{n,n+1})^2}$	N is quote updates
Volatility$_{5min}$	Percent	$\sqrt{\sum_{l=1}^{L} (\mathrm{R}_{l,l+5min})^2}$	L is number of 5 minute intervals
Volume	shares and dollars	$open + close + \sum_{t=1}^{T} size_t$	T is trades
Average Trade Size	shares & dollars	$(1/T)\sum_{t=1}^{T} size_t$	T is trades
Price	Dollars	$\sum_{t=1}^{T} sw_t \cdot price_t$	share-weighted, T is trades
Realized Spread$_\tau$	dollars & percent of midquote	$\sum_{t=1}^{T} sw_t \cdot Buy_t \cdot 2 \cdot (price_t - midquote_{t+\tau})$	share-weighted, T is trades, τ is the horizon
Price Impact$_\tau$	dollars & percent of midquote	$\sum_{t=1}^{T} sw_t \cdot Buy_t \cdot (midquote_{t+\tau} - midquote_t)$	share-weighted, T is trades, τ is the horizon

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



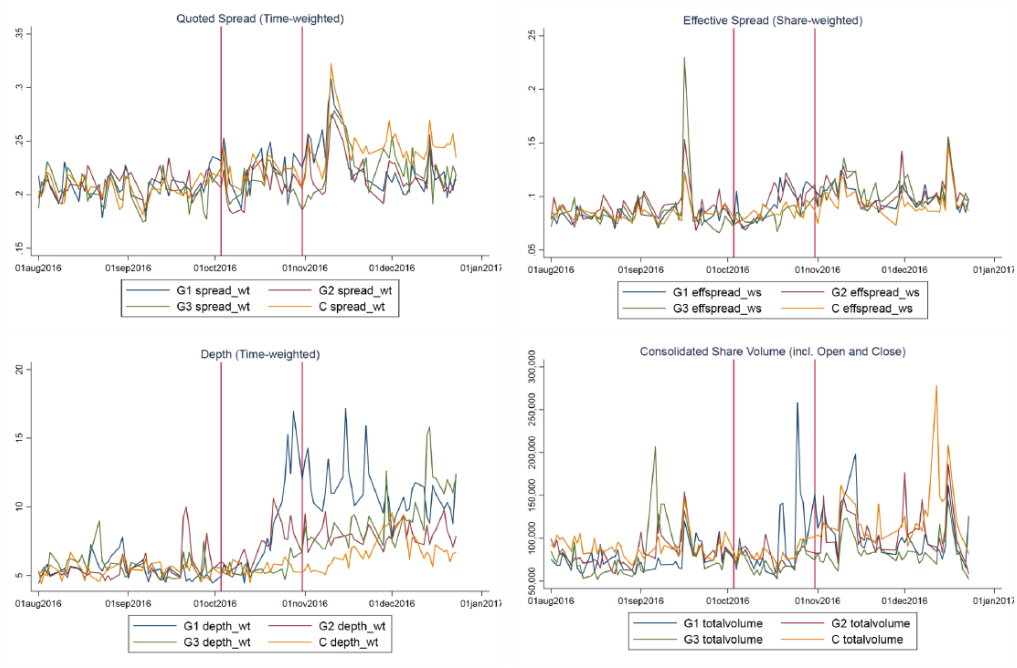
This figure plots the daily average market quality measures clock-wise from the upper left hand corner: time-weighted quoted spread, share-weighted effective spread, depth, and consolidated share volume including open and close for control stocks C and for test groups G1, G2, and G3 respectively. The 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)



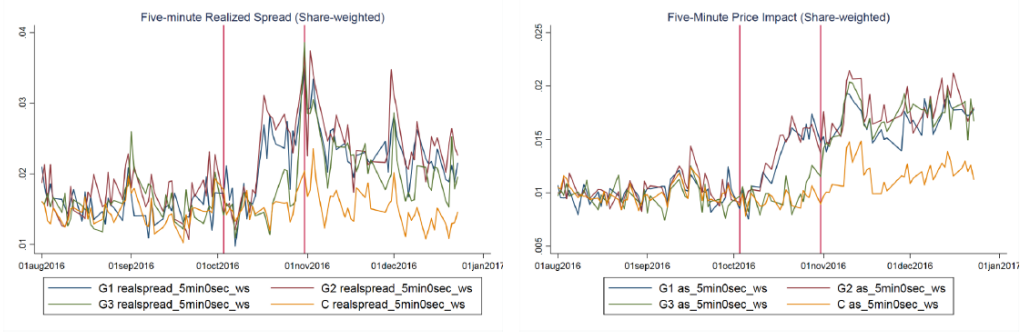
This figure plots the daily average market quality measures for tick-constrained stocks clock-wise from the upper left hand corner: time-weighted quoted spread, share-weighted effective spread, depth, and consolidated share volume including open and close for control stocks C and for test groups G1, 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)



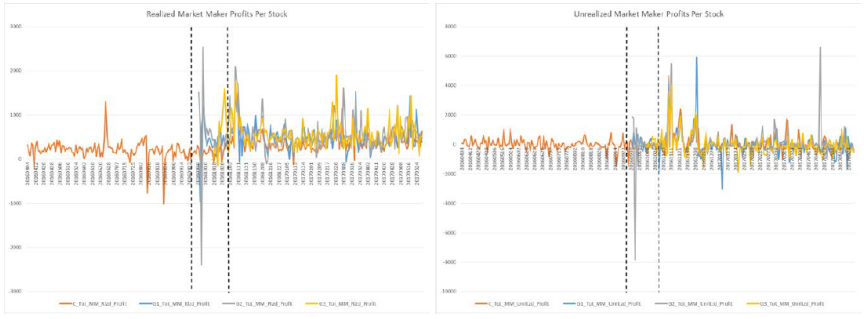
This figure plots the daily average market quality measures for unconstrained stocks clock-wise from the upper left hand corner: time-weighted quoted spread, share-weighted effective spread, depth, and consolidated share volume including open and close for control stocks C and for test groups G1, G2, 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.

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 the square root of the realized variance of midquote returns. 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	Post-Pre	*t*-stat	Z-value	Mean	Mean	Post-Pre	*t*-stat	Z-value	Mean	Mean	Post-Pre	*t*-stat	Z-value	Mean	Mean	Post-Pre	*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	22.75	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 the square root of the realized variance of midquote returns. 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:

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

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. 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 TRTH. Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars and in percent of the midquote, Depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares and in dollars, and Volatility is the square root of the realized variance of midquote returns. Volume is consolidated volume including open and close measured in shares and in dollars while Average Trade Size is based on continuous trading only and is measured in shares and dollars. Price is the average daily share-weighted stock price in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. The estimated coefficients for the group dummies are suppressed to conserve space. 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:

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

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 TRTH. Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars and in percent of the midquote, Depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares and in dollars, and Volatility is the square root of the realized variance of midquote returns. Volume is consolidated volume including open and close measured in shares and in dollars while Average Trade Size is based on continuous trading only and is measured in shares and dollars. Price is the average daily share-weighted stock price in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. The estimated coefficients for the group dummies are suppressed to conserve space. 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 TRTH. Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars and in percent of the midquote, Depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares and in dollars, and Volatility is the square root of the realized variance of midquote returns. Volume is consolidated volume including open and close measured in shares and in dollars while Average Trade Size is based on continuous trading only and is measured in shares and dollars. Price is the average daily share-weighted stock price in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. The estimated coefficients for the group dummies are suppressed to conserve space. 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 for Boundary and Holdout Stocks

		Control Stocks		Controls at Boundary		Controls Propensity Matched to Holdout		Boundary Stocks		Holdout Stocks	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A. Firm Characteristics											
Market Capitalization	('000 dollar)	758,261	735,121	1,364,071	1,139,519	904,863	783,793	1,970,299	2,177,299	911,236	900,589
Price	(dollar)	22.55	20.85	27.58	27.56	14.72	11.66	29.07	41.80	14.64	14.45
Nfirms		1,013		137		69		90		69	
B. Quote Quality											
Quoted Spread	(dollar)	0.0826	0.1096	0.0525	0.0626	0.0389	0.0488	0.0405	0.0485	0.0627	0.1840
Effective Spread	(dollar)	0.0388	0.0494	0.0295	0.0344	0.0211	0.0274	0.0157	0.0105	0.0195	0.0454
Depth	(100 shares)	8.28	14.72	11.83	17.74	11.28	12.00	15.08	22.32	8.32	15.94
Volatility	(midquote)	0.0292	0.0223	0.0314	0.0293	0.0285	0.0204	0.0429	0.0510	0.0501	0.0660
C. Trading Activity											
Volume	(shares)	221,510	367,893	469,846	632,223	346,501	461,577	830,038	1,592,614	562,603	797,872
Average Trade Size	(shares)	133.66	259.04	158.85	127.56	144.28	71.66	237.70	176.83	200.74	665.48
Nobs		38,499		5,219		2,590		3,474		2,713	

This table summarizes descriptive statistics for the U.S. tick size pilot sample, boundary and holdout stocks based on data from the period August 1 – September 23, 2016. Control stocks are those that will continue being quoted and traded in decimals, controls at boundary are a subset of control stocks that are closest to the cutoffs for price, market capitalization, and trading volume respectively. Boundary stocks consist of three groups of stocks that were never part of the U.S. tick size pilot: stocks that have stock prices between $1.50 and $2.00 but otherwise satisfy the pilot parameters, stocks with market capitalization between $3bn and $6bn but otherwise satisfy the pilot parameters, and stocks with share volume between 1mn and 2mn but otherwise satisfy the pilot parameters. Holdout stocks are stocks that were eligible according to the price, size, and volume criteria on August 31, 2016, but were eliminated by the SEC in early September 2016. Data was drawn from TRTH, NYSE Trade and Quote (TAQ) data, 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 the square root of the realized variance of midquote returns. Volume is consolidated volume including open and close measured in shares while Average Trade Size is measured during continuous trading only.

Table 7. Changes for Boundary Stocks and Holdout Stocks relative to Control Stocks

	Quote Quality					Trading Activity				
A. Boundary Stocks Relative to Controls	Quoted Spread (dollar)	Effective Spread (dollar)	log Depth (shares)	log Depth (dollar)	Volatility Midquote	log Volume (shares)	log Volume (dollar)	log Average Trade Size (shares)	log Average Trade Size (dollar)	Price (dollar)
Intercept	0.0839 ***	0.0348 ***	1.882 ***	4.747 ***	0.0260 ***	11.690 ***	14.552 ***	4.819 ***	7.528 ***	27.21 ***
	0.0011	0.0008	0.008	0.008	0.0005	0.013	0.013	0.006	0.006	0.06
Event	0.0179 ***	0.0054 ***	0.055 ***	0.083 ***	0.0052 ***	0.293 ***	0.322 ***	0.013 ***	0.041 ***	1.58 ***
	0.0004	0.0003	0.003	0.003	0.0001	0.005	0.005	0.002	0.002	0.02
B*Event	-0.0149 ***	-0.0053 ***	-0.091 ***	-0.117 ***	-0.0018 *	-0.162 ***	-0.188 ***	0.022 ***	0.062 ***	-0.75 ***
	0.0006	0.0004	0.013	0.013	0.0009	0.021	0.022	0.008	0.011	0.13
VIX	-0.0004 ***	0.0001 **	-0.006 ***	-0.017 ***	0.0003 ***	-0.006 ***	-0.017 ***	-0.002 ***	-0.012 ***	-0.29 ***
	0.0001	0.0001	0.001	0.001	0.0000	0.001	0.001	0.000	0.000	0.00
Nobs	82,387	82,386	82,387	82,387	82,387	82,386	82,386	82,386	82,386	82,386
R2 within	0.0216	0.0047	0.0047	0.0168	0.0150	0.045	0.052	0.001	0.013	0.082

	Quote Quality					Trading Activity				
B. Boundary Stocks Relative to Controls Close to Boundary	Quoted Spread (dollar)	Effective Spread (dollar)	log Depth (shares)	log Depth (dollar)	Volatility Midquote	log Volume (shares)	log Volume (dollar)	log Average Trade Size (shares)	log Average Trade Size (dollar)	Price (dollar)
Intercept	0.0466 ***	0.0212 ***	2.076 ***	4.712 ***	0.0318 ***	12.608 ***	15.242 ***	5.054 ***	6.933 ***	32.83 ***
	0.0011	0.0011	0.020	0.019	0.0012	0.033	0.034	0.014	0.016	0.19
Event	0.0078 ***	0.0028 ***	0.022 ***	-0.040 ***	0.0065 ***	0.219 ***	0.156 ***	0.025 ***	-0.040 ***	0.38 ***
	0.0005	0.0006	0.008	0.008	0.0005	0.013	0.013	0.005	0.006	0.08
B*Event	-0.0053 ***	-0.0028 ***	-0.060 ***	0.002	-0.0030 ***	-0.087 ***	-0.025	0.010	0.138 ***	0.44 ***
	0.0007	0.0006	0.015	0.015	0.0010	0.024	0.025	0.009	0.012	0.15
VIX	0.0001	0.0002 ***	-0.004 ***	-0.013 ***	0.0002 ***	-0.006 ***	-0.015 ***	-0.002 **	-0.008 ***	-0.29 ***
	0.0001	0.0001	0.001	0.001	0.0001	0.002	0.002	0.001	0.001	0.01
Nobs	16,610	16,609	16,610	16,610	16,610	16,609	16,609	16,609	16,609	16,609
R2 within	0.0185	0.0033	0.0016	0.0087	0.0096	0.0169	0.0106	0.0026	0.0124	0.0261

Table 7. Changes for Boundary Stocks and Holdout Stocks relative to Control Stocks (continued)

C. Holdout Stocks Relative to Controls	Quote Quality					Trading Activity				
	Quoted Spread (dollar)	Effective Spread (dollar)	log Depth (shares)	log Depth (dollar)	Volatility Midquote	log Volume (shares)	log Volume (dollar)	log Average Trade Size (shares)	log Average Trade Size (dollar)	Price (dollar)
Intercept	0.0860 ***	0.0353 ***	1.862 ***	4.724 ***	0.0260 ***	11.638 ***	14.498 ***	4.809 ***	7.550 ***	25.976 ***
	0.0012	0.0009	0.008	0.008	0.0005	0.013	0.013	0.006	0.006	0.057
Event	0.0179 ***	0.0054 ***	0.055 ***	0.083 ***	0.0052 ***	0.293 ***	0.321 ***	0.013 ***	0.041 ***	1.572 ***
	0.0004	0.0003	0.003	0.003	0.0002	0.005	0.005	0.002	0.002	0.023
H*Event	-0.0347 ***	-0.0096 ***	-0.063 ***	-0.139 ***	-0.0032 **	-0.151 ***	-0.227 ***	0.020 *	0.080 ***	-1.818 ***
	0.0029	0.0012	0.014	0.013	0.0016	0.025	0.026	0.011	0.013	0.058
VIX	-0.0004 ***	0.0002 **	-0.006 ***	-0.017 ***	0.0003 ***	-0.005 ***	-0.016 ***	-0.002 **	-0.012 ***	-0.284 ***
	0.0001	0.0001	0.001	0.001	0.0000	0.001	0.001	0.000	0.000	0.004
Nobs	81,328	81,206	81,328	81,328	81,328	81,206	81,206	81,206	81,181	81,206
R2 within	0.0188	0.0046	0.0046	0.0170	0.0127	0.0456	0.0516	0.0008	0.0135	0.0922

D. Holdout Stocks Relative to Propensity Matched Controls	Quote Quality					Trading Activity				
	Quoted Spread (dollar)	Effective Spread (dollar)	log Depth (shares)	log Depth (dollar)	Volatility Midquote	log Volume (shares)	log Volume (dollar)	log Average Trade Size (shares)	log Average Trade Size (dollar)	Price (dollar)
Intercept	0.0536 ***	0.0194 ***	1.999 ***	4.411 ***	0.0354 ***	12.353 ***	14.769 ***	5.040 ***	6.509 ***	17.235 ***
	0.0036	0.0016	0.023	0.023	0.0024	0.041	0.042	0.018	0.022	0.103
Event	0.0075 ***	0.0021 ***	0.029 ***	0.031 ***	0.0051 ***	0.343 ***	0.346 ***	0.020 **	0.020 **	0.938 ***
	0.0008	0.0005	0.011	0.011	0.0005	0.018	0.019	0.007	0.008	0.059
H*Event	-0.0245 ***	-0.0063 ***	-0.037 **	-0.088 ***	-0.0030 *	-0.198 ***	-0.251 ***	0.015	0.098 ***	-1.261 ***
	0.0029	0.0012	0.017	0.017	0.0016	0.030	0.031	0.013	0.015	0.078
VIX	-0.0002	0.0001	-0.007 ***	-0.017 ***	0.0003 *	-0.008 ***	-0.017 ***	-0.004 ***	-0.009 ***	-0.186 ***
	0.0002	0.0001	0.002	0.002	0.0002	0.003	0.003	0.001	0.002	0.007
Nobs	10,345	10,223	10,345	10,345	10,345	10,223	10,223	10,223	10,198	10,223
R2 within	0.0067	0.0031	0.0020	0.0118	0.0028	0.0289	0.0266	0.0023	0.0134	0.0729

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

$$MQ_{i,t} = \gamma_0 + \gamma_1 \cdot f_i + \gamma_2 \cdot Event + \gamma_3 \cdot S \cdot Event + \gamma_4 \cdot X_t + \mu_{i,t}, \qquad (3)$$

where $MQ_{i,t}$ is a market quality measure (quote quality and trading activity) for stock i on day t, f_i are individual firm dummies, *Event* is a dummy that takes on a value of one for days in the post-period, S is the boundary stock (holdout stock) group dummy, 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, boundary stocks, and holdout stocks continue being quoted and traded in decimals. Boundary stocks consist of three groups of stocks: stocks with prices between $1.50 and $2.00 but otherwise satisfy the pilot parameters, stocks with market capitalization between $3bn and $6bn but otherwise satisfy the pilot parameters, and stocks with share volume between 1mn and 2mn but otherwise satisfy the pilot parameters. Holdout stocks are stocks that were eligible according to the price, size, and volume criteria on August 31, 2016, but were eliminated by the SEC in early September 2016. Measures are calculated based on data from TRTH and TAQ data. 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 the square root of the realized variance of midquote returns. Volume is consolidated volume including open and close measured in shares while Average Trade Size based on continuous trading only is measured in shares. Price is the average daily share-weighted stock price in dollars. We report results for Quoted and Effective Spreads in dollars, 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. 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 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 the square root of the realized variance of midquote returns. Volume is consolidated volume including open and close measured in shares while Average Trade Size is based on continuous trading and is measured in shares.

Table 9. Changes in Market Quality for Tick-Constrained and Unconstrained Stocks: Panel Regressions (Rules)

	Quoted Spread		Effective Spread		log Depth				Volatility	
A. Quote Quality	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

	log Volume				log Average Trade Size				Price	
B. Trading Activity	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:

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

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 TRTH. Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars and in percent of the midquote, Depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares and in dollars, and Volatility is the square root of the realized variance of midquote returns. Volume is consolidated volume including open and close measured in shares and in dollars while Average Trade Size is based on continuous trading only and is measured in shares and dollars. Price is the average daily share-weighted stock price in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. The estimated coefficients for the group dummies are suppressed to conserve space. 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 10. Changes in Market Quality for Tick-Constrained and Unconstrained Stocks: Collapsed Panel Regressions (Rules)

	Quoted Spread		Effective Spread		log Depth				Volatility	
A. Quote Quality	Tick Constrained (dollar)	Unconstrained (dollar)	Tick Constrained (dollar)	Unconstrained (dollar)	Tick Constrained (shares)	Tick Constrained (dollar)	Unconstrained (shares)	Unconstrained (dollar)	Tick Constrained midquote	Unconstrained 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

	log Volume				log Average Trade Size				Price	
B. Trading Activity	Tick Constrained (shares)	Tick Constrained (dollar)	Unconstrained (shares)	Unconstrained (dollar)	Tick Constrained (shares)	Tick Constrained (dollar)	Unconstrained (shares)	Unconstrained (dollar)	Tick Constrained (dollar)	Unconstrained (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:

$$MQ_{g,t} = \beta_0 + \beta_1 \cdot Q + \beta_2 \cdot T + \beta_3 \cdot TA + \beta_4 \cdot Event + \beta_5 \cdot Q \cdot Event + \beta_6 \cdot T \cdot Event + \beta_7 \cdot TA \cdot Event + \beta_8 \cdot X_t + \varepsilon_{g,t}, \quad (5)$$

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 TRTH. Quoted Spreads are time-weighted, and Effective Spreads are share-weighted and both are measured in dollars and in percent of the midquote, Depth denotes the time-weighted NBBO depth and is reported in round lots of 100 shares and in dollars, and Volatility is the square root of the realized variance of midquote returns. Volume is consolidated volume including open and close measured in shares and in dollars while Average Trade Size is based on continuous trading only and is measured in shares and dollars. Price is the average daily share-weighted stock price in dollars. Furthermore, we report results for the logarithm of the following skewed variables: Depth, Volume, and Average Trade Size. The estimated coefficients for the group dummies are suppressed to conserve space. 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. 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 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 12. 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:

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

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 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. The estimated coefficients for the rule dummies are suppressed to conserve space. 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 13. Changes in the Realized Spreads and Price Impacts for Boundary Stocks Relative to Control Stocks: Panel Regressions

	Boundary Stocks Relative to Control Stocks		Boundary Stocks Relative to Control Stocks Close to Boundary		Holdout Stocks Relative to Control Stocks		Holdout Stocks Relative to Propensity Matched Control Stocks	
	Realized Spread (dollar)	Price Impact (dollar)	Realized Spread (dollar)	Price Impact (dollar)	Realized Spread (dollar)	Price Impact (dollar)	Realized Spread (dollar)	Price Impact (dollar)
Intercept	0.0106 ***	0.0104 ***	0.0074 ***	0.0058 ***	0.0110 ***	0.0104 ***	0.0098 ***	0.0043 ***
	0.0008	0.0003	0.0012	0.0005	0.0008	0.0003	0.0024	0.0009
Event	0.0009 ***	0.0020 ***	0.0019 ***	0.0003	0.0009 ***	0.0020 ***	0.0014 **	0.0002
	0.0003	0.0001	0.0005	0.0002	0.0003	0.0001	0.0006	0.0003
B*Event	0.0001	-0.0024 ***	-0.0007	-0.0009 ***	-0.0052 **	-0.0020 **	-0.0055 **	-0.0003
	0.0006	0.0003	0.0007	0.0003	0.0023	0.0009	0.0023	0.0009
VIX	0.0002 ***	-0.0001 ***	0.0000	0.0001 **	0.0002 ***	-0.0001 ***	0.0000	0.0000
	0.0001	0.0000	0.0001	0.0000	0.0001	0.0000	0.0002	0.0001
Nobs	82,385	82,385	16,609	16,609	81,205	81,205	10,223	10,223
R2 within	0.0004	0.0038	0.0012	0.0008	0.0005	0.0034	0.0012	0.0001

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

$$MQ_{i,t} = \gamma_0 + \gamma_1 \cdot f_i + \gamma_2 \cdot Event + \gamma_3 \cdot B \cdot Event + \gamma_4 \cdot X_t + \mu_{i,t}, \qquad (3)$$

where $MQ_{i,t}$ is a market quality measure (five-minute realized spreads and price impacts) for stock i on day t, f_i are individual firm dummies, *Event* is a dummy that takes on a value of one for days in the post-period, B is a boundary stock group dummy, 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 and boundary stocks continue being quoted and traded in decimals. Boundary stocks belong to three groups: stocks with prices between $1.50 and $2.00 but otherwise satisfy the pilot parameters, stocks with market capitalization between $3bn and $6bn but otherwise satisfy the pilot parameters, and stocks with share volume between 1mn and 2mn but otherwise satisfy the pilot parameters. Holdout stocks are stocks that were eligible according to the price, size, and volume criteria on August 31, 2016, but were eliminated by the SEC in early September 2016. Measures are calculated based on data from TRTH and TAQ data. Realized Spreads and Price Impacts are share-weighted and measured in dollars. We compute each measure at the five-minute horizon. 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 14. 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 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. The estimated coefficients for the rule dummies are suppressed to conserve space. 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.