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Abstract

This paper studies a recent tick size reduction in the U.S. Treasury securities market and identifies its effects on the market's liquidity and price efficiency. Employing difference-in-difference regressions, we find that the bid-ask spread narrows significantly after the change, even for large trades, and that trading volume increases. Market depth declines markedly at the inside tier and across the book, but cumulative depth close to the top of the book changes little or even increases slightly. Furthermore, the smaller tick size enables prices to adjust more easily to information and better reflect true value, resulting in greater price efficiency. Price informativeness remains largely similar before and after, suggesting that the reduction in trading costs does not result in increased information acquisition. However, there is clear evidence of an information shift from the futures market toward the smaller-tick-size cash market. Overall, we conclude that the tick size reduction improves market quality.

Key words: tick size reduction, bid-ask spread, market liquidity, price efficiency, Treasury securities

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1 Introduction

Tick size, or the minimum price increment, is an important market design feature that influences trading strategies and market outcomes. This is particularly true for limit order book markets, which typically rely on price and time priority rules to determine which orders get executed first. Harris (1994) states that a smaller tick size makes it easier to obtain price precedence and facilitates price competition, thereby reducing transaction costs for those needing to trade. However, Harris (1994) also points out that the smaller tick size reduces the bid-ask spread earned by limit order traders, cutting into the profitability of their strategies. Moreover, the smaller tick lessens the incentive for limit order traders to display order size given that time priority is of lower value and price-improving on existing orders is easier. As a result, the interaction among market participants with varying trading strategies, needs, and incentives, gives rise to market outcomes that are specific to the chosen tick size.

To date, understanding of the effects of tick size on market quality is based on the large literature that examines the history of tick size changes in U.S. equity markets. U.S. equity markets transitioned from a 1/8 dollar tick size to 1/16 in 1997, and from 1/16 to penny pricing in 2001. Many studies find evidence that a smaller tick size leads to lower bid-ask spreads and transaction costs (e.g., Harris 1994, Ahn et al. 1996, Bacidore 1997, Porter and Weaver 1997, and Bessembinder 2000), lower adverse selection costs (e.g., Chakravarty et al. 2005), greater trading volume (e.g., Chordia and Subrahmanyam 1995), and improved price efficiency (e.g., Chung and Chuwonganant 2002 and Zhao and Chung 2006). However, the effects of a smaller tick size on market depth are less conclusive. Some studies find that a smaller tick size does not significantly affect market depth (e.g., Ahn et al. 1996, Bessembinder 2000, and Biais et al. 2005), while others find that market depth is lower or can be lower for certain stocks (e.g., Harris 1994, Bacidore 1997, Porter and Weaver 1997, Goldstein and Kavajecz 2000, Jones and Lipson 2001, and Aitken and Comerton-Forde 2005).

That a small tick size can fail to attract sufficient interest from liquidity providers and harm market depth is especially a concern for smaller and emerging companies because illiquidity in the secondary market can hinder these companies' access to capital. The JOBS Act in 2012 directed the SEC to conduct a study on the effects of the penny tick size on the market quality of small cap stocks. Congress subsequently authorized the SEC to undertake a tick size pilot program, which involved increasing the minimum price increment for roughly 1200 randomly chosen stocks from $0.01 to $0.05, staggered over the month of October 2016. Albuquerque et al. (2018) find that spreads, price impact, and market depth all increased after the tick size increase, and that trading volume declined. Moreover, the authors find that the larger tick size resulted in value loss for the affected firms.

The evidence from the tick size changes in the equity markets indicates a tick size reduction might improve market quality in some dimensions but worsen it in others. Theoretically, both Goettler et al. (2005) and Seppi (1997) intuit that a tick size change has different effects on different groups of market participants, although Seppi (1997) shows that no market participant prefers the tick size to become infinitesimal. Werner et al. (2015) suggest that the effects of a tick size change depend on the existing level of liquidity in the market, the types of traders populating the market, and market structure. Thus, what we have learned from the equity markets might not be germane to what happens in a fixed income market when a tick size reduction occurs.

The fixed income markets still use fractional prices. Although the tick size varies from one instrument to another, there has not been a market-wide change in tick size as in equity markets. Only recently, BrokerTec, an interdealer platform, halved the tick size on the on-the-run 2-year note, from 1/4 to 1/8 of a 32nd of a point (where a point equals one percent of par), starting with the November 19, 2018 trading day. Prior to this event, the tick size on the benchmark 2-, 3-, and 5-year notes had been 1/4 of a 32nd since the platform's inception in 2000, and 1/2 of a 32nd on the longer maturities (7, 10, and 30 years).

We assess how this tick size change affects market liquidity and price efficiency of the 2-year note. This issue is particularly important given the important roles of Treasury securities. They provide pricing benchmarks for other fixed-income securities, and serve as collateral and hedging instruments in numerous financial transactions. They are also a key instrument of monetary policy and store of value, especially during times of market turmoil. It follows that the liquidity and efficiency of the Treasury market are of critical importance to participants in not only the Treasury market but in financial markets generally.

We exploit the fact that the tick size reduction applies only to the 2-year note, and not other benchmark Treasury securities trading on the BrokerTec platform, to identify the effects of the change on market quality. We employ difference-in-difference (DiD) regressions to control for the confluence of factors other than the tick size that might explain changes in market quality. As a result, we can quantify the impact of the tick size change on spreads, trading activity, liquidity provision, and price efficiency.

We find that the bid-ask spread narrows significantly following the tick size reduction. This result obtains because the previous tick size was constraining, as shown by Fleming et al. (2018). A smaller tick relaxes this constraint and enables traders to compete more easily on price, resulting in a tighter spread. We find that the spread faced by large trades also narrows significantly. With lower spreads, transaction costs for market order trades are lower, resulting in greater trading volume. The increase in trading volume appears to be driven by greater use of small, but not the smallest, orders.

We next examine if liquidity supply decreases and the transparency of the supply schedule declines when the tick size is reduced. According to Harris (1997), a smaller price increment makes price-improving easier at the expense of limit order traders. Moreover, the narrower bid-ask spread resulting from a smaller tick reduces the profitability of limit order trading strategies. As a result, limit order traders might switch to using market orders (given that the cost of doing so is smaller), reduce their liquidity provision, and have a greater incentive to hide their order sizes to avoid attracting competition. We find that the tick size reduction leads to lower market depth across the whole book, including depth at the inside tier, although cumulative depth within 2/256 (the pre-change tick size) of the best bid-ask midpoint is comparable with, or even slightly higher than, the pre-change inside depth. Therefore, concern about a reduction of liquidity supply in a smaller tick size environment is seemingly not borne out, at least for market depth near the top of the book.

Our analysis also considers the effects of a smaller tick on the price efficiency of the market. We first establish that the smaller tick improves pricing flexibility, with price moves more frequent after the tick size reduction. Nonetheless, realized volatility decreases, consistent with a shrinking microstructure noise component attributable to price discreteness. Next, we show that with a finer pricing grid, the magnitude of autocorrelation of price changes decreases significantly, and the variance ratio of 10-second returns and 1-minute returns gets closer to 1. Zero autocorrelation in price changes and a unity variance ratio are important properties of a price process that follows a random walk and in which information is incorporated immediately. Thus, the shrinking autocorrelation after the tick size change implies that the price process is getting closer to its efficient benchmark. Bolstering this conclusion is our evidence of a significant decrease in pricing errors following the tick size reduction event.

The most novel part of our findings is the evidence that the smaller tick size, and hence lower trading costs, does not result in increased information acquisition. Price impact of trades does not change, while information share of trades even decreases. Information measure based on data from both the cash and futures markets corroborates the lack of an increase in the amount of information in the market. However, there is strong evidence of an information shift toward the cash market after its tick size is lowered.

Overall, our findings suggest that the tick size reduction improves liquidity. It also improves price quality, mainly through greater price efficiency rather than increased information. Many of our findings are consistent with prior evidence documented for equity markets. However, different from equity markets, we find that the tick size reduction does not adversely affect the cost of large trades and does not discourage liquidity provision near the inside of the market. In addition, unique to our work is the opportunity to analyze the joint cash-futures price discovery, which helps shed lights on aggregate information and the role of tick size in informed traders' decisions and preferences. Our study complements the extant literature on tick size by contributing the first empirical analysis of the impact of a tick size change in the U.S. Treasury securities market.[1]

The paper is organized as follows. In Section 2, we provide key institutional details about the U.S. Treasury securities market and the tick size reduction. In Section 3, we review the related literature to highlight our contributions and develop key hypotheses. We then describe the data and variables in Section 4. We present a univariate analysis of key market quality metrics around the tick size reduction event in Section 5. Section 6 reports multivariate analysis results. Section 7 provides concluding remarks and outlines planned future work.

2 Background

U.S. Treasury securities are debt instruments issued by the U.S. government through public auctions and subsequently traded in the secondary market. The secondary market is structured as a multi-dealer, over-the-counter market, in which the dealers trade with their customers and one another. Inter-dealer trading prior to 1999 was based on a network of voice-assisted brokers. Fully electronic trading started in 1999 with the introduction of the eSpeed platform, followed by the BrokerTec platform in 2000. Nearly all inter-dealer trading of on-the-run U.S. coupon securities occurs via electronic platforms and BrokerTec accounts for about 80% of trading in this segment of the market.[2] From November 2, 2018, BrokerTec is under the ownership of CME Group, which operates the Treasury futures market.

[1]Alampieski and Lepone (2009) analyze the impact of a tick size reduction in the Australian Treasury futures market and find that the reduction improves liquidity and reduces execution costs.

[2]Electronic brokers account for 87% of trading in on-the-run coupon securities that occurs through interdealer brokers; see https://libertystreeteconomics.newyorkfed.org/2018/11/breaking-down-trace-volumes-further.html. According to Greenwich Associates, based on 2017 Q4 data, BrokerTec's market share in the electronic inter-dealer market is 80%, that of NASDAQ Fixed Income (formerly eSpeed) is 11%, and the rest of the market is split among Dealerweb, LiquidityEdge, FENICS, and dealer-owned internalization/crossing platforms. For more details, see https://www.greenwich.com/blog/does-cme-own-us-treasury-market.

Trading in the inter-dealer market spans 22-23 hours per day during the week, commencing around the start of the trading day in Tokyo (at 18:30 EST or 19:30 EDT the previous day in the U.S.) and concluding with the end of the trading day in New York (at 17:30 ET; see Fleming 1997). During these hours, dealers enter orders with brokers which may then be executed, modified, or cancelled. Each order specifies a quantity and price, and whether it is for purchase or sale. Whether an order is aggressive or passive is determined by the order price relative to the prevailing best prices in the limit order book. Aggressive orders are typically priced at the prevailing best price on the opposite side and are immediately executed.[3] Passive orders are queued in the order book according to the price and time priority until executed or cancelled.

Historically, participation in the two largest electronic platforms was limited to dealers. However, as the platforms opened to other professional traders in recent years, the presence of non-dealer participants increased significantly. According to the Joint Staff Report (2015), principal trading firms (PTFs) account for 56% of trading volume in the on-the-run 10-year note on BrokerTec, compared to bank-dealers' share of 35%.[4]

Consistent with the increased speed of quoting and trading in electronic markets, the platforms upgraded their technology over the years, and instituted a number of market design changes. The most recent and significant market design change occurred when BrokerTec and eSpeed halved the minimum price increment in the 2-year note, effective with the start of trading on November 19, 2018. With that change, the tick size for the note became 1/8 of a 32nd of a point, equivalent to 1/256 or 3.90625 cents per $1,000 par, whereas the tick size on all other Treasury securities remained unchanged. Prior to this change, the 2-, 3-, and

[3]Aggressive orders are rarely priced beyond the best price on the opposite side because of the availability of the workup protocol, which allows market participants to transact additional quantities at an existing trade price. See Fleming and Nguyen (2018) for further details. Also note that we use the terms "aggressive order" and "market order" interchangeably in this paper

[4]The remaining 9% is split among non-bank dealers and hedge funds. Statistics are based on data from April 2-17, 2014.

5-year notes all had a tick size of 1/4 of a 32nd (or 1/128). The longer-term notes (7- and 10-) and the 30-year bond all have a tick size of 1/2 of a 32nd (or 1/64).

The tick size on the 2-year Treasury futures contract traded on the CME Group's CBOT remained unchanged at 1/4 of a 32nd when the tick size reduction occurred in the cash market, but was lowered to the same tick size on January 13, 2019. The phasing in of the tick size reduction, first in the cash market and subsequently in the futures market, provides for a great empirical setup to identify the impact of the tick size reduction on the change in price informativeness between the cash and futures markets.

3 Related Literature and Hypothesis Development

The minimum price increment in a limit order market affects the economic incentives of participants in demanding and supplying liquidity. Tension exists between the need for greater price competition versus the sufficiency of incentives to encourage liquidity provision. Traders demanding liquidity (by submitting market orders) benefit from the increased price competition enabled by a smaller tick size. Traders providing liquidity (by submitting limit orders), in contrast, suffer from the lower profit of such activity and the increased probability of being price-improved by other traders when the tick size is smaller. The interactions of these opposing incentives give rise to four main hypotheses, which we test here.

First, a smaller tick size is expected to narrow the bid ask spread and increase liquidity demand. As Harris (1997) argues, a finer pricing grid makes it easier for traders to improve on prices to gain priority. The pricing competition will tighten the bid-ask spread if the previous tick size was constraining. A constrained tick size is indeed the case for the 2-year note before the tick size reduction. Based on BrokerTec data over the 2010-2011 period, Fleming et al. (2018) show that the bid-ask spread on the 2-year note equals one tick nearly 95% of the time. A reduced tick size relaxes this constraint and enables traders to compete more easily on price, resulting in a tighter bid-ask spread. A large number of empirical studies on the

U.S. equity markets find evidence supporting this prediction (see e.g., Harris 1994, Ahn et al. 1996, Bacidore 1997, Porter and Weaver 1997, and Bessembinder 2000).

A direct consequence of a tighter bid-ask spread is lower transaction costs for market order trades. Consequently, some traders who otherwise would have submitted a limit order may choose to submit a market order instead. Indeed, Goettler et al. (2005) show theoretically that a smaller tick size improves welfare for market order submitters at the expense of limit order submitters. Furthermore, if a finer pricing grid encourages more information acquisition, as we later explain in the formulation of hypothesis 4, the increased information will likely increase the demand for liquidity, resulting in higher trading volume and frequency. The evidence on the SEC's tick size pilot program documented in Albuquerque et al. (2018) supports this argument (albeit in the opposite scenario), with an increased tick size leading to decreased trading volume.

Thus, to evaluate the view that a smaller tick size is beneficial to demanders of liquidity, we test the following hypothesis:

> *Hypothesis 1: After the tick size reduction, the bid-ask spread decreases, while trading volume and trading frequency increase.*

We next consider the liquidity supply side. Traders who submit limit orders provide liquidity to the market. In doing so, however, they expose their trading intention (see Harris 1997). They trade off the speed of execution and the exposure of trading intention for earning the bid-ask spread. If lower bid-ask spreads indeed prevail after the tick size reduction, it follows that the profitability of the limit order submission strategy is reduced. Goettler et al. (2005) predict a general reduction in depth because fewer traders are willing to provide liquidity given the lower profitability. Furthermore, the fraction of market order traders increases relative to that of limit order traders, resulting in faster execution of limit orders and consequently fewer limit orders in the book. Biais et al. (2005) also predict that a decrease in tick size will reduce depth at each price on the new pricing grid. However, they argue that cumulative depth at the original set of prices should remain unchanged. Essentially, liquidity providers redistribute market depth on a finer pricing grid.

Werner et al. (2015) propose a new model of limit order markets with less restrictive assumptions than that in Goettler et al. (2005). They find that traders do not necessarily switch from limit orders to market orders following a tick size reduction as in Goettler et al. (2005). Instead, in an already liquid market, a reduction in the tick size increases competition among liquidity providers, resulting in increased aggregate depth. This prediction is opposite to the prediction in Goettler et al. (2005), although both models predict a narrower spread and lower inside depth.

Empirically, studies by Harris (1994), Bacidore (1997), Porter and Weaver (1997), Goldstein and Kavajecz (2000), Jones and Lipson (2001), and Bacidore et al. (2003) all document an overall reduction in depth, not just the depth at the new, narrower bid-ask spread. The evidence in these studies suggests that limit order traders reduce their liquidity provision (relative to the liquidity consumption by market order traders), rather than just redistributing liquidity on the new finer pricing grid.

With our data on the full limit order book, we are able to test whether liquidity supply decreases at various tiers, at various distances from the best bid-ask midpoint, and across the whole book. Our findings can therefore contribute to the above literature by delineating whether there is just a redistribution of depth in the book or an overall reduction in liquidity.

We also expect that limit order traders are likely to reduce their order exposure through the use of less transparent order types available and/or through a reduction in order size. This is a natural response to the increased risk of attracting competition in a smaller tick size environment. The issue of order exposure strategies varying with tick size is extensively discussed in Harris (1994, 1996, 1997). Empirically, Harris (1996) investigates the unconditional relation between order exposure and tick size using data from the Paris Bourse and the Toronto Stock Exchange, and finds that traders are more likely to display orders when the tick size is larger. Likewise, Bacidore et al. (2003) find that traders reduce limit order size following the NYSE's decimalization. On the BrokerTec platform, traders can manage their order exposure through orders submitted in workups (see Fleming and Nguyen 2018), or iceberg orders (i.e., orders with partially displayed size).[5] We expect to see the use of these order types and minimum-sized orders increase after the tick size change.

Our hypothesis on the effects of the tick size reduction on liquidity supply is:

> *Hypothesis 2: After the tick size reduction, market depth decreases. Cumulative depth within the same distance from the best bid-ask midpoint also decreases. The prevalence of workups and iceberg orders increases. The prevalence of minimum-sized orders increases.*

After addressing market liquidity, we next study whether the tick size reduction improves price quality in terms of incorporating information. Such an improvement could derive from the greater flexibility with which prices can move and the greater price competition enabled by a smaller tick size, and can occur even in the absence of increased information acquisition. This is one of the insights of Goettler et al. (2005)'s work, which concludes that a smaller tick size increases the precision of observed prices as a proxy for the true value. Harris (1997) argues that a smaller tick size benefits fast traders the most. They can price-improve more easily, and, with the diminished value of time precedence, they can submit and cancel orders more frequently in response to changing market conditions and news arrival. In consequence, we expect the observed price process to exhibit properties that approach those of a random walk of the efficient price process.

Empirical evidence to date provides support for the above predictions. Chung and Chuwonganant (2002) study the effect of tick size reduction on quote revisions in U.S. equity markets, first from 1/8 to 1/16 in 1997, and second from 1/16 to 0.01 in 2001. They find that as the tick size becomes smaller, price competition increases, and prices become less

[5] Completely hidden orders are not available on the BrokerTec platform.

rigid and more efficient. Consistent with this, Albuquerque et al. (2018)'s study on the SEC tick size pilot program finds a decline in price efficiency for stocks whose tick size increases.

Based on prior theoretical and empirical works, we expect that price efficiency improves after the tick size on the 2-year note is reduced and formulate our hypothesis as follows:

> *Hypothesis 3: After the tick size reduction, quote revisions increase. The frequency of price movement increases. Prices become more efficient.*

Price quality might also improve from increased information acquisition as a result of the tick size change. Anshuman and Kalay (1998) argue that when the tick size is smaller, the cost of price discreteness is lower, thereby raising the net gain from acquiring and trading on private information. They predict that informed traders will invest more in information acquisition, which results in more information being subsequently incorporated into prices. Thus, prices become more informative when the tick size is reduced. That said, a countervailing force to increased information acquisition is that a smaller tick size also makes price-improving easier and less costly. Traders who can free-ride on the information can dampen the incentive of informed traders to acquire information. Empirically, Zhao and Chung (2006) find evidence that a tick size reduction increases information-based trading, suggesting that the free-riding concern is not strong enough to outweigh the information acquisition incentive.

However, recent work by Davila and Parlatore (2019) indicates that a change in trading costs can increase or decrease price informativeness, depending on the nature of heterogeneity among market participants. More specifically, a reduction in trading costs increases (decreases) price informativeness if the overall demand of informed traders is more (less) sensitive to trading costs than that of liquidity traders. If market participants are ex-ante identical, trading costs are irrelevant to price informativeness. In consequence, the effect of the tick size reduction on information acquisition can be ambiguous and is an open empirical question.

We therefore state our null hypothesis as follows, noting that a rejection of the null in either direction would shed some lights on the sensitivity of informed traders' asset demand to trading costs in this market.

Hypothesis 4: After the tick size reduction, price informativeness does not change.

It is important to note that the staggered timing of the tick size reductions in the Treasury cash and futures markets provides a unique opportunity to investigate how tick size affects informed traders' decisions. The existence of two parallel markets for the price discovery of the 2-year interest rate allows for the extraction of the underlying efficient price process, based on which we can make inferences about the amount of information aggregated into prices. By studying the contributions of the cash and futures instruments to the variation of the common efficient price process around the tick size reduction, we contribute novel findings on the effect of the change on informed traders' trading preferences.

4 Data and Variable Construction

4.1 Data

Our analysis is based on order message data from the BrokerTec platform. All order messages sent to the platform are captured and time-stamped to the microsecond. We reconstruct the limit order book by accumulating these order changes at the appropriate price tiers from the beginning of each trading day. This results in a tick-by-tick dataset with market depths measured in millions of dollars (par value), and prices reported in 256ths of a point, where a point equals one percent of par.

We also extract the complete transaction history for each security based on the raw order message data. The data clearly indicates which side initiates a given trade, along with the traded quantity and price. The data also contains information to flag whether a trade is executed during a workup.

Our sample period is the fourth quarter of 2018. This period brackets the introduction of the smaller tick size on November 19, 2018. We exclude the last five trading days of December (i.e., after December 21, 2018) from our analysis so as not to confound the effects of the tick size reduction with the extreme volatility across financial markets at the time, as well as the usual year-end decline in trading activity and liquidity. Our sample has 56 trading days in total, of which 33 are in the pre- and 23 are in the post-change subsample. Even though the market operates almost round the clock, the majority of activity occurs during New York trading hours (7:30–17:30 ET). Thus, to avoid the effects of potential irregularities during the overnight hours, we use data for the New York trading hours in our main analysis.

Data on Treasury futures contracts (2-, 5-, 10-, and 30-year tenors) are from Thomson Reuters Tick History. The futures data are at the one-second frequency, and include last trade price, best bid and ask prices, number of trades, and trading volume. Given the limited scope of the futures data, we can only compute trading activity measures and price-based liquidity measures. As is standard in the literature, we use the front-month contract (i.e., the contract with the closest maturity) for each tenor until the first day of the delivery month, at which point we switch to using data on the next maturity contract. Front-month contracts are typically the most liquid contracts until just before the first day of the delivery month when traders roll over their interests to the next maturity contracts.

4.2 Variable Construction

To test the first hypothesis, we construct the following variables. BAS is the inside bid-ask spread, which is the difference between the best ask price and the best bid price. For intraday analyses, we use the BAS measured as of the end of each minute. For analyses requiring the daily average, we use the simple average of end-of-minute BAS during the day. To see the impact of the tick size change on large trades, we also compute BAS_L, which is the bid-ask spread for executing a large trade ($50 million), defined by the 99th percentile of the trade size distribution prior to the tick size change. $Pct1Tick$ is the percent of time the bid-ask spread is at one tick, indicating how constraining the tick size is. TV and $Tfreq$ are the total trading volume and the total number of trades in a given time interval.

Next, we compute the following variables capturing the liquidity supply side of the market. $D1$ and $D5$ are respectively depth at the inside tier and at the best 5 tiers.[6] To facilitate a fairer comparison of the change in depth when the market transitions to a finer pricing grid, we compute (for the 2-year note only) $D1A$ and $D5A$ as the cumulative depth within one pre-change tick (2/256) and five pre-change ticks (10/256) of the bid-ask midpoint respectively (corresponding to 2 and 10 post-change ticks). Thus, $D1A$ and $D5A$ measure the amount of liquidity available at a fixed spread cost for liquidity demanders. These adjusted depths help us isolate the change in quantity from the effect of the increased granularity of the price grid. To provide a complete view of the change in liquidity supply between the two tick regimes, we also compute DT, the total depth across the whole book. All these depth measures reflect the average of the bid and ask depth. As with the spread variables, we compute these depth variables at the end of each minute. Where daily statistics are needed, we aggregate depths to the daily level by averaging end-of-minute observations for the day.

To examine how the tick size reduction alters traders' exposure strategies, we calculate the propensity to use iceberg orders and workups. These are order types available to traders to reduce the exposure of their trading interests. Specifically, iceberg orders allow limit order traders to display just part of their order size. We compute ICE as the fraction of orders submitted with some hidden size.[7] Workups, on the other hand, are helpful particularly for market order traders with a large trading interest because they can trigger a trade with a smaller initial size and subsequently work it up subject to available liquidity in the market. We measure workup activities by the fraction of workup trades, both in terms of count ($WKUP\_N$) and volume ($WKUP\_V$).

[6] Although market participants with API access to the platform can view the complete order book, many market participants can only see the best five tiers within the live orderbook as they trade.

[7] Since April 1, 2015, the BrokerTec tick history files have not revealed the extent of the hidden size, but they do still indicate whether an order contains hidden size.

Another strategy that traders can utilize to manage their exposure is to reduce order size, in which case the size of each execution will be smaller. For this, we compute $AVSZ$, the average trade size, and $MinSz$, the fraction of minimum-sized trades (the minimum order size is \$1 million par). Both of these variables allow us to study whether aggressive traders alter their order sizing strategy. A parallel construct for limit order traders is $MinSz\_LO$, the fraction of minimum-sized limit orders. We also compute the total number of limit orders submitted to the limit order book each day NLO to better understand if the change in sizing decision is accompanied by a change in the frequency of order activities.

To examine whether prices become more flexible and efficient after the tick size reduction, we compute the following measures. $ZeroBA$ is the fraction of zero one-minute midpoint returns during a trading day. This measure captures the extent to which the best bid and ask prices do not change. If quote revisions are more frequent and price competition is more intense with a smaller tick size, we should see this fraction decrease. $ZeroT$ is computed similarly, except that the returns are based on the last trade price of each minute. $CancelTime$ measures the time from order submission to order modification or cancellation. This variable reflects the intensity with which limit order traders update their orders. RV is realized volatility based on one-minute changes in log mid-point price, i.e., $RV = \sqrt{\sum_{t=1}^{N}[\ln(p_t) - \ln(p_{t-1})]^2}$.

We compute the following measures of price efficiency. $AR30$ is the absolute autocorrelation of 30-second returns based on the best bid-ask midpoint (so that the measure is not contaminated by the bid ask bounce associated with trade prices). If the price process follows a random walk, autocorrelation should be zero. A reduction in the magnitude of the autocorrelation indicates that the observed price process gets closer to its random walk benchmark. $VR_{10s,1m}$ is the ratio of six times the daily variance of 10-second returns to that of 1-minute returns. The variance ratio should equal 1 if the price process is a random walk. In our tests, we use $|VR - 1|$ because we are interested in seeing whether the variance ratio gets closer to 1 after the tick size change.

The third price efficiency measure is the standard deviation of Hasbrouck (1993)'s pricing error $PErr$. Hasbrouck (1993) decomposes observed price into an efficient component and a pricing error. The standard deviation of the pricing error component indicates how precise the observed price reflects the efficient price. A smaller $PErr$ implies a more efficient (observed) price. For the decomposition, we follow Boehmer and Kelley (2009)'s vector autoregression specification, which has 5 lags and consists of log trade-by-trade return, trade sign indicator (1 for buyer-initiated trades and -1 for seller-initiated trades), signed volume (positive trade size for buyer-initiated trades and negative trade size for seller-initiated trades), and signed square root of volume (to capture any non-linear effects of trade size on returns). Returns are computed from the bid-ask midpoint prevailing at the time of trade, again to avoid the effect of the bid-ask bounce in trade prices.

The last group of variables aim to measure price informativeness. The first is the price impact of trade PI_V. This is a proxy for the degree to which information is revealed through trades (in the spirit of Kyle 1985's lambda), and helps us assess the impact of the tick size change on the amount of private information being traded upon. We measure PI_V by the slope coefficient from the regression of one-minute bid-ask midpoint changes on net order flow over the same minute. We compute net order flow as the difference between buyer-initiated and seller-initiated trade volume. We scale the resulting coefficient so that it reflects the price impact in basis points (bps) per \$100 million increase in net order flow.

To supplement the price impact measure, which might include transitory effects unrelated to information, we also compute the information share of trades. We compute this from the VAR(5) model discussed above for estimating $PErr$. From this model, we compute the information share of trade $Trade\_IS$, which is the contribution of trade-related variables to the variance of efficient returns. An increase in $Trade\_IS$ indicates increased information being revealed through trades. Because the information share is sensitive to the causal ordering of variables in the VAR model, we calculate both the lower and upper bounds for

$Trade\_IS$, corresponding to when trade variables are placed last and first in the ordering, respectively. We often focus on the lower bound in the discussion of results to be conservative.

Finally, we construct a proxy for the amount of information in the market by exploiting the fact that the cash market and the parallel market for the 2-year note futures are tightly linked through the no-arbitrage principle. Mizrach and Neely (2008) establish that on-the-run cash and futures prices are cointegrated. According to Hasbrouck (1995), we can extract the underlying efficient price process from the two observed price processes with a vector error correction model (VECM). We estimate a VECM with 10 lags on cash and futures prices sampled at one-second frequency (the highest frequency available for futures price data) separately for each day and calculate the variance of the random walk process Var_RW. Var_RW measures the amount of information in the market and is useful for our tests of whether the tick size reduction encourages greater information acquisition. Furthermore, we compute the contribution of the price variation in the cash market to Var_RW. Examining the evolution of the cash-futures split in price discovery through the tick size reduction in the cash market helps yield insights into the role of tick size in attracting informed traders.

5 Univariate Analysis of Market Quality Changes

This section provides a univariate analysis of market liquidity and quality metrics of the 2-year note before and after the tick size reduction. These metrics are aggregated to the daily level. From the daily statistics, we compute the pre- and post-change averages, perform t-tests on the differences, and report the results in Table 1. We provide time series plots for several key metrics in Figures (1)–(6).

Panel (a) of Figure 1 shows an immediate drop in spreads following the tick size reduction. The inside bid-ask spread decreases by almost one half (47% decrease per Table 1) to just slightly above the new tick size. The bid-ask spread faced by large trades BAS_L decreases as well, but to a lesser extent than that of small trades. The plot of $Pct1Tick$ in Panel (b) indicates that the new tick size is less constraining. As reported in Table 1, the fraction of time the spread equals 1 tick decreases from roughly 99.2% for the old tick to about 92.6% for the new tick. Overall, the evidence suggests that the market for the 2-year note is liquid enough such that a reduction in the tick size does not adversely affect the cost of executing large trades, and that a reduction in the tick size eases the constraint on the spread.

The pattern of trading activity plotted in Figure 2 indicates a slight upward trend in both trading volume and trading frequency after the tick size reduction. Table 1 shows that the daily trading volume in the 2-year note increases by about $6.9 billion, or 33%. The number of trades increases an even larger 60%. Consistent with both facts, the average trade size decreases by nearly 20% from $6.97 million to $5.64 million. Interestingly, the decrease in the average trade size is not driven by an increased use of the smallest possible orders. The fraction of $1 million-sized trades (i.e., trades at the minimum trade size) actually decreases by about 4 percentage points. Panel (a) of Figure 3 compares the distributions of trade size before and after the tick size reduction, and reveals a sharply increased prevalence of $2 million trades after the tick size reduction. Moreover, the prevalence of extreme trade sizes (defined as trades of $20 million and above) decreases, contributing to lowering the average trade size after the tick size change. Lastly, volume of workup trades does not seem to change, although the percentage of workup trades decreases slightly from 85% to 80%.

Analyzing market depth, we learn several important facts. Figure 4 shows that market depth at the inside tier ($D1$) and at the best 5 tiers ($D5$) drops abruptly. However, considering the increased granularity of the price grid after the tick size reduction, a fairer comparison is on depth at a given price distance from the bid-ask midpoint. If one compares cumulative depth within 1 pre-change tick of the midpoint, post-change depth even upticks slightly ($DA1$). Cumulative depth within 5 pre-change ticks of the midpoint ($D5A$) also appears comparable. In short, the amount of liquidity that matters for immediate execution at the same spread cost remains similar to before.

Nevertheless, total depth across the book does decline, consistent with Goettler et al. (2005)'s argument that a smaller tick size reduces welfare for limit order traders relative to that of market order traders. To gain further insights into order strategies by limit order traders, we report in Table 1 the total number of limit orders submitted per day (NLO) and the fraction of minimum-sized orders ($MinSz\_LO$). After the tick size reduction, the daily number of limit order submissions increases by roughly 19%, but the fraction of minimum-sized limit orders also increases significantly, from 17.5% to 22.4% of the order flow (also see Panel (b) of Figure 3). These preliminary results are consistent with the prediction that limit order traders submit more minimum-sized orders in response to the increased probability of being price-improved in a smaller tick size environment.

We next examine how the smaller tick size affects the flexibility and efficiency of prices. Figure 5 shows the patterns of the fraction of zero-return intervals ($ZeroBA$), return autocorrelation ($|AR30|$), realized volatility (RV), and the standard deviation of intraday pricing errors ($PErr$). The top left panel for $ZeroBA$ shows a significant drop, implying that prices move more frequently on a finer pricing grid. This flexibility is important for price efficiency because it allows prices to respond to even small information shocks, thereby more accurately reflecting the true price. If so, prices should behave more like a random walk with no return autocorrelation. Indeed, the absolute value of 30-second return autocorrelation declines, as shown in the bottom left panel of Figure 5.[8] It is important to point out that the increased frequency of price updating does not increase realized volatility – it actually decreases per Table 1. This is possible because the noise component of price due to price discreteness shrinks significantly with a smaller tick size, as shown in the bottom right panel for $PErr$. Table 1 provides supporting t-test results on these variables and other price efficiency measures, all indicating an improvement in price efficiency.

In contrast, evidence of a change in price informativeness is lacking. Figure 6 shows the information content of trades, as measured by price impact (PI_V) and information share ($Trade\_IS$) of trades. There is either no change, or a decrease in the amount of private information revealed through trades. Table 1 also shows no change in the variance of the

[8]For our purpose, we are interested in the magnitude of the return autocorrelation, but note that in our sample, the autocorrelation is always negative. It becomes less negative in the post-change period.

underlying random walk, i.e., no change in the amount of information being incorporated into prices. Nevertheless, an important result emerges from Table 1: while the amount of information may not change, there is a greater concentration of information in the cash market after its tick size reduction, as indicated by a significant increase in the information share of the cash market (IS_Cash).

6 Multivariate Analysis

The above univariate analysis provides initial evidence on how market liquidity and price quality of the 2-year note change after its tick size is halved. To better ascertain whether these changes are attributable to the tick size change, we perform a multivariate analysis that controls for changing market conditions and uses other Treasury securities without any tick size change for identification. We describe our empirical methodology and results below.

6.1 Empirical Methodology

The main empirical methodology is difference-in-difference regressions on each market quality metric:

$$X_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Post_t \times Treatment_i + \theta' Z_{i,t} + \epsilon_{i,t}, \tag{1}$$

where $Treatment$ is an indicator variable equal to 1 for the 2-year note and 0 otherwise, and $Post$ is an indicator variable equal to 1 for the period after the tick size reduction, i.e., from November 19, 2018 to December 21, 2018 (the end of our sample). $Z_{i,t}$ are variables to control for market conditions and security-specific variation. We include the following: 1) market wide volatility (as measured by the $MOVE$ index) to account for changing market conditions, 2) security fixed effects, 3) security fixed effects interacted with $MOVE$ to allow for security-specific response to changing market conditions, and 4) day-of-week dummies. We include all on-the-run nominal coupon securities traded on the BrokerTec platform: 2-, 3-, 5-, 7-, 10-, and 30-year securities. To avoid multicolinearity (between the 2-year fixed effect and the $Treatment$ indicator), we drop the $Treatment$ indicator from the regression model and include only its interaction with the $Post$ indicator. The causal effect of the tick size reduction is reflected in β_2.

Maximizing the regression sample size by including all on-the-run Treasury securities is not without cost. A possible concern is that not all of the above securities are perfect controls for the 2-year note. For example, the 30-year bond might behave very differently due to the vast difference in duration and perhaps clientele. Thus, we also estimate the regressions using only the 3-year note, and the 3-year and 5-year notes, as controls. These notes are more similar to the 2-year note in duration and liquidity conditions. In such regressions, security fixed effects and $MOVE$, without their interactions, are sufficient to control for security and time variation because the assumption of parallel trends is more likely to hold.

Another issue that warrants some discussion is that the level of an outcome variable might differ across securities (e.g., trade volume). To address this issue, we also estimate the regressions in log form, in which case β_2 indicates the percentage change in a given outcome variable. If the results obtained from the level regressions and log regressions are consistent, that provides additional assurance that the documented effects are robust.

6.2 Is the Smaller Tick Size Beneficial to Liquidity Demanders?

Our tests of hypothesis 1 focus on variables capturing liquidity demand. Table 2 contains the coefficient estimates from the DiD regressions described above. Each column is for one outcome variable; the rows show the coefficients of the regression for the outcome variable. Security fixed effects, their interactions with the $MOVE$ index, and day-of-week effects are included in the model but not reported for brevity. The coefficient on $Post$ x $Treatment$ reveals the impact of the tick size reduction on a given outcome variable.

Consistent with our descriptive statistics in section 4, the bid-ask spread decreases by a full 1/256. The bid-ask spread applicable for large trades also decreases by roughly the same amount. Meanwhile, the tightness of spreads around the new tick size, as captured by

$Pct1Tick$, lessens. The coefficient indicates a reduction of about 5 percentage points in the percent of times the spread equals 1 tick.

The tick size reduction has a significant and positive impact on both trade volume and trade frequency. However, each trade is significantly smaller—by roughly $1.15 million—in size. Interestingly, the fraction of minimum-sized trades (not reported) also decreases significantly. These findings are consistent with our univariate results showing that the smaller average trade size is driven by a lower prevalence of extremely large trades and a greater prevalence of small ($2 million), but not the smallest ($1 million), market orders.

In robustness checks, we obtain qualitatively similar results if we run the regressions on log transformed outcome variables or if we include only the 3-year note as the control group. When we include both the 3- and 5-year notes as controls, trading volume and frequency do increase but are not statistically significant, because the 5-year note also experienced a significant increase in trading activity in late 2018.

6.3 Does the Smaller Tick Size Improve Liquidity Provision?

Table 3 presents the tests for hypothesis 2, which examines the impact of the smaller tick size on liquidity provision. Depth at the inside tier ($D1$) and the top 5 tiers ($D5$) drop significantly. This result is hardly surprising given that the distance between the best price (likewise, the 5th best price) from the midpoint is almost surely smaller in the smaller tick regime. However, fixing the price distance at 2/256—the old tick— from the midpoint, the amount of depth available ($D1A$) actually increases significantly, controlling for market developments and the time variation in market depth of other securities. However, cumulative depth within 5 pre-change ticks (equivalent to 10 post-change ticks) of the midpoint ($D5A$) declines significantly. The full extent of the decline is a large $2.7 billion decrease in total depth across the whole book.

We perform various robustness checks on the above results. First, to alleviate the concern that the daily depth statistics aggregated from one-minute snapshots might not be sufficiently representative, we compute daily depth from one-second snapshots and obtain similar results. Second, we estimate the regression using logged depth variables. Results remain robust except that $D5A$ does not change significantly. Similarly, when we use only the 3-year note, and the 3- and 5-year notes, as the control group, the coefficient β_2 for $D5A$ is either insignificant or significantly negative. However, the increase in $D1A$ and the decrease in total depth are robust across all checks.

We conclude that even though there is an overall reduction in liquidity provision, the increased competition induced by the smaller tick size seems to push greater liquidity closer to the top of the book. This liquidity is more than sufficient to absorb easily even large trades. While the 99th percentile of the trade size distribution is $50 million, the post-change depth at the inside tier is $285 million and depth within 2/256 of the bid-ask midpoint is $927 million per Table 1. This result corroborates the earlier finding that the bid-ask spread for large trades also reflects the full extent of the tick size reduction.

In addition to changes in the quantity supplied, an important question is whether traders alter their order exposure strategies. Table 4 reports the effects of the tick size reduction on the use of workup orders and orders of the smallest possible size. Workups are used somewhat less often in the smaller tick environment, contrary to our prior that workups–being useful for traders to manage the exposure of their trading interest–would be used more frequently. Perhaps the smaller tick size lessens the appeal of locking in an existing trade price, which might outweigh the motive to use workups for order exposure management. In addition, unlike the univariate analysis showing increased use of minimum-sized orders as predicted, the change is not statistically significant in multivariate analysis.[9] In contrast, consistent with our univariate results, we find that the number of limit orders increases, as does the cancellation rate. These variables could reflect an alternative channel through which traders, especially fast traders, manage their exposure.

[9]Aitken and Comerton-Forde (2005) also find no evidence of order exposure change in response to the minimum tick size change based on 1995 data from the Australian Stock Exchange.

6.4 Does the Smaller Tick Size Improve Price Efficiency?

We next test for the effects of the tick size reduction on price efficiency. We first establish evidence of increased price updating activity. In Table 5, the coefficients on $Post$ x $Treatment$ for $ZeroBA$ and $ZeroT$ are significantly negative. Specifically, the fraction of one-minute intervals over which the inside bid and ask prices do not move decreases significantly due to the tick size change, by nearly 20 percentage points. However, realized volatility does not change significantly (similar results obtained when we compute volatility from trade prices in place of midpoint prices). That said, given the low volatility of the 2-year note relative to that of other securities, any volatility change due to the tick size change might appear negligible in comparison to volatility changes of other securities.

When estimating the regression model on logged volatility, or using only the 3-year note or the 3- and 5-year notes as controls, we consistently observe that realized volatility decreases significantly. This is consistent with a shrinking market microstructure noise component due to smaller price discreteness.

The last three columns in Table 5 report our tests of the effects of the tick size reduction on price efficiency. We argue that a finer pricing grid allows prices to incorporate even small information shocks and hence converge more closely to the true value. We see this intuition borne out in all three price efficiency measures. The results indicate that return autocorrelation is getting closer to 0 and the variance ratio closer to 1, both of which are properties of a random walk process. The significant reduction in the standard deviation of intraday pricing errors only strengthens this finding further. Importantly, the findings on $AR30$ and $PErr$ remain robust across various regression specifications (the coefficient on the variance ratio consistently has the correct sign but is not always significant). In sum, after the tick size change, the price process updates more frequently, becomes more accurate (less pricing errors), and exhibits less return predictability, thereby moving closer to the efficient price benchmark.

6.5 Does the Smaller Tick Size Affect Price Informativeness?

Aside from showing that the price has become more efficient, a separate question is whether the tick size change alters incentives for information acquisition, resulting in a change in the amount of information being incorporated into prices. Table 6 shows our tests on price informativeness measures. The first three columns are for price impact PI_V and information share of trades $Trade\_IS$ (both lower and upper bounds). These measures are based solely on trade and return dynamics within BrokerTec, and they reflect the amount of private information being revealed through trading activity on the platform. A smaller tick size, by reducing trading costs for demanders of liquidity, might increase incentives for information acquisition. If so, the information content of trades would increase, as long as informed traders choose market orders over limit orders in exploiting their information. However, we do not find strong support for this hypothesis. The coefficient on $Post$ x $Treatment$ for price impact is not significant. Moreover, the information contribution of trades to price discovery in fact decreases. These results are robust through various regression specifications.

Arguably, measuring the information content of trades on BrokerTec alone might not be sufficient to permit a conclusion regarding the amount of information being generated and incorporated, because market participants can choose to trade in the futures market instead.[10] The existence of the futures market, which is tightly linked with the cash market through the no-arbitrage principle, provides a more complete view based on which we can examine information-related issues. Specifically, the work of Hasbrouck (1995) and Mizrach and Neely (2008) helps establish that cash on-the-run Treasury prices and futures prices are cointegrated. This in turn implies that they share a common random walk fundamental process. The variance of this process, Var_RW, reflects the aggregate amount of information incorporated into prices via either the cash or the futures market. Nevertheless, our test

[10] Market participants may also choose to trade on other cash market platforms, for which we do not have data, but BrokerTec is thought to account for the vast majority of inter-dealer trading in on-the-run Treasury securities, as discussed earlier.

indicates that this variance does not change around the tick size reduction event, further ruling out the idea that a smaller tick size can encourage more information acquisition.

The final part of our inquiry on price informativeness looks at the information split between the cash and futures markets. The fact that the tick size is reduced only in the cash market provides a rare opportunity to study the role of tick size in attracting information trading. In Figure 7, we plot the information share of the cash market over the sample period for the four tenors for which both cash and futures instruments are available. An increase in the cash market's information share is clearly visible in the 2-year tenor after the cash tick size reduction, a pattern that does not exist in the tenors with unchanged tick size. This result is formally confirmed in our regression result (see column IS_Cash in Table 6), and remains in all robustness checks.

Overall, based on our analysis of a battery of price informativeness measures, we conclude that the tick size reduction improves price discovery mainly through greater price efficiency rather than increased private information acquisition. However, the smaller cash tick size helps concentrate more information onto the cash market and accordingly raises the role of the cash market in the price discovery process.

7 Conclusion

We study a recent tick size reduction in the U.S. Treasury securities market and identify the effects of this market design change on the market's liquidity and price discovery. Based on difference-in-difference regressions, we find that the bid-ask spread narrows significantly, even for large trades, coupled with increased trading activity. Market depth is markedly lower at the inside tier and decreases across the whole book, but cumulative depth at the previous tick size (2/256) is comparable with, or even slightly higher than, the pre-change inside depth. There is little evidence indicating a significant change in order exposure strategy, except that traders tend to post more, and cancel more, orders.

Furthermore, the smaller tick size enables prices to move more frequently and incorporate even small information shocks, resulting in greater price efficiency. We present novel evidence, based on an analysis of the cash and futures markets' joint price discovery around the tick size event, that the tick size change does not translate to more information acquisition, but attracts informed traders to the cash market with the smaller tick size. We will continue to investigate the implications on the futures market, including whether the cash tick size change affects market quality and arbitrage activities. We can strengthen our findings by examining also the effects on both markets when the tick size in the futures market is reduced to the same level as the cash market in January 2019.

In future work, we plan to quantify the economic importance of this market microstructure shock. In particular, we will measure the extent to which narrower spreads in the interdealer market affect transaction costs in the dealer-to-customer (DtC) market. That is, how much of the transaction cost savings in the interdealer market gets passed on to Treasury investors. We will also examine the extent to which the more efficient prices in the interdealer market help improve the price efficiency in the DtC market.

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Table 1: Market Quality Metrics of 2-Year Note Around Tick Size Reduction

Statistic	Pre	Post	Post-Pre	% Diff	t-stat
Spread Measures:					
BAS	2.016	1.074	-0.942***	-46.71	-149.99
BAS_L	2.109	1.318	-0.791***	-37.5	-36.07
$Pct1Tick$	0.992	0.926	-0.066***	-6.67	-11.76
Trading Activity Measures:					
TV	20782	27645	6863***	33.02	3.82
$Tfreq$	3101	4964	1863***	60.08	5.33
$AVSZ$	6.969	5.641	-1.329***	-19.07	-4.94
$MinSz$	0.326	0.282	-0.043***	-13.32	-4.89
$WKUP\_V$	0.693	0.683	-0.010	-1.42	-0.8
$WKUP\_N$	0.853	0.802	-0.052***	-6.05	-7.53
Liquidity Supply Measures:					
$D1$	855	285	-571***	-66.73	-13.05
$D5$	5230	2882	-2348***	-44.9	-16.64
DT	10017	6916	-3101***	-30.96	-15.11
$D1A$	854	927	72	8.47	1.27
$D5A$	5224	4728	-496***	-9.49	-2.98
NLO	103899	123949	20050	19.3	1.63
$MinSz\_LO$	0.175	0.224	0.049**	27.82	2.37
Price Variation and Efficiency Measures:					
$ZeroBA$	0.875	0.666	-0.209***	-23.91	-12.9
$ZeroT$	0.922	0.777	-0.145***	-15.73	-9.79
RV (% ann.)	1.018	0.88	-0.138**	-13.55	-2.43
$\|AR30\|$	0.225	0.15	-0.075***	-33.41	-4.93
$VR_{10s,1m}$	1.861	1.618	-0.244***	-13.1	-3.7
$PErr(\times 10^5)$	2.358	1.000	-1.358***	-57.59	-24.07
Information Measures:					
PI_V	0.158	0.16	0.002	1.35	0.17
$Trade\_IS$	0.385	0.292	-0.093***	-24.12	-5.62
$varRW(\times 10^6)$	0.107	0.102	-0.004	-3.89	-0.31
IS_Cash	0.477	0.774	0.297***	62.34	13.04

This table reports summary statistics of market quality metrics for the 2-year note on the BrokerTec platform before and after the tick size change on November 19, 2018. Description of the metrics is in Section 4.2 in the text. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. Variables are based on data over New York trading hours from 7:30 to 17:30 Eastern Time.

Table 2: Effects of Tick Size Reduction on Transaction Costs and Liquidity Demand

	BAS	BAS_L	$Pct1Tick$	$Tfreq$	TV	$AVSZ$
$Post$	0.064***	0.181***	-0.016***	454	1068	-0.041
	(0.015)	(0.031)	(0.003)	(447)	(1068)	(0.054)
$Post$ x $Treatment$	-1.008***	-0.992***	-0.05***	1883*	6813***	-1.151***
	(0.036)	(0.075)	(0.008)	(1074)	(2568)	(0.13)
$MOVE$	-0.001	0.003	0.000	66	281	-0.087***
	(0.004)	(0.008)	(0.001)	(115)	(276)	(0.014)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Security Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Security x $MOVE$	Yes	Yes	Yes	Yes	Yes	Yes
Day-of-week Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.992	0.981	0.896	0.726	0.736	0.939
# of Observations	336	336	336	336	336	336

This table shows the effects of the tick size reduction on the bid-ask spreads and liquidity demand. The regression model is $X_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Post_t \times Treatment_i + \theta' Z_{i,t} + \epsilon_{i,t}$, where $Treatment$ is an indicator variable equal to 1 for the 2-year note and 0 otherwise, and $Post$ is an indicator variable equal to 1 for the period after the tick size reduction on November 19, 2018. The dependent variable is shown in each column header. BAS is the difference between the best ask price and the best bid price. BAS_L is the bid-ask spread for executing a large trade ($50 million). $Pct1Tick$ is the percent of time the bid-ask spread is at one tick. TV and $Tfreq$ are the total trading volume and the total number of trades. $AVSZ$ is the average trade size. $Z_{i,t}$ are variables to control for security-specific variation over time due to changing market conditions, including market wide volatility measured by the $MOVE$ index, security fixed effects, security fixed effects interacted with $MOVE$, and day-of-week dummies. Variables are measured at the daily frequency for all on-the-run nominal coupon securities traded on the BrokerTec platform: 2-, 3-, 5-, 7-, 10-, and 30-year securities. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. Variables are based on data over New York trading hours from 7:30 to 17:30 Eastern Time.

Table 3: Effects of Tick Size Reduction on Liquidity Supply

	$D1$	$D5$	$D1A$	$D5A$	DT
$Post$	-26.49***	-149.52***	-26.44***	-153.04***	-202.64***
	(7.36)	(24.34)	(9.12)	(27.71)	(40.77)
$Post$ x $Treatment$	-514.43***	-2066.47***	143.12***	-192.12***	-2711.79***
	(17.70)	(58.52)	(21.93)	(66.6)	(98.01)
$MOVE$	-19.18***	-80.78***	-27.69***	-92.67***	-110.34***
	(1.90)	(6.28)	(2.36)	(7.15)	(10.52)
Constant	Yes	Yes	Yes	Yes	Yes
Security Fixed Effects	Yes	Yes	Yes	Yes	Yes
Security x $MOVE$	Yes	Yes	Yes	Yes	Yes
Day-of-week Effects	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.94	0.983	0.944	0.982	0.987
# of Observations	336	336	336	336	336

This table shows the effects of the tick size reduction on market depth. The regression model is $X_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Post_t \times Treatment_i + \theta' Z_{i,t} + \epsilon_{i,t}$, where $Treatment$ is an indicator variable equal to 1 for the 2-year note and 0 otherwise, and $Post$ is an indicator variable equal to 1 for the period after the tick size reduction on November 19, 2018. The dependent variable is shown in each column header. $D1$ is the depth at the inside tier. $D5$ is the cumulative depth at the top five tiers in the book. DT is the total depth across the whole book. $D1A$ and $D5A$ are the cumulative depth at 1 pre-change tick and 5 pre-change ticks respectively (corresponding to 2 and 10 post-change ticks for the 2-year note). $Z_{i,t}$ are variables to control for security-specific variation over time due to changing market conditions, including market wide volatility measured by the $MOVE$ index, security fixed effects, security fixed effects interacted with $MOVE$, and day-of-week dummies. Variables are measured at the daily frequency for all on-the-run nominal coupon securities traded on the BrokerTec platform: 2-, 3-, 5-, 7-, 10-, and 30-year securities. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. Variables are based on data over New York trading hours from 7:30 to 17:30 Eastern Time.

Table 4: Effects of Tick Size Reduction on Order Strategies

	$WKUP\_V$	$WKUP\_N$	$MinSz\_LO$	NLO	$\%Cancelled$
$Post$	0.004	-0.001	0.027***	-34704***	0.004**
	(0.003)	(0.003)	(0.006)	(12209)	(0.002)
$Post$ x $Treatment$	-0.016*	-0.046***	0.014	61382**	0.011**
	(0.008)	(0.007)	(0.016)	(29352)	(0.005)
$MOVE$	0.003***	-0.001	0.006***	3499	0.001***
	(0.001)	(0.001)	(0.002)	(3152)	(0.001)
Constant	Yes	Yes	Yes	Yes	Yes
Security Fixed Effects	Yes	Yes	Yes	Yes	Yes
Security x $MOVE$	Yes	Yes	Yes	Yes	Yes
Day-of-week Effects	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.845	0.922	0.957	0.676	0.628
# of Observations	336	336	336	336	336

This table shows the effects of the tick size reduction on order exposure strategies. The regression model is $X_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Post_t \times Treatment_i + \theta' Z_{i,t} + \epsilon_{i,t}$, where $Treatment$ is an indicator variable equal to 1 for the 2-year note and 0 otherwise, and $Post$ is an indicator variable equal to 1 for the period after the tick size reduction on November 19, 2018. The dependent variable is shown in each column header. $WKUP\_V$ is the fraction of volume traded in workups. $WKUP\_N$ is the fraction of trades that occur in workups. $MinSz\_LO$ is the percentage of minimum-sized limit orders. NLO is the total number of limit orders submitted to the book each day. $\%Cancelled$ is the percent of orders that are subsequently cancelled. $Z_{i,t}$ are variables to control for security-specific variation over time due to changing market conditions, including market wide volatility measured by the $MOVE$ index, security fixed effects, security fixed effects interacted with $MOVE$, and day-of-week dummies. Variables are measured at the daily frequency for all on-the-run nominal coupon securities traded on the BrokerTec platform: 2-, 3-, 5-, 7-, 10-, and 30-year securities. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. Variables are based on data over New York trading hours from 7:30 to 17:30 Eastern Time.

Table 5: Effects of Tick Size Reduction on Price Variation and Efficiency

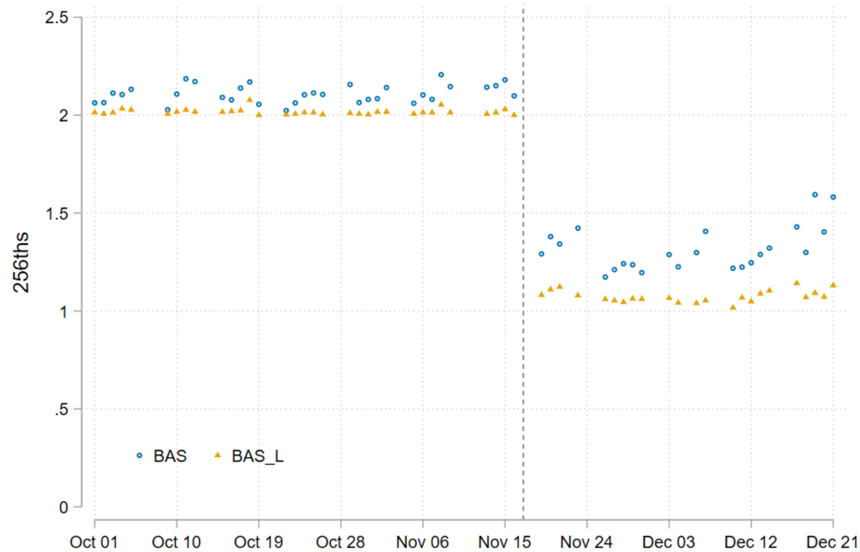
	$ZeroBA$	$ZeroT$	RV	$\|AR30\|$	$\|VR_{10s,1m} - 1\|$	$PErr$
$Post$	-0.012	-0.007	-0.11	-0.012*	-0.026	-0.173**
	(0.008)	(0.008)	(0.113)	(0.006)	(0.032)	(0.084)
$Post$ x $Treatment$	-0.197***	-0.138***	0.082	-0.063***	-0.217***	-1.178***
	(0.019)	(0.018)	(0.271)	(0.015)	(0.078)	(0.202)
$MOVE$	-0.006***	-0.006***	0.013	-0.001	-0.006	-0.006
	(0.002)	(0.002)	(0.029)	(0.002)	(0.008)	(0.022)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Security Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Security x $MOVE$	Yes	Yes	Yes	Yes	Yes	Yes
Day-of-week Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.891	0.89	0.911	0.537	0.423	0.641
# of Observations	336	336	336	336	336	336

This table shows the effects of the tick size reduction on price revisions. The regression model is $X_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Post_t \times Treatment_i + \theta' Z_{i,t} + \epsilon_{i,t}$, where $Treatment$ is an indicator variable equal to 1 for the 2-year note and 0 otherwise, and $Post$ is an indicator variable equal to 1 for the period after the tick size reduction on November 19, 2018. The dependent variable is shown in each column header. $ZeroBA$ is the fraction of zero minute-by-minute midpoint returns during a trading day. $ZeroT$ is computed similarly, except that the returns are based on last trade price of each minute. RV is the realized volatility based on one-minute changes in log midpoint price, calculated as $RV = \sqrt{\sum_{t=1}^{N} [\ln(p_t) - \ln(p_{t-1})]^2}$. $|AR30|$ is the absolute autocorrelation of 30-second mid-point returns. $VR_{10s,1m}$ is six times the ratio of the daily variance of 10-second returns and that of one-minute returns. $PErr$ is the daily standard deviation of intraday pricing errors, scaled by 10^5. $Z_{i,t}$ are variables to control for security-specific variation over time due to changing market conditions, including market wide volatility measured by the $MOVE$ index, security fixed effects, security fixed effects interacted with $MOVE$, and day-of-week dummies. Variables are measured at the daily frequency for all on-the-run nominal coupon securities traded on the BrokerTec platform: 2-, 3-, 5-, 7-, 10-, and 30-year securities. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. Variables are based on data over New York trading hours from 7:30 to 17:30 Eastern Time.

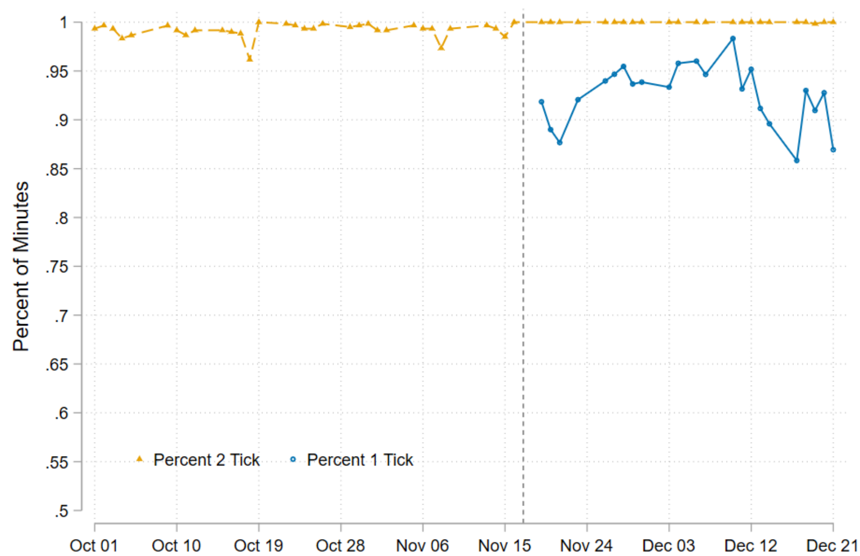
Table 6: Effects of Tick Size Reduction on Price Informativeness

	PI_V	$Trade\_IS\_L$	$Trade\_IS\_U$	Var_RW	IS_Cash
$Post$	0.092	-0.027***	-0.016***	0.135	0.023
	(0.096)	(0.006)	(0.006)	(0.382)	(0.017)
$Post$ x $Treatment$	-0.102	-0.063***	-0.043***	0.084	0.266***
	(0.23)	(0.015)	(0.014)	(0.744)	(0.034)
$MOVE$	0.003	-0.004**	-0.004***	-0.016	0.007*
	(0.025)	(0.002)	(0.001)	(0.076)	(0.003)
Constant	Yes	Yes	Yes	Yes	Yes
Security Fixed Effects	Yes	Yes	Yes	Yes	Yes
Security x $MOVE$	Yes	Yes	Yes	Yes	Yes
Day-of-week Effects	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.943	0.679	0.371	0.786	0.62
# of Observations	336	336	336	221	221

This table shows the effects of the tick size reduction on price efficiency. The regression model is $X_{i,t} = \alpha + \beta_1 Post_t + \beta_2 Post_t \times Treatment_i + \theta' Z_{i,t} + \epsilon_{i,t}$, where $Treatment$ is an indicator variable equal to 1 for the 2-year note and 0 otherwise, and $Post$ is an indicator variable equal to 1 for the period after the tick size reduction on November 19, 2018. The dependent variable is shown in each column header. PI_V captures the price impact of trade (in bps per \$100 million net order flow). $Trade\_IS\_L$ and $Trade\_IS\_U$ are the lower and upper bounds of the information share of trades, computed from a VAR(5) model of returns, trade sign, signed volume, and signed squared volume. Var_RW is the variance of efficient price increments extracted from a VECM(10) on one-second cash and futures prices, scaled by 10^6. IS_Cash is the information share of the cash market. $Z_{i,t}$ are variables to control for security-specific variation over time due to changing market conditions, including market wide volatility measured by the $MOVE$ index, security fixed effects, security fixed effects interacted with $MOVE$, and day-of-week dummies. Variables are measured at the daily frequency for all on-the-run nominal coupon securities traded on the BrokerTec platform: 2-, 3-, 5-, 7-, 10-, and 30-year securities. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. Variables are based on data over New York trading hours from 7:30 to 17:30 Eastern Time.



(a) Daily Average of Bid-Ask Spreads



(b) Percent of Time At Specific Spread or Better

Figure 1: Bid-Ask Spreads Around Tick Size Reduction.
Panel (a) shows the evolution of the daily average of the bid-ask spreads of the 2-year note on the BrokerTec platform. BAS is the difference between the best ask and best bid prices. BAS_L is the bid-ask spread for executing a large trade, defined as the 99th percentile of the trade size distribution prior to the tick size change ($50 million par). Panel (b) shows the percent of time in a day at which the spread is 2/256 or better. In the post-change period, we also plot the percent of time at which the spread equals the new tick size of 1/256. Data is from BrokerTec. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. The vertical line represents the tick size change on November 19, 2018.

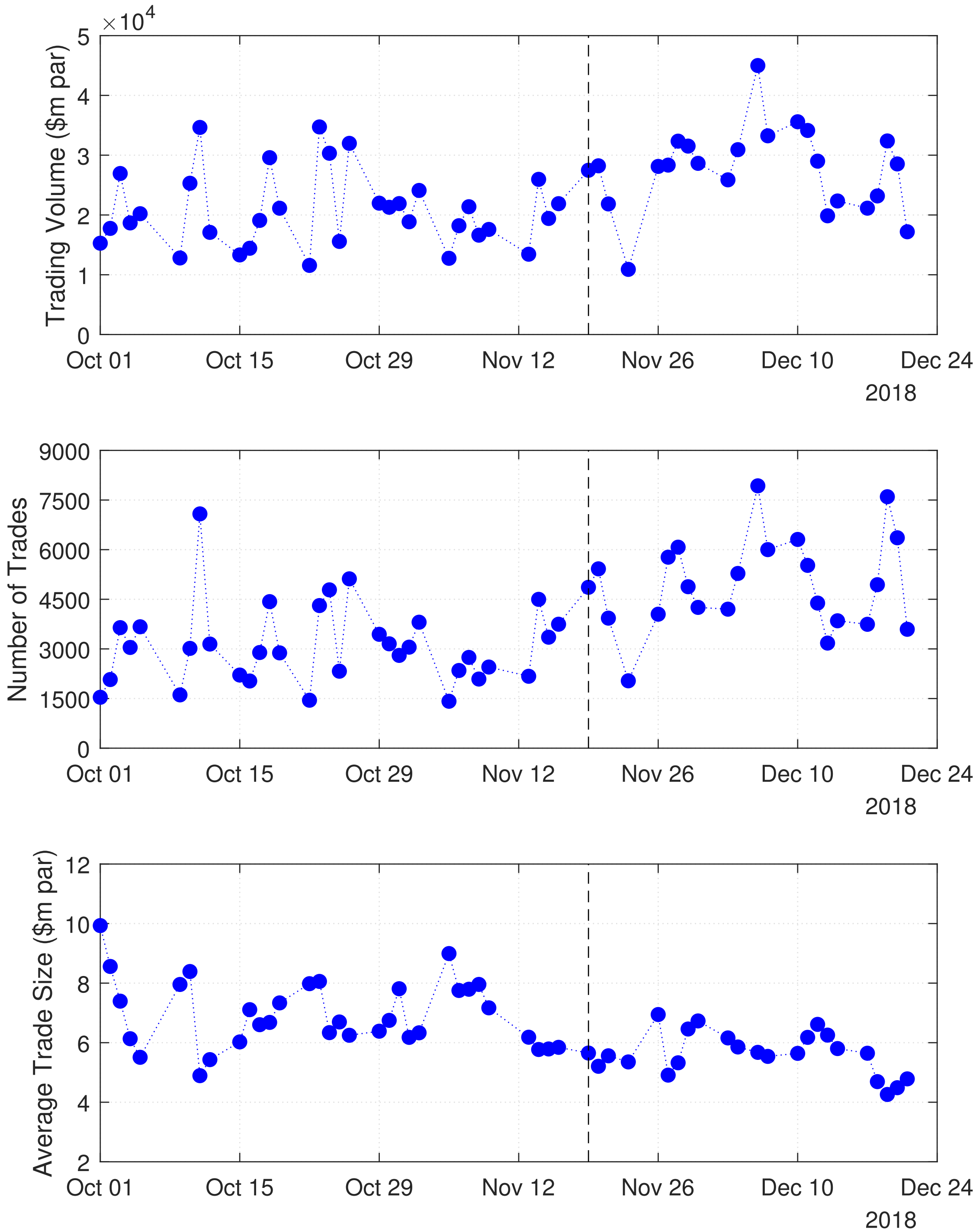
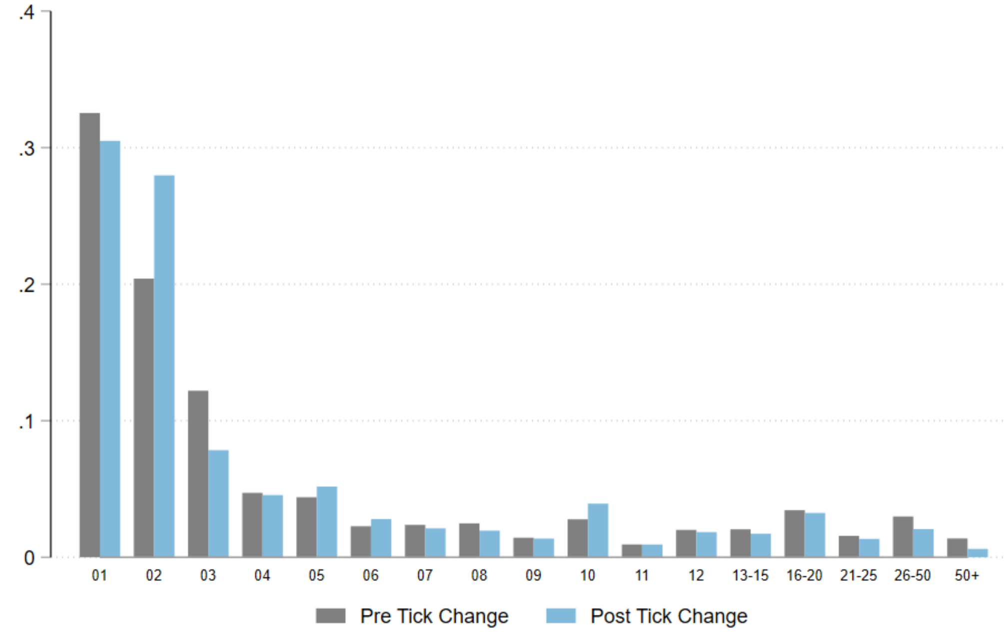
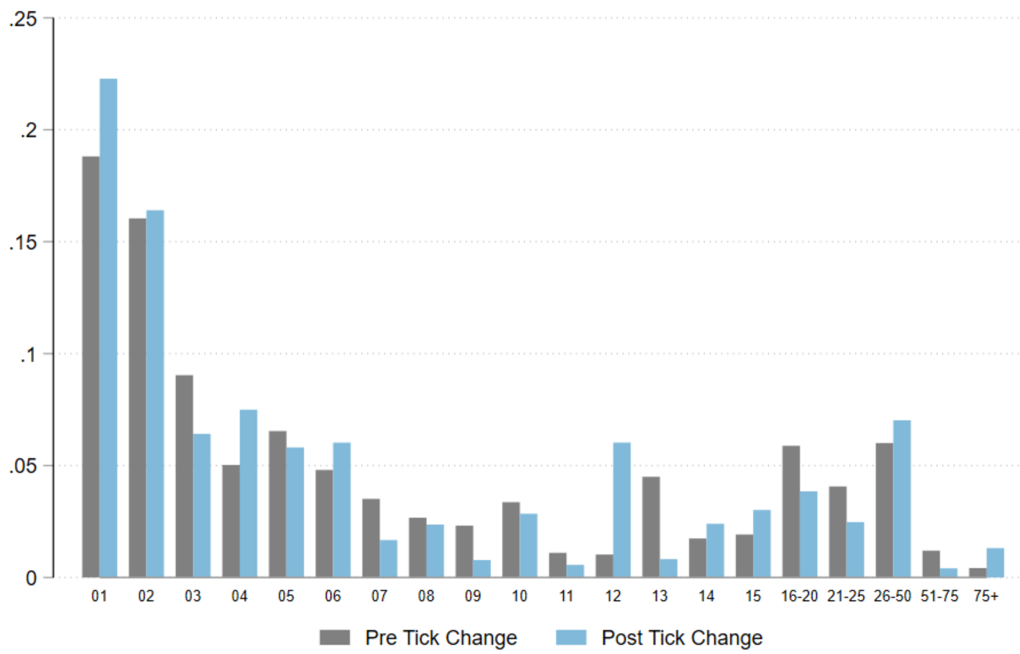


Figure 2: Daily Trading Activity Around Tick Size Reduction.
Panel (a) shows the total daily trading volume (in $million par). Panel (b) shows the daily number of trades. Data is from BrokerTec. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. The vertical line represents the tick size change on November 19, 2018.



(a) Histogram of Trade Size



(b) Histogram of Limit Order Size

Figure 3: Distribution of Trade Size and Limit Order Size Around Tick Size Reduction. This figure shows the histogram of the 2-year note's trade size (upper panel) and limit order size (lower panel) before and after the tick size reduction. The vertical axis shows the relative frequency. Data is from BrokerTec. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. The vertical line represents the tick size change on November 19, 2018.

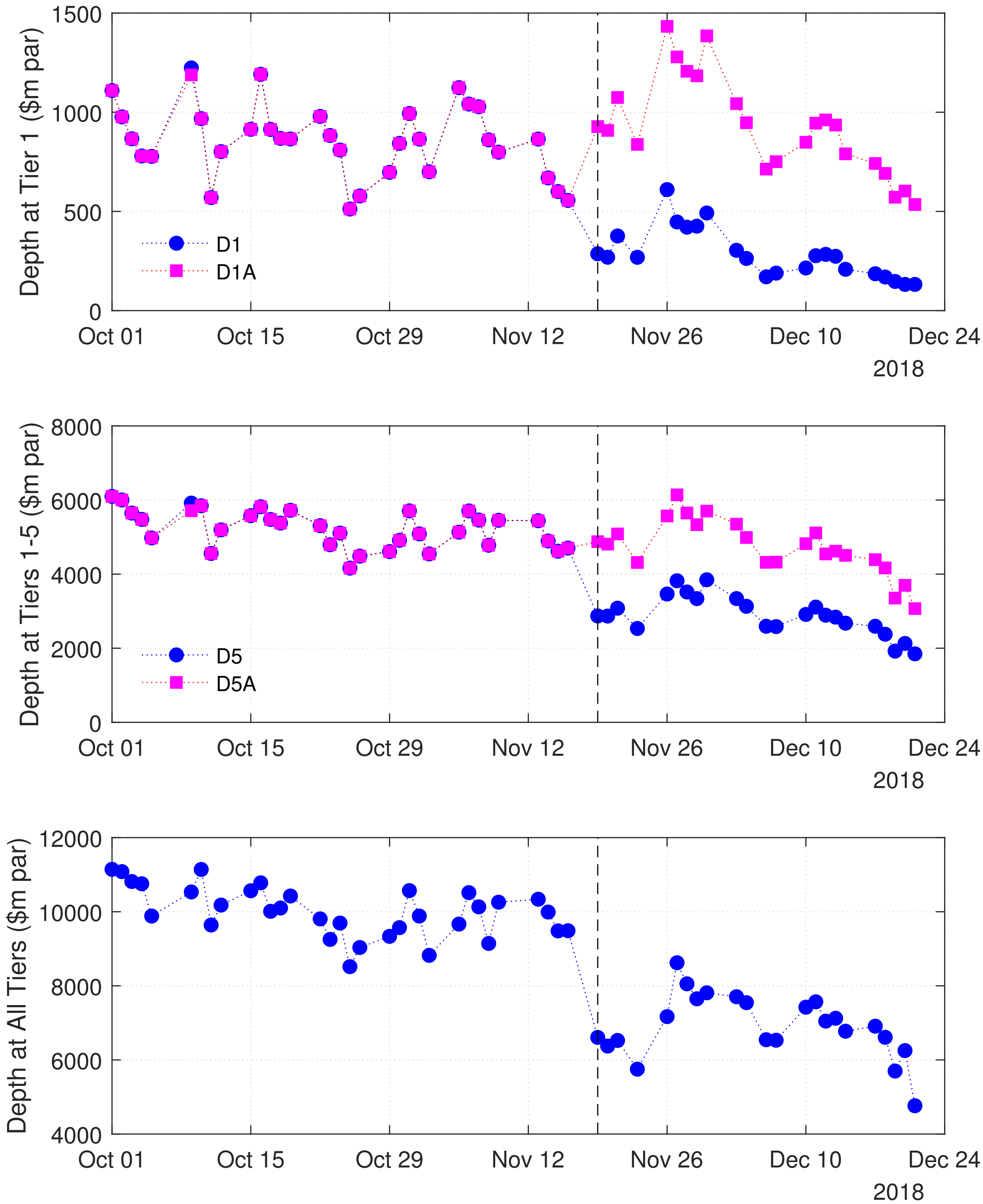


Figure 4: Market Depth Around Tick Size Reduction.
The top panel shows the daily average of depth at the inside tier $D1$. Also plotted in the post-change period is $D1A$, the cumulative depth at 1 pre-change tick (corresponding to 2 post-change ticks). The middle panel shows the daily average of cumulative depth at the top 5 tiers $D5$. Also plotted in the post-change period is $D5A$, the cumulative depth at 5 pre-change ticks (corresponding to 10 post-change ticks). The bottom panel shows the daily average of depth across all tiers (in $million par). Data is from BrokerTec. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. The vertical line represents the tick size change on November 19, 2018.

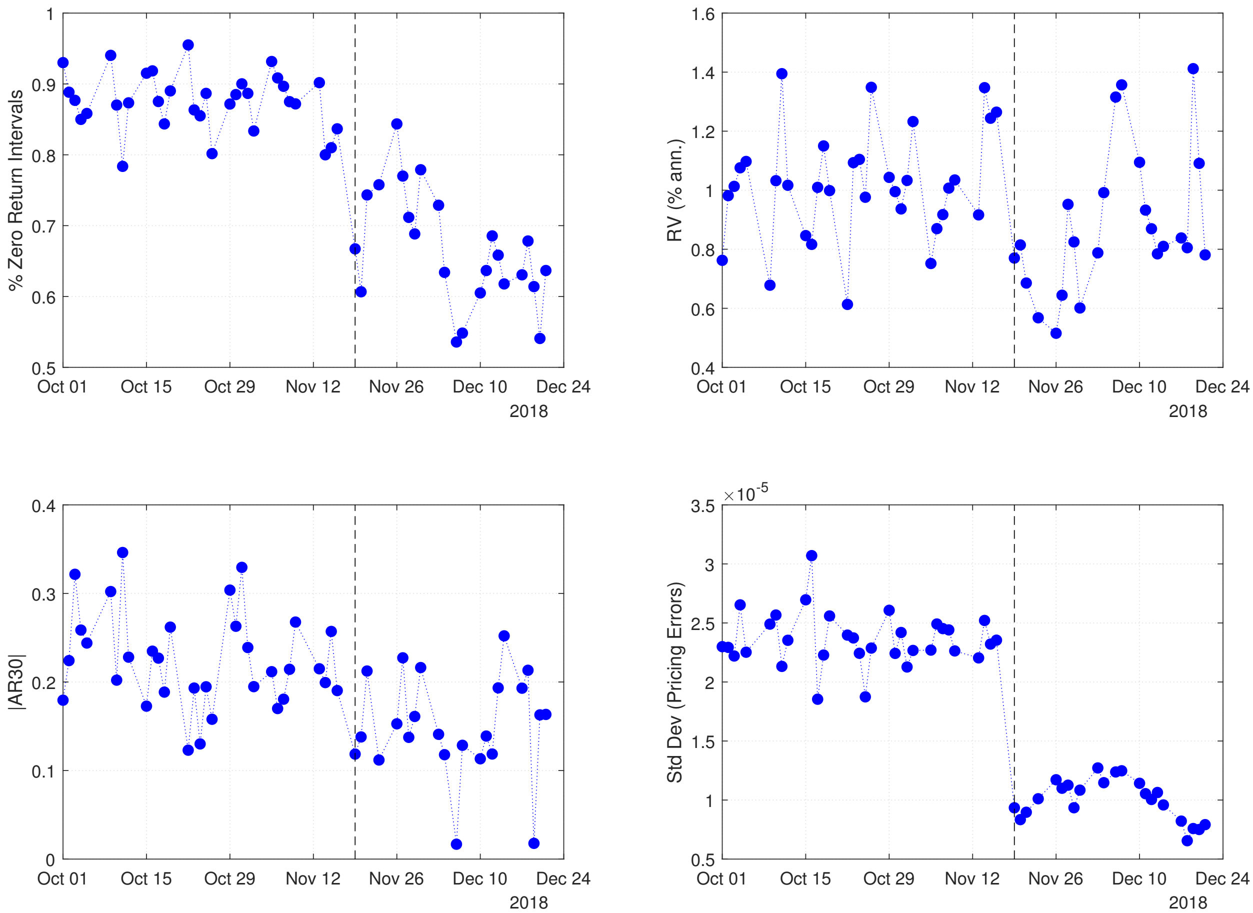
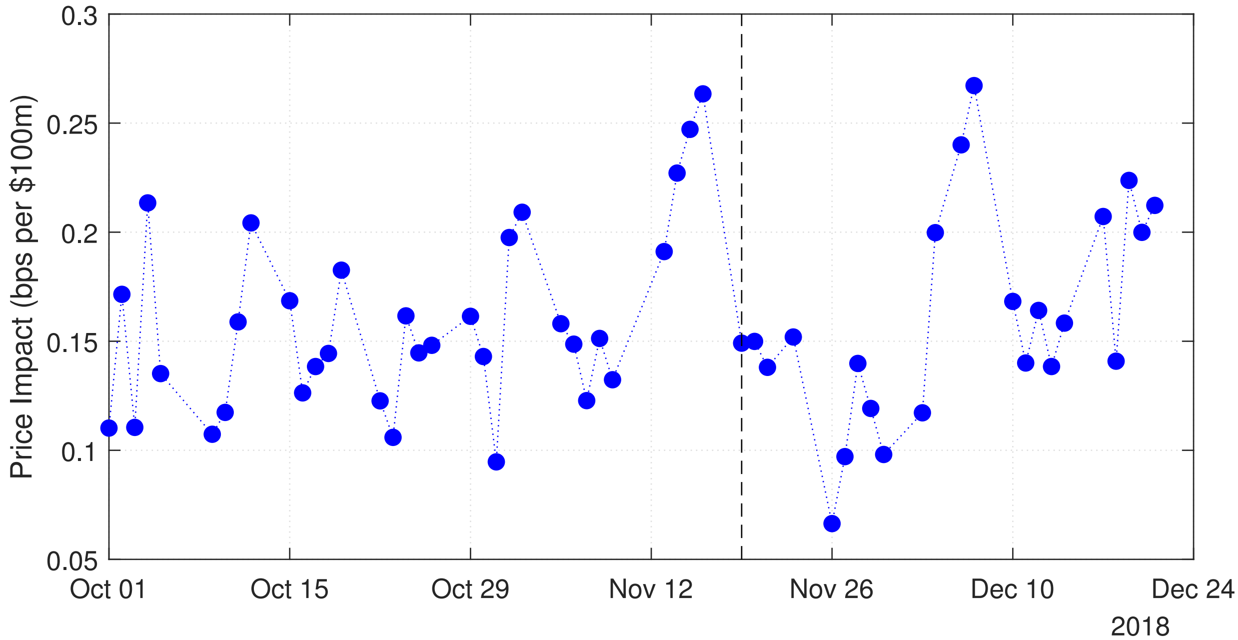


Figure 5: Price Efficiency Around Tick Size Reduction.
The top left graph shows the percent of minutes with zero mid-point returns for each day in the sample. The top right graph shows the daily realized volatility computed from one-minute midpoint returns. The bottom left graph shows the absolute value of autocorrelation of 30-second midpoint returns. The bottom right graph shows the standard deviation of pricing errors computed from a VAR(5) model of midpoint returns, trade sign, signed trade volume, and signed square root of trade volume. Data is from BrokerTec. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. The vertical line represents the tick size change on November 19, 2018.



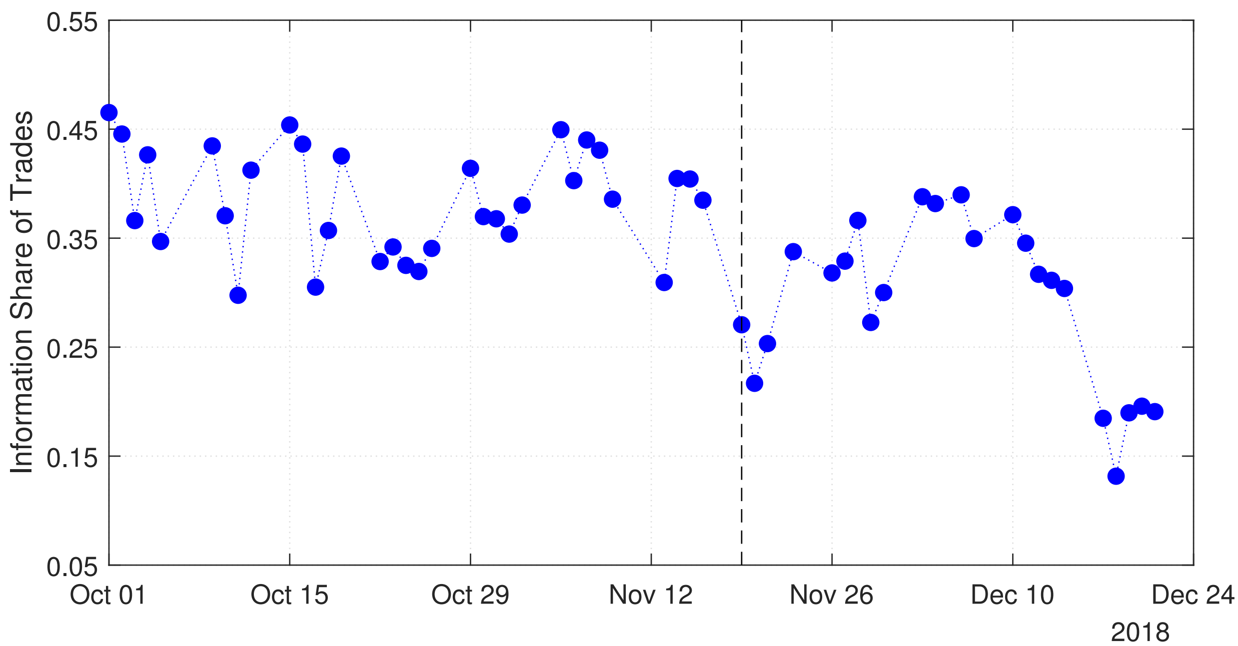


Figure 6: Information Content of Trades Around Tick Size Reduction.
The top panel shows the price impact per $100 million in net buy volume for each day in the sample. Price impact is the slope coefficient from the regression of mid-point return on net order flow at the one-minute frequency. The bottom panel shows the information share of trades (the lower bound), computed from a VAR(5) model of midpoint returns, trade sign, signed trade volume, and signed square root of trade volume. Data is from BrokerTec. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. The vertical line represents the tick size change on November 19, 2018.

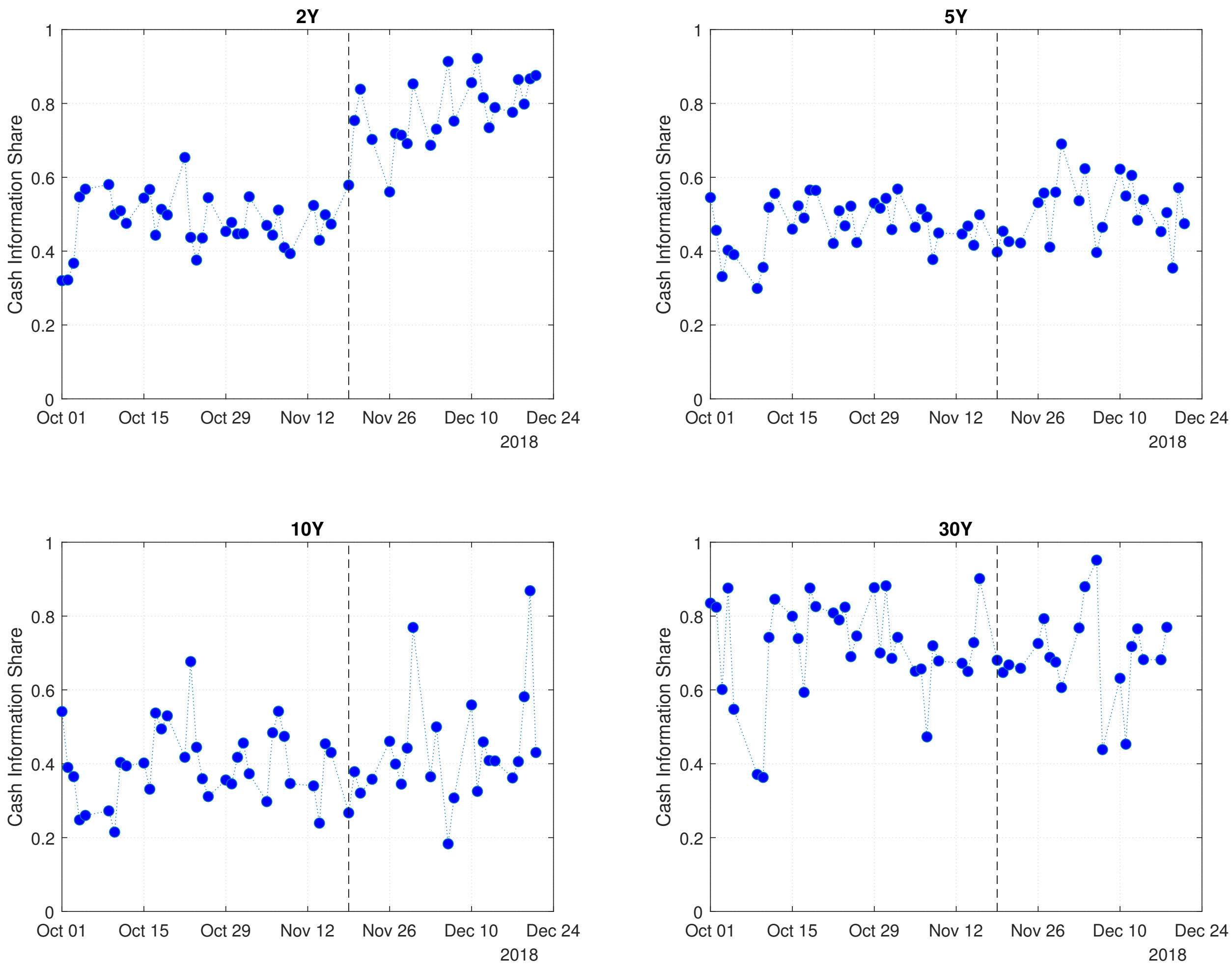


Figure 7: Information Share of Cash Market Around Tick Size Reduction.
This figure shows the information share of the cash market for each cash-futures pair. The information share is the fraction of the efficient return variance explained by the price variation in the cash market. Efficient return variance and information share are computed from a VECM (10) of cash and futures prices sampled at the one-second frequency. Data for cash instruments is from BrokerTec. Data for futures instruments is from Thomson Reuters Tick History. The sample period is 2018Q4, excluding the five trading days after December 21, 2018. The vertical line represents the tick size change on November 19, 2018.