Tick Sizes and Market Quality: Revisiting the Tick Size Pilot*

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Abstract

Existing research offers scant guidance regarding how tick size changes affect market quality for all but tick constrained stocks. Using comprehensive depth of book data from MIDAS, we examine both the imposition and conclusion of the tick size pilot (TSP) using quantile and OLS regressions, and perform a more granular analysis of non-tick constrained stocks than is provided in the existing literature. Our results support characterizing a tick size change as a tradeoff between allowing markets to establish equilibrium prices (pricing fidelity) and complexity/undercutting concerns. Our analysis suggests that TSP stocks with fewer than two (more than 15) ticks intra spread generally experience an improvement in liquidity when the tick size is reduced (increased).

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1 Introduction

Tick sizes affect many aspects of financial markets and regulators around the globe are paying increased attention to them. The Securities and Exchange Commission's tick size pilot (TSP) which increased the minimum tick from 1¢ to 5¢ for some stocks provides a prime opportunity to evaluate the effects of a tick size change and numerous studies have used the TSP to do just that (see e.g. Hu, Hughes, Ritter, Vegella, and Zhang (2018), Chung, Lee, and Rösch (2020), Griffith and Roseman (2019), Rindi and Werner (2019), and O'Hara, Saar, and Zhong (2019) among others). Intuitively this literature finds that the larger tick was generally harmful to market quality in stocks that became tick constrained by the larger tick.[1] However, for non-tick constrained stocks, which comprise approximately three-fourths of dollar trading volume, the literature offers almost no consistency regarding the effects of the larger tick.[2]

We view the lack of consistency in the TSP literature for non-tick constrained stock as resulting from existing studies treating all non-tick constrained stocks the same in their empirical analysis. This practice misses an important tradeoff. Tick sizes offer a market quality tradeoff between price fidelity (how accurately realized prices can reflect fundamental values) and complexity/undercutting concerns.[3] Consequently, the same tick size change can impact stocks differently depending on which force plays a bigger role. We use numerous measures of market complexity and document evidence consistent with the notion that the larger tick size led to a simpler trading environment.

For tick and near tick-constrained stocks we expect price fidelity concerns to play a primary role and so a larger tick size may harm market quality by preventing markets from establishing spreads narrow enough to equate liquidity supply with liquidity demand.[4] For stocks with very wide spreads, a larger tick size could improve market quality by mitigating undercutting and complexity concerns. Indeed this pattern is exactly what we observe. For stocks that became tick or near-tick

[1] a stock is tick constrained when it is consistently trading with a quoted spread that equals the minimum tick, thus a stock became tick constrained by the TSP if it had a pre pilot quoted spread of less than 5¢˙ff

[2] This literature is reviewed in depth in Section II.

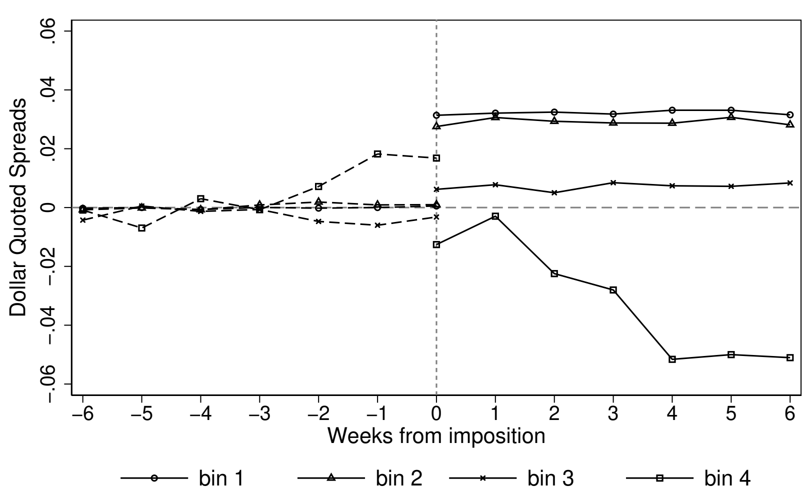
[3] a smaller tick size can increase the complexity associated with both sourcing and providing liquidity by fragmenting liquidity over more price levels and potentially across more venues. Undercutting, referred to as pennying in industry, occurs when a market participant cuts to the front of the limit order queue by posting a quote that, while technically superior to resting quotes, offers economically trivial price improvement. Pennying can harm market quality by making market participants less willing to post displayed liquidity. See e.g. Foley, Dyhrberg, and Svec (2022)

[4] empirically we define near-tick constrained stocks as those that generally trade with between one and two ticks intra-spread

constrained by the 5¢ tick, the TSP harmed market quality across most metrics. For stocks with very wide spreads (i.e., 15¢ or more) the TSP generally improved market quality.

Figure 1 provides a succinct summary of the overall empirical message of this study. This Figure presents the effect of the imposition of the TSP on quoted spreads for four categories of stocks. Tick constrained stocks, near-tick constrained stocks, intermediate-spread stocks, and wide-spread stocks. As is seen clearly, for stocks that became tick or near-tick constrained (bins 1 and 2) by the imposition of a 5¢ tick[5] the larger tick increased quoted spreads by about 3f̂or both bins. For stocks with intermediate spreads (9¢-15¢), a 5¢ tick which rendered approximately 2-3 ticks intra spread, had very little impact on quoted spreads. For stocks with very wide spreads (15¢+) moving from 1¢ to 5¢ narrowed spreads by about 4¢. This pattern reflects the expectation that for stocks with already narrow spreads, an increase in the tick size will harm market quality by making it more difficult for prices to find equilibrium. Additionally, for stocks with very wide spreads, a wider tick helps to mitigate complexity and undercutting concerns leading to better market quality.

Figure 1. Quoted Spread's Response to a Minimum Tick Size Increase.
The figure presents visual evidence of the causal impacts of an exogenous increase in the minimum quoting and trading increment, i.e., an increase from 1¢ to 5¢ in tick size, for deferentially tick-constrained stocks. Stocks are classified into four tick constraint bins based on their average May and June 2016 quoted spreads: bin 1, no more than 4¢; bin 2, 4¢ to 8¢; bin 3, 8¢ to 15¢; and bin 4, greater than 15¢. Each week, median quoted spread is calculated by tick constraint bin for control and pilot stocks after controlling for date fixed effects. The time-series of the difference in medians of control and pilot firms are plotted against weeks from the day of increase in tick size, with 08/12/2016-09/30/2016 and 10/24/2016-12/14/2016 used as pre- and post-event intervals, respectively.



[5] i.e., those with quoted spreads less than 9¢ and thus had fewer than 2 ticks intra spread with a 5¢ tick

Our other results using top of book liquidity measures, such as effective spread, generally follow the pattern presented in Figure 1. For stocks that would become tick or near-tick constrained by a 5¢ tick, i.e., stocks with quoted spreads less than 10¢ imposing the larger tick was generally harmful to market quality; and when the TSP ended market quality generally improved. For stocks with very wide spreads (i.e., 15¢+) a 5¢ tick appeared to offer superior market quality to a 1¢. For intermediate stocks (those with 8¢ to 15¢ spreads) the effects of moving from a 1¢ to a 5¢ or from 5¢ back to 1¢ were not conclusive.

We also examine the effect of the tick size on displayed order book depth at and beyond the NBBO. Consistent with prior studies we find that a wider tick size is associated with increased depth at the NBBO. This finding is consistent with the idea that a wider tick forces quotes that would have spread out onto fewer discrete prices which increases the amount of shares available at a given point. Looking beyond the top of the book, we use comprehensive depth of book data from MIDAS to study the effect of the TSP on cumulative depth beyond the top of book. Our analysis combines the advantages of Griffith and Roseman (2019) and Chung et al. (2020). Griffith and Roseman (2019) study depth all along the order book for TSP and control stocks but only have depth of book data from one exchange. Chung et al. (2020) have depth of book data across all exchanges, but only study depth at one level - within 20¢ or 5% of the NBBO. The two studies disagree as to the effect of the TSP on cumulative depth beyond the NBBO with Chung et al. (2020) finding that cumulative depth increased while Griffith and Roseman (2019) find that depth was unchanged or slightly worse for TSP stocks. Our analysis is more consistent with Chung et al. (2020). We find that that cumulative depth increased with the TSP but that the pattern of the increase was different for tick constrained stocks and those with wide spreads. For stocks that were tick constrained by the 5¢ tick, the increase in cumulative depth was felt deeper in the book, at 25¢ from the NBBO and deeper, while the exact opposite pattern obtains for stocks featuring wide spreads, with most of the increase in cumulative depth occurring closer to the quote midpoints.

An increase in cumulative depth does not necessarily translate directly into a lower cost of trading. Our results are more nuanced than those in prior studies. Like our analysis of cumulative depth, we seek to combine the advantages of both Griffith and Roseman (2019) and Chung et al. (2020) by using comprehensive depth of book data across all exchanges and by studying the effect of the TSP on round trip costs to trade across the spectrum of trade sizes. Two key results characterize our findings. First, for small trades a wider tick size increases the cost to trade for tick constrained stocks but decreases it for stocks with wide spreads. These results are consistent with the fundamental price fidelity versus complexity/undercutting concerns associated with a tick size change. The second result is that for all stocks the effect of a larger tick size becomes more positive (or less negative) as the size of trade considered increases. We find that for trades of 10,000 shares the 5¢ tick was associated with a reduction in the cost to trade for all stocks— even tick constrained. We interpret this finding as consistent with the idea that as trade sizes increase and traders must source liquidity deeper into the book, market complexity and undercutting concerns will play a larger role in order executions. For stocks in between the tick constrained and wide spread spectrum the results are not always clear as the TSP imposition and conclusion analyses sometimes do not agree. We also interpret this result as consistent with the tradeoff because for these stocks the two effects of the tick size change will tend to offset one another. Our analysis adds significant color to the existing literature's analysis of the effect of the TSP on the cost to trade. Chung et al. (2020) document that for tick constrained stocks the TSP increased the cost to execute orders of 500 shares but had no effect on orders of 5,000 shares (findings that we replicate). Their study's findings for non-tick constrained stocks are unclear due to their specific model selection and the fact that they combine all non-tick constrained stocks together into one group for empirical analysis. Griffith and Roseman (2019) who also combine all non-tick constrained stocks into one category find that for trade sizes ranging from 250 shares to 5,000 shares the TSP increased the cost of trading for tick constrained stocks but had no effect on the cost to trade for non-tick constrained stocks.

We also evaluate the effect of the TSP on price efficiency. The existing TSP literature on price efficiency provides results that run the spectrum with some studies showing increases, decreases, or no effect on price efficiency. A wider tick will limit the ability for HFTs to trade on short term price deviations simply because the deviation will need to be greater than the tick size for the HFT to be able to act on it. Consequently, price efficiency measures that use intraday data are likely to find a reduction in price efficiency. Longer term price efficiency measures, such as daily autocorrelation data, are less likely to be affected by HFT behavior and are likely more indicative of the behavior of end investors trading on information. However, it is unclear how a wider tick would affect end investors. Some have argued that because a wider tick inhibits HFT behavior it will be easier to implement a trade for a non-HFT leading to more information acquisition and better price efficiency (Lee and Watts (2021) and Ahmed, Li, and Xu (2020)). Others have argued that, to the extent that a wider tick makes it more expensive to transact (through wider spreads) with will discourage gathering and trading on information (Li and Xia (2021)). The net effect is uncertain. Our price efficiency analysis suggests that intraday measures of price efficiency such as intraday variance ratios and autocorrelations suggest that the larger tick size decreased price efficiency- consistent with it inhibiting HFTs from trading on small price deviations. However, our longer horizon price efficiency results suggest no significant effect on price efficiency.

A natural concern relating to the TSP is its generalizability. The TSP focused on small-cap stocks. Thus, there is a concern that findings from the TSP may not generalize outside of small-cap stocks. We address this concern by exploring the robustness of our findings in various ways. We re-run key analysis on only the top half of TSP stocks in terms of average trading volume, we include a robust set of stock characteristic control variables, we exclude penny stocks, and we estimate quartile regressions at the first and third quartiles. In all of these robustness tests, not only does the pattern of results hold, it generally strengthens. At the lest these findings mitigate concerns that the patterns described are being driven by very small and low volume securities.

We also attempt to more specifically clarify the thresholds in terms of ticks intra-spread where the TSP stocks traded with more liquidity with either a 5¢ or 1¢ tick size. To accomplish this we estimate quantile regressions with rolling bins across the quoted spread spectrum for both the TSP imposition and conclusion and across many market quality measures. This analysis indicates that across most metrics, stocks for which the 5¢ tick size resulted in fewer than 2 ticks intra-spread traded better with the 1¢ tick than the 5¢ tick. Stocks with more than 15 ticks intra-spread with the 1¢ tick traded better with the 5¢ tick size.

In sum, our analysis has numerous advantages over prior studies. We study the effect of the TSP tick size changes across a broad spectrum of stocks with various quoted spread characteristics. Our study also provides an advantage in terms of data relative to most prior studies. We use standard TAQ based measures of market quality, but we also use comprehensive depth of order book data from MIDAS to provide a more complete picture of the impact of a tick size change on market quality across many dimensions. Depth of book information is critical because a tick size change mechanically affects the amount of liquidity at the top of the book and average trade sizes.

Consequently, top of book or trade based measures of market quality may not provide a full picture of the impact of a change in the tick size on market quality.[6]

MIDAS data also allows us to study the impact of the TSP on market complexity in ways prior research has not been able to. For example we study how a tick size change affects the number of exchanges that must be visited in order to execute an order of a given size.[7]

Another advantage of this study is that we study both the imposition and conclusion of the TSP. Doing so increases confidence in our results as we identify clear effects as those that occur upon the imposition of the TSP and reverse upon its conclusion. Given the lack of consensus in the existing empirical literature regarding many of the TSP effects, we view this as a key advantage of our study.

Lastly, our study uses somewhat different methodologies than are employed in prior studies. Most studies rely primarily on some version of OLS regressions, we instead use quantile (median) regressions as our primary research tool. Quantile regressions mitigate the impact of outliers. Outliers are a significant concern in microstructure settings when spread based measures like price impact or realized spread can be dramatically altered by just a few stocks experiencing large price events. When using OLS regressions great care must be used to properly deal with outliers and results can often be dependent on how the researcher chooses to handle outliers. While we use OLS regressions to provide robustness to our main findings, quantile regressions mitigate concerns that our results are outlier driven.

With these advantages, our study is able to provide some much needed clarity to the existing literature studying the effects of the tick size change.

[6]E.g. if trade size decreases and liquidity spreads out over more layers, then effective spread based measures of transaction will mechanically report a decline in effective spread that is due to the smaller trade sizes and is not reflective of how expensive it is to transact a particular dollar amount.

[7]Prior studies by Griffith and Roseman (2019) and Chung et al. (2020) also examine depth of book data—albeit from different source. However both studies bin all non-tick constrained stocks together for empirical analysis and are limited to studying only the TSP imposition. Additionally, as discussed in greater detail in Section 2, the two studies produce conflicting results in key areas.

2 Motivation and Hypotheses Development

2.1 Related Literature

The majority of empirical tick size studies use one of two events: (1) the Securities and Exchange Commission's Tick Size Pilot (TSP) which occurred from 2016-2018 and temprarily increased the tick size from 1¢ to 5¢ for a group of stocks and (2) the process of decimalization which began in the late 1990s when the tick was reduced from $\$\frac{1}{8}$ to $\$\frac{1}{16}$ and ultimately to 1¢. Both events have advantages and disadvantages. The TSP was a recent market experiment but was limited to a set of small-cap stocks whereas the process of decimalization was a broad-based market change, but it occurred over 20 years ago when computerized trading was still in its infancy. Given the dramatic changes in virtually every aspect of financial markets since decimalization we have chosen to rely more heavily on the TSP literature and other more recent studies when reviewing the current state of the tick size literature and deriving hypotheses related to the effect of a tick size change on various aspects of market quality.

For stocks that became tick constrained by the imposition of the 5¢ tick, the existing TSP literature documents across almost all liquidity measures analyzed that the TSP harmed liquidity. All studies document that depth at the top of the book increases with the 5¢ tick, but that this increase in depth is not enough to compensate for the mechanically wider spreads imposed by the 5¢ tick. As such, both quoted and effective spreads increase significantly for tick constrained stocks during the TSP (see e.g. Hu et al. (2018), Rindi and Werner (2019), Penalva and Tapia (2017), Chung et al. (2020), and Griffith and Roseman (2019)). Chung et al. (2020) and Griffith and Roseman (2019) go further in their analysis and also study the effects of the TSP on liquidity deeper in the order book. Both studies report generally harmful effects of the TSP for tick constrained stocks on liquidity deeper in the book—although Chung et al. (2020) find when analyzing liquidity very deep in the book (e.g. 5.000 shares) that the TSP improved liquidity even for tick constrained stocks while Griffith and Roseman (2019) observe the opposite effect.

The relative consistency of results documented in the TSP literature for tick constrained stocks does not extend to non-tick constrained stocks which make up approximately three fourths of total dollar trading volume. For these stocks the literature examining the effects of the TSP on liquidity are quite muddled. Hu et al. (2018) find that for non-tick constrained stocks, increasing the tick size largely had no effect on either quoted or effective spreads. Rindi and Werner (2019) in contrast find that quoted spreads go up but effective spreads go down with the larger tick for non-tick constrained stocks. Chung et al. (2020) find that quoted spreads decrease for non-tick constrained stocks. The confusion extends beyond analysis of trade based or top of book based measures of liquidity. For example, Chung et al. (2020) find that for non-tick constrained stocks the cost of transacting large trades fell with a larger tick. In contrast Griffith and Roseman (2019) use different data and methods to document that for non-tick constrained stocks, increasing the tick size led to either no effect or an increase in the cost of executing a large trade.

The literature is not just muddled regarding the effect of the TSP on standard measures of liquidity for non-tick constrained stocks, it also has produced results running the spectrum in terms of the effect of the TSP on price efficiency. Hu et al. (2018) find for tick constrained stocks price efficiency diminishes and, depending on the measure used, for non-tick constrained stocks price efficiency is either unchanged or declines. Chung et al. (2020) find evidence that pricing efficiency broadly increased. Li and Xia (2021) find evidence that price efficiency was harmed across all stocks and they argue that the mechanism was lower liquidity discouraging investors from gathering information in pilot stocks. In contrast Lee and Watts (2021) and Ahmed et al. (2020) both argue and present empirical evidence supporting the notion that the TSP was a negative shock to high frequency trading which improved information gathering opportunities for fundamental investors—improving price efficiency. Further, Albuquerque, Song, and Yao (2020) document significant pricing effects of the TSP specifically for tick-constrained stocks while Pachare and Rainer (2018) find no such effect.

2.2 The Trade off Between Pricing Fidelity and Complexity/Undercutting

Tick sizes provide an inherent tradeoff between pricing fidelity and concerns relating to market complexity and undercutting. We refer to pricing fidelity as the ability for markets to establish prices that are reflective of the underlying forces of liquidity supply and demand. Perfect pricing fidelity would imply that the bid and ask prices are set such that liquidity supply equals liquidity demand on both sides of the market. For example, demanding liquidity is more expensive but it guarantees an immediate transaction. Providing liquidity is less costly but there is no guarantee of an execution. With perfect pricing fidelity the bid and ask prices would be set such that investors are generally indifferent between providing and demanding liquidity. A tick size that is too wide will lead to spreads that are wider than equilibrium spreads. Spreads that are too wide act as a subsidy to liquidity provision. This subsidy skews the tradeoff between demanding and providing liquidity and leads to an oversupply of liquidity relative to the amount of traders willing to cross the spread and demand liquidity. Thus, when pricing fidelity concerns dominate spreads are wider, queue lengths are longer, and the probability of executing an order via a limit order decrease.

On the other end, a stock that has too many ticks intra-spread can see transaction costs increase due to complexity and undercutting concerns. When there are many ticks intra-spread, liquidity will spread out over many price levels. This makes trading more complexity given the order protection rule in US financial markets. This rule prevents stocks from trading at prices that are not the protected NBBO price. This rule makes sourcing liquidity for larger trades more complex. For example, an order cannot walk the book on one exchange if doing so would trade trough a protected quote on another exchange. For instance if exchange A had 100 shares offered at \$10.00, and 100 shares offered at \$10.02 and exchange B had 100 shares offered at \$10.01, a trader wishing to buy 200 shares could not simply submit a 200 share order to exchange A. If it did so, exchange A would execute 100 shares, and then re-route the remaining 100 shares to exchange B and then charge the trader a re-routing fee that is generally levied on the number of shares re-routed—which increases the cost of the transaction. Alternatively, the trader could submit an order for 100 shares to both exchanges. However, here timing is important. If the order for 100 shares arrives at exchange B before the 100 shares are lifted from Exchange A, then exchange B would need to re-route the order to exchange A. Consequently, the trader would need to time the order such that the first one executes prior to the arrival of the second order. As the number of pricing levels that traders must make trade evaluations across increases, so too does the complexity of these order routing decisions. For liquidity providers, who aim to earn the spread, their quotes can only execute if they are (1) at the protected price and (2) crossed by a marketable order. Consequently, as the number of pricing levels increases, so too does the complexity and cost associated with providing liquidity.

Related to complexity is undercutting. Undercutting occurs when a liquidity provider gets to the front of the queue by submitting a limit order that, while technically superior to existing orders, offers economically trivial price improvement. Undercutting increases the cost of providing liquidity because it makes it easier for very fast and sophisticated high frequency traders to cut to the front of the queue if they receive signals that prices are likely to change. Undercutting makes liquidity providers less likely to display liquidity because it can increase the likelihood of a fill. For example, if an HFT does not know that there is a hidden order at a superior price and they attempt to undercut they may not do so by enough to beat the price of the hidden order, and thus when a marketable order arrives it will execute against the hidden order. Hidden orders are not costless, posting hidden orders is more expensive than displayed orders in terms of exchange fees, and a hidden order may decrease the likelihood that an exchange is at the NBBO and so receives an order. Edwards, Hughes, Ritter, Vegella, and Zhang (2021) document numerous negative market quality affects associated with an increased use of hidden orders. Undercutting can also increase adverse selection costs for displayed orders. For instance, if a slower liquidity provider has a trade execute, it could be simply because the faster liquidity provider received a signal that prices were going to move against the posted quote and so they chose not to undercut—a behavior akin to sniping (Li, Wang, and Ye (2021)).

Consistent with this tradeoff, Harris (1994) argues that whenever the tick size constrains the bid-ask spread to a level greater than what it otherwise be, there will be an oversupply of liquidity relative to the amount demanded at that price and a smaller tick would allow spreads to close in on the narrower latent spread.The previously mentioned TSP literature that demonstrating the largely negative effects of the TSP on stocks that became tick constrained by the 5¢ spread are consistent with the notion that for tick constrained stocks pricing fidelity effects will play a predominate role.

There are also three recent studies providing evidence of the negative effects of undercutting. Foley et al. (2022) study a crypto-currency exchange with effectively no tick-size and document substantial improvements to liquidity provision following the imposition of a minimum pricing level. The authors credit these improvements to the tick size making undercutting behavior more costly and thus encouraging liquidity provision. Foley, Meling, and Ødegaard (2021) examines a 2009 "tick size war" in Scandinavian markets where some exchanges undercut the larger primary exchanges with a smaller tick size. They document evidence of undercutting behavior on the exchanges offering smaller ticks. O'Hara et al. (2019) explore explicitly the adverse selection costs associated with various tick sizes. They focus on relative tick sizes, i.e., the tick size relative to the price, and show, using a unique NYSE data set, that the risk of having a high frequency market maker with better information about current market conditions cut in front of an order is a function of the tick size. Theoretically, Harris (1991) argues that under common price-time priority rules, better priced orders supersede the time precedence of older limit orders and smaller tick sizes decrease the cost of undercutting existing liquidity and discourage liquidity provision. Additionally, Seppi (1997) models a hybrid market with limit orders and a NYSE-style specialist, he finds that too small a tick size makes it easier for the specialist to undercut other liquidity providers and a larger tick mechanically widens the spread but promotes depth. Portniaguina, Bernhardt, and Hughson (2006) endogenize the liquidity demand in Seppi's model to find an exacerbated negative impact from a smaller tick and that the tick has to be sufficiently large in order for the order book to not be empty.

Other studies also suggest a differential effect of tick sizes on market quality for different stocks. Bonart (2017) conducts a cross-sectional analyses, examining relative tick sizes on NASDAQ, and finds that execution costs fall with a decreasing relative tick size up to a point after which they start to rise. The literature on decimalization provides additional support for the notion that the same change in tick size will not affect all stocks the same. While most studies examining the process of decimalization found positive results (e.g., Bacidore, Battalio, and Jennings (2003), Chordia, Roll, and Subrahmanyam (2008), and Zhao and Chung (2006)), Bessembinder (2003) finds that when the tick in US markets moved from $\$\frac{1}{16}$ to 1¢ liquidity and spreads improved for the market as a whole with the most substantial improvements being in heavily traded stocks.Li and Ye (2021) model the optimal number of ticks intra-spread and find that approximately two ticks provides a theoretically optimal number. However, their model abstracts away from undercutting concerns and thus we expect that two ticks intra-spread may be too few. Lastly, Angel (1997) argues that firms use stock splits to increase their relative tick size which benefits market makers to promote liquidity provision while balancing the costs a wider spread has on investors.

3 Data and Methodology

3.1 Data

Our data covers two event windows, one around the implementation of TSP and the other around its conclusion. For our analysis of the implementation of the TSP we examine the time window of 08/11/2016 through 12/15/2016. We follow Griffith and Roseman (2019) and exclude from this window the trading days spanning the staggered implementation of the TSP which comprise 10/03/2016–10/23/2016.[8] Our analysis of the implementation of the TSP has a pre-period where both the pilot and control stocks had a tick of 1¢ running from 8/11/2016 to 10/02/2016 and a treatment period where pilot stocks had a 5¢ tick and control stocks had a 1¢ tick running from 10/24/2016 to 12/15/2016. Our analysis of the conclusion of the TSP runs from 08/07/2018 through 11/20/2018, during which the minimum tick size for stocks in TSP Test Groups was simultaneously reduced from 5¢ to 1¢ on 10/01/2018.[9]

This study compares microstructure outcomes of control stocks, denoted C, to those of TSP Test Groups 1 and 2, denoted G1 and G2, respectively.[10] However, we verify the robustness of our main findings for Test Group 3 stocks, denoteg G3; indeed, we estimate all the main effects for each individual TSP Test Group relative to control stocks. We use the "`tick size pilot indicator`" flag in TAQ data to identify control and pilot stocks as well as the exact dates tick size changes were enforced for each stock in the experiment. This allows us to identify exact actual enforcement dates for the few stocks whose TSP restrictions where enforced with delays relative to the dates intended by the program. G1 stocks had imposed a 5¢ quoting increment while G2 stocks had the 5¢ tick apply to both quoting and trades. However, in practice there was very little functional difference between these two stocks. Both G1 and G2 stocks had an exception from the 5¢ tick size for midpoint and benchmark trades like VWAP trades. Additionally, for exchanges and ATSs the G2 restriction on trading was generally non-binding because exchanges and ATSs are essentially crossing networks where incoming quotes are matched—which would need to be denominated in the 5¢ increment. The trading restriction would be most binding for trades internalized by wholesalers who routinely execute marketable orders in sub-penny increments. However, even here the trading restriction was relatively lax because it contained an exception from the requirement to trade in increments of 5¢ so long as the trade received price improvement of 0.5¢ or greater. Thus very little trading volume would actually have been affected by the trading requirement. Reflecting minimal

[8]Some effects related to the tick size change may not occur instantaneously as market participants may need time to optimize systems and adapt behavior. Excluding the implementation period helps mitigate some of this noise that may muddle inference of the steady state effects of the tick size change.

[9]Following Rindi and Werner (2019), we remove trading days coinciding with Labor Day, Thanksgiving, and Black Friday from our sample. We also do not omit the period surrounding the conclusion of the TSP as we do with the implementation of the TSP because all TSP stocks returned to a 1¢ tick on the same day and because market participants were returning to a familiar trading environment, and one that had continued to operate on the majority of stocks. Thus, we believe that the effects of the end of the TSP would have occurred very quickly.

[10]We remove a stock from our sample if its group assignment changes during the two-year TSP interval.

differences between G1 and G2, Hu et al. (2018) study extensively the differential effects of the TSP on all three test groups and find that the TSP produced no statistically significant difference between G1 and G2 stocks across any measure used.

In contrast, G3 was subject to a trade-at rule which would prevent an exchange from executing a trade unless that exchange was currently posting the best quote at the time of the trade. If the exchagne was not posting at the best quote it could either re-route an order to the exchange with the best quote or it could price improve relative to the most aggressive quote. Extant literture shows that the trade-at rule did cause significant differential effects for stocks in G3 relative to G1 and G2.[11] For these reasons we exclude G3 stocks from our main analysis. In Appendix A we present all our main analyses for each of the three test groups separately.

We construct daily measures of time-weighted average quoted spreads and size-weighted average effective spreads during regular trading hours from Daily TAQ data, following Holden and Jacobsen (2014). Additionally, we construct daily measures of size-weighted average realized spreads and price impacts by comparing transaction prices of signed trades with the quote midpoints x seconds forward, with $x \in \{15, 60, 300\}$, reflecting the findings of Conrad and Wahal (2020). We also construct effective spreads, realized spreads, and price impacts focusing on Intermarket Sweep Orders (ISOs) only. From WRDS Intraday Indicators, we obtain daily measures of time-weighted quoted depth at the National Best Bid and Offer prices (NBBO); total trading volume; and share of ISO trading volume in daily volume, constructed using information from regular trading hours.

From MIDAS data, we obtain daily measures of Cancel-to-trade ratio, which divides the daily number of canceled orders by the total daily number of trades; Hidden ratio, which divides the daily number of trades involving hidden orders by the total daily number of trades; and odd-lot ratio, which divides the daily number trades involving odd-lot orders by the total daily number of trades. From MIDAS, we also extract measures of cumulative depth in the order book as well as the the per share cost (in dollars) associated with round-trip trades. For each stock day in our sample, we take snapshots of the entire order book every 15 minutes from 9:45am through 3:45pm. Across these snapshots, we calculate the average cumulative depth on the ask and bid sides of the order book at z cents away from the corresponding midpoint, with

[11] see e.g. Conrad and Wahal (2020), Farley, Kelley, and Puckett (2018), **?**,Edwards et al. (2021), among others

$z \in \{-60, -40, -25, -15, -10, 10, 15, 25, 40, 60\}$.[12] We also calculate the hypothetical round-trip per share cost associated executing y-round-lot orders, with $y \in \{1, 2.5, 5, 10, 25, 50, 100\}$.[13]

Using Quote and NBBO files from Daily TAQ, we construct various high-frequency measures of price efficiency. After identifying NBBO prices, we construct 5-minute returns of each stock. We estimate AR(1) models of these returns by stock and day, storing the respective absolute values of R^2 and AR(1) coefficients as measures of price efficiency—full price efficiency, i.e., a martingale price process, translates into R^2 or AR(1) coefficients that equal zero. From WRDS Intraday Indicators, we also obtain return variance ratios for horizons 15 seconds to 3×5 seconds, 1 minute to 4×15 seconds, and 5 minutes to 5×1 minute.

3.2 Empirical Method

To control for the extent of minimum tick constraints, we partition stocks based on their time-weighted average quoted spreads prior to each event. For the implementation window, stocks are classified into four tick constraint bins according to the average quoted spreads in May and June of 2016. Bin 1: no more than 4¢, Bin 2: 4¢ to 8¢, Bin 3: 8¢ to 15¢, and Bin 4: greater than 15¢. For the conclusion window, stocks are classified into four tick constraint bins according to the average quoted spreads in May and June of 2018. Bin 1: no more than 6¢, Bin 2: 6¢ to 9¢, Bin 3: 9¢ to 15¢, and Bin 4: greater than 15¢.[14] Our choices of these cutoffs place a sufficient number of control and treated stocks into each tick constraint category to provide comparable levels of statistical test power across these categories.

Table 1 reports the distribution of control and treated stocks across these tick constraint bins for each event. Treated stocks comprise 20-45% of the stocks falling in each tick constraint category, providing meaningfully large treatment groups. In addition, the table indicates no statistically significant differences in market-capitalization, dollar volume, and return volatility across control and treated stocks in any of the categories.[15] As such, consistent with the design of TSP, any

[12] We use natural logs of all depth variables to provide a percentage DiD estimate for treatment effect, and we replace the natural log of depth with zero when the respective depth quantity is zero, i.e., we assume a depth of zero is equivalent to a depth of one share.

[13] A missing value is assigned to cumulative depth when the quoted price in the order book falls below \$1. Similarly a missing value is assigned to round-trip costs when there is not enough depth available to fill a y-round-lot order.

[14] The literature normally uses a cutoff of 5¢ to identify tick-constrained stocks in the implementation phase of TSP. Such a cutoff may not be used for the conclusion phase because it would exclude all treated stocks, featuring a 5¢ minimum tick, from being tick constrained.

[15] Note that quoted spreads of control and treated stocks in Groups 1 & 2 of the TSP conclusion window are

significant effect associated with a change in tick size within our tick constrained categories may not be attributed to non-random differences in these firm characteristics.

[Insert Table 1 about here.]

We employ a difference-in-difference strategy to estimate the impacts of an exogenous change in tick size on a given outcome variable, Y_{jt}. We estimate

$$Y_{jt} = \alpha_0 + \alpha_p Pilot_j + \alpha_e Event_{jt} + \beta \left(Pilot_j \times Event_{jt} \right) + u_{jt}, \quad (1)$$

where $Ploit_t$ is an indicator variable that equals 1 for treated stocks (G1 or G2) and equals 0 for control stocks; $Event_{jt}$ of a treated stock equals 0 prior to a change in minimum tick size and equals 1 after the change, accounting for the enforcement date differences across stocks; and $Event_{jt}$ of a control stock in the implementation (conclusion) window equals zero before 10/03/2016 (10/01/2018) and equals 1 as of 10/24/2016 (10/01/2018).

To estimate the treatment effect β, we fit equation (1) using quantile regressions, with median regressions underlying our main result, while we report qualitatively robust estimates based on first- and third-quartile regressions in the Appendix. In addition, we corroborate many findings of the existing literature by fitting OLS estimates after winsorizing each outcome variable, Y_{jt}, at its 5^{th} and 95^{th} percentiles by tick constraint and treatment category.[16] All of our estimates control for date fixed effects and double-clustered standard errors at the stock-date level.[17] In additional robustness analysis, we document that our findings are more pronounced among stocks with high trading volumes. Moreover, we establish robustness to augmenting equation (1) to include market-capitalization, dollar volume, and return volatility as additional controls. We also examine the robustness of our findings to exclusion of "penny" stocks, whose average share prices fall below \$5 prior to the respective event window.

statistically different. This is a consequence of the TSP experiment design, where tick constrained treated stocks must trade at or above the 5¢ tick, while tick constrained control stocks must only trade at or above the 1¢ tick.

[16]Winsorizing at the 1^{st} and 99^{th} percentiles has no material impacts on our findings with the exception of OLS estimates for realized spreads and price impacts whose distributions feature very long tails.

[17]The introduction of date fixed effects reflects the fact that for some stocks the enforcement/lifting dates of TSP restrictions differ from the intended dates by the program. However, in unreported results, we verify robustness to, instead, the use of stock fixed effects or the use of both date and stock fixed effects.

4 Results

4.1 Complexity

At the heart of this study is the tradeoff between pricing fidelity and complexity/undercutting. This section provides empirical evidence validating that fundamental tradeoff. the role of tick sizes on complexity. As discussed in Section 2, a narrower tick size can increase complexity through multiple dimensions: it spreads liquidity over more price levels and potentially over more venues, it also increases undercutting behavior which can make providing liquidity more complex. We look for evidence of increased market complexity using the following metrics: (a) cancel-to-trade ratio, (b) hidden ratio, (c) odd-lot ratio, and (d) the percent intermarket-sweep-order (ISO) volume share.

The cancel to trade ratio is a MIDAS based measure that captures the number of orders that are canceled relative to the number of trades that execute. A high cancel-to-trade ratio is indicative of complexity because it inherently means that posted liquidity is less stable. Navigating an unstable order book is more complex than navigating one that is more firm. The hidden ratio is the ratio of hidden orders to displayed orders. Increased use of hidden orders can signify complexity as it indicates that LPs are not willing to expose their orders perhaps out of a fear that doing so could endogenously cause prices to move against them. The odd lot ratio is the ratio of executed odd lot trades to round lot trades. An increase in the odd lot ratio can signal increased complexity as it signifies that market participants shredding large parent orders into smaller child orders. An ISO order allows traders to execute orders from the top of the book simultaneously across multiple venues even if an exchange is not currently priced at the NBBO. It is a way to circumvent the order protection rule. An ISO order allows market participants to trade relatively larger quantities in one shot thus making it more difficult for markets to anticipate the order and adjust prices against the user of the ISO (see Lohr (2021)). We view ISO usage as a response to market complexity, particularly to fragmented liquidity and potential adverse selection concerns. We view an increase in any of these metrics as suggestive of a more complex market. Consequently, we hypothesize that across all metrics, moving from a 1¢ to a 5¢ tick will lead to a reduction in all four measures and that the reverse will occur at the end of the TSP when the tick is again lowered from 5¢ to 1¢

Our difference in difference analysis on the effect of the TSP on market complexity is presented in Table 2 and provides evidence consistent with the market complexity hypothesis. Analysis of the

TSP imposition and conclusion uniformly suggest that a 5¢ tick led to lower cancel-to-trade ratios across all stocks. This finding is true for all spread bins but was most pronounced in the wide spread bin—where complexity concerns would predominate with a narrower tick. Table 2 also shows a significant decrease in the use of hidden orders associated with the wider tick size for all but tick constrained stocks. For tick constrained stocks the TSP imposition indicates no-effect while the TSP conclusion suggested a reduction in the use of hidden orders. This pattern is consistent with a narrow tick for wide spread stock decreasing the incentive to display liquidity due to concerns about undercutting. The 5 tick was also associated with a decrease in the use of odd lot orders that appears relatively constant across spread bins. Fewer odd-lot trades can be indicative of traders not feeling that they need to as aggressively shred orders in order to minimize execution costs. We view this analysis as consistent with the notion that a smaller tick size increases complexity. Lastly we find that ISO volume fell on the TSP imposition and then rose again upon its conclusion for tick and near-tick constrained stocks. For intermediate spread stocks and stocks with wide spreads we find no consistent effect on ISO volume. While the ISO effect may be the most pronounced for tick and near-tick constrained stocks is that these stocks experience the greatest relative fragmentation of liquidity with a 1¢ tick relative to a 5¢ tick. As we will observe in Table 4, the TSP increased depth at the NBBO, and the increase was greatest for tick and near-tick constrained stocks. The more liquidity is available at the NBBO, the less incentive there is to use ISO orders. In sum, we view the analysis presented in Table 2 as consistent with the notion that a narrower tick size leads to increased complexity.

[Insert Table 2 about here.]

4.2 Quoting Behavior

If the market for liquidity provision is competitive, then the bid and ask prices will be set at the price just worse (from the liquidity demander's perspective) than the break even prices. In this case the tick size has two effects on the equilibrium quoted spread: it limits the lattice where bid and ask prices can be set, and it potentially endogenously affects the cost of providing liquidity. Consider a competitive market where liquidity providers would post quotes with a 12¢ spread (but not lower) that has a 5¢ tick restricting spreads to a {5¢,10¢,15¢,...} grid. In this case 12¢ is not a feasible price and so the spread would widen to 15¢, all else equal. However, the price point at which LPs are willing to supply liquidity is itself affected by the pricing grid. If the pricing grid is set too fine, the cost of undercutting quotes falls, market complexity rises, and the spreads at which LPs supply liquidity may need to widen to provide compensation for the hazardous market structure. Put differently, the higher fidelity of a smaller tick size allows for spreads to narrow in on the equilibrium spread, up to a point, after which increased fidelity causes the equilibrium spread to widen and the complexity of high fidelity pricing out-weigh its benefits.

We hypothesize that for stocks with narrow spreads, a wider tick will lead to a wider quoted spread until a point whereupon spreads are sufficiently wide that a larger tick improves the trading environment by reducing complexity and the risk of undercutting.

The results provided in Table 3, which provided DID analysis of the effect of the TSP imposition and conclusion on time-weighted quoted spread for each of the four spread bins are consistent with our hypothesis. For tick and near-tick constrained stocks the imposition of the 5¢ tick increased quoted spread by 2.6¢ and 2.8¢ for the median tick and near-tick constrained stock respectively. An effect with reverses upon the conclusion of the TSP. For stocks with wide spreads the imposition of the TSP decreased spreads by 3.9¢ a result that more than reverses at the conclusion of the TSP. For intermediate stocks the effect is uncertain. Both the TSP imposition and conclusion suggest an increase in spreads, although the magnitudes of the effect are weakly smaller than any other test group. We interpret our findings as consistent with the hypothesis. For stocks with narrower spreads the 5¢ tick led to wider spreads while for stocks with wide spreads the opposite occurs.

[Insert Table 3 about here.]

We next examine the percentage change in quoted depth at the NBBO as a result of a change in the tick size. Depth at the NBBO is important because of the order protection rule, which prohibits an exchange from executing an order at a price worse than the prevailing NBBO. Thus when submitting a marketable order a trader can either use an ISO order, which allows the trader to get around the order protection rule and take liquidity at the top of the book across multiple exchanges simultaneously regardless whether the exchange is at the NBBO or not. Or they can execute with one order depth at the NBBO, wait for markets to refill liquidity and then send another order at the new NBBO. Having significant liquidity at the NBBO simplifies trading by making it easier to source a larger number of shares directly.

We hypothesize that the 5¢ tick size will lead to an increase in depth at the NBBO across all test bins, a finding already demonstrated in prior literature, but we also hypothesize that the effect will be particularly strong for stocks with narrower spreads. A wider tick forces liquidity to congregate at fewer price points. This is true across all stocks. However, for stocks with very narrow spreads the relative fraction of total depth that is forced to congregate at the wider tick price levels is greater than it is for stocks with wide spreads.

Our empirical analysis of depth at the NBBO presented in Table 3 confirms this hypothesis. While quoted depth at the NBBO rises for all spread bins with the 5¢ spread, the relative increase varies significantly across these bins with the greatest increases occurring in tick and near-tick constrained stocks. As minimum tick size rises from 1¢ to 5¢, quoted NBBO depth of the median stock rises by 108%, 104%, 53%, and 20% for tic constrained, near-tick constrained, intermediate spread, and wide spread stocks respectively. For all quoted spread bins the effect reverses upon the conclusion of the TSP with the greatest declines in NBBO depth occurring in tick and near-tick constrained stocks.

[Insert Table 4 about here.]

We provide further evidence of the heterogeneous impacts of a tick size change on the cost of undercutting resting quotes by examining the effect of a tick size change on cumulative depth at different price levels in the order book. Using MIDAS data, we construct average cumulative ask- and bid-side quoted depth at 10¢, 15¢, 25¢, 40¢, and 60¢ away from the midpoint for each stock-day. We then estimate the effect of a tick size increase (decrease) on cumulative depth measures using Equation (1) at the TSP imposition (conclusion). Figure 2 plots median regression point estimates and the corresponding 95% confidence intervals against the order book location relative to the midpoint—in unreported results, we find qualitatively similar patterns using OLS estimates.

[Insert Figure 2 about here.]

Consistent with the trade-off between price fidelity and the cost of undercutting, the effects of tick-size change on cumulative quoted depth follows strikingly different patterns across differently tick constrained stocks. For tick and near-tick constrained stocks these effects are largest deeper in the order book, whereas for wide-spread stocks effects are strongest closer to the midpoint. Specifically, Figure 2 presents treatment effect patterns that differ dramatically between tick constrained and wide spread stocks. For tick constrained stocks a change in the tick size, and hence, the price floor will mechanically affect the quoted depth near the midpoint. For example, in the case of tick constrained stocks at TSP imposition, increased tick from 1¢ to 5¢ pushes all the quoted depth to the next available best prices. This simple movement of existing depth to worse prices should leave cumulative depth deep in the book unaffected. However, we find significant monotonic increases in cumulative depth up to 25¢ away from the midpoint. Specifically, cumulative depth of the median stock rises by approximately 20%, 40%, and 50% at 10¢, 15¢, and 25¢ away from the midpoint—a reduction in tick size and the TSP conclusion yields qualitatively similar effects in the opposite direction. We attribute these incremental increases (reductions) in cumulative depth to higher (lower) cost of undercutting due to a larger (smaller) tick size at TSP imposition (conclusion). That is, increased (decreased) costs of undercutting leads to increased (reduced) liquidity provision at all price levels.

The effects of the costs of undercutting on liquidity provision is most pronounced for wide spread stocks. Because minimum tick is not binding for these stocks, LPs can easily quote at prices better than the dominant NBBO. This could be in the form of quoting round-lots that would tighten the NBBO or in the form odd-lot quotes inside the NBBO. These possibilities raise the importance of the risk of being undercut by competitors. For instance, LPs in bin 4 stocks prior to TSP imposition could provide liquidity inside the current NBBO on a grid featuring 39 intra-spread ticks. Nonetheless, their quotes could be undercut by competitors who offer only 1¢ price improvements. Increased tick size from 1¢ to 5¢ would reduce intra-spread ticks to 7, significantly raising the protection against competitors who now would have to price improve by 5¢ in order to undercut. Consistent with this increased margin of safety for resting liquidity against undercutting, and contrary to bin 1 stocks, Figure 2 shows that the positive effects of an increased tick size on cumulative depth of bin 4 stocks are remarkably larger closer to the midpoint. Similarly, for bin 4 stocks at TSP conclusion, cumulative depth shrinks disproportionately more at price levels closer to the midpoint as tick size falls from 5¢ to 1¢. Such a mechanism would be nearly absent in tick constrained bin 1 stocks. These stocks would certainly (likely) remain tick constrained after the tick-size change at TSP imposition (conclusion), offering no (limited) inside-quote liquidity provision.

4.3 Trading Costs and Trading Activity

We next analyze the effects of a change in tick size on various measures of trading costs and trading activity. Specifically, we examine the manifestation of the changes in quoting choices of LPs described in Section 4.2 on trading costs. Our measures of trading costs include effective spreads, obtained from TAQ, as well as round-trip per share cost associated executing y-round-lot orders, with $y \in \{1, 2.5, 5, 10, 25, 50, 100\}$, constructed using MIDAS order book data.[18]

We hypothesize that we should observe the same overall pattern of results in terms of the effect of the TSP on effective spreads as we do with the effect of the TSP on quoted spreads: for narrow spread stocks the wider tick will lead to higher transaction costs as pricing fidelity effects dominate. For wide spread stocks we expect the opposite to occur. The wider tick simplifies markets and reduces the risk of pennying leading to lower transaction costs.

Table 5 provides evidence consistent with this hypothesis. For stocks that were tick or near-tick constrained by the imposition of the 5¢ tick size, effective spreads increased by 2.6¢ and 3.2¢ respectively as a result of the wider tick size. This effect results reverse upon the conclusion of the TSP. For wide spread stocks effect of the larger tick size was to reduce effective spreads. The TSP imposition was associated with a 1.8¢ reduction in effective spreads and the TSP conclusion a 3.2¢ increase in effective spreads for these stocks. For intermediate stocks the TSP imposition and conclusion results were not clear. The TSP imposition was associated with an increase in effective spreads of 1.1¢ while the TSP conclusion indicated no statistically significant effect.

[Insert Table 5 about here.]

Effective spreads can be mechanically affected by trade sizes, as larger trades may have to walk the book more to find executions. We do document in Table 5 that average trade size increases by between 4 and 17%, with the largest increases in trade size associated with tick and near-tick constrained stocks. However, we do not believe that increased trade size is the key driver of increased effective spreads. First, the order protection rule only allows trades not at the NBBO to

[18] In untabulated robustness analysis, we document qualitatively similar results based on the per-dollar round-trip execution costs of z-thousand-dollar positions, with $z \in \{1, 2.5, 5, 10, 25, 50, 100, 250\}$.

occur as a result of ISO orders. For non-ISO orders marketable orders, an order that would exhaust more liquidity than exists at the NBBO would either be canceled back to the originator or split into multiple orders that each separately execute at the NBBO. An increased usage of ISO orders could lead to wider effective spreads due to larger trade sizes. However, as shown in Table 2 the usage of ISO orders fell with the 5¢ tick. Rather we view the increase in trade size as a nature response to the increase in depth at the NBBO. Recall from Table 4 that NBBO depth rose between 20-108%, with the greatest increases in depth occurring in tick and near-tick constrained stocks. These are the same stocks that also experience the largest increases in trade size.

In Table 5 we also examine the impact of the TSP on trading volume. A tick size change could have two competing effects on trading volume. If the tick size increases transaction costs it can increase trading volume by inducing market making high frequency traders to enter the market to take advantage of the increased compensation for liquidity provision. Menkveld (2013) observes that such HFTs tend to trade actively a significant fraction of the time in order to manage inventory—increasing trading volumes. However, standard supply and demand arguments suggest that as the price of a good increases the demand for that good will decrease. Thus, as the price of liquidity goes up the demand for liquidity will go down—perhaps as traders less frequently balance their portfolios to avoid high transaction costs. The net effect is an empirical question and we do not find consistent evidence across the TSP imposition and TSP conclusion for any of the test bins that the TSP significantly affected trading volumes.

We also explore the cost of transacting deeper in the book using the cost of a round trip trade measure 'CRT'. Similar measures are employed by both Griffith and Roseman (2019) and Chung et al. (2020). These measures estimate the average round trip cost to walk the book on either side of the market up to a given level of shares. The order protection rule prevents trades from occurring at prices other than the NBBO, and thus it is not possible to submit an order that simply walks the book. However, executing a rapid succession of orders can produce a similar effect. For example, if the first order executes at the NBBO the next best prices then become the new NBBO and a subsequent order can execute against those quotes. Thus by submitting a rapid succession of orders a trader could do something akin to walking up the book to execute a large trade. Thus, we believe it is useful to explore the average cost to transact a large order. Additionally, this analysis can help resolve the fact that Griffith and Roseman (2019) and Chung et al. (2020) find conflicting results.

The total trading cost associated with the execution of an order that removes liquidity deep in the order book reflects the net effect of two opposing factors: pricing and cumulative depth. Trading costs increase in the distance between the prices at which LPs quote and the NBBO midpoint, but they decrease in the cumulative depth that is available at any given price. While our prior results have established the effects of a tick size change on bid-ask spreads and cumulative depth, it is yet to be determined how these effects net out to determine trading costs deeper in the book.

Table 6 documents two distinct patterns that generally hold across CRT round lot sizes and for the imposition and the conclusion of the TSP. First, the effect of a larger tick size on CRT levels becomes less negative (or more positive) as quoted spreads increase. Specifically, the coefficient on the effect of the TSP imposition on CRTs for wide spread stocks is always less in than the coefficient for stocks with less wide spreads, and the relation is usually monotonic. For example, the imposition of the TSP on a 5 round lot trade was to make this trade 3.6¢ more expensive for tick constrained stocks. For near-tick constrained stock the coefficient decreases indicating a 2.3¢ effect, for Group 3 stocks the effect was a statistically insignificant, and for wide spread stocks the 5¢ tick lowered lowed the CRT by 4.6¢. This pattern is always the case when comparing the effect of the TSP on tick constrained and wide spread stocks and usually holds across all 4 price levels.

The second pattern that emerges from this analysis is that as the trade size considered increases, a larger tick size becomes less harmful (or more beneficial) to CRT transaction costs. For example, for wide spread stocks and for one round lot, the imposition of TSP decreased transaction costs by 3.8¢ for a one round lot trade and by 43¢ for a 100 round lot trade. Similarly, for tick-constrained stocks, the TSP conclusion lowered one round lot CRTs by 4.8¢ and 11¢ for 100 round lot trades.

We interpret the fact that the effect of the larger tick size is less harmful (or more beneficial) as quoted spreads increase as being consistent with a wider tick size creating pricing fidelity concerns among stocks with tighter spreads leading to less favorable conditions in which to execute a large order. Pricing fidelity concerns mitigate as spreads wide until complexity concerns dominate—concerns that are ameliorated by a wider tick. Thus, we view this pattern as consistent with the pricing fidelity and complexity/undercutting tradeoff.

[Insert Table 6 about here.]

4.4 Profits to Liquidity Provision

The tradeoff between pricing fidelity and undercutting/complexity also has implications for the profits to liquidity provision. The direct compensation for providing liquidity is the spread that the LP earns. The spread can be decomposed into two components: the realized spread and adverse selection components. The adverse selection component of the spread is measured as the proportional change in the midpoint between the time of the trade and some future time. It is the portion of the spread that compensates liquidity providers for their trading losses that accrue due to trading with others that are more informed than they are. The remainder of the spread, referred to as the realized spread, compensates LPs for all non-adverse selection costs and also provides their profit.[19]

For tick constrained stocks we expect the increase in the tick size to increase realized spread by mechanically increasing the spread. Additionally, by de-emphasizing price in the price-time priority rules, an increase in the tick size inherently creates an environment that emphasizes speed in trading execution. This tilting of the playing field towards faster traders can increase adverse selection by increasing the role that sophisticated high speed traders play in markets.

For stocks with wider spreads, tick concerns relate to undercutting and to market complexity. As liquidity becomes spread over more price levels and potentially across more venues it can be more expensive to source liquidity because systems need to be built and maintained that monitor a larger number of price levels and venues. This effect would increase realized spread. Undercutting concerns could increase adverse selection if slower traders transact only when faster traders cancel their quotes.

For both tick constrained stocks and stocks with wide spreads a tick that is too narrow or too wide can increase transaction costs through both the realized spread and adverse selection channels. The relative importance between these two effects is an empirical question. Table 7 presents our empirical analysis of the effect of the tick size change on realized spread and adverse selection. While we present results using 15, 60, and 300 second horizons, following Conrad and Wahal (2020) we focus our discussion on results using a 60 second horizon because the TSP focused on small-cap stocks.

[19] See Dixon (2021) appendix C for a more complete discussion of how the effective spread decomposes into realized spread and adverse selection components.

For tick and near tick constrained stocks, both the analysis of the TSP imposition and conclusion suggest that realized spread and adverse selection costs play a role in increasing effective spreads. However, the analysis suggests that adverse selection played by far the larger impact. The increase in effective spreads for the median tick constrained stock due to increased realized spread was about 0.4¢ while the effect of adverse selection was five times larger at 2.1¢. For wide spread stocks the results are more balanced. Both the TSP imposition and conclusion suggest that these stocks had both lower realized spread and adverse selection costs with the 5¢ tick size, but the effect of the two channels appears more balanced with adverse selection exerting only a moderately larger influence on effective spreads than realized spread. As with much of our other analysis the results for intermediate spread stocks are not unambiguous given that the results from the TSP imposition and conclusion do not always agree in terms of sign or statistical significance.

[Insert Table 7 about here.]

4.5 Price Efficiency

The pricing fidelity/complexity and pennying tradeoff also can inform the effect of the TSP on price efficiency. At a base level a wider tick makes it harder for prices to realize their equilibrium levels meaning that HFTs can only trade on a misspricing is larger than the tick size - implying that misspricings or return patterns that are smaller than the tick size will persist. Also, a more complex trading environment plays to the advantages of fast and sophisticated traders such as high frequency traders. Thus, the larger tick associated with the TSP could inhibit HFT trading strategies by constraining their activity to a coarser lattice.[20]. High frequency traders are adept at trading on short lived price changes, and thus they help reduce intra-day price predictability (see e.g. Brogaard, Hendershott, and Riordan (2014) among others). Consequently, we expect that price efficiency measures that are computed using intra-day variance ratios or auto-correlation patterns will likely show a decrease in price efficiency.

Another dimension of price efficiency relates to how much stock prices reflect knowable information and how quickly that that information is incorporated into stock prices. This dimension of price efficiency relates more to the activities of individuals performing fundamental research and

[20]This view is similar to that articulated by both Lee and Watts (2021) and Ahmed et al. (2020)

then choosing to purchase or sell stocks accordingly. This type of behavior will affect stock prices are horizons longer than intra-day. The effect of the TSP on this type of behavior is less clear. Research shows that when it becomes more difficult to trade on information, traders collect less information - leading to worse price efficiency (see e.g. Dixon (2021)). However, it is unclear how the wider tick size will affect the ability to trade on fundamental information. If, as Lee and Watts (2021) and Ahmed et al. (2020) argue, HFTs eat some of the profit of information gathering, then limiting HFTs will improve price efficiency. In contrast, if less liquidity makes it more expensive to transact, then there could be less information gathering as argued by Li and Xia (2021). The net effect is uncertain.

We examine price efficiency using both intra-day and day to day price efficiency measures. For intra-day price efficiency we use two processes. The first is an AR(1) process that measures the auto-correlation of five minute midpoint returns. This estimation is measured each stock each day and the AR(1) coefficient is from each regression is saved producing a unique panel of autocorrelation coefficients for each stock each day. Our other intra-day price efficiency measure is 15 to 5 second variance ratios and 5minute to 1 minute variance ratios. For both intra-day measures we use the same DID procedure as in our prior tests with the various price efficiency measure as the dependent variable. To measure price efficiency at a longer horizon, we use an AR(1) panel regression employing. To avoid concerns relating to the opening and closing auctions (Bogousslavsky and Muravyev (2022)) we calculate 1pm to 1pm returns and then estimate the following regression with these daily returns as our dependent variable,[21]

$$Y_{jt} = \rho_0 + \rho_1 R_{j,t-1} + \rho_2 Pilot_j R_{j,t-1} + \rho_3 Event_{jt} R_{j,t-1} + \rho_4 (Pilot_j \times Event_{jt}) R_{j,t-1} + u_{jt}. \quad (2)$$

Our results are presented in Table 8.

[Insert Table 8 about here.]

Table 8 indicates that price efficiency largely deteriorated at an intra-day level. Intuitively, this decline in efficiency appears to be strongest among tick and near-tick constrained stocks where the

[21] In untabulated tests, we find quantitatively similar results using open to open or close to close returns

5¢ tick size would have been most binding on HFT behavior. The quantile regressions indicate that intraday negative autocorrelation became stronger for all but wide-spread stocks during the TSP and for wide-spread stocks intraday autocorrelation was not affected by the wider tick. Further, variance ratios decline indicating a deviation from unity in the ratio and also indicating less price efficiency at an intra-day level.

Our results using 1pm to 1pm autocorrelation indicate no change in price efficiency at the 24 hour level. This finding could be indicative of either no-effect, or of a lack of power in our test design. We believe that our results are more consistent with no-effect because while the R_{t-1} coefficient is generally negative, as expected, for both the imposition and conclusion of the TSP the signs of the interaction coefficient often do not agree between the TSP imposition and conclusion and sometimes switch from spread bin to spread bin. In sum, our results indicate that the 5¢ tick decreased intra-day price efficiency which is consistent wiht the wider tick making it more difficult for HFTs to trade on intra-day price patterns and thus allowing some of those patterns to persist. However, our null result using 24hour autocorrelation suggests that the wider tick did not affect price efficiency using longer horizons - consistent with fundamental traders not being overly sensitive to the wider tick when determining how much information to gather and trade on.

4.6 Robustness

A natural concern using the TSP is generalizeability. The TSP only included small-cap stocks and thus it is not clear how applicable results using the TSP are to the broad spectrum of stocks. There is no way to completely resolve this shortcoming of the TSP. However, we try and mitigate concerns about generalizability in multiple ways. We first estimate our main analysis using quartile regressions. This analysis lets us examine whether the patterns that we document occur across the distribution of the dependent variable—rather than just near the center. It is a way of asking whether a stock at the 25th or 75th percentile of the distribution of the dependent variable is affected in the same manner as one at the median. These results are presented in Table 9. The next way we address generalizability concerns is by bifurcating the TSP sample and estimating our key analysis using only stocks with higher than median trading volume among TSP and control stocks. Specifically, we evaluate trading volume in May of 2016 (for the TSP imposition) and May of 2018 (for the TSP conclusion) and eliminate from our analysis stocks that had below median trading volume in these months from our analysis. We then replicate key analysis exactly as before. Results are presented in Table 10. Our second approach to addressing the generalizability of our analysis is to exclude all penny stocks from our analysis. Specifically, if a stock had an average closing price across all trading days in May and June of 2016 for the TSP imposition and 2018 for the TSP conclusion, then it was excluded from our sample. These results are presented in Table 12. Lastly, we estimate our analysis including a robust set of control variables.[22] These results are presented in Table Table 11

Across all robustness methodologies we find that the basic patterns documented in the main tests. Quoted and effective spreads increase for tick and near-tick constrained stocks but decrease for stocks with wide spreads with a 5¢ tick size. Depth at the NBBO increases across all spread bins. The TSP imposition and conclusion indicate that for these stocks, quoted spreads increase for tick and near-tick constrained stocks but decrease for wide spread stocks with the 5¢ tick. Depth at the NBBO increases with a 5¢ tick. The patterns of realized spread and price impact remain: adverse selection point estimators are always larger than are realized spread point estimators. CRT trading costs for large orders increase for tick and near-tick constrained stocks but decrease for stocks with wide spreads. Complexity measures indicate an increase in complexity, and so on. While these results do not allay all concerns relating to how applicable our results would be applied to stocks with different characteristics they, at the least alleviate concerns that they results we present here are driven by low volume and microcap stock.

In sum, this analysis suggests that for stocks with less than two ticks intra-spread, a 1-to-5 reduction in the tick size was beneficial to market quality across almost all metrics. For stocks with more than 15 ticks intra-spread a 5-to-1 increase in the tick size was beneficial to market quality across almost all metrics. For stocks with approximately 2-3 ticks intra-spread with the 5¢ tick or approximately 9-14 ticks intra spread with the 1¢ tick neither tick size regime appears to have been dominate in terms of effects on market quality.

[Insert Table 9 about here.]

[Insert Table 10 about here.]

[Insert Table 12 about here.]

[22] Talk about the control variables

[Insert Table 11 about here.]

4.7 A More Granular Analysis of Trading Costs

The prior sections demonstrate evidence consistent with the notion that the same tick size adjustment will affect stocks differently depending on the stock's prevailing quoted spread consistent with the tick size tradeoff between pricing fidelity and complexity/undercutting concerns. In this section, we attempt to more precisely identify thresholds in terms of prevailing quoted spread where the TSP tick size change was beneficial, harmful, or undetermined.

Our analysis sorts TSP and control stocks into overlapping bins based on their pre-shock (i.e., pre imposition or conclusion) levels of quoted spreads; we use average quoted spread from May and June 2016 for the TSP imposition and from May and June 2018 for the TSP conclusion. Stock bins reflect overlapping intervals that increase by 1¢ in each bin of pre-shock quotes spreads $\{(0, 6¢), (1¢, 7¢), \ldots, (15¢, 21¢), (16¢, 22¢)$. We estimate Equation 1 using the data in each bin, and then plot the point estimates for the Equation 1 difference-in-difference coefficient along with the 95% confidence intervals.

To create our thresholds we use the following rule of thumb. If point estimators between the TSP imposition and conclusion have opposite signs and at least one set of tests is statistically significant then we count the bin as having a determinable effect. If both the TSP imposition and conclusion are statistically insignificant or the sign of the coefficients are in the same direction (indicating a lack of agreement as to the direction of the effect), then we label the effect of the TSP on market quality for that bin as undetermined.

Figure 3 presents results for this analysis for for effective spreads and 500 share CRT. For effective spreads both the TSP imposition and conclusion suggest that for stocks with quoted spreads less than 10¢ the 5¢ tick imposed by the TSP increased effective spreads and that the effect was greater the narrower the stock's spreads. Alternatively, the analysis suggests that for stocks with quoted spreads greater than approximately 16¢ the 5¢ tick decreased effective spreads. In between these ranges the effect of the TSP on effective spreads is unclear. For 500 share CRT the the analysis suggests that for stocks with spreads below approximately 9¢ the TSP increased transaction costs, and for stocks with spreads above approximately 11¢ the TSP improved 500 share CRT.

Figure 4 presents this same analysis for CRT at the 100, 250, and 1000 share level. For 100 share CRT the the analysis suggests that for stocks with spreads below approximately 9¢ the TSP increased transaction costs with the effect on spreads being greatest for stocks with the narrowest spreads and declining as spreads widen. For stocks with spreads above approximately 13¢ the TSP improved 100 share CRT with the effect being greatest for stocks with the widest spreads. In between these ranges the effect is not clear.

For 250 share CRT the the analysis suggests that for stocks with spreads below approximately 9¢ the TSP increased transaction costs with the effect on spreads being greatest for stocks with the narrowest spreads and declining as spreads widen. For stocks with spreads above approximately 14¢ the TSP improved 100 share CRT with the effect being greatest for stocks with the widest spreads. In between these ranges the effect is not clear.

For 1,000 share CRT the the analysis suggests that for stocks with spreads below approximately 7¢ the TSP increased transaction costs with the effect on spreads being greatest for stocks with the narrowest spreads and declining as spreads widen. For stocks with spreads above approximately 11¢ the TSP improved 1,000 share CRT with the effect being greatest for stocks with the widest spreads. In between these ranges the effect is not clear.

Figure 5 presents this same analysis for CRT at the 2,500, 5,000, and 10,000 share level. Consistent with Table 6, at virtually every price point (except perhaps for 2,500 share CRT for stocks with very narrow spreads) the TSP almost uniformly lowered transaction costs for these extremely large trades.

Trades larger than 1,000 shares are quite rare. Thus focusing on the effective spread and CRT analysis for trades less than 1,000 shares suggests the following general result. For stocks with spreads equal to approximately 9¢ or less the 1¢ tick size provided a superior trading environment. For these stocks a 5¢ spread implied that they generally traded with fewer than two ticks intra spread whereas with a 1¢ tick there were up to 9 ticks within the spread. On the other end, stocks with quoted spreads larger than approximately 15¢ generally had lower transaction costs with the 5¢ tick. For these stocks a 5¢ tick provided 3+ ticks intra spread whereas a 1¢ tick provided 15+ ticks intra spread.

While this analysis cannot identify the theoretically optimal number of ticks intra-spread because it only compares two tick regimes it does clearly indicate that for stocks with fewer than two ticks intra spread pricing fidelity concerns could justify a narrower tick and for stocks with more than 15 ticks intra-spread potential complexity and undercutting concerns suggest that a wider tick is merited.

5 Conclusion

This study characterizes tick sizes as offering a fundamental tradeoff between allowing markets to establish prices with greater fidelity on one hand and complexity and undercutting concerns on the other. This tradeoff means that the same tick size change may affect stocks, even stocks that are not tick constrained by the tick size, differently depending on which effect dominates. Existing research that combines all non-tick constrained stocks together for analysis misses this important nuance. Consistent with this tradeoff we find that for stocks that have quoted spreads less than 10¢, and thus became tick- or near-tick constrained by the imposition of a 5¢ tick size, a 1¢ tick generally provided a superior trading environment. For stocks with very wide spreads, i.e., 15¢ or more, the 5¢ regime appeared to offer a superior trading environment. Between these two thresholds the results of the 5¢ tick on market quality were mixed—suggesting no clear ranking between a 1¢ and a 5¢ tick.

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Figures and Tables

Figure 2. Minimum Tick Size and Order Book Depth: quantile regression. The figure presents visual evidence of the causal impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, for deferentially tick-constrained stocks. Stocks in the TSP imposition period 08/12/2016-12/14/2016, where tick size increased from 1¢ to 5¢ for pilot stocks, are classified into four tick constraint bins based on their average May and June 2016 quoted spreads: bin 1, no more than 4¢; bin 2, 4¢ to 8¢; bin 3, 8¢ to 15¢; and bin 4, greater than 15¢. Stocks in the TSP imposition period 08/08/2018-11/20/2018, where tick size decreased from 5¢ to 1¢ pilot stocks, are classified into four tick constraint bins based on their average May and June 2018 quoted spreads: bin 1, no more than 6¢; bin 2, 6¢ to 9¢; bin 3, 9¢ to 15¢; and bin 4, greater than 15¢. Average cumulative quoted depth on the bid and ask sides of the order book is measured at 10¢, 15¢, 25¢, and 40¢ away on each side of the midpoint price. The effect of a tick size change on the natural log of cumulative depth is estimated by Equation (1) using quantile (median) regressions that control for date fixed effects and double-cluster standard errors by stock and date. Point estimates of the treatment effects along with the corresponding 95% confidence intervals are plotted against the distance from the midpoint.

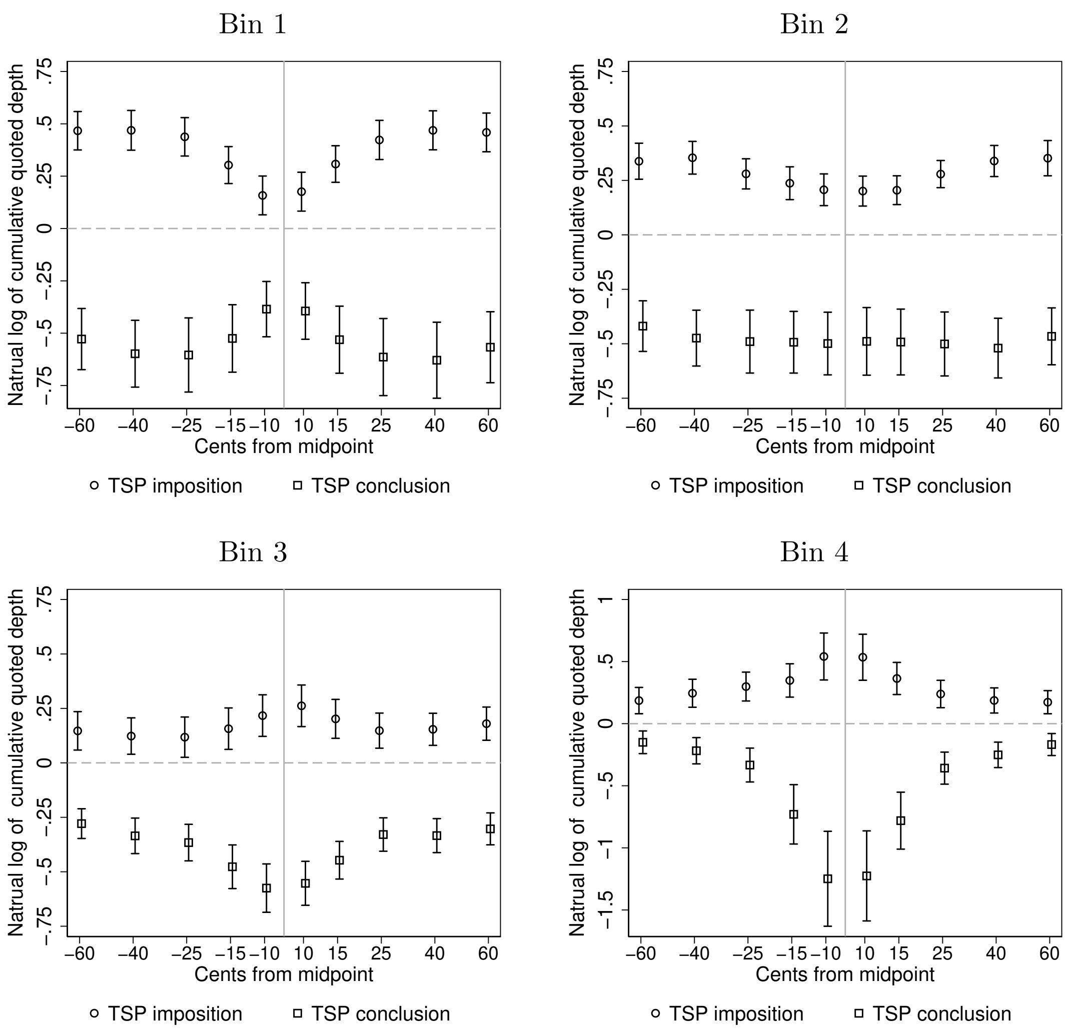

Figure 3. Effective Spreads and Round-Trip Cost of 500 shares: TSP Treatment Effect and Tick Constraints. The figure presents visual evidence of the causal impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, for deferentially tick-constrained stocks. Stocks in the TSP imposition period 08/12/2016-12/14/2016, where tick size increased from 1¢ to 5¢ for pilot stocks, are grouped into overlapping 6¢ intervals of average May and June 2016, i.e., pre-shock, quoted spreads: $\{(0, 6¢), (1¢, 7¢), \ldots, (15¢, 21¢), (16¢, 22¢)\}$. Likewise, stocks in the TSP conclusion period 08/12/2016-12/14/2016, where tick size decreased from 5¢ to 1¢ for pilot stocks, are grouped into overlapping 6¢ intervals of average May and June 2018, i.e., pre-shock, quoted spreads. For each intervals, the effect of a tick size change on dollar effective spreads and the per-share round-trip cost of trading 500 shares are estimated by Equation (1) using quantile (median) regressions that control for date fixed effects and double-cluster standard errors by stock and date. Point estimates of the treatment effects along with the corresponding 95% confidence intervals are plotted against the median pre-shock quoted spread in the respective interval.

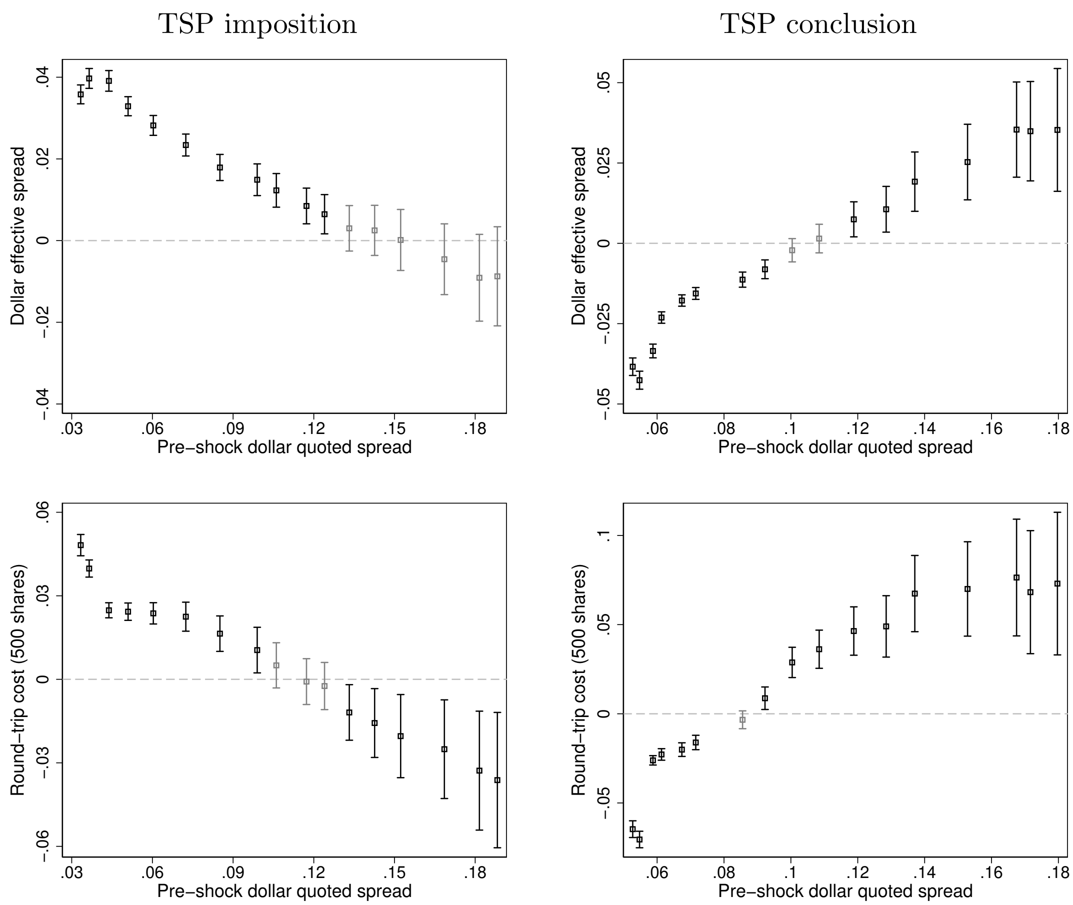

Figure 4. Round-Trip Cost of 100, 250, and 1,000 shares. The figure presents visual evidence of the causal impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, for deferentially tick-constrained stocks. Stocks in the TSP imposition period 08/12/2016-12/14/2016, where tick size increased from 1¢ to 5¢ for pilot stocks, are grouped into overlapping 6¢ intervals of average May and June 2016, i.e., pre-shock, quoted spreads: $\{(0, 6¢), (1¢, 7¢), \ldots, (15¢, 21¢), (16¢, 22¢)$. Likewise, stocks in the TSP conclusion period 08/12/2016-12/14/2016, where tick size decreased from 5¢ to 1¢ for pilot stocks, are grouped into overlapping 6¢ intervals of average May and June 2018, i.e., pre-shock, quoted spreads. For each intervals, the effect of a tick size change on per-share round-trip cost of trading 100, 250, and 1,000 shares are estimated by Equation (1) using quantile (median) regressions that control for date fixed effects and double-cluster standard errors by stock and date. Point estimates of the treatment effects along with the corresponding 95% confidence intervals are plotted against the median pre-shock quoted spread in the respective interval.

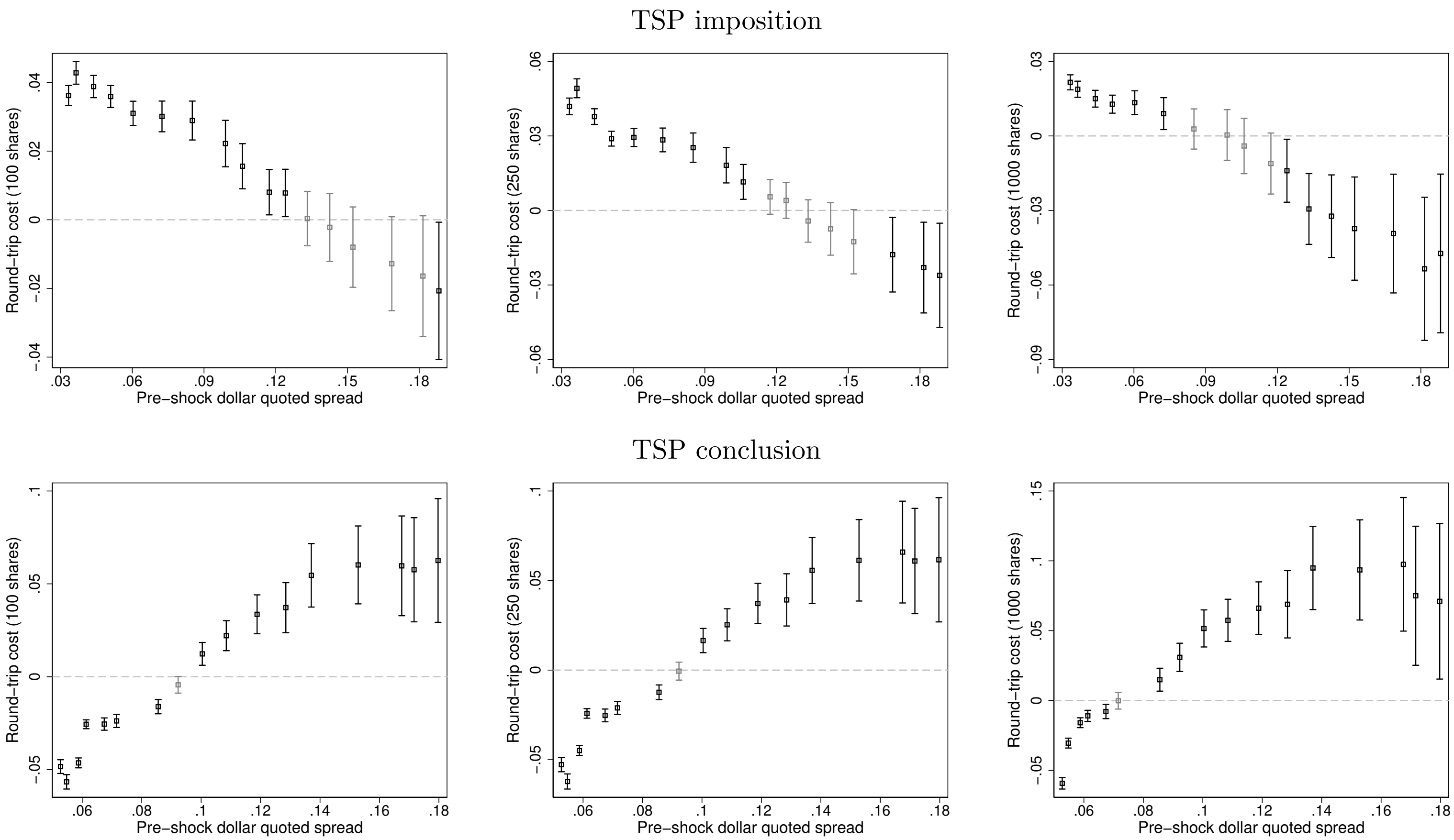

Figure 5. Round-Trip Cost of 1,500, 5,000, and 10,000 shares. The figure presents visual evidence of the causal impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, for deferentially tick-constrained stocks. Stocks in the TSP imposition period 08/12/2016-12/14/2016, where tick size increased from 1¢ to 5¢ for pilot stocks, are grouped into overlapping 6¢ intervals of average May and June 2016, i.e., pre-shock, quoted spreads: $\{(0, 6¢), (1¢, 7¢), \ldots, (15¢, 21¢), (16¢, 22¢)\}$. Likewise, stocks in the TSP conclusion period 08/12/2016-12/14/2016, where tick size decreased from 5¢ to 1¢ for pilot stocks, are grouped into overlapping 6¢ intervals of average May and June 2018, i.e., pre-shock, quoted spreads. For each intervals, the effect of a tick size change on per-share round-trip cost of trading 2,500, 5,000, and 10,000 shares are estimated by Equation (1) using quantile (median) regressions that control for date fixed effects and double-cluster standard errors by stock and date. Point estimates of the treatment effects along with the corresponding 95% confidence intervals are plotted against the median pre-shock quoted spread in the respective interval.

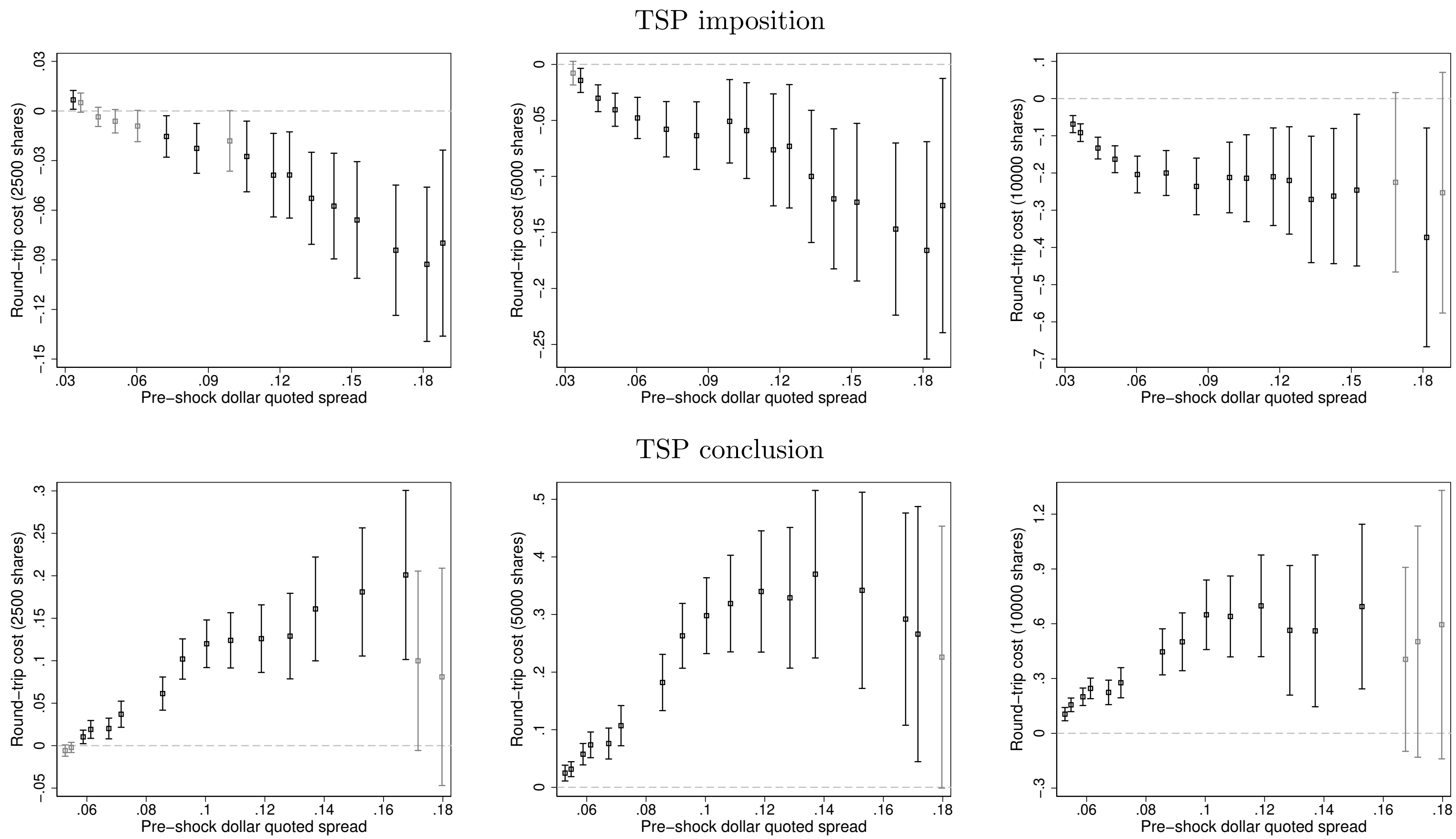

Table 1. Summary Statistics for Key Stock Characteristics. The table presents stock characteristics of the firms involved in Tick Size Pilot program. Stock characteristics are measured in the month of May prior to an increase (from 1¢ to 5¢ in Oct, 2016) and a reduction (5¢ to 1¢ in Oct, 2018) in the minimum tick sizes of treated (G1 and G2) stocks. Means of dollar quoted spread, market-capitalization (in $million), monthly dollar volume ($million), and daily return volatility are calculated for differentially tick-constrained control and treated firms. Differences in means of control and treated firms in each category are reported along with the difference-in-means t-statistics are presented. Panel A presents results for control and treated stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents results for control and treated stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. The numbers in brackets are *t*-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

		Panel A: TSP imposition				Panel B: TSP termination			
		May-June 2016 quoted spread bin				May-June 2018 quoted spread bin			
Variable	Group	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Number of Stocks	Control	369	319	212	259	507	139	126	243
	Treatment	221	193	151	171	231	285	249	209
$ Quoted Spread	Control	0.03	0.06	0.11	0.45	0.03	0.07	0.12	0.53
	Treatment	0.02	0.06	0.11	0.37	0.05	0.08	0.11	0.50
	Difference	0.001	0.001	0.001	0.081	−0.023***	−.002**	.005**	0.033
	t-statistic	[0.53]	[0.70]	[0.50]	[1.20]	[−17.1]	[−2.24]	[2.36]	[0.54]
Market-cap ($M)	Control	646.9	782.8	601.4	449.9	895.1	1324.3	1458.6	844.9
	Treatment	694.2	733.1	591.0	395.7	912.4	1128.2	1287.6	787.5
	Difference	−47.3	49.7	10.4	54.2	−17.3	196.1	171.0	57.4
	t-statistic	[−0.62]	[0.51]	[0.11]	[0.66]	[−0.15]	[1.29]	[1.03]	[0.44]
Dollar Volume ($M)	Control	120.7	139.8	113.6	75.7	200.2	353.2	305.3	165.9
	Treatment	117.5	133.3	128.2	69.1	212.8	243.5	244.8	145.6
	Difference	3.2	6.5	−14.6	6.6	−12.6	109.7	60.5	20.2
	t-statistic	[0.20]	[0.26]	[−0.48]	[0.27]	[−0.35]	[1.37]	[1.21]	[0.43]
Return Volatility	Control	0.029	0.027	0.025	0.024	0.025	0.026	0.020	0.020
	Treatment	0.028	0.026	0.028	0.021	0.026	0.023	0.020	0.019
	Difference	.001	.000	−.004	.003	−.001	.003	.000	.002
	t-statistic	[0.80]	[0.20]	[−1.97]	[1.69]	[−0.50]	[0.95]	[0.15]	[1.00]

Table 2. Minimum Tick Size and the Trade Execution Complexity. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on the complexity of trading trading strategies for differentially tick-constrained stocks. Cancel-to-trade ratio divides the daily number of order cancellations by the daily number of trades; hidden ratio divides the daily number of trades involving hidden orders to the daily number of trades; odd-lot ratio divides the total number of trades involving odd-lot orders by the daily number of trades; and ISO volume share divides the share volume of executed ISOs by total trading volume. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is estimated using median (quantile) and OLS regressions. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: TSP imposition

	QR				OLS			
Dependent variable:	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Cancel-to-Trade	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × Event	−4.26***	−8.27***	−6.54***	−14.3***	−3.72***	−7.98***	−10.2***	−21.6***
	[−7.72]	[−9.81]	[−4.82]	[−7.46]	[−5.78]	[−7.62]	[−4.66]	[−5.31]
Hidden Ratio (×100)								
Pilot × Event	−0.29	−6.15***	−10.6***	−12.1***	−0.44	−6.00***	−11.0***	−13.2***
	[−0.91]	[−17.08]	[−16.24]	[−12.54]	[−1.50]	[−17.98]	[−18.98]	[−15.47]
Odd-lot Ratio (×100)								
Pilot × Event	−2.67***	−3.49***	−1.86**	−2.57**	−1.48***	−2.50***	−1.04	−2.00**
	[−4.59]	[−6.17]	[−2.52]	[−2.36]	[−3.25]	[−5.02]	[−1.42]	[−2.04]
ISO Volume share (%)								
Pilot × Event	−4.90***	−2.58***	−1.63***	−0.69	−4.07***	−2.31***	−2.15***	−0.0092
	[−12.27]	[−6.64]	[−3.59]	[−1.16]	[−13.05]	[−7.86]	[−5.70]	[−0.02]

Panel B: TSP conclusion

	QR				OLS			
Dependent variable:	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Cancel-to-Trade	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × Event	5.24***	9.32***	7.34***	11.9***	4.97***	6.55***	7.17***	18.1***
	[8.32]	[13.22]	[9.79]	[8.90]	[6.40]	[7.76]	[8.57]	[8.50]
Hidden Ratio (×100)								
Pilot × Event	−5.68***	5.35***	15.4***	14.8***	−5.35***	5.07***	15.3***	16.8***
	[−9.80]	[8.28]	[18.78]	[13.01]	[−8.84]	[7.66]	[19.10]	[17.63]
Odd-lot Ratio (×100)								
Pilot × Event	6.29***	5.25***	3.24***	2.69***	5.61***	5.30***	3.01***	2.35***
	[7.98]	[6.91]	[3.94]	[3.08]	[10.45]	[7.59]	[4.17]	[2.88]
ISO Volume share (%)								
Pilot × Event	5.58***	1.74***	−0.24	0.12	5.69***	1.85***	0.13	−0.43
	[11.08]	[4.30]	[−0.59]	[0.25]	[13.19]	[4.82]	[0.39]	[−0.92]

Table 3. Minimum Tick Size and Quoted Spreads. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on time-weighted average dollar quoted spreads for differentially tick-constrained stocks. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is estimated using median (quantile) and OLS regressions. Estimatess control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: TSP imposition

	QR				OLS			
Dependent variable:	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Quoted Spread	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × Event	0.026***	0.028***	0.013***	−0.039***	0.033***	0.025***	0.0091***	−0.027*
	[20.31]	[14.85]	[3.63]	[−3.43]	[68.72]	[20.37]	[2.99]	[−1.77]
Observations	41620	36154	25107	28711	41620	36154	25107	28711

Panel B: TSP conclusion

	QR				OLS			
Dependent variable:	May & June 2018 quoted spread bin				May & June 2018 quoted spread bin			
Quoted Spread	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × Event	−0.055***	−0.023***	0.023***	0.099***	−0.034***	−0.028***	0.023***	0.11***
	[−26.94]	[−9.80]	[5.05]	[4.94]	[−35.39]	[−10.10]	[3.87]	[5.35]
Observations	45769	22221	21536	26270	45769	22221	21536	26270

Table 4. Minimum Tick Size and Quoted Depth at the Best Prices. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on the natural log of time-weighted average quoted depth, in round lots, at the best bid/ask prices for differentially tick-constrained stocks. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is estimated using median (quantile) and OLS regressions. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: TSP imposition

	QR				OLS			
Dependent variable:	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Ln(NBBO Depth)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × *Event*	1.08***	1.04***	0.53***	0.20***	1.05***	0.77***	0.46***	0.19***
	[19.65]	[23.17]	[13.89]	[6.29]	[35.67]	[30.44]	[17.94]	[6.86]
Observations	41620	36154	25107	28711	41620	36154	25107	28711

Panel B: TSP conclusion

	QR				OLS			
Dependent variable:	May & June 2018 quoted spread bin				May & June 2018 quoted spread bin			
Ln(NBBO Depth)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × *Event*	−1.16***	−1.29***	−0.61***	−0.069***	−1.23***	−0.76***	−0.35***	−0.067***
	[−12.51]	[−21.78]	[−17.51]	[−3.18]	[−38.09]	[−29.80]	[−16.58]	[−3.11]
Observations	45769	22221	21536	26270	45769	22221	21536	26270

Table 5. Minimum Tick Size and Trading Outcomes. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on size-weighted average dollar effective spreads, the natural log of average trade size, and regular-hours trading volume, in 1,000 shares, for differentially tick-constrained stocks. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is estimated using median (quantile) and OLS regressions. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: TSP imposition

	QR				OLS			
	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Dependent variable: Dollar Effective Spread	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × *Event*	0.026***	0.030***	0.011***	−0.018***	0.026***	0.018***	0.014***	−0.012
	[26.39]	[22.59]	[5.32]	[−2.95]	[38.38]	[4.15]	[3.59]	[−1.08]
Ln(Trade Size)								
Pilot × *Event*	0.11***	0.090***	0.040***	0.043***	0.089***	0.070***	0.042***	0.044**
	[9.16]	[7.84]	[3.59]	[2.66]	[8.74]	[6.68]	[3.45]	[2.54]
Trading Volume								
Pilot × *Event*	−2.05	2.78	−7.98**	−1.87*	−22.9**	−3.25	−5.93	−2.41
	[−0.20]	[0.49]	[−2.44]	[−1.98]	[−2.06]	[−0.44]	[−1.41]	[−1.45]

Panel B: TSP conclusion

	QR				OLS			
	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Dependent variable: Dollar Effective Spread	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × *Event*	−0.038***	−0.017***	0.0015	0.032***	−0.021***	−0.022***	0.0094**	0.032***
	[−27.59]	[−12.21]	[0.65]	[3.13]	[−8.75]	[−6.72]	[2.10]	[2.76]
Ln(Trade Size)								
Pilot × *Event*	−0.17***	−0.10***	−0.045***	−0.035**	−0.13***	−0.12***	−0.046***	−0.029*
	[−8.17]	[−7.13]	[−3.17]	[−2.31]	[−11.48]	[−8.88]	[−3.52]	[−1.84]
Trading Volume								
Pilot × *Event*	−0.61	−10.7	−7.65	−0.60	43.6**	21.6**	7.67	−7.67**
	[−0.06]	[−1.36]	[−1.66]	[−1.00]	[2.47]	[2.07]	[0.97]	[−2.57]

Table 6. Minimum Tick Size and Round-trip Trading Costs. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on the round-trip cost of trading for different order sizes of differentially tick-constrained stocks. The round-trip cost captures the costs, in dollars per share, of immediately buying and selling a given position size, accounting for available depth in the entire order book. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is estimated using median (quantile) and OLS regressions. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A: TSP imposition								Panel B: TSP conclusion							
Dependent variable:	QR				OLS				QR				OLS			
Round-trip cost of	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
1 round lot	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × Event	.024***	.028***	.013***	−.038***	.034***	.026***	.0081***	−.028*	−.048***	−.024***	.022***	.095***	−.034***	−.028***	.022***	0.12***
	[20.55]	[16.38]	[4.06]	[−3.60]	[76.77]	[23.41]	[2.91]	[−1.96]	[−25.58]	[−10.58]	[5.37]	[4.97]	[−37.73]	[−10.80]	[3.89]	[5.37]
2.5 round lots																
Pilot × Event	.027***	.026***	.0090***	−.046***	.033***	.024***	.0056*	−.037**	−.053***	−.021***	.025***	.096***	−.034***	−.027***	.023***	0.12***
	[20.35]	[14.95]	[2.71]	[−3.90]	[65.55]	[19.78]	[1.87]	[−2.28]	[−26.06]	[−9.08]	[5.53]	[4.74]	[−34.93]	[−9.80]	[3.95]	[4.92]
5 round lots																
Pilot × Event	.036***	.023***	0.0033	−.052***	.030***	.019***	0.0013	−.044**	−.065***	−.014***	.036***	0.11***	−.032***	−.024***	.029***	0.13***
	[20.49]	[12.32]	[0.86]	[−4.07]	[48.07]	[13.55]	[0.38]	[−2.42]	[−27.06]	[−5.41]	[6.63]	[4.85]	[−29.66]	[−7.67]	[4.56]	[4.77]
10 round lots																
Pilot × Event	.045***	.013***	−.0072	−.069***	.024***	.0090***	−.0078	−.061***	−.059***	0.0065	.057***	0.15***	−.029***	−.016***	.044***	0.16***
	[20.64]	[5.81]	[−1.31]	[−4.12]	[26.15]	[4.63]	[−1.62]	[−2.67]	[−28.32]	[1.65]	[7.46]	[4.71]	[−20.44]	[−4.01]	[5.54]	[4.87]
25 round lots																
Pilot × Event	.014***	−.0075	−.030***	−0.10***	.013***	−.013***	−.035***	−.098**	−.0058*	.054***	0.12***	0.18***	−.020***	0.0061	0.10***	0.27***
	[6.04]	[−1.55]	[−2.83]	[−2.99]	[7.21]	[−3.36]	[−3.66]	[−2.52]	[−1.70]	[5.17]	[7.47]	[2.81]	[−8.53]	[0.75]	[6.98]	[5.55]
50 round lots																
Pilot × Event	0.003	−.047***	−.064***	−0.16**	−.0024	−.059***	−.087***	−0.23*	.025***	0.16***	0.32***	0.12	−.0052	.070***	0.23***	0.30***
	[0.68]	[−5.03]	[−2.96]	[−2.38]	[−0.73]	[−7.81]	[−4.67]	[−1.98]	[3.53]	[6.05]	[7.46]	[0.99]	[−1.29]	[4.22]	[8.92]	[3.34]
100 round lots																
Pilot × Event	−.032***	−0.19***	−0.22***	−0.43***	−.066***	−0.24***	−0.29***	0.18	0.11***	0.39***	0.64***	0.42	.035***	0.22***	0.51***	−1.72**
	[−3.80]	[−7.73]	[−3.83]	[−2.72]	[−8.60]	[−13.09]	[−6.51]	[0.20]	[5.68]	[6.38]	[5.66]	[1.51]	[3.90]	[5.16]	[6.89]	[−2.20]

Table 7. Minimum Tick Size, Realized Spreads, and Price Impacts. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on size-weighted average dollar realized spreads and price impacts for differentially tick-constrained stocks. Three versions of realized spreads are calculated with respect to the quote midpoints at 15, 60, and 300 seconds after each transaction. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is estimated using median (qantile) and OLS regressions. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A: TSP imposition								Panel B: TSP conclusion							
	QR				OLS				QR				OLS			
Dependent variable:	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Realized Spread 15s	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Pilot × Event	.0047***	.0045***	.0035***	−.0064***	.0064***	.0037***	.0025***	−.00036	−.0050***	−.0035***	.0033***	.017***	−.0067***	−.0032***	.0076***	.023***
	[21.10]	[13.88]	[4.56]	[−2.92]	[25.33]	[3.33]	[2.76]	[−.08]	[−18.23]	[−8.05]	[4.06]	[4.82]	[−12.57]	[−4.25]	[5.09]	[4.97]
Price Impact 15s																
Pilot × Event	.020***	.020***	.0093***	−.0092**	.019***	.014***	.0094***	−.0057	−.025***	−.016***	−.0021	.018***	−.014***	−.018***	0.0024	.020**
	[26.93]	[18.52]	[5.63]	[−2.29]	[28.85]	[4.71]	[3.21]	[−0.76]	[−25.09]	[−12.67]	[−1.26]	[3.03]	[−7.26]	[−6.72]	[0.77]	[2.45]
Realized Spread 60s																
Pilot × Event	.0042***	.0044***	.0045***	−.0043**	.0060***	.0038**	.0032***	0.00096	−.0045***	−.0035***	.0015*	.015***	−.0055***	−.0037***	.0053***	.019***
	[20.33]	[15.14]	[6.49]	[−2.25]	[24.10]	[2.59]	[3.67]	[0.23]	[−17.02]	[−9.02]	[1.99]	[4.80]	[−11.82]	[−4.18]	[3.75]	[4.12]
Price Impact 60s																
Pilot × Event	.021***	.020***	.0075***	−.0090**	.020***	.015***	.0082***	−.0079	−.026***	−.016***	−.00046	.019***	−.015***	−.019***	0.0048	.023***
	[27.15]	[17.61]	[4.50]	[−2.14]	[28.28]	[5.46]	[2.74]	[−1.00]	[−24.99]	[−11.89]	[−0.25]	[2.98]	[−8.59]	[−6.61]	[1.45]	[2.73]
Realized Spread 300s																
Pilot × Event	.0038***	.0041***	.0049***	−.0041**	.0053***	.0036***	.0044***	0.0026	−.0041***	−.0038***	−.0011	.012***	−.0049***	−.0036***	.0026*	.016***
	[18.97]	[13.93]	[6.79]	[−2.18]	[20.41]	[4.18]	[4.64]	[0.61]	[−16.88]	[−8.30]	[−1.46]	[4.63]	[−8.11]	[−4.47]	[1.85]	[3.39]
Price Impact 300s																
Pilot × Event	.022***	.020***	.0066***	−.0097**	.021***	.015***	.0075**	−.0075	−.027***	−.016***	0.0022	.024***	−.014***	−.018***	.0081**	.032***
	[27.23]	[17.42]	[3.65]	[−2.24]	[28.43]	[5.65]	[2.40]	[−0.91]	[−24.02]	[−11.08]	[1.13]	[3.52]	[−7.04]	[−6.46]	[2.27]	[3.55]

Table 8. Minimum Tick Size and Price Efficiency. The table presents impacts of an exogenous change in tick size on the efficiency of market prices for differentially tick-constrained stocks. AR(1) models of 5-minute midpoint returns are estimated by stock-day. The first two measures reflect the R-squared and the slope coefficients of the AR(1) models. Variance ratios reflect return volatility over given horizon divided by the volatility over a shorter horizon, scaled to fit the horizon of the numerator volatility: 15-second/3×5-minute and 5-minute/5×1-minute. Equation (1) is estimated for these outcomes using median (quantile) and OLS regressions. Daily returns of stock j on day t, calculated using midpoint prices at the open, 1pm, and 4pm, are used to estimate $R_{jt} = \rho_0 + \rho_1 R_{j,t-1} + \rho_2 Pilot_j R_{j,t-1} + \rho_3 Event_{jt} R_{j,t-1} + \rho_4 \left(Pilot_j \times Event_{jt}\right) R_{j,t-1} + u_{jt}$, with ρ_1 and ρ_4 reported in the table. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A: TSP imposition								Panel B: TSP conclusion							
	QR				OLS				QR				OLS			
Dependent variable:	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Intyraday Return AR(1)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Coefficient																
Sample Median/Mean	−.062	−.075	−.087	−0.105	−.067	−.083	−.096	−0.125	−.043	−.044	−.040	−.062	−.053	−.070	−.056	−.092
Pilot × *Event*	−.016***	−.015**	−.0071	.012	−.022***	−.011**	−.0065	.013*	.020**	.022***	.030***	−.0026	.037***	.022***	.029***	−.0015
	[−3.03]	[−2.47]	[−1.07]	[1.40]	[−4.94]	[−2.30]	[−1.12]	[1.87]	[2.53]	[3.51]	[3.91]	[−0.36]	[7.10]	[4.11]	[4.43]	[−0.23]
Variance Ratios																
15s/3×5s																
Pilot × *Event*	−.083***	−.078***	−.052***	−.016***	−.073***	−.062***	−.035***	−.012***	.066***	.062***	.063***	.031***	.067***	.054***	.045***	.033***
	[−1.02]	[−11.74]	[−8.69]	[−3.90]	[−9.09]	[−11.42]	[−7.51]	[−3.04]	[15.46]	[11.86]	[10.39]	[7.02]	[17.68]	[15.66]	[11.06]	[8.60]
5m/5×1m																
Pilot × *Event*	−.087***	−.075***	−.054***	.008	−.060***	−.047***	−.027***	−.00014	.066***	.055***	0.10***	.021***	.057***	.046***	.060***	.020***
	[−7.75]	[−6.47]	[−5.38]	[1.02]	[−8.51]	[−6.79]	[−7.81]	[−.03]	[10.13]	[6.18]	[9.19]	[2.74]	[11.26]	[8.34]	[9.47]	[4.36]
Daily Return AR(1)																
R_{t-1}	−.0081	.0017	−.025***	−.040***	−.0099	.034*	−.062***	−.096***	−.0032	−.011	−.021	−.025***	.0055	−.083	−.012	−0.11**
	[−0.96]	[0.23]	[−3.00]	[−5.18]	[−0.61]	[1.85]	[−2.69]	[−4.15]	[−0.56]	[−1.00]	[−1.54]	[−3.68]	[0.32]	[−1.56]	[−0.52]	[−2.44]
Pilot × *Event* × R_{t-1}	.0025	.011	−.015	.0050	−.052*	.031	−.052	.012	.023*	.014	.0026	.026	.066*	−.056	.024	.041
	[0.20]	[0.79]	[−1.18]	[0.36]	[−1.77]	[0.87]	[−1.09]	[0.29]	[1.79]	[0.78]	[0.15]	[1.47]	[1.85]	[−0.80]	[0.52]	[0.57]

Table 9. Minimum Tick Size and Microstructure Outcomes: Robustness to Estimation at the 1st the 3rd Quartiles. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on various market microstrucure outcomes for differentially tick-constrained stocks. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is augmented with stock characteristics, including market-capitalization, dollar volume, and average quoted spread, measured in the preceding month of June and estimated quantile regressions at the first and third quartile of the respective outcome variable. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A: TSP implementation								*Panel B*: TSP conclusion							
	1st Quartile				3rd Quartile				1st Quartile				3rd Quartile			
Quoted Spread	.010***	.017***	.024***	−.0078	.091***	.047***	−.0056	−.028	−.021***	−.030***	.0084***	.055***	−.032***	−.016***	.025**	0.15***
	[9.82]	[9.33]	[6.16]	[−1.07]	[73.62]	[15.28]	[−1.29]	[−1.15]	[−12.11]	[−12.34]	[2.68]	[3.65]	[−18.28]	[−4.85]	[2.40]	[3.51]
Ln(NBBO Depth)	0.63***	0.32***	0.25***	0.16***	1.33***	1.10***	0.68***	0.23***	−.023	−0.10***	−0.15***	−.056***	−2.45***	−1.30***	−0.46***	−0.13***
	[14.05]	[13.89]	[9.62]	[7.72]	[15.67]	[16.67]	[10.66]	[4.18]	[−0.85]	[−3.69]	[−5.96]	[−3.03]	[−19.80]	[−13.97]	[−8.59]	[−3.53]
Effective Spread	.0067***	.015***	.017***	−.0044	.045***	.025***	0.0037	−.016	−.013***	−.026***	−.0064***	.024***	−.031***	−.013***	.015***	.043**
	[11.70]	[12.43]	[8.54]	[−1.14]	[42.78]	[13.27]	[1.03]	[−0.94]	[−13.89]	[−15.76]	[−4.50]	[3.42]	[−20.37]	[−4.71]	[2.89]	[2.35]
Round-trip cost (bps)	.022***	.012***	0.0072	−.045***	.023***	.010***	−.024***	−.053	−.036***	−.012***	.046***	.065***	−.012***	−.0045	.036**	0.17***
	[9.95]	[5.35]	[1.34]	[−3.72]	[10.63]	[2.75]	[−3.53]	[−1.37]	[−11.71]	[−4.09]	[7.28]	[2.86]	[−5.72]	[−0.65]	[2.48]	[2.66]
Realized Spread (60s)	.0019***	.0022***	.0028***	−.00083	.011***	.0090***	.0047***	−.0025	−.0020***	−.0020***	.0018***	.0075***	−.012***	−.0043***	.0052***	.024***
	[11.97]	[8.01]	[5.38]	[−0.65]	[25.27]	[14.56]	[4.03]	[−0.38]	[−10.84]	[−6.01]	[3.23]	[4.16]	[−21.56]	[−6.37]	[2.91]	[3.18]
Price Impact (60s)	.0064***	.011***	.010***	−.00065	.043***	.019***	0.0026	−.0099	−.013***	−.019***	−.0062***	.012**	−.023***	−.014***	.0066*	.033**
	[13.14]	[10.74]	[7.02]	[−0.22]	[30.63]	[12.46]	[0.93]	[−1.00]	[−15.11]	[−13.06]	[−4.61]	[2.56]	[−15.32]	[−6.32]	[1.83]	[2.55]
Trading Volume	−10.8*	−2.07	−3.63**	0.18	−47.9**	−5.49	−5.81	−3.65	−2.14	−3.11	0.90	−0.30	53.7**	42.3**	8.06	−0.17
	[−1.95]	[−0.61]	[−2.40]	[0.40]	[−2.34]	[−0.39]	[−0.72]	[−1.09]	[−0.39]	[−0.79]	[0.63]	[−0.73]	[2.24]	[2.40]	[0.56]	[−.06]
Cancel-to-Trade	−3.83***	−6.18***	−5.99***	−11.1***	−5.18***	−11.5***	−8.49***	−26.1***	4.73***	6.71***	6.67***	8.31***	5.21***	9.23***	8.01***	21.3***
	[−8.94]	[−1.07]	[−6.48]	[−7.56]	[−4.93]	[−6.07]	[−2.89]	[−4.94]	[11.06]	[12.10]	[11.02]	[8.87]	[4.06]	[6.06]	[5.74]	[6.78]
Hidden Ratio (×100)	0.056	−4.86***	−13.2***	−18.5***	−0.65	−7.26***	−9.65***	−11.2***	−4.09***	4.95***	20.7***	20.3***	−7.18***	4.27***	12.2***	13.7***
	[0.24]	[−15.64]	[−19.51]	[−14.08]	[−1.36]	[−13.51]	[−10.50]	[−7.51]	[−8.56]	[9.89]	[26.15]	[14.91]	[−7.54]	[4.58]	[10.37]	[9.08]
Odd-lot Ratio (×100)	−.080	−2.43***	−1.36	−2.14	−3.95***	−3.99***	−1.59*	−3.24***	5.84***	4.73***	3.10***	3.20***	5.39***	5.73***	3.99***	3.08***
	[−0.14]	[−3.78]	[−1.33]	[−1.61]	[−5.83]	[−6.49]	[−1.84]	[−2.78]	[5.71]	[4.39]	[3.25]	[2.78]	[7.73]	[6.67]	[4.98]	[3.46]
ISO Volume Share	−4.44***	−2.16***	−2.12***	−0.69	−4.28***	−2.22***	−2.30***	0.17	6.63***	2.30***	−0.39	−0.42	4.90***	1.71***	0.011	−0.21
	[−10.72]	[−5.13]	[−4.73]	[−1.12]	[−9.61]	[−5.20]	[−4.35]	[0.28]	[13.65]	[5.86]	[−0.95]	[−0.98]	[7.95]	[3.31]	[.02]	[−0.36]

Table 10. Minimum Tick Size and Microstructure Outcomes: High-Volume Stocks. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on various market microstrucure outcomes for differentially tick-constrained stocks. The sample includes stocks with above median dollar volume in month of May prior to the respective change in tick size. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is augmented with stock characteristics, including market-capitalization, dollar volume, and average quoted spread, measured in the preceding month of June and estimated using median (quantile) and OLS regressions. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A: TSP imposition								Panel B: TSP conclusion							
	QR				OLS				QR				OLS			
	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2018 quoted spread bin				May & June 2018 quoted spread bin			
Dependent variable:	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Quoted Spread	.015***	.024***	.016**	−.033**	.034***	.028***	.011**	0.003	−.075***	−.027***	.015***	0.18***	−.040***	−.033***	.013*	0.11***
	[8.04]	[7.84]	[2.54]	[−2.32]	[38.97]	[17.63]	[2.38]	[.08]	[−32.00]	[−8.85]	[2.94]	[4.85]	[−33.71]	[−9.30]	[1.87]	[4.16]
Ln(NBBO Depth)	1.05***	0.44***	0.27***	0.16***	1.03***	0.80***	0.47***	0.18***	−0.18***	−0.48***	−0.37***	−0.10***	−1.22***	−0.82***	−0.39***	−.098***
	[11.78]	[14.26]	[10.61]	[6.42]	[25.19]	[16.80]	[11.40]	[4.22]	[−3.42]	[−11.78]	[−13.17]	[−4.02]	[−39.37]	[−27.77]	[−15.01]	[−4.55]
Effective Spread	.014***	.028***	.015***	−.017***	.027***	.019***	.013***	0.002	−.041***	−.018***	−0.0028	.064***	−.025***	−.019***	0.011	.042***
	[11.87]	[11.88]	[4.35]	[−2.81]	[25.87]	[11.41]	[3.04]	[0.12]	[−23.44]	[−12.13]	[−1.29]	[4.78]	[−15.66]	[−7.95]	[1.44]	[5.08]
Round-trip cost (bps)	.034***	.013***	0.003	−.051**	.025***	.011***	0.00086	−0.012	−.039***	0.00066	.052***	0.23***	−.037***	−.023***	.034***	0.11***
	[8.41]	[3.79]	[0.32]	[−2.64]	[14.81]	[3.54]	[0.13]	[−0.27]	[−12.09]	[0.13]	[5.36]	[4.14]	[−19.84]	[−4.09]	[3.62]	[3.46]
Realized Spread (60s)	.0026***	.0028***	.0036***	−0.003	.0050***	.0033***	.0029***	0.0021	−.0038***	−.0022***	.0023***	.013***	−.0049***	−.0018***	.0058***	.013***
	[11.16]	[7.23]	[3.54]	[−1.24]	[15.65]	[7.89]	[2.81]	[0.88]	[−15.39]	[−5.48]	[3.56]	[4.47]	[−17.50]	[−3.38]	[3.42]	[4.66]
Price Impact (60s)	.013***	.022***	.012***	−0.0076	.022***	.016***	.0099***	−0.0003	−.032***	−.019***	−.0052**	.041***	−.020***	−.018***	0.0038	.025***
	[12.45]	[12.24]	[4.29]	[−1.62]	[21.86]	[10.12]	[2.97]	[−.02]	[−23.83]	[−11.73]	[−2.48]	[4.06]	[−13.16]	[−8.34]	[0.70]	[4.83]
Trading Volume	−6.17	1.94	5.05	1.75	−35.8**	2.87	−1.07	−10.4*	−2.94	15.1	0.32	8.32	73.4***	44.9***	−4.06	−20.1**
	[−0.37]	[0.16]	[0.38]	[0.18]	[−2.04]	[0.20]	[−.08]	[−1.72]	[−0.17]	[1.14]	[.03]	[0.88]	[2.75]	[3.29]	[−0.32]	[−2.38]
Cancel-to-Trade	−5.05***	−8.35***	−6.44***	−8.40***	−4.86***	−9.30***	−6.34***	−17.3**	7.34***	10.1***	7.09***	11.0***	7.15***	7.36***	6.33***	12.3***
	[−5.74]	[−8.51]	[−4.42]	[−3.88]	[−5.09]	[−5.68]	[−3.18]	[−2.59]	[9.20]	[13.23]	[9.10]	[11.41]	[6.74]	[7.68]	[6.80]	[5.61]
Hidden Ratio (×100)	−0.13	−5.02***	−8.03***	−10.1***	−0.13	−4.64***	−7.55***	−12.0***	−6.57***	4.94***	14.6***	11.6***	−6.80***	3.51***	11.6***	14.7***
	[−0.26]	[−8.41]	[−8.34]	[−8.56]	[−0.28]	[−9.44]	[−11.79]	[−12.90]	[−10.65]	[6.69]	[16.15]	[10.64]	[−9.82]	[5.93]	[17.92]	[16.59]
Odd-lot Ratio (×100)	−5.00***	−5.17***	−4.30***	−2.93*	−4.20***	−5.25***	−4.03***	−3.10**	5.69***	4.38***	3.68***	0.75	5.24***	4.86***	3.76***	1.99**
	[−6.24]	[−6.27]	[−5.00]	[−1.93]	[−7.15]	[−7.36]	[−4.95]	[−2.47]	[6.57]	[5.55]	[4.89]	[0.83]	[7.92]	[7.80]	[5.66]	[2.45]
ISO Volume Share	−5.74***	−2.54***	−1.93**	−0.54	−5.15***	−1.91***	−1.61**	−0.28	6.80***	1.41***	−0.10	0.62	7.28***	1.77***	0.026	0.37
	[−10.14]	[−4.40]	[−2.42]	[−0.73]	[−10.44]	[−3.97]	[−2.33]	[−0.36]	[12.31]	[2.91]	[−0.23]	[0.96]	[13.50]	[3.87]	[.07]	[0.68]

Table 11. Minimum Tick Size and Microstructure Outcomes: Robustness to Inclusion of Stock Characteristics. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on various market microstrucure outcomes for differentially tick-constrained stocks. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is augmented with stock characteristics, including market-capitalization, dollar volume, average quoted spread, and return volatility measured in the preceding month of June and estimated using median (quantile) and OLS regressions. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A: TSP imposition								Panel B: TSP conclusion							
	QR				OLS				QR				OLS			
	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2018 quoted spread bin				May & June 2018 quoted spread bin			
Dependent variable:	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Quoted Spread	.019***	.025***	.012**	−.037**	.034***	.026***	.011**	−0.026	−.057***	−.023***	.021***	0.10***	−.034***	−.027***	.025***	0.13***
	[11.63]	−1.05	[2.44]	[−2.08]	[47.28]	[15.84]	[2.45]	[−1.09]	[−24.45]	[−9.07]	[4.46]	[4.68]	[−29.24]	[−8.83]	[3.89]	[5.47]
Ln(NBBO Depth)	1.03***	0.74***	0.42***	0.21***	1.04***	0.78***	0.46***	0.18***	−0.91***	−1.12***	−0.61***	−.062***	−1.21***	−0.75***	−0.34***	−.059**
	[13.77]	[14.82]	[9.87]	[4.18]	[24.71]	[22.24]	[12.51]	[4.56]	[−9.99]	[−19.08]	[−16.60]	[−2.76]	[−35.29]	[−26.00]	[−14.59]	[−2.60]
Effective Spread	.019***	.028***	.010***	−.018*	.027***	.018***	.013***	−0.013	−.037***	−.017***	0.0014	.034***	−.021***	−.017***	.024**	.046***
	[15.99]	[14.43]	[3.42]	[−1.95]	[35.34]	[9.74]	[3.12]	[−0.81]	[−24.75]	[−11.75]	[0.60]	[3.03]	[−13.58]	[−6.90]	[2.49]	[3.65]
Round-trip cost (bps)	.040***	.012***	−0.0074	−.065**	.025***	.0083***	−0.0044	−.079**	−.044***	.0075*	.060***	0.16***	−.028***	−.016***	.047***	0.16***
	[12.28]	[3.90]	[−0.95]	[−2.52]	[18.82]	[3.09]	[−0.65]	[−2.34]	[−19.05]	[1.77]	[7.28]	[4.55]	[−16.65]	[−3.42]	[5.45]	[4.54]
Realized Spread (60s)	.0036***	.0038***	.0047***	−.0054*	.0059***	.0045***	.0035***	−0.00015	−.0043***	−.0032***	.0023***	.015***	−.0055***	−.0023***	.0081***	.020***
	[13.61]	[9.48]	[4.92]	[−1.83]	[18.65]	[8.91]	[3.28]	[−.03]	[−15.56]	[−7.44]	[2.94]	[4.20]	[−18.09]	[−3.72]	[3.78]	[4.29]
Price Impact (60s)	.015***	.018***	.0074***	−.011*	.021***	.014***	.0095**	−0.012	−.026***	−.017***	−0.001	.019***	−.015***	−.015***	.014**	.025***
	[16.51]	[11.65]	[3.02]	[−1.81]	[28.92]	[8.54]	[2.64]	[−1.11]	[−23.00]	[−11.45]	[−0.54]	[2.71]	[−11.14]	[−7.00]	[2.20]	[2.87]
Trading Volume	3.82	7.28	−8.01	0.80	−32.0**	1.08	−8.45	−2.97	−10.5	−12.9	−6.33	−0.51	53.6**	29.1**	−0.33	−8.49**
	[0.25]	[0.86]	[−1.64]	[0.50]	[−2.08]	[0.10]	[−1.20]	[−1.23]	[−0.89]	[−1.32]	[−0.98]	[−0.55]	[2.43]	[2.50]	[−.04]	[−2.49]
Cancel-to-Trade	−3.61***	−8.16***	−7.14***	−14.7***	−3.00***	−8.82***	−13.3***	−29.7***	5.02***	9.32***	7.36***	12.0***	4.80***	6.76***	6.88***	18.8***
	[−4.76]	[−7.77]	[−4.11]	[−5.61]	[−3.64]	[−6.35]	[−4.34]	[−4.92]	[7.75]	[12.98]	[9.71]	[8.85]	[6.07]	[7.99]	[8.29]	[8.85]
Hidden Ratio (×100)	−0.14	−6.14***	−9.71***	−11.0***	−0.40	−5.78***	−11.3***	−12.8***	−5.87***	5.34***	15.4***	14.9***	−5.52***	5.05***	15.4***	16.9***
	[−0.31]	[−11.83]	[−12.68]	[−8.38]	[−1.00]	[−13.06]	[−13.55]	[−11.18]	[−1.06]	[8.15]	[18.64]	[12.89]	[−9.02]	[7.55]	[19.03]	[17.53]
Odd-lot Ratio (×100)	−2.61***	−3.65***	−1.86**	−3.04**	−1.54**	−2.91***	−1.40	−2.15	6.21***	5.37***	3.16***	2.73***	5.54***	5.35***	2.88***	2.38***
	[−3.20]	[−4.74]	[−2.26]	[−2.13]	[−2.57]	[−4.31]	[−1.57]	[−1.62]	[7.64]	[7.14]	[3.78]	[3.12]	−1.01	[7.92]	[3.88]	[2.95]
ISO Volume Share	−5.19***	−2.55***	−1.29**	0.13	−4.63***	−2.09***	−1.57***	0.95	5.60***	1.77***	−0.26	0.05	5.80***	1.95***	−0.04	−0.44
	[−1.07]	[−5.01]	[−2.08]	[0.19]	[−11.85]	[−5.23]	[−3.08]	[1.43]	[11.19]	[3.88]	[−0.63]	[0.10]	[13.44]	[4.54]	[−0.11]	[−0.92]

Table 12. Minimum Tick Size and Microstructure Outcomes: Robustness to Excluding Penny Stocks. The table presents estimated impacts of an exogenous change in the minimum quoting and trading increment, i.e., tick size, on various market microstrucure outcomes for differentially tick-constrained stocks. Panel A presents the impacts of an increase in tick size from 1¢ to 5¢, using data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Panel B presents the impacts of a reduction in tick size from 5¢ to 1¢, using data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size reduction. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is estimated using median (quantile) and OLS regressions after excluding stocks whose average closing price in the same year's May and June was below $5. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

	Panel A: TSP imposition								Panel B: TSP conclusion							
	QR				OLS				QR				OLS			
	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2018 quoted spread bin				May & June 2018 quoted spread bin			
Dependent variable:	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Quoted Spread	.033***	.026***	.0081**	−.031*	.025***	.027***	.011***	−.047***	−.060***	−.024***	.024***	0.10***	−.037***	−.031***	.025***	0.11***
	[61.90]	[19.86]	[2.61]	[−1.87]	[17.30]	[13.64]	[3.07]	[−3.83]	[−27.13]	[−1.08]	[5.20]	[5.03]	[−33.56]	[−10.91]	[4.02]	[5.49]
Ln(NBBO Depth)	1.03***	0.79***	0.46***	0.17***	1.09***	0.85***	0.49***	0.21***	−0.42***	−0.93***	−0.59***	−.073***	−1.24***	−0.79***	−0.35***	−.067***
	[36.21]	[29.91]	[18.67]	[6.04]	[19.40]	[23.69]	[14.14]	[6.46]	[−7.09]	[−19.15]	[−18.34]	[−3.38]	[−37.65]	[−32.56]	[−16.86]	[−3.22]
Effective Spread	.025***	.015**	.012***	−.014	.025***	.030***	.011***	−.021***	−.039***	−.018***	0.0015	.034***	−.026***	−.027***	.0100**	.031***
	[34.21]	[2.61]	[3.12]	[−1.13]	[23.55]	[21.25]	[5.27]	[−3.33]	[−25.79]	[−12.55]	[0.68]	[3.28]	[−11.56]	[−6.20]	[2.37]	[2.66]
Round-trip cost (bps)	.023***	.0093***	−.011**	−.067***	.040***	.012***	−.011*	−.074***	−.035***	0.0064	.059***	0.15***	−.032***	−.019***	.047***	0.17***
	[21.68]	[4.36]	[−2.17]	[−2.66]	[17.24]	[5.02]	[−1.93]	[−4.05]	[−14.34]	[1.52]	[7.46]	[4.78]	[−19.50]	[−4.56]	[5.56]	[4.98]
Realized Spread (60s)	.0054***	0.0029	.0034***	−.00012	.0037***	.0040***	.0040***	−.0052**	−.0043***	−.0034***	.0019**	.016***	−.0057***	−.0043***	.0055***	.019***
	[22.05]	[1.18]	[3.93]	[−.03]	[17.73]	[13.41]	[5.68]	[−2.58]	[−16.52]	[−8.57]	[2.62]	[5.14]	[−12.75]	[−3.86]	[4.01]	[4.14]
Price Impact (60s)	.020***	.013***	.0069**	−.0092	.021***	.021***	.0078***	−.012***	−.029***	−.017***	−.00074	.020***	−.021***	−.023***	0.0044	.023***
	[26.08]	[3.94]	[2.33]	[−1.06]	[24.35]	[16.88]	[4.50]	[−2.71]	[−23.34]	[−12.16]	[−0.41]	[3.07]	[−11.67]	[−6.41]	[1.42]	[2.76]
Trading Volume	−16.4	−1.32	−3.56	−1.67	4.77	1.05	−6.93*	−1.56	9.99	−3.13	−5.59	−0.88	58.5***	28.2***	4.60	−7.79**
	[−1.29]	[−0.16]	[−0.75]	[−0.90]	[0.40]	[0.16]	[−1.82]	[−1.62]	[0.88]	[−0.37]	[−1.13]	[−1.42]	[2.65]	[2.67]	[0.56]	[−2.61]
Cancel-to-Trade	−4.24***	−8.49***	−8.64***	−21.4***	−4.90***	−8.34***	−7.19***	−14.0***	6.82***	9.86***	7.48***	12.0***	6.99***	7.30***	7.11***	18.2***
	[−6.31]	[−8.31]	[−4.61]	[−5.19]	[−8.20]	[−10.26]	[−5.46]	[−7.40]	[10.63]	[15.23]	[10.57]	[8.96]	[7.61]	[9.07]	[9.16]	[8.65]
Hidden Ratio (×100)	−0.45	−5.58***	−10.7***	−13.6***	−0.26	−5.74***	−10.6***	−12.3***	−5.67***	5.13***	15.3***	15.0***	−5.60***	3.89***	14.7***	17.0***
	[−1.44]	[−17.20]	[−19.29]	[−15.97]	[−0.74]	[−16.05]	[−16.13]	[−12.70]	[−9.64]	[7.68]	[18.85]	[13.07]	[−9.49]	[6.69]	[18.93]	[17.69]
Odd-lot Ratio (×100)	−3.27***	−3.84***	−1.10	−2.75***	−4.12***	−4.13***	−1.92**	−3.00***	6.07***	4.96***	3.33***	2.97***	5.75***	5.27***	3.18***	2.70***
	[−7.26]	[−7.93]	[−1.56]	[−2.76]	[−7.08]	[−7.24]	[−2.58]	[−2.76]	[8.17]	[6.59]	[4.09]	[3.52]	[9.70]	[8.04]	[4.48]	[3.41]
ISO Volume Share	−4.30***	−2.24***	−2.06***	0.08	−4.94***	−2.61***	−1.68***	−0.63	6.03***	1.83***	−0.24	0.03	6.25***	2.05***	−0.18	−0.56
	[−12.40]	[−7.20]	[−5.28]	[0.15]	[−11.40]	[−5.36]	[−3.59]	[−1.08]	[10.59]	[4.39]	[−0.58]	-0.06	[11.95]	[5.44]	[−0.51]	[−1.20]

A Main Effects of Individual Test Groups

This section provides robustness analysis comparing each TSP Test Group, i.e., G1, G2, G3, against the control stocks. This analysis ensures that our main findings are mainly attributable to the changes in tick sizes, rather than the known differences between trading rules across the three groups of treated stocks.

Tables A.1 and A.2 report our estimates for individual Test Groups for TSP imposition and conclusion, respectively. Our main results qualitatively extend across individual Test Groups, indicating that our more granular decomposition of the stocks, based on the extent to which they are tick constraint, helps identifying the very different effects that can emerge as a result of a uniform change in tick size.

The only exception is the share of ISO volume. For G1 and G2, a larger tick leads to a decreased use of ISOs, especially for tick and near-tick constrained stocks. In sharp contrast, a larger tick leads to a significant *increase* in ISO usage in G3 stocks. This finding is consistent with the reliance of institutional investors on ISOs and ATSs. For G1 and G2 stocks, a larger tick raises the depth at the top of the order book, and more so for tick and near-tick constrained stocks. As such, institutions can remove significantly more liquidity from one exchange, which reduces their need to use ISOs that would reveal their significant liquidity needs to other market participants, including predatory high-frequency traders. Recall that G3 stocks are also subject to the Trade-At requirement that significantly limits inside quote off-exchange executions (Comerton-Forde, Grégoire, and Zhong (2019)), an important source of liquidity for institutional investors. Reflecting the migration of liquidity to exchanges in response to the Trade-At requirement, institutional investors must seek liquidity accordingly. It follows that due to the exclusive availability of ISOs to institutional investors, ISO usage must rise, offsetting the negative effects on ISOs driven by the wider tick. Our findings are consistent with the the effect of the Trade-At rule dominating the effect of a wider tick on ISO usage.

Table A.1. Minimum Tick Size and Microstructure Outcomes by TSP Groups: Imposition. The table presents estimated impacts of an exogenous increase from 1¢ to 5¢ in the tick size on various market microstrucure outcomes for differentially tick-constrained stocks. The sample includes data from 08/12/2016-12/14/2016, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2016 quoted spreads of: (1) no more than 4¢, (2) 4¢ to 8¢, (3) 8¢ to 15¢, and (4) greater than 15¢. Equation (1) is estimated using median (quantile) regressions, comparing, separately, stocks in each TSP Test Group to control stocks. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

	Test Group 1				Test Group 2				Test Group 3			
	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Dependent variable:	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Quoted Spread	.021***	.026***	.012**	−.048***	.020***	.026***	.014***	−.032**	.021***	.023***	.013***	−0.023
	[14.61]	[10.96]	[2.58]	[−3.76]	[12.75]	[11.46]	[3.21]	[−2.07]	[15.73]	[9.31]	[2.69]	[−1.58]
Ln(NBBO Depth)	1.05***	0.83***	0.45***	0.18***	1.00***	0.87***	0.50***	0.24***	1.06***	0.79***	0.42***	0.25***
	[14.67]	[16.06]	[9.31]	[4.48]	[13.34]	[15.73]	[10.63]	[5.18]	[15.39]	[16.17]	[9.06]	[5.90]
Effective Spread	.020***	.028***	.013***	−.020***	.019***	.030***	.011***	−.016*	.020***	.021***	.011***	−0.0043
	[18.02]	[16.83]	[4.63]	[−2.70]	[17.02]	[16.35]	[4.03]	[−1.99]	[19.73]	[12.51]	[3.76]	[−0.57]
Round-trip cost (bps)	.043***	.014***	−0.0081	−.078***	.042***	.013***	−0.0076	−.060***	.046***	.0097***	−0.00021	−.062***
	[14.39]	[4.55]	[−1.07]	[−3.67]	[12.88]	[4.55]	[−1.09]	[−2.80]	[16.20]	[3.01]	[−.03]	[−3.11]
Realized Spread (60s)	.0037***	.0042***	.0042***	−.0052**	.0036***	.0042***	.0049***	−0.004	.0032***	.0029***	.0040***	−0.0014
	[15.10]	[10.63]	[5.03]	[−2.18]	[14.22]	[11.34]	[5.52]	[−1.59]	[14.92]	[7.59]	[4.51]	[−0.54]
Price Impact (60s)	.016***	.017***	.0088***	−.011**	.015***	.020***	.0071***	−0.0077	.016***	.015***	.0063***	0.0015
	[18.72]	[13.60]	[3.65]	[−2.00]	[17.18]	[13.39]	[3.38]	[−1.46]	[19.92]	[11.09]	[3.18]	[0.29]
Trading Volume	−9.82	−1.06	−9.45**	−2.76***	9.60	6.91	−5.65	−1.10	3.40	−2.07	−16.0***	−4.99***
	[−0.78]	[−0.15]	[−2.43]	[−4.42]	[0.69]	[0.94]	[−1.47]	[−0.74]	[0.25]	[−0.29]	[−3.73]	[−3.92]
Cancel-to-Trade	−4.86***	−7.96***	−5.31***	−14.0***	−3.54***	−8.32***	−6.97***	−14.5***	−6.04***	−7.94***	−8.31***	−18.0***
	[−7.08]	[−7.30]	[−3.15]	[−6.22]	[−4.71]	[−7.95]	[−4.11]	[−5.56]	[−8.78]	[−8.26]	[−5.24]	[−7.27]
Hidden Ratio (×100)	−0.45	−6.10***	−9.91***	−11.6***	−0.097	−6.13***	−9.75***	−11.0***	−3.41***	−9.67***	−12.9***	−14.1***
	[−1.17]	[−14.09]	[−11.72]	[−9.72]	[−0.22]	[−12.00]	[−12.85]	[−8.58]	[−7.63]	[−16.79]	[−14.19]	[−11.84]
Odd-lot Ratio (×100)	−3.08***	−3.49***	−2.01**	−2.08	−2.41***	−3.70***	−1.95**	−3.15**	−5.88***	−5.11***	−3.61***	−5.65***
	[−4.52]	[−5.34]	[−2.07]	[−1.58]	[−2.99]	[−4.81]	[−2.42]	[−2.24]	[−8.66]	[−5.58]	[−3.63]	[−4.37]
ISO Volume Share	−4.61***	−2.55***	−1.75***	−0.90	−5.19***	−2.60***	−1.58***	−0.50	6.21***	5.61***	6.12***	6.80***
	[−8.94]	[−4.85]	[−3.05]	[−1.23]	[−10.36]	[−5.25]	[−2.95]	[−0.73]	[11.66]	[10.21]	[10.28]	[9.98]

Table A.2. Minimum Tick Size and Microstructure Outcomes by TSP Groups: Conclusion. The table presents estimated impacts of an exogenous decrease from 5¢ to 1¢ in the tick size on various market microstrucure outcomes for differentially tick-constrained stocks. The sample includes data from 08/08/2018-11/20/2018, for stocks with different tick constraint status prior to tick size increase. Stocks are classified into four tick constraint bins according to the average May and June 2018 quoted spreads of: (1) no more than 6¢, (2) 6¢ to 9¢, (3) 9¢ to 15¢, and (4) greater than 15¢. Equation (1) is estimated using median (quantile) regressions, comparing, separately, stocks in each TSP Test Group to control stocks. Estimates control for date fixed effects and double-cluster standard errors by stock and date. The numbers in brackets are t-statistics with ***, **, and * identifying statistical significance at the 1%, 5%, and 10% levels, respectively.

	Test Group 1				Test Group 2				Test Group 3			
	May & June 2016 quoted spread bin				May & June 2016 quoted spread bin				May & June 2016 quoted spread bin			
Dependent variable:	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Quoted Spread	−.049***	−.025***	.020***	0.15***	−.049***	−.022***	.025***	.064**	−.048***	−.018***	.023***	0.11***
	[−18.12]	[−8.97]	[3.51]	[5.03]	[−19.19]	[−7.05]	[4.32]	[2.60]	[−18.40]	[−6.84]	[3.22]	[3.31]
Ln(NBBO Depth)	−0.94***	−0.77***	−0.61***	−.067**	−0.73***	−0.64***	−0.58***	−.073**	−0.96***	−0.88***	−0.64***	−0.19***
	[−8.30]	[−11.57]	[−12.40]	[−2.59]	[−6.77]	[−11.18]	[−12.63]	[−2.50]	[−7.91]	[−13.33]	[−11.36]	[−5.89]
Effective Spread	−.034***	−.019***	0.00056	.047***	−.034***	−.016***	0.0028	0.02	−.033***	−.012***	0.0033	.044***
	[−19.42]	[−10.45]	[0.19]	[3.31]	[−20.14]	[−9.39]	[1.01]	[1.63]	[−19.35]	[−7.72]	[1.00]	[3.26]
Round-trip cost (bps)	−.069***	0.0038	.051***	0.21***	−.070***	0.0085	.056***	0.11***	−.070***	.015***	.052***	0.15***
	[−19.64]	[0.85]	[5.27]	[4.68]	[−22.16]	[1.47]	[5.94]	[2.78]	[−20.75]	[2.85]	[4.48]	[3.16]
Realized Spread (60s)	−.0040***	−.0041***	0.00073	.019***	−.0042***	−.0030***	.0024**	.0096**	−.0032***	−.0010**	.0024**	.022***
	[−13.16]	[−7.84]	[0.72]	[4.68]	[−10.69]	[−6.25]	[2.49]	[2.57]	[−10.32]	[−2.22]	[2.15]	[5.57]
Price Impact (60s)	−.025***	−.017***	−0.0016	.027***	−.026***	−.016***	0.0013	.014*	−.023***	−.014***	0.0016	.023**
	[−16.73]	[−9.50]	[−0.74]	[3.04]	[−19.69]	[−9.71]	[0.60]	[1.79]	[−17.09]	[−9.27]	[0.64]	[2.61]
Trading Volume	−0.15	−1.76	−8.88*	−1.44***	1.60	−21.8***	−6.90	−0.17	13.6	−6.10	6.47	−0.34
	[−.01]	[−0.19]	[−1.70]	[−2.84]	[0.11]	[−2.82]	[−1.37]	[−0.19]	[1.22]	[−0.71]	[1.11]	[−0.35]
Cancel-to-Trade	5.85***	9.50***	7.19***	14.4***	4.24***	8.92***	6.95***	9.27***	7.79***	9.52***	9.52***	13.7***
	[7.32]	[10.87]	[7.65]	[8.55]	[4.51]	[9.42]	[8.10]	[5.49]	[8.99]	[11.04]	[9.56]	[7.38]
Hidden Ratio (×100)	−5.72***	4.92***	13.2***	16.3***	−5.64***	4.39***	12.1***	12.4***	0.69	9.46***	12.7***	16.2***
	[−7.38]	[7.05]	[13.73]	[10.43]	[−6.70]	[4.74]	[13.11]	[8.86]	[0.91]	[10.90]	[11.32]	[9.85]
Odd-lot Ratio (×100)	5.86***	5.49***	2.98***	4.16***	6.09***	5.75***	3.71***	1.34	4.71***	5.44***	4.21***	1.14
	[6.48]	[5.94]	[3.06]	[4.34]	[5.32]	[5.73]	[4.03]	[1.24]	[4.55]	[6.85]	[4.68]	[0.97]
ISO Volume Share	5.62***	1.78***	−0.43	−0.50	5.35***	1.69***	−0.049	0.63	−4.20***	−5.62***	−6.35***	−6.36***
	[8.77]	[3.78]	[−0.85]	[−0.84]	[7.68]	[3.38]	[−0.10]	[1.10]	[−7.87]	[−11.43]	[−9.83]	[−9.54]