Nocturnal Trading*

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Abstract. While several venues have offered trading prior to the U.S. equity market open and after the close for decades, only recently have alternative trading systems started offering trading between 8 p.m. in the evening and 4 a.m. the next day – nocturnal trading. This innovation enables U.S. retail investors to trade U.S. stocks and exchange traded products 24 hours, five days a week. Importantly, it also enables Asian investors to trade U.S. stocks during Asian business hours. We document the explosive growth of nocturnal trading in the last three years – a development that has recently motivated several additional venues to seek SEC approval to also offer nocturnal trading. We find that while effective spreads during the nocturnal hours are worse than during regular trading hours, realized spreads are about the same or better. We also find that significant price discovery takes place between 8 p.m. and 4 a.m., particularly for exchange-traded products. Finally, we rely on a quasi-natural experiment to study how nocturnal trading affects pre-open, regular, and after-hours trading.

Key words: Nocturnal Trading, Dark Pools, Wholesalers, Execution Quality

JEL: G20; G24; G28

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1. Introduction

This paper studies nocturnal trading in U.S. equities, a relatively new phenomenon that is quickly gaining traction.[1] As of this writing, there are two Alternative Trading Systems (ATSs) that operate during the nocturnal period, 8 p.m. to 4 a.m., Blue Ocean ATS (BOATS) and Interactive Broker's platform IBKR EOS ATS (IBEOS), serving predominantly retail investors. However, several additional platforms and exchanges are about to launch. On October 25, 2024, ICE announced that it plans to extend trading on Arca to 22 hours, five days a week.[2] On November 20, 2024, OTC Markets Group announced the launch of the MOON ATS, a platform that intends to offer nocturnal trading in NMS securities.[3] The U.S. Securities and Exchange Commission (SEC) approved 24X National Exchange, LLC, on November 27, 2024.[4] On December 10, 2024, PEAK6 Investments announced plans to launch the nocturnal trading platform Bruce ATS developed through a collaboration between Nasdaq and Peak6 subsidiary Apex Fintech solutions, in early 2025.[5]

We examine the emergence of 24-hour trading and its implications for financial markets. In particular, what are the effects on market quality and price discovery, both during the nocturnal period as well as during the traditional trading hours? Because nocturnal trading is a recent development, little is known about it. While some industry participants praise the startups pioneering this space, others worry that thin liquidity and lax market oversight during late-night hours may compromise execution quality for retail investors. There is also concern that extending trading into new time periods could dilute liquidity during traditional hours, potentially harming overall market quality. Further, it is unclear if nocturnal trades are mostly noise or if they actually contribute to price discovery.

[1] https://bit.ly/4joe9UI
[2] https://bit.ly/4aqPtGM
[3] https://bit.ly/42mwLOU
[4] https://bit.ly/3DYKFMR
[5] https://prn.to/3C4bmzj

We document substantial growth in nocturnal trading. As illustrated in Figure 1, nocturnal trading was essentially non-existent as recently as the end of 2022, before experiencing explosive growth in 2023 and 2024. Our back of the envelope calculations suggest that recent nocturnal trading makes up as much as 10-20% of retail volume in securities that actively trade overnight. As can be seen in Figure 1, the vast majority of nocturnal volume occurs on the Blue Ocean ATS (BOATS). Conversations with Blue Ocean suggest that about 80% of nocturnal volume comes from the Asia-Pacific region. Growth in nocturnal trading declines in the third quarter of 2024 due to a temporary service interruption on BOATS. Korean brokerages, which reportedly made up approximately 40% of BOATS trading volume prior to the service interruption, have yet to return, which led to a drop in nocturnal volume from its peak. However, reports suggest that the Korean brokers that previously allowed nocturnal trades will begin to route nocturnal volume to BOATS again in March of 2025.

[Figure 1]

We next study market quality during the nocturnal trading hours. Given the limited number of competing liquidity providers, it is natural to wonder if execution quality is poor. However, although effective spreads are somewhat wider during the nocturnal period compared to regular market hours on exchanges, realized spreads are narrower for stocks that trade frequently overnight. These nocturnal realized spreads are also narrower than those offered during regular market hours by wholesale market makers, who execute most liquidity-demanding orders of U.S. retail investors. Meanwhile, stocks that trade less frequently overnight have realized spreads that are about the same or only slightly wider during the nocturnal period compared to regular hours.

Price impacts are at least three to four times greater during the 8 p.m. to 4 a.m. window compared to regular trading hours. This result seems at least in part to be driven by large, positive nocturnal order imbalances, which are 0.20 on average for frequently-traded stocks and 0.26 on average for the broader sample. These findings are consistent with herding behavior and active

price discovery via trades during the nocturnal period.

How does price discovery during the nocturnal period compare to price discovery during other times of the day? We find significant price discovery during the 8 p.m. to 4 a.m. window that mostly does not reverse. Using weighted price contribution (WPC) to compare price discovery across trading periods, we find that for a sample of 484 liquid securities, the nocturnal period contributes about 9% to price changes during the 24-hour window. This percentage is remarkably high, especially considering that nocturnal volume is currently less than 2% of overall volume and that it is dominated by retail investors. We find that about two-thirds of these price changes do not reverse by the following close. We also document significant cross-sectional variation. For example, nocturnal trading in ETFs contributes an especially large amount to price discovery, as we find that ETF WPC during the nocturnal period is over 17% of total price discovery during the 24-hour window.

Finally, we exploit a quasi-natural experiment to evaluate the effect of nocturnal trading on trading activity and market quality during pre-open, regular, and after-hours trading in the U.S. Blue Ocean (BOATS) experienced a service interruption, causing it to shut down its system on August 5, 2024 and partially reopen on August 12. It resumed without restrictions starting the week of August 19. While the U.S. and some Asian brokers resumed allowing its clients to use BOATS for overnight trading, the Korea Financial Investment Association (KoFIA) prohibited all 19 Korean brokers from using the platform citing investor protection concerns. As described earlier in the introduction, this move effectively shut off demand for overnight trading by Korean investors, which reportedly represented roughly 40% of BOATS volume prior to the crash. We conduct a difference-in-differences analysis that defines Treated securities as those with nocturnal trading in the pre-period, but no nocturnal trading in the post-period. In other words, we assume that Korean traders, given the opportunity, would have continued trading the same stocks on BOATS in the post-period as they did in the pre-period. The Control sample, which is constructed with propensity score matching, includes the securities that were traded both by Korean and

other nocturnal traders during the pre-period and continued trading in the post-period by other nocturnal traders.

We find that trading activity outside the nocturnal period following the BOATS crash decreased significantly for Treated relative to Control stocks. The drop is particularly large during pre-open trading, as there is a 31.1% reduction, presumably a result of less nocturnal trading for U.S. traders to react to. However, regular hour trading falls by 10.5% for Treated stocks relative to controls following the service interruption. Similarly, we observe a significant reduction in after-hours trading (-16.4%). We do not find significant changes to quoted spreads, effective spreads, price impacts, or realized spreads. The volume results suggest that nocturnal trading and trading in the 4 a.m. to 8 p.m. periods are complements, and this is particularly true for pre-open and after-hours, which are strongly positively related to nocturnal trading activity. However, the fact that regular trading activity also falls significantly, and by an economically large amount, hints at the possibility that Treated stocks that are no longer trading overnight fell out of favor more generally. It begs the question to what extent these changes in trading activity are caused by the BOATS crash? Propensity-score matching should reduce the concern that a confounding common factor affects both the treatment and the outcomes surrounding the BOATS crash, but we cannot rule this out without further analyses.

1.1 Related Literature

Our paper is closely related to the literature on quote and trade activity during the pre-open and after-hours periods. Biais, Hillion, and Spatt (1999) study price discovery and learning during the pre-open on the Paris Bourse, while Cao, Ghysels, and Hatheway (2000) study Nasdaq price discovery without trading during the pre-open market maker quotes. Barclay and Hendershott (2008) study price discovery during the pre-open period for Nasdaq stocks, and find that as pre-open trading volume increased, the opening price became more efficient and price discovery

shifted from the opening trade to the pre-open, but only for the highest-volume stocks. By the end of their sample period, pre-open trading reached 4% of share volume, exceeding after-hours trading volume at 3%.

Mcinish, Van Ness, and Van Ness (2002) document after-hours trading activity on regional exchanges for NYSE stocks. They find very little price discovery during after-hours trading, and that almost all of the trades take place at either the NYSE closing ask, bid, or the last trade price. Barclay and Hendershott (2003) study pre-open and after-hours trading activity and price discovery, while Barclay and Hendershott (2004) examine after-hours trading costs and liquidity externalities, for Nasdaq stocks. They find that trading outside of regular trading hours is sparse, focused on the most liquid stocks, and concentrated during select days. They document high volatility outside of regular trading hours, which they attribute to significant informed trading causing adverse selection for market makers. Perhaps as a result, they find trading costs that are three to four times as large as those during the regular trading hours.

We contribute to the literature on pre-open and after-hours trading by studying trading costs and price discovery during the nocturnal period, 8 p.m. to 4 a.m. To our knowledge, the first academic paper to document U.S. nocturnal trading is Barclay and Hendershott (2003), who report that in 2000, about one-third of trading days featured nocturnal trading for the top 250 Nasdaq stocks. Such trading often took place through late-night batch trading systems available to select institutions, with Instinet's midnight cross being the most prominent. We document that nocturnal trading activity for U.S. securities today is concentrated for select securities favored by Asian investors, and that price discovery for these securities disproportionately occurs between 8 p.m. and 4 a.m. We also document wider effective and quoted spreads in the nocturnal period, but unlike the evidence from pre-open and after-hours trading, we find that realized spreads, which are trading costs net of adverse selection, are about the same or even lower during the 8 p.m. to 4 a.m. window.

Several authors have studied the timing of corporate news announcements and noted that

these increasingly occur away from regular trading hours. deHaan, Shevlin, and Thornock (2015) document an increasing tendency to report earnings outside of regular trading hours and argue that managers "hide" bad news by announcing earnings during periods of low attention and by providing less forewarning of an upcoming earnings announcement. Similarly, Cunat and Groen-Xu (2017) document that firms strategically select when to release news across sub-periods: big news is released early after-hours allowing for trading opportunities without price feedback, complex news is released late after-hours when investor attention is maximized, and bad news is released in the overnight period when institutional traders are less likely to pay attention.

In turn, this pattern of disclosure has motivated others to study trading activity and price discovery in connection with after-hours earnings announcements. Jiang, Likitapiwat, and McInish (2017) find that after-hours trading is heightened and that a significant fraction of price discovery occurs following earnings announcements released outside of the normal trading hours for S&P 500 stocks. Li (2016) finds that prices for S&P 1500 securities adjust slowly in response to public news such as earnings announcements during the after-hours trading period. More recently, Cui, Gozluklu, and Haykir (2024) study the reaction of traders in the after-hours period to scheduled earnings announcements and unscheduled corporate news, and find that news attracts Robinhood retail traders, especially when the news is positive. In contrast, we do not find significant evidence of price discovery in the nocturnal period, 8 p.m. and 4 a.m., surrounding earnings announcement. This evidence is consistent with our finding that most price discovery from 8 p.m. to 4 a.m. occurs in exchange traded products as opposed to individual stocks.

2. Background

This section provides an overview of the nocturnal trading market. The Internet Appendix provides a more detailed discussion of the institutional details.

2.1 Institutional Details

Nocturnal trading dates at least back to 2018 via tZERO Group. tZERO initially operated under its broker-dealer subsidiary, PRO Securities, before taking over the ATS starting in 2019 (their MMID throughout this time was PROS). In the meantime, tZERO Group formed Blue Ocean Technologies after acquiring the assets of Blue Ocean Financial Technology. Blue Ocean Technologies establishes a subsidiary, Blue Ocean ATS (BOATS), with the intent of becoming a broker-dealer that offers overnight trades. BOATS went live for trading U.S. NMS securities in June of 2021 (MMID: BLUE), taking over the nocturnal trading business from tZERO ATS, which ceased its operations in NMS securities. Since its inception, BOATS has been the primary platform executing trades from 8 p.m. to 4 a.m. in the U.S. (see Figure 1). Conversations with Blue Ocean suggest that 80% of their volume is from retail brokers in the Asia-Pacific region, with most of the rest coming from U.S. retail brokers. Blue Ocean has also suggested that institutional investors do not currently have a very large presence on their platform.

Although BOATS handles most of the nocturnal volume, it is not the only ATS executing trades from 8 p.m. to 4 a.m. Interactive Brokers, via their platform IBKR Eos ATS (IBEOS), announced that they were offering nocturnal trading in November 2022. In addition to their own volume, Interactive Brokers has affiliates all over the world, including the Asia-Pacific region, that were given access to IBEOS during the nocturnal period. In July of 2023, Interactive Brokers announced that they were increasing the number of symbols available for nocturnal trading to 10,000, and that they had entered into a partnership with BOATS to access supplemental liquidity. In addition to BOATS and IBEOS, other platforms are set to join the nocturnal market. For example, MOON ATS has very recently launched an overnight trading platform.

As illustrated in Figure 2, many of the major U.S. retail brokers offer nocturnal trading, though the securities offered and how they were phased in varies across brokers (Figure 3). TD Ameritrade and E*Trade initially offered a list of 12 liquid ETFs for nocturnal trading in

2018, and they expanded to 24 symbols in 2019. Interactive Brokers adopted the same list in 2022. Robinhood began to allow nocturnal trading of mega-cap stocks in May of 2023, before rapidly expanding to approximately 900 securities. Interactive Brokers quickly followed suit by announcing nocturnal trading for 10,000 symbols. Schwab, which now includes TD Ameritrade, announced in October 2024 expanded nocturnal trading offerings in index stocks and additional liquid ETFs.

[Figure 2]

[Figure 3]

Many foreign brokers also allow their clients to trade U.S. NMS securities between 8 p.m. and 4 a.m. U.S. Eastern time. These brokers either have partnerships with BOATS or IBEOS or access the platforms through a U.S. registered sponsoring broker. It is unclear which securities the foreign brokers allow their clients to trade, but it seems to have historically been a broad list. For example, when Samsung Securities began offering trading on BOATS in February of 2022, the number of securities traded on the platform increased from 31 to 524 (Figure 4). Still, trading remains concentrated in a few popular symbols, including Asia-focused securities. For example, trading activity for two Direxion Daily FTSE China 50 Index (3X) Leveraged ETFs – YINN (Bull) and YANG (Bear) – both exceeded 5% of consolidated volume in December 2024.

BOATS and IBEOS both invite professional liquidity providers, such as Virtu Financial and Jane Street, to their platforms. It is our understanding that other major OTC market makers such as Citadel have so far elected not to participate in nocturnal trading. In addition, OTC market makers act as executing brokers for some zero commission U.S. retail brokers. Therefore, these brokers do not route to BOATS and IBEOS directly, instead relying on wholesalers to either execute the nocturnal orders on a principal basis or route them to the ATS.

2.2 Growth in Nocturnal Trading

Using FINRA ATS Transparency Data, Figure 4 shows trading activity on the BOATS platform weekly since its inception in June 2021. The top panel illustrates the number of unique symbols traded on the platform, and the bottom panel reports share volume. The vertical lines indicate when large brokers started using BOATS. From left to right: Samsung Securities (South Korea), Futubull (China/Hong Kong), Robinhood (U.S. retail), and Interactive Brokers (U.S. advanced retail). The final vertical line indicates the week when the BOATS service was interrupted. Nocturnal trading volume on BOATS substantially increased from 2022 until the service disruption in August of 2024. On August 5, Blue Ocean shut down its system due to high demand from a global market selloff. The platform re-opened for limited trading in 29 ETFs on August 12, and fully resumed trading without restrictions on August 19. BOATS volume did not fully recover from pre-service interruption levels, as the association representing Korean brokerages prohibited them from trading on BOATS, citing investor protection concerns. It is anticipated that Korean brokers will start using BOATS again in March of 2025.

[Figure 4]

Figure 5 shows weekly trading activity on the IBEOS platform since its inception in October 2022. We again report the number of unique symbols traded on the platform in the top panel, while share volume is reported in the bottom panel. The first vertical line indicates when Interactive Brokers announced that they were expanding the availability of overnight trading to 10,000 NMS securities and at the same time started offering their clients to use the BOATS platform. As volume for some symbols migrated to BOATS, which was more liquid based on share volume, the number of securities traded on IBEOS fell slightly despite the announced increased in overnight trading availability. The second vertical line indicates the BOATS service interruption, and shows that some volume migrated to IBEOS during and following the interruption. In terms of share volume, the loss of liquidity from BOATS is much more than the gain in liquidity on

IBEOS. The reason is that IBEOS primarily caters to Interactive Brokers and its Asian affiliates, and other brokers would have had to develop connectivity to IBEOS for their retail clients which takes time. Hence, it is likely mostly Interactive Brokers' clients that switch to IBEOS during the BOATS service interruption.

[Figure 5]

3. Data

We obtain data to shed light on nocturnal trading from a variety of sources, which are described in this section.

The Securities Information Processors (SIPs) consolidate and distribute real-time market data from multiple market centers. They operate from 4 a.m. to 8 p.m., making this the only time window during which trades can be reported. However, since at least 2018, trading has occurred between 8 p.m. and 4 a.m. the next day. The overnight trades that occur between midnight and 4 a.m. are included in the regular DTAQ consolidated trade files. These are typically reported by the FINRA Trade Reporting Facility (TRF) or the FINRA Alternative Display Facility (ADF) between 8 and 8:15 a.m. the day of the trade.[6] They have a sale condition that includes "T" indicating Extended Hours. Trades between 8 p.m. and midnight are also reported by BOATS and IBEOS to a FINRA Trade Reporting Facility (TRF) between 8:00 and 8:15 a.m. the next day (called a prior-day or as/of trade).[7] These trades are not included in the DTAQ consolidated trade files.

We obtain the prior-day trade records for Tape A and B securities from the NYSE (ICE) for 2021-2024. These originate from the Canceled and As-of Trades Reports that market centers were required to submit to FINRA (Rule 4540). These reports were suspended effective November 30,

[6] https://www.finra.org/rules-guidance/notices/09-52
[7] Ibid.

2023, although the NYSE continues to produce them.[8] The reports have the same format as DTAQ consolidated trade files, and were produced by NYSE (ICE) from the original TRF trade reports. Specifically, for each trade they report the date and time-stamp that indicates when the trade was reported to the NYSE TRF or one of the Nasdaq TRFs. In addition, the records have a date and time-stamp when the trade occurred, so if a trade occurred on March 27, 2024, at say 21:42:51, it would be recorded in the prior day file for March 28, 2024, when it was reported to the SIP, between 8:00 and 8:15 a.m. Sale condition code that includes "T" indicates that the trade took place during extended trading hours.

Our prior-day files cover all individual trades in Tape A and B securities that occurred between 8 p.m. and midnight starting Monday (reported on Tuesday) through Thursday (reported on Friday). As discussed above, BOATS and IBEOS offer trading starting 8 p.m. on Sunday evening into Monday morning at 4 a.m., and the last session for the week is Thursday 8 p.m. to Friday at 4 a.m. We have learned from discussions with the NYSE that Sunday evening trades are not reportable to FINRA. As a result, we do not have trades reported to the NYSE TRF for this period. However, the Monday prior-day reports appear to include prior-Friday trades reported to the Nasdaq TRFs.

The DTAQ and prior-day records data have limitations in that we only observe trades, not quotes, during the nocturnal period, and we have yet to obtain prior-day records for Tape C securities. We therefore augment these datasets with trade and quotes data on the BOATS ATS. We obtain this dataset from ICE.

Additionally, we access FINRA ATS Transparency Data to collect measures of trading activity, such as volume and number of symbols traded, at the ATS level. These data include not only BOATS, but also the other nocturnal trading platforms, including IBEOS and the now defunct PROS. Finally, we use CRSP/Compustat data to obtain security characteristics.

[8] https://bit.ly/4joqRTq

4. Nocturnal Volume, Market Quality, and Price Discovery

4.1 Trading Activity and Price Discovery Analysis

To study nocturnal trading on all ATS platforms, we begin our analysis using the DTAQ and prior-day records trade data. To have consistent coverage across the trading day, this analysis focuses on Tape A and B securities, since those are the ones for which these data are available for the 8 p.m. to midnight period. The sample period covers January-May 2024. To ensure that we have sufficient data, we require the securities to have at least ten trades in each sub-period of the 24 hour trading day. This leaves us a sample with 484 securities that appear in at least one day of the sample period.

We begin by analyzing trading activity and price discovery during the nocturnal hours. Since the DTAQ and prior-day records data do not contain quotes during the nocturnal hours, our ability to measure trading costs with these datasets is limited. We do study measures of trading costs with these data in the Internet Appendix, but our main analysis of nocturnal market quality is below with the BOATS trade and quote data.

We compute the following price discovery measures:

- WPC, the weighted price contribution, and WPCT, the weighted price contribution per trade. The WPC measures the average percentage share that each sub-period contributes to price changes over the 24 hour trading period. The WPCT measures the effect of price discovery per trade. We follow Barclay and Hendershott (2003) in constructing these measures.

- Reversals, which estimates the extent to which price changes during sub-periods reverse. We follow Bogousslavsky and Muravyev (2023) in constructing the Reversals measure. Specifically, we perform regression analysis where the independent variable is the return during the sub-period, and the dependent variable is the return following the sub-period

until the close. The estimated slope coefficient is the measure of reversals. It takes a value of 0 if the price change during the sub-period does not reverse at all and a value of -100% if the price change completely reverses.

We also compute the fraction of share volume and the fraction of trades in each sub-period of the 24 hour trading day, and the range defined as the difference between the high and low prices divided by the mean trade price in the sub-period. These measures are equally-weighted across stock-days, then equally-weighted across days. The WPC measures are equally-weighted across days.

Table 1 reports trading activity and price discovery in each sub-period of the 24-hour trading day based on the sample of 484 securities for January-May 2024. Panel A shows that 12.8% of share volume and 4.2% of trades executes outside regular trading hours (including open and close). The bulk of this activity takes place during the pre-open period 4 a.m. to open, and the after-hours period, 4 p.m. to 8 p.m. During the nocturnal period, 8 p.m. to 4 a.m., 0.38% of share volume and 0.68% of trades execute on average. The range between high and low prices for the nocturnal period is roughly comparable to the pre-open and after-hours periods, with the range for the 8 p.m. to midnight at 3.20% being notably higher than the range for the midnight to 4 a.m. period of 2.03%.

The nocturnal period significantly contributes to price discovery, with WPC estimates of 5.08% for 8 p.m. to midnight and 3.57% for midnight to 4 a.m. This nearly 9% contribution to price discovery is remarkable, given the large presence of retail traders during the nocturnal period and the relatively low nocturnal trading activity. Further, the reversals measure suggests that most of the price change during the nocturnal period does not reverse by the following close.

[Table 1]

We next consider how these measures vary by security type. In Table 2, we group the statistics into 347 stocks and ADRs (Panel A) and 132 securities of all other types, which we refer to as

the ETFs group (Panel B). This analysis contains 5 fewer securities than the preceding one due to missing share code values. The share of nocturnal trading activity is higher for our sample of ETFs. For example, the share of number of trades is 0.90% for the former versus 0.58% for the latter from 8 p.m. to 4 a.m. Most striking is variation in price discovery. Nocturnal trading plays a substantial role in price discovery for the ETFs. The WPC for the ETFs is a combined 17.40% for the two nocturnal periods, and the vast majority of the price change does not reverse. In contrast, the WPC for the sample of stocks and ADRs is a combined 4.40% for the two nocturnal periods, and about half of the price effect reverses.

[Table 2]

To further understand cross-sectional variation, Table 3 sorts stock-days into terciles based on either total volume from the previous year or the nocturnal share of total volume from that day. We continue to group securities into stocks and ADRs versus ETFs. The nocturnal share of price discovery, as measured by WPC, continues to concentrate in ETFs, and for the volume sorts, the nocturnal price discovery is strongest for low-volume stocks. For the nocturnal volume share sorts, the nocturnal WPCs are especially strong for the stocks-days with the highest nocturnal share of overall volume. The nocturnal WPCs for ETFs in this group is a whopping 28%, which confirms that elevated nocturnal trading has a direct and significant effect on price discovery.

[Table 3]

4.1.1 Earnings Announcements One natural setting is to examine the role nocturnal trading plays around information events. For example, does nocturnal trading facilitate quicker price discovery around information events? We study earnings announcements to examine this question. We focus on price discovery for individual stocks on the earnings announcement days (Table 4). We separate the events into earnings announcements that occur during the pre-open period of 4 a.m. to 9:30 a.m. (Panel A) and those that occur during the post-close period of 4 p.m. to 8 p.m.

(Panel B). In our sample, over 90% of earnings announcements occur during these two windows. We also study non-earnings announcement stock-days for stocks in our sample that had at least one earnings announcement (Panel C). To address outlier stock-day effects, we compute median WPC measures, in addition to the traditional measures based on means.

Focusing on median WPCs, we see very little price discovery during the nocturnal periods on the earnings announcement days. While our earlier results suggest that there is not much nocturnal price discovery for individual stocks on average, this analysis suggests that even on important information days, there continues to be little price discovery during the nocturnal periods. Instead, abnormal price discovery tends to occur during the period when earnings are announced, suggesting that prices quickly react to news. For example, median WPC is over 36% during the 4 a.m. to 9:30 a.m. window for pre-open announcements and over 70% during the 4 p.m. to 8 p.m. period for post-close announcements.

4.2 Market Quality Analysis

We next evaluate nocturnal market quality. Since the DTAQ and prior-day records data do not include quoting activity, we focus on trade and quote data for BOATS. As we previously discussed, the vast majority of nocturnal trading currently occurs on BOATS. We consider two samples from January to May 2024. One is a sample of 393 symbols that trade every day on BOATS during our sample period, and the other is a group of 3,026 symbols that trade on BOATS at least once during the sample period.

We present quote statistics in Table 5. We compare equal-weighted and volume-weighted quote statistics on BOATS to volume-weighted statistics during regular trading hours, sourced from the WRDS TAQ Intraday Indicators. For the frequently-traded sample (Panel A), volume-weighted quoted spreads are a little wider during the nocturnal period (28 basis points) versus regular trading hours (20 basis points), while nocturnal quoted depth is only about half of regular

hours depth. For the larger sample that includes many infrequently-traded symbols (Panel B), quoted spreads are substantially wider during the nocturnal period compared to regular trading hours. Volume-weighted quotes are over 89 basis points on BOATS compared to about 37 bps during regular hours. Volume-weighted quoted depth, however, is similar during the two periods.

[Table 5]

The trade statistics are presented in Table 6. Panel A reports nocturnal trading summary statistics for both the frequently-traded group and the full sample, which includes infrequently-traded symbols. Average trade size is small, ranging from 117 to 133 shares, which is unsurprising, given that retail traders dominate the nocturnal market. The vast majority of trades execute at either the best bid or ask, given that essentially zero trades execute inside the best quotes and less than 10% execute outside. Absolute order imbalances are large, ranging from 0.20 to 0.26, suggesting that nocturnal traders tend to herd.

Compared to the analysis of quoting activity in the previous table, the trading costs measures in Panels B and C of Table 6 suggest a nuanced story. Volume-weighted quoted spreads prevailing at the time of trades, as well as effective spreads, continue to be wider during nocturnal hours compared to regular hours trading, which we measure with the Intraday Indicators data and also with Rule 605 data. The latter captures market quality delivered during regular trading hours to retail traders by the six largest U.S. wholesalers. For the frequently-traded symbols, price impacts during the nocturnal period actually exceed effective spreads, and realized spreads are negative. Realized spreads are positive for the same stocks during regular trading hours. The negative realized spread values suggest that investors trading during nocturnal hours face relatively low intermediation costs when trading liquid stocks.

As expected, nocturnal trading costs are higher for the sample that includes infrequently-traded stocks (Panel C). Effective spreads measured conventionally (69 bps) and with the Hagströmer (2021) adjustment (64 bps) are wider compared to those during the regular trading hours (30

bps). However, price impacts continue to make up most of the effective spreads, and nocturnal realized spreads are either about the same as regular-hours realized spread if measured with the Hagströmer (2021) adjustment or about 4 basis points greater if measured conventionally.

[Table 6]

5. Effect of Nocturnal Trading on Other Trading Hours

In August 2024, Blue Ocean experienced a service interruption due to high demand during a global market sell-off. The company had to shut down its system shortly after 3 a.m. on August 5, and once the platform reopened on August 12, clients were limited to trading in 29 ETFs. Blue Ocean migrated to a new technology system provided by MEMX that allowed it to handle more trade-related messages, and trading resumed without restrictions starting the week of August 19, 2024.

While the U.S. and some Asian brokers resumed allowing its clients to use BOATS for overnight trading, the Korea Financial Investment Association (KoFIA) prohibited all 19 Korean brokers from using the platform citing investor protection concerns.[9] This effectively shut off demand for overnight trading by Korean investors – an investor group that prior to the BOATS crash represented roughly 40% of BOATS volume according to BOATS officials.

The event provides a quasi-natural experiment that we use to evaluate the effect of nocturnal trading on market activity during pre-open, regular, and after-hours trading in the U.S. We also examine the effect on market quality during regular U.S. market hours. We define the pre-event window as the period July 8-26, and the post-even window as the period August 19-September 9.[10] We exclude the week immediately prior to the BOATS crash due to rising turmoil in Asian

[9] According to Korean media, due to BOATS rejecting buy and sell requests from 90,000 account holders after 2:45 p.m. (Korean standard time) on August 5, 2024, investors incurred 630 billion won ($428 million) in losses.

[10] Our results are qualitatively robust to pushing the pre-event and post-event periods further apart.

markets, the week of the crash since BOATS was unavailable for all traders, and the week after the crash as only 29 symbols were trading on BOATS the week of August 12.

We define Treated securities as those with nocturnal trading in the pre-period, but no nocturnal trading (on either BOATS or IBEOS) in the post-period.[11] In other words, we assume that Korean traders, given the opportunity, would have continued trading the same stocks on BOATS in the post-period as they did in the pre-period. The Control sample includes the securities that were traded both by Korean and other nocturnal traders during the pre-period, and continued trading in the post-period by other nocturnal traders. In total, 1,858 Treated stocks and 1,602 Control stocks satisfy these criteria, but the two subsamples have significantly different characteristics. For example, as illustrated in Figure 6, Treated stocks are heavily skewed towards low-price stocks consistent with Korean traders being particularly attracted to securities with lottery-like features. To arrive at more comparable Treated and Control stocks, we use nearest-neighbor propensity score matching based on June 2024 nocturnal volume as a fraction of CRSP volume, logarithm of price and of shares outstanding, and volatility measured as (high-low)/high. The result is a matched sample of 838 Treated and 884 Control stocks.

[Figure 6]

We draw trading activity (pre-open, regular, and after-hours), market quality (quoted, effective, and 5-minute price impact, and realized spreads), and an estimate of regular-hours retail trading volume (Boehmer, Jones, Zhang, and Zhang, 2021, BJZZ) from WRDS intraday indicators. We take the logarithm of share volume variables and spread variables as the data is highly skewed.[12] Table 7 reports the descriptive statistics for Treated and Control stocks after propensity-score matching.[13] The trading activity and costs measures are generally well matched across the

[11] We require a stock price of at least $1 in the pre-period, as the tick size is smaller for stocks with prices below $1. To avoid recently listed stocks, we also require that securities are traded nocturnally in June 2024.

[12] We add the absolute value of the minimum price impact (realized spread) plus epsilon [0.77 (0.09)] to ensure we have positive numbers before taking logs.

[13] The average price of Treated (Control) stocks after matching is $62.77 and $33.67, respectively.

treated and control groups in the pre-crash period.

[Table 7]

To evaluate any effect of Korean traders being shut-out from BOATS, we conduct a panel difference-in-difference analysis for our outcome variables Y_{it}.

$$Y_{it} = \alpha_i + \gamma_t + \beta \cdot POST \cdot TREATED + \delta \cdot X_{it} + \varepsilon_{it} \quad (1)$$

where POST takes on the value of 1 in the post-period and 0 otherwise, TREATED is a dummy that takes on the value of 1 for Treated stocks and 0 for Controls, X_{it} denote control variables (daily closing price, return, and range defined as daily high-low divided by high price) for security i on day t. We estimate the regressions with security and day fixed effects, and double-clustered standard errors by security and date. Because our variables are all in logarithms, the coefficient of interest, β, is measured in percent. Table 8 reports the results.

[Table 8]

Panel A reveals that trading activity following the BOATS crash decreased significantly for Treated relative to Control stocks. Particularly large is the 31.1% reduction in pre-open trading, presumably as a result of less nocturnal trading for U.S. traders to react to. However, also regular hour trading falls by 10.5% for Treated stocks relative to controls. Similarly, we observe significant reductions in after-hours trading (-16.4%) and U.S. retail trading (-7.5%). We find no significant changes in quoted spreads, effective spreads, price impacts, or realized spreads in Panel B.

Taken together, these results suggest that nocturnal trading and trading in the 4 a.m. to 8 p.m. periods are complements, and this is particularly true for pre-open and after-hours, which are strongly positively related to nocturnal trading activity. However, the fact that regular trading activity also falls significantly, and by an economically large amount for treated relative to control

stocks, hints at the possibility that treated stocks that are no longer trading overnight fell out of favor more generally. It begs the question to what extent these changes in trading activity are caused by the BOATS crash? Propensity-score matching should reduce the concern that a confounding common factor affects both the treatment and the outcomes surrounding the BOATS crash, but we cannot rule this out without further analyses.

6. Conclusions

This paper studies nocturnal trading and its implications for market quality and price discovery, both during the overnight window as well as during traditional trading hours. We document explosive growth in round-the-clock trading, as volume during the 8 p.m. to 4 a.m. window rose from essentially nothing in 2022 to as high as 1.6 billion shares in quarterly volume in 2024.

Price discovery during the nocturnal period is remarkably large, as the 8 p.m. to 4 a.m. window contributes nearly 9% to daily price movements in our sample. We also document significant cross-sectional variation. For example, ETFs traded nocturnally contribute an especially large amount to price discovery, as we find that their weighted price contribution during the nocturnal period is over 17% of total price discovery during the 24-hour window.

We also study market quality during the nocturnal trading hours. Although quoted and effective spreads are wider during the nocturnal period compared to regular market hours, realized spreads are narrower for stocks that trade frequently overnight. Meanwhile, stocks that trade less frequently overnight have realized spreads that are about the same or only slightly wider during the nocturnal period compared to regular hours.

Finally, we exploit a service interruption on BOATS in August 2025 as a quasi-natural experiment to evaluate the effect of nocturnal trading on trading activity and market quality during pre-open, regular, and after-hours trading in the U.S. We find that trading activity during non-nocturnal hours following the BOATS crash decreased significantly for securities that traded

before the crash but not after, relative to securities that traded in both the pre- and post-even period. We find no significant effects on measures of trading costs. The volume results suggest that nocturnal trading and trading in the 4 a.m. to 8 p.m. periods are complements. However, though propensity-score matching should reduce the concern that a confounding common factor affects both the treatment and the outcomes surrounding the service interruption, we cannot completely rule out this possibility.

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Table 1
Nocturnal Trading Activity and Price Discovery

The table reports trading activity and price discovery for a pilot sample of 484 NMS securities based on DTAQ and CTS data for January 2024-May 2024. Panel A reports the fraction of share volume and the fraction of trades in each sub-period of the 24 hour trading day, and the range defined as the high - low divided by average trade price in the sub-period. Panel B reports price discovery measures. WPC is the Weighted Price Contribution, and WPCT is the Weighted Price Contribution per Trade. Reversals measure the extent to which price changes during the sub-period reverse by the close. The trading activity measures are equally-weighted within each stock-period, then equally-weighted each period, and the WPC measures are equally-weighted across days.

Panel A: Trading Activity				
Time period	# Stocks	Volume %	Trades %	Range
4p.m. to 8p.m.	484	3.42%	0.84%	2.60%
8p.m. to Midnight	484	0.27%	0.34%	3.20%
Midnight to 4a.m.	484	0.11%	0.34%	2.03%
4a.m. to 9:30a.m.	484	2.03%	2.64%	4.78%
Open	484	1.26%	0.02%	
Regular Hours	484	87.18%	95.81%	6.11%
Close	484	5.75%	0.01%	
Panel B: Price Discovery				
Time Period	# Stocks	WPC	WPCT	Reversals
4p.m. to 8p.m.	484	9.64%	6.67	-11.42%
8p.m. to Midnight	484	5.08%	14.42	-38.87%
Midnight to 4a.m.	484	3.57%	0.61	-37.15%
4a.m. to 9:30a.m.	484	19.59%	3.80	-5.77%
Open	484	0.56%	46.12	15.53%
Regular Hours	484	61.26%	0.66	-0.28%
Close	484	0.21%	23.69	

Table 2
Trading Period Statistics Grouped by Security Type

The table reports trading activity and price discovery from January 2024-May 2024 for securities grouped by stocks and ADRs (Panel A) and everything else, mainly ETFs (Panel B). Panel A contains 347 securities and Panel B contains 132. The table reports the fraction of share volume and the fraction of trades in each sub-period of the 24 hour trading day, and the range defined as the high - low divided by average trade price in the sub-period. WPC is the Weighted Price Contribution, and WPCT is the Weighted Price Contribution per Trade. Reversals measure the extent to which price changes during the sub-period reverse by the close. The trading activity measures are equally-weighted within each stock-period, then equally-weighted each period, and the WPC measures are equally-weighted across days.

Panel A: Stocks and ADRs							
Time Period	# Stocks	Vol %	Trades %	Range	WPC	WPCT	Reversals
4p.m. to 8p.m.	347	3.80%	0.73%	3.09%	11.10%	9.57	-9.82%
8p.m. to Midnight	347	0.18%	0.31%	3.71%	2.18%	11.17	-53.80%
Midnight to 4a.m.	347	0.09%	0.27%	2.41%	2.27%	7.45	-46.48%
4a.m. to 9:30a.m.	347	1.93%	2.28%	5.68%	17.27%	5.03	-8.95%
Open	347	1.35%	0.02%		0.46%	34.98	13.05%
Regular Hours	347	85.71%	96.39%	7.21%	66.07%	0.70	-0.17%
Close	347	6.94%	0.01%		0.52%	113.27	
Panel B: All Other Security Types (Mainly ETFs)							
Time Period	# Stocks	Vol %	Trades %	Range	WPC	WPCT	Reversals
4p.m. to 8p.m.	132	2.48%	1.07%	1.33%	4.98%	2.91	-26.60%
8p.m. to Midnight	132	0.50%	0.41%	1.92%	11.29%	17.41	1.79%
Midnight to 4a.m.	132	0.15%	0.49%	1.08%	6.11%	-0.73	-16.00%
4a.m. to 9:30a.m.	132	2.20%	3.37%	2.49%	23.59%	3.04	4.20%
Open	132	1.02%	0.02%		0.71%	71.50	22.04%
Regular Hours	132	90.85%	94.63%	3.24%	53.44%	0.60	-0.59%
Close	132	2.81%	0.01%		-0.20%	-58.89	

Table 3
Trading Period Statistics Sorted by Total Volume or Nocturnal Volume Share

The table reports trading activity and price discovery statistics from January 2024-May 2024 for securities sorted into terciles based on either total volume from the fourth quarter of 2023 or the daily nocturnal share of total volume. Securities are grouped by stocks and ADRs and everything else, mainly ETFs. The table reports the fraction of share volume in each sub-period of the 24 hour trading day, WPC (Weighted Price Contribution), and Reversals, which measures the extent to which price changes during the sub-period reverse by the close. The trading activity measures are equally-weighted within each stock-period, then equally-weighted each period, and the WPC measures are equally-weighted across days.

	Sorted by Total Volume from 2023Q4						Sorted Daily by Nocturnal Volume Share of Total Volume					
	Stocks and ADRs			All Others (Mainly ETFs)			Stocks and ADRs			All Others (Mainly ETFs)		
Panel A: Low Stocks												
Times	Vol %	WPC	Reversals	Vol %	WPC	Reversals	Vol %	WPC	Reversals	Vol %	WPC	Reversals
4p.m. to 8p.m.	3.31%	14.50%	-15.21%	2.18%	2.73%	-60.01%	4.70%	7.86%	15.56%	2.41%	4.88%	-2.59%
8p.m. to Midnight	0.25%	-0.07%	-60.24%	0.66%	14.83%	2.97%	0.01%	1.75%	-116.92%	0.01%	5.63%	-56.79%
Midnight to 4a.m.	0.11%	2.69%	-43.02%	0.15%	8.10%	-16.28%	0.01%	1.79%	-4.56%	0.01%	1.78%	-52.60%
4a.m. to 9:30a.m.	2.26%	13.93%	-4.62%	1.86%	21.27%	3.11%	1.21%	21.38%	0.88%	1.58%	26.20%	7.56%
Open	1.44%	0.86%	-1.11%	1.41%	1.06%	15.63%	1.19%	-0.04%	49.08%	1.05%	0.52%	-17.58%
Regular Hours	86.41%	67.12%	-0.18%	90.98%	51.75%	-0.70%	84.65%	67.09%	0.21%	91.80%	60.82%	-0.40%
Close	6.21%	0.92%		2.76%	-0.15%		8.24%	0.02%		3.13%	0.16%	
Panel B: Medium Stocks												
Times	Vol %	WPC	Reversals	Vol %	WPC	Reversals	Vol %	WPC	Reversals	Vol %	WPC	Reversals
4p.m. to 8p.m.	4.76%	7.37%	9.16%	2.95%	6.50%	4.51%	4.14%	9.21%	1.25%	2.81%	5.23%	2.51%
8p.m. to Midnight	0.07%	3.21%	-41.17%	0.47%	13.17%	4.96%	0.02%	-0.05%	-62.18%	0.08%	7.71%	-16.56%
Midnight to 4a.m.	0.05%	1.32%	-47.81%	0.20%	6.06%	-21.52%	0.02%	0.80%	-25.74%	0.06%	4.29%	-50.78%
4a.m. to 9:30a.m.	1.30%	19.63%	-9.19%	2.24%	22.16%	12.62%	1.54%	21.64%	2.10%	2.19%	23.47%	7.77%
Open	1.28%	0.26%	25.80%	0.78%	0.46%	35.38%	1.35%	0.62%	36.90%	1.02%	0.86%	85.66%
Regular Hours	83.75%	67.76%	-0.08%	90.11%	51.98%	-0.59%	85.73%	67.23%	0.06%	91.63%	58.45%	-0.61%
Close	8.80%	0.14%		3.26%	-0.27%		7.20%	0.18%		2.22%	-0.03%	
Panel C: High Stocks												
Times	Vol %	WPC	Reversals	Vol %	WPC	Reversals	Vol %	WPC	Reversals	Vol %	WPC	Reversals
4p.m. to 8p.m.	4.66%	7.03%	-3.19%	2.56%	5.70%	21.30%	3.18%	12.70%	-15.40%	2.52%	4.11%	-39.61%
8p.m. to Midnight	0.04%	-2.66%	-32.31%	0.18%	6.57%	-11.89%	0.33%	4.17%	-42.10%	1.43%	17.37%	12.79%
Midnight to 4a.m.	0.02%	1.97%	-61.08%	0.08%	4.61%	-6.33%	0.17%	3.24%	-57.87%	0.33%	10.74%	1.60%
4a.m. to 9:30a.m.	1.34%	24.96%	-19.16%	2.92%	25.13%	-1.24%	2.65%	11.75%	-16.50%	3.05%	20.52%	0.40%
Open	1.06%	0.38%	78.93%	0.45%	0.72%	29.01%	1.49%	0.84%	-5.73%	0.97%	0.68%	3.17%
Regular Hours	85.23%	68.12%	-0.23%	91.49%	57.49%	-0.47%	86.40%	66.20%	-0.39%	89.79%	46.85%	-0.65%
Close	7.64%	0.32%		2.33%	-0.20%		5.79%	1.08%		1.92%	-0.51%	

Table 4
Earnings Announcements

The table reports trading activity and price discovery for earnings announcements versus non announcement days from the first quarter of 2024. Panel A includes days with pre-open earnings announcements, and Panel B includes days with post-close earnings announcements. Panel C includes non-earnings announcement days for securities in the sample that had an earnings announcement. The table reports the fraction of share volume and the fraction of trades in each sub-period of the 24 hour trading day, and the range defined as the high - low divided by average trade price in the sub-period. WPC is the Weighted Price Contribution. We also compute the median stock value for WPC, denoted WPC mdn. The trading activity measures are equally-weighted within each stock-period, then equally-weighted each period, and the non-median WPC measures are equal-weighted averaged across days.

Panel A: Days with Pre-Open Earnings Announcements						
Time period	# Stocks	Volume %	Trades %	Range	WPC	WPC mdn
4p.m. to 8p.m.	66	2.74%	0.46%	4.46%	3.93%	-3.67%
8p.m. to Midnight	66	0.03%	0.06%	2.65%	-38.19%	-4.35%
Midnight to 4a.m.	66	0.02%	0.06%	1.54%	62.58%	5.92%
4a.m. to 9:30a.m.	66	3.73%	4.27%	8.90%	34.53%	36.07%
Open	66	1.24%	0.00%		-2.99%	0.62%
Regular Hours	66	86.95%	95.15%	8.30%	39.03%	45.01%
Close	66	5.29%	0.00%		-1.90%	-0.03%
Panel B: Days with Post-Close Earnings Announcements						
Time period	# Stocks	Volume %	Trades %	Range	WPC	WPC mdn
4p.m. to 8p.m.	42	1.76%	0.78%	3.93%	69.03%	70.14%
8p.m. to Midnight	42	0.14%	0.25%	4.40%	-1.91%	-1.04%
Midnight to 4a.m.	42	0.10%	0.26%	2.20%	-1.35%	0.00%
4a.m. to 9:30a.m.	42	3.15%	5.07%	11.94%	4.38%	10.29%
Open	42	1.57%	0.01%		0.72%	-0.12%
Regular Hours	42	90.04%	93.63%	10.17%	32.46%	18.12%
Close	42	3.24%	0.00%		-1.47%	-0.01%
Panel C: Days with no Earnings Announcements						
Time period	# Stocks	Volume %	Trades %	Range	WPC	WPC mdn
4p.m. to 8p.m.	104	4.43%	0.75%	2.26%	3.71%	2.19%
8p.m. to Midnight	104	0.08%	0.15%	1.92%	2.42%	1.37%
Midnight to 4a.m.	104	0.06%	0.18%	1.15%	3.68%	2.38%
4a.m. to 9:30a.m.	104	1.20%	1.73%	2.86%	17.55%	17.79%
Open	104	1.51%	0.01%		0.83%	1.53%
Regular Hours	104	84.04%	97.18%	5.03%	70.70%	70.80%
Close	104	8.69%	0.00%		0.54%	0.18%

Table 5
BOATS Quoting Activity

The table presents summary statistics on quoting activity on Blue Ocean ATS (BOATS) from January to May 2024. Results are reported for two samples: (i) a subset of 393 stocks that trade on BOATS every day of each sample month (Panel A), and (ii) the full sample of 3,026 stocks that traded on BOATS at least once during the sample period (Panel B). The reported statistics include (i) the number of quotes per stock per night, (ii) the average quoted spread (in basis points), (iii) quoted depth (in shares), and (iv) the percentage of time the market (a) quotes only one side of the BBO, (b) is locked (bid quote equals ask quote), or (c) is crossed (bid quote exceeds ask quote). For BOATS, statistics are time-weighted up to the stock-day level, then averaged across days, and finally either equal-weighted or volume-weighted across stocks. For comparison, we also report quoted spreads and depths for the same stocks on the day following nocturnal BOATS trading, sourced from WRDS TAQ Intraday Indicators.

	# Quotes	Quoted spread	Quoted depth	One-sided BBO	Locked	Crossed
Panel A: Frequently-traded sample (393 stocks)						
BOATS, equal-weighted	2,901	60.27	1,375	0.00	0.00	0.00
BOATS, volume-weighted	10,651	27.61	6,991	0.00	0.00	0.00
Regular hours, volume-weighted		19.72	14,980			
Panel B: Full sample (3,026 stocks)						
BOATS, equal-weighted	725	478.51	442	0.01	0.00	0.00
BOATS, volume-weighted	8,404	89.36	5,519	0.00	0.00	0.00
Regular hours, volume-weighted		36.61	5,624			

Table 6
BOATS Trading Activity and Trading Costs

The table presents summary statistics on trading activity and trading costs on Blue Ocean ATS (BOATS) from January to May 2024. Results are reported for two samples: (i) the frequently-traded sample, consisting of 393 stocks that trade on BOATS every day of each sample month (first line in Panel A and all of Panel B), and (ii) the full sample, comprising 3,026 stocks that traded on BOATS at least once during the sample period (second line in Panel A and all of Panel C). The reported statistics include the number of trades, average trade size, stock price, and absolute order imbalance, calculated as the absolute difference between buyer- and seller-initiated share volumes divided by the total traded share volume. We also report the proportion of trades executing inside and outside the posted BBO, as well as key trading cost measures: the quoted spread, which reflects the prevailing spread at the time of trades; the effective spread, defined as twice the signed difference between the traded price and the prevailing BBO midquote; the price impact, measured as twice the signed difference between the midquote at the time of the trade and the midquote five minutes later; and the realized spread, which is the difference between the effective spread and the price impact. Trades are signed using the Lee-Ready algorithm. For BOATS, all statistics are volume-weighted at each aggregation step. For comparison, we also report volume-weighted trading cost statistics for the same stocks on the day following nocturnal BOATS trading, sourced from WRDS TAQ Intraday Indicators. Additionally, for stocks that trade on BOATS daily (the frequently-traded sample), we provide volume-weighted trading cost statistics from Rule 605 data, which captures market quality delivered during regular trading hours to retail traders by the six largest U.S. wholesalers. Spreads are reported in basis points.

Panel A: Trading activity

	# Trades	Trade size	Price	Order imb.	Inside	Outside
Frequently-traded sample	2,946	133	43.56	0.20	0.00	0.08
Full sample	2,508	117	37.24	0.26	0.00	0.07

Panel B: Trading costs, frequently-traded sample

	Quoted spread	Effective spread	Price impact	Realized spread
BOATS, conventional	25.20	28.09	32.42	-4.33
BOATS, Hagströmer	25.22	26.00	32.76	-6.75
Regular hours	N/A	16.34	9.82	6.51
Rule 605	15.99	9.86	5.54	4.32

Panel C: Trading costs, full sample

	Quoted spread	Effective spread	Price impact	Realized spread
BOATS, conventional	63.92	68.65	51.04	17.47
BOATS, Hagströmer	64.34	64.34	51.04	13.51
Regular hours	N/A	29.76	16.09	13.10

Table 7
Descriptive Statistics: Treated and Control Securities

The table presents summary statistics on trading activity and regular hour trading costs for securities with nocturnal trading in the three week pre-BOATS crash period July 8th - July 26th, 2024. Treated securities are those with no nocturnal trading during the post-BOATS crash period August 19th - September 6th, 2024, while Control stocks have nocturnal trading both in the pre- and post-BOATS crash periods, and are propensity-matched to Treated stocks based on June 2024 nocturnal fraction of CRSP volume, the logarithm of price and shares outstanding, and volatility defined as (high-low)/high. The reported trading activity statistics in Panel A. include the (logarithm of) share volume during pre-open, regular hours, and after hours, as well as from retail trades, based on the BJZZ (2021) algorithm. The market quality statistics in Panel B. include the (logarithm of) percent time-weighted quoted spread, and the percent share-volume-weighted effective spread, price impact, and realized spread. The last two variables are calculated at the 5-minute frequency, and we add its respective minimum value before taking logs. Daily trading activity and market quality statistics are drawn from WRDS Intraday Indicators, while weekly nocturnal trading activity is from FINRA ATS Transparency data. Unless otherwise specified, statistics are share-volume-weighted.

Panel A: Trading activity

	Treated			Controls		
	# obs	Mean	Std. Dev.	# obs	Mean	Std. Dev.
Pre-open	11,428	5.69	2.79	12,858	8.00	2.90
Regular	12,549	13.29	1.34	13,260	13.84	1.66
After-Hours	12,076	9.31	2.57	12,840	9.75	2.49
Retail	12,532	10.53	1.43	13,257	11.45	1.76

Panel B: Trading costs

	Treated			Controls		
	# obs	Mean	Std. Dev.	# obs	Mean	Std. Dev.
Quoted spread	12,549	-6.55	1.23	13,260	-6.47	1.12
Effective spread	12,549	-7.03	1.18	13,260	-6.84	1.08
Price impact	12,549	-0.26	0.01	13,260	-0.26	0.03
Realized spread	12,549	-2.40	0.05	13,260	-2.40	0.04

Table 8
The Effect of the BOATS Crash

The table presents difference-in-difference regressions evaluating the effect of the BOATS crash on trading activity and regular-hour trading costs. We define the pre-BOATS crash period as July 8th - July 26th, 2024. Treated securities are those with no nocturnal trading during the post-BOATS crash period August 19th - September 6th, 2024, while Control stocks have nocturnal trading both in the pre- and post-BOATS crash periods, and are propensity-matched to Treated stocks based on June 2024 nocturnal fraction of CRSP volume, the logarithm of price and shares outstanding, and volatility defined as (high-low)/high. We estimate the following regressions for outcome variables Y_{it}:

$$Y_{it} = \alpha_i + \gamma_t + \beta \cdot POST \cdot TREATED + \delta \cdot X_{it} + \varepsilon_{it}$$

where $POST$ takes on the value of 1 in the post-period and 0 otherwise, $TREATED$ is a dummy that takes on the value of 1 for Treated stocks and 0 for Controls, X_{it} denote control variables (daily closing price, return, and range defined as daily high-low divided by high price). Y_{it} includes trading activity variables: the (logarithm of) share volume during pre-open, regular hours, and after hours, as well as from retail trades, based on the BJZZ (2021) algorithm; and market quality variables: the (logarithm of) percent time-weighted quoted spread, and the percent share-volume weighted effective spread, price impact, and realized spread. The last two variables are calculated at the 5-minute frequency. Regressions are share-volume-weighted, and include controls, security and date fixed effects, and standard errors are clustered by security and date.

Panel A: Trading activity						
	# obs	β Coeff	Std. Error.	t-stat	p-value	Within R-sq
Pre-open	45,734	-0.311	0.110	-2.83	0.008	0.036
Regular	49,037	-0.105	0.021	-5.09	0.000	0.316
After-Hours	47,229	-0.164	0.045	-3.68	0.001	0.034
Retail	49,006	-0.075	0.023	-3.24	0.003	0.266
Panel B: Trading costs						
	# obs	β Coeff	Std. Error.	t-stat	p-value	Within R-sq
Quoted spread	49,037	0.016	0.011	1.49	0.147	0.023
Effective spread	49,037	-0.015	0.013	-1.10	0.279	0.016
Price impact	49,037	0.000	0.000	0.48	0.634	0.001
Realized spread	49,037	-0.000	0.001	-0.41	0.688	0.010

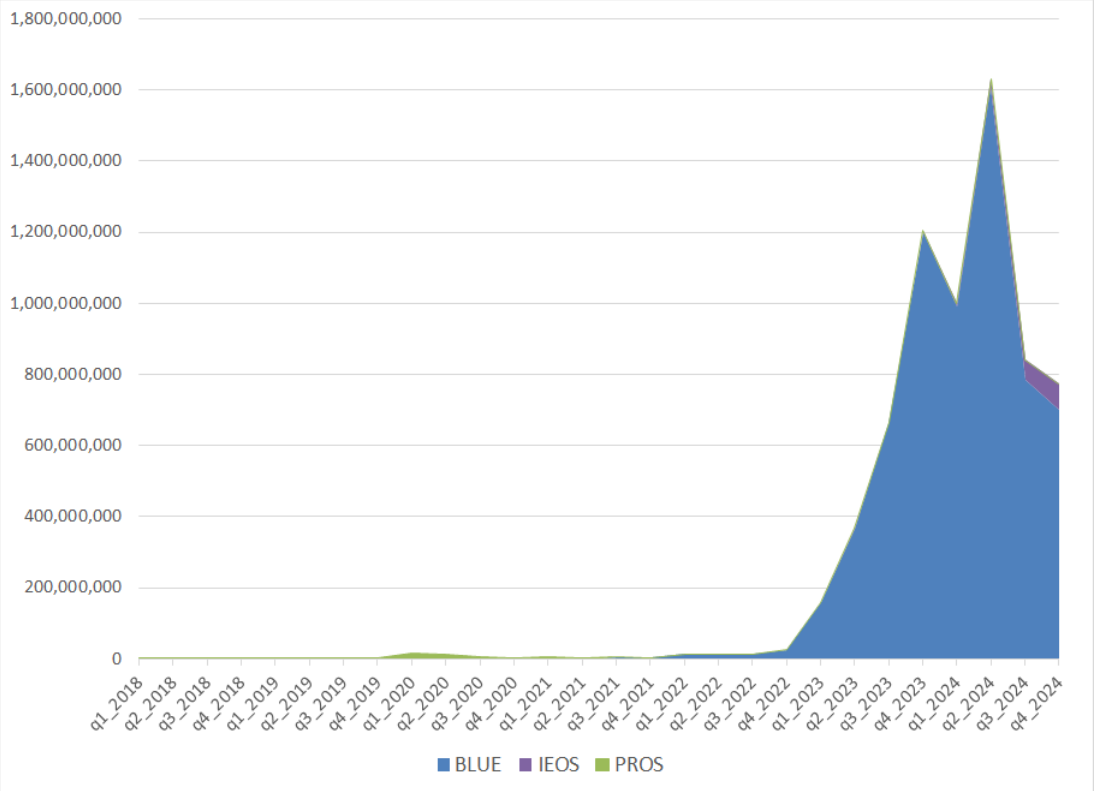

Figure 1. Nocturnal Trading

The figure reports quarterly share volume by PRO Securities ATS (PROS), Blue Ocean ATS (BOATS), and Interactive Brokers EOS ATS (IBEOS) for the Q1 2018 - Q4 2024 period. These ATSs operate exclusively in the overnight period, 8 p.m. to 4 a.m., starting 8 p.m. on Sunday, ending at 4 a.m. on Friday. The source for the data is the FINRA ATS Transparency data for all NMS securities.

24-Hour Trading for Major Brokerages

Broker/Firm	Pre-Market	After-Hours	24-Hour Trading
Charles Schwab	7:00 a.m. - 9:25 a.m.	4:05 p.m. - 8:00 p.m.	Gradually expanding 24-hour trading for S&P 500, Nasdaq-100, and ETFs as of early 2025.
Fidelity Investments	7:00 a.m. - 9:28 a.m.	4:00 p.m. - 8:00 p.m.	Does not offer 24-hour trading.
Interactive Brokers	7 a.m. until 9:30 a.m.	4:05 p.m. - 8:00 p.m.	Most extensive variety of tradeable securities; 8:00 p.m. - 3:50 a.m. for U.S. stocks and ETFs.
Robinhood	7 a.m. until 9:30 a.m.	4:05 p.m. - 8:00 p.m.	8:00 p.m. (Sunday) to 8:00 p.m. (Friday) for select stocks and ETFs.
E*TRADE	7 a.m. until 9:30 a.m.	4:05 p.m. - 8:00 p.m.	Offers 24-hour trading for select securities.

All hours are given in Eastern Time. In addition, 24-hour trading begins at 8:00 p.m. Sunday and ends Friday at market close, 4:00 p.m. All information is courtesy of the individual brokerages and are subject to change.

Table: Investopedia/Peter Gratton

Investopedia

Figure 2. Major Retail Broker Overnight Offerings
Source: Investopedia.

TD Ameritrade January 22, 2018 (PROS)

FXI, SPY, EEM, GLD, SLV, DIA, UNG, TLT, IWM, QQQ, USO and SH.

E*Trade February 20, 2018 (PROS)

FXI, SPY, EEM, GLD, SLV, DIA, UNG, TLT, IWM, QQQ, USO and SH.

TD Ameritrade April 9, 2019 (PROS)

FXI, SPY, EEM, GLD, SLV, DIA, UNG, TLT, IWM, QQQ, USO, SH,
RWM, PSQ, AGG, DOG, EWA, EFA, EWJ, IJH, VTI, XLF, XLE, and XLK

E*Trade Summer, 2019 (PROS)

FXI, SPY, EEM, GLD, SLV, DIA, UNG, TLT, IWM, QQQ, USO, SH,
RWM, PSQ, AGG, DOG, EWA, EFA, EWJ, IJH, VTI, XLF, XLE, and XLK

BOATS launch June 14, 2021

Interactive Brokers October 22/November 21, 2021 (IBEOS)

FXI, SPY, EEM, GLD, SLV, DIA, UNG, TLT, IWM, QQQ, USO, SH,
RWM, PSQ, AGG, DOG, EWA, EFA, EWJ, IJH, VTI, XLF, XLE, and XLK.

Robinhood May 11, 2023 (BOATS)

FXI, SPY, EEM, GLD, SLV, DIA, UNG, TLT, IWM, QQQ, USO, SH,
RWM, PSQ, AGG, DOG, EWA, EFA, EWJ, IJH, VTI, XLF, XLE, and XLK

AAPL, MSFT, GOOGL, AMZN, NVDA, TSLA, META, DIS, F, AMD,
NIO, RIVN, COIN, TQQQ, LCID, CVNA, SOXL, SQQQ, SOXS,

Expanded to over 900 securities.

Interactive Brokers July 25, 2023 (IBEOS and BOATS)

All NMS stocks 10,000 symbols

Schwab October 30, 2024 (BOATS)

FXI, SPY, EEM, GLD, SLV, DIA, UNG, TLT, IWM, QQQ, USO, SH,
RWM, PSQ, AGG, DOG, EWA, EFA, EWJ, IJH, VTI, XLF, XLE, and XLK.

Planned roll-out: Constituents of Dow Jones Industrial Average, the Standard & Poor's 500 Index, and the Nasdaq 100 Index, plus hundreds of ETFs.

Figure 3. List of Nocturnal Securities for U.S. Retail Brokers
Source: Web search for announcements.

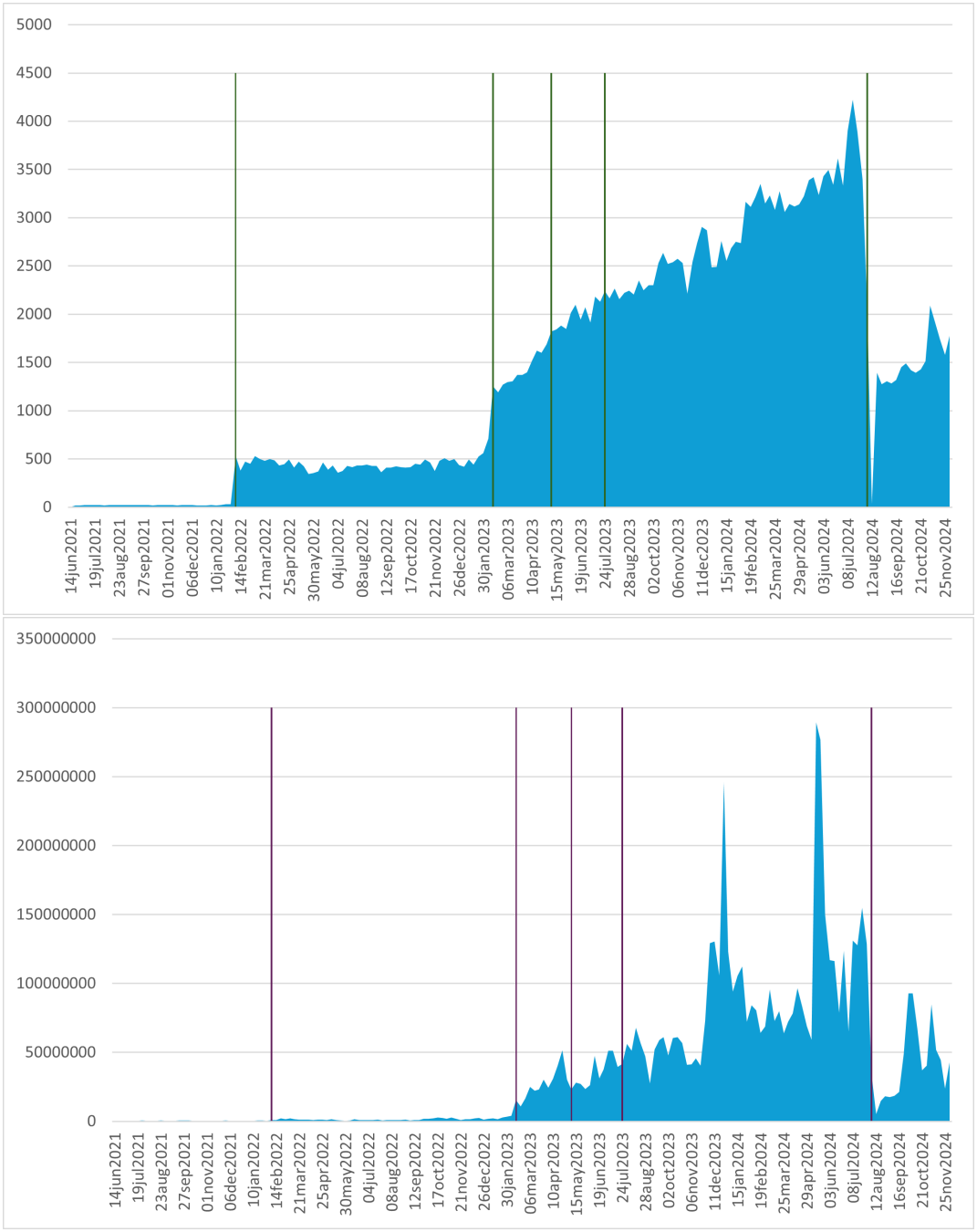

Figure 4. Nocturnal Trading Activity on BOATS

The figure shows trading activity on the BOATS platform weekly since its inception. The top panel illustrates the number of unique symbols traded on the platform and the bottom panel reports share volume. The first vertical line indicates when Samsung Securities started using the platform, the second one when Futubull started using the platform, the third one when Robinhood started using the platform, the fourth one is when Interactive Brokers started using the platform, and the last one is the week when the BOATS service was interrupted. Source: FINRA ATS Transparency Data.

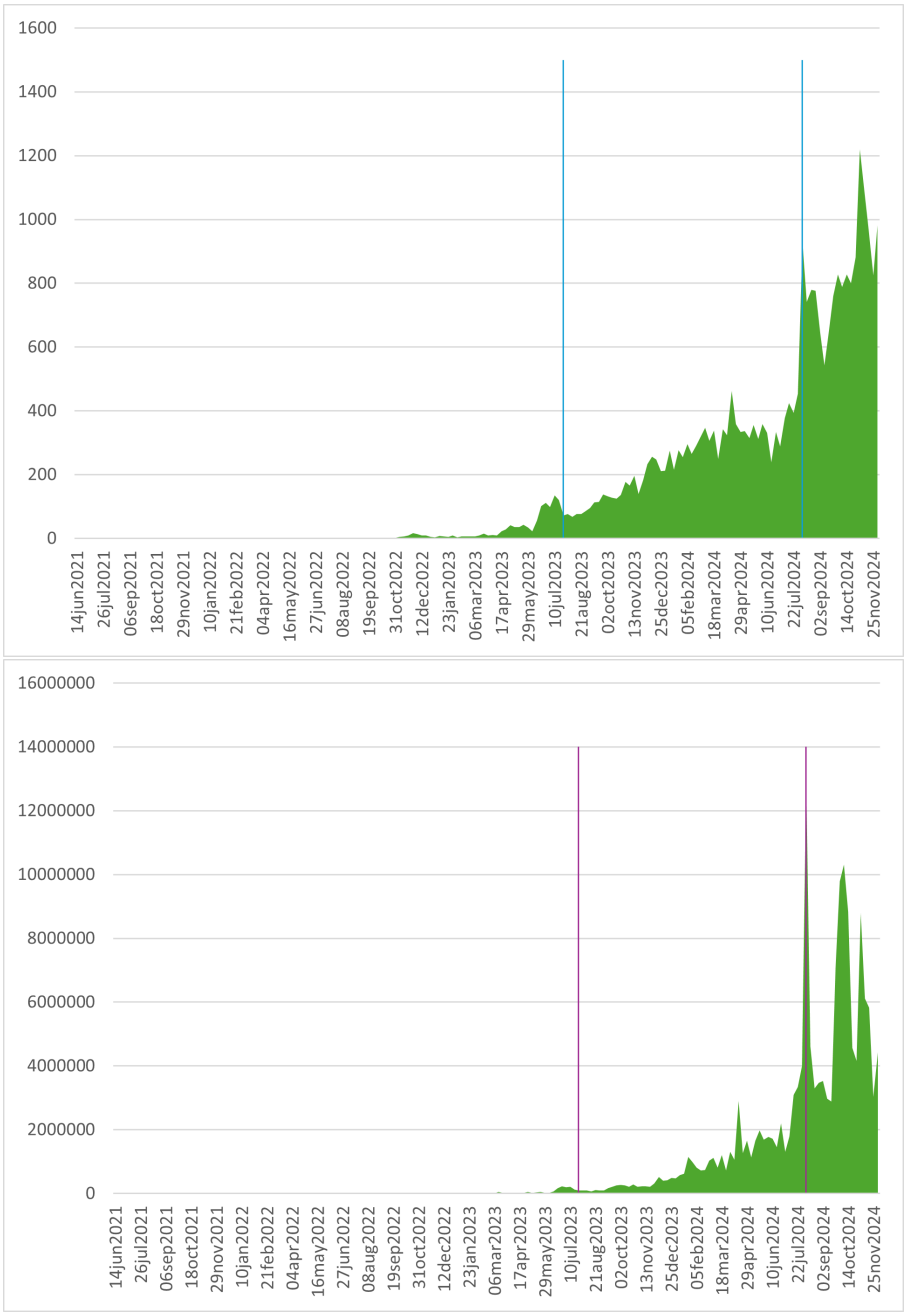

Figure 5. Nocturnal Trading Activity on IBEOS

The figure shows trading activity on the IBEOS platform weekly. The top panel illustrates the number of unique symbols traded on the platform and the bottom panel reports share volume. The first vertical line indicates when Interactive Brokers started using BOATS as well as IBEOS and the second one indicates when the BOATS service was interrupted. Source: FINRA ATS Transparency Data.

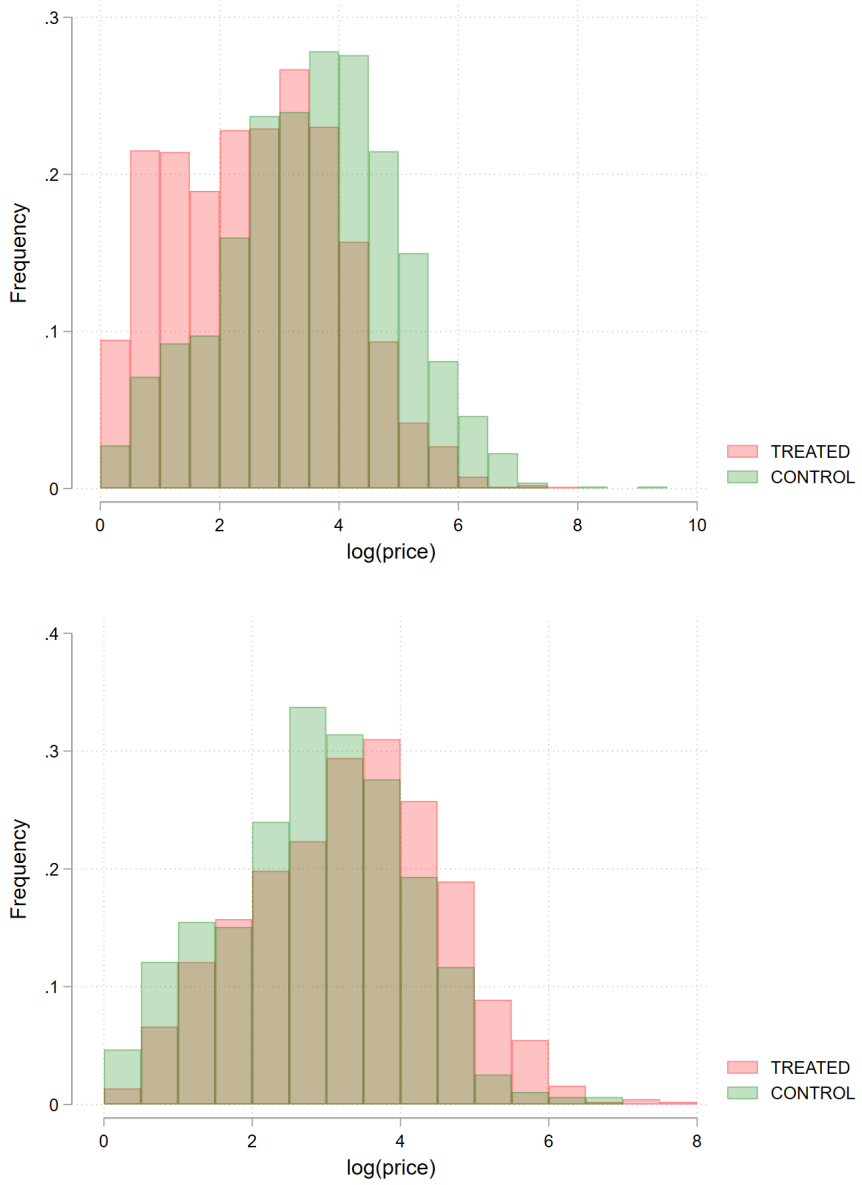

Figure 6. Distribution of Prices

The figure shows the distribution of prices for unmatched Treated and Control stocks (top), and propensity-score matched Treated and Control stocks (bottom). Propensity-score matching was conducted using nearest neighbor matching without replacement based on June 2024 nocturnal volume as a fraction of CRSP volume, price, shares outstanding, and volatility. Source: WRDS Intraday Indicators and FINRA ATS Transparency Data.

Internet Appendix to "Nocturnal Trading"

IA1. Extended Discussion of Institutional Details

This section provides further discussions of the institutional details of nocturnal trading, which dates back to at least 2017 (see Figure IA1.1).

[Figure IA1.1]

IA1.1 Blue Ocean ATS (BOATS)

tZERO Group was founded in 2014 with the goal of utilizing blockchain technology and is a portfolio company of Medici Ventures, the blockchain subsidiary of Overstock.com. tZERO Group is not a registered broker-dealer, and any broker-dealer services were provided through broker-dealer subsidiaries PRO Securities, LLC, and SpeedRoute, LLC, both broker dealers registered with the SEC and members of FINRA and SIPC. Starting as early as 2014, tZERO Group's subsidiary PRO Securities, LLC, operated an ATS for trading NMS securities and in so-called "blockchain," "digital" or "digitally enhanced" securities pursuant to a Form ATS. By December 2014, tZERO Group and its affiliated broker-dealer had an arrangement with an unregistered Singaporean firm Blue Ocean Financial Technology, Pte. Ltd. to facilitate trading in certain NMS stocks and ETFs after U.S. markets had closed.[14]

In early 2017, tZERO Group (t0.com) formed Blue Ocean Technologies, LLC after acquiring the assets of Blue Ocean Financial Technology, Pte. Ltd. According to the January 12, 2017 press release:[15]

The newly-formed Blue Ocean Technologies will offer the first transparent, electronic marketplace for trading U.S.-listed securities during non-U.S. trading hours. This electronic mar-

[14] https://bit.ly/4h2udK8
[15] https://bit.ly/40lBY6Y

ketplace creates a new opportunity for firms, traders, and investors to manage risk and take advantage of opportunities created outside of U.S. regular trading hours. Also, foreign investors will have after-hours access to the full capabilities of the U.S. capital markets, which make up the second largest class of investments across Asia and Europe (behind country-specific home markets), while allowing for U.S.-based traders to track off-hours market movement and react accordingly.

"Blue Ocean Technologies will provide investors in the rapidly growing Asian region with an avenue to execute U.S. equities during their usual business hours," said t0 President Joe Cammarata. "This concept is the first of its kind, and has already attracted the attention of several large market-making clients to provide daily liquidity within our platform."

PRO Securities operated an ATS for NMS securities that reported to the FINRA ATS transparency data as early as the week of February 19, 2018. Starting in October 2019, once its initial Form ATS-N became effective, tZERO LLC, took over the operations of PRO Securities ATS and continued reporting under the same MMID, PROS. tZERO ATS operated each evening before the NYSE Trade Reporting Facility is open so that trades effected on the ATS could be reported. Subscribers/sponsored access clients could submit orders to the ATS beginning at 6:15 p.m. on the days of operation of the ATS. Matching in NMS Stocks on the ATS occurs from 8 p.m. to 4 a.m. the following day if the TRF was open for trade reporting on that following day. The tZERO ATS for NMS securities ceased operations in June 2021.

Blue Ocean Technologies established another subsidiary, Blue Ocean ATS, LLC, (BOATS) with the intent to become a broker dealer and to operate an ATS in 2019. Blue Ocean ATS, LLC, became a FINRA member/broker-dealer in 2020, and the platform went live for trading U.S. NMS securities in June of 2021, with an official launch on October 5, 2021.[16] At this point, BOATS starts reporting under MMID BLUE, and takes over the business of nocturnal trading in

[16] https://bit.ly/4g7begi and https://bit.ly/4arRMd2

NMS securities from tZERO ATS which has been reporting under MMID PROS.[17]

BOATS' core offering is the Blue Ocean Session, which operates overnight in the U.S. from 8 p.m. to 4 a.m. (Sunday-Thursday). It operates only on those calendar days when the NYSE Trade Reporting Facility (TRF) is open for reporting the following morning. Trades executed between 8 p.m. and 12 a.m. will carry a trade date of the following trade day. Settlement date will reflect the first business day following the transaction (T+1). The platform is available to U.S. broker dealers registered with the SEC and a member of at least one U.S. self-regulatory organization (SRO). It operates as an electronic limit order book with price and time priority. The platform only accepts limit day (session) orders, does not accept fractional share orders, and does not accept orders in excess of $5 million. All orders on the ATS order book are canceled at the end the trading session. The only time-in-force instruction accepted by the ATS is DAY. BOATS does not route orders out.

BOATS uses a 20% price band during its trading session. Orders entered into the ATS at the open and during the trading session that are priced at more than 20% away from the reference price for that NMS Stock are rejected. The reference price is the last sale price for each security printed on a national securities exchange as of 7:30 p.m. In addition to the 20% band, BOATS also employs single order share size and notional value checks on each order.

BOATS charges subscribers a per-executed-share fee based on the following schedule:[18]

1. Early Adopters (Subscribers who were ATS participants as of its first operating session):
    (a) For adding liquidity, there is a rebate of $.0006
    (b) For taking liquidity, the charge is $.0014 - $.0015
2. Standard Pricing:
    (a) For adding liquidity, there is a rebate of $.0006

[17] Based on FINRA ATS Transparency data, tZERO LLC ATS continues trading OTC securities.
[18] https://bit.ly/4hmKg5f

(b) For taking liquidity, the charge is $.0020

3. For stocks below $1.00:

   (a) There is no rebate for adding liquidity

   (b) The fee for taking liquidity is $.0030 per dollar of volume (i.e., 0.0030%, thirty basis points).

BOATS subscribers can obtain full depth-of-book access directly from BOATS or from third-party distributors. BOATS charges subscribers and sponsored access clients for market data. Depending on setup costs, recurring fees, and technology integration costs, BOATS incurs costs to fully integrate its direct market data feed into the third-party distributors platform. BOATS charges $12,500 for the third-party distributors and charges $5,000 for receiving market data directly from BOATS (i.e., subscribers and sponsored access clients). As of March 13, 2023, ICE provides access to the BOATS real-time equity data feed.[19]

BOATS' first U.S. retail broker client was TD Ameritrade that started offering nocturnal trading in 12 exchange traded funds on its Thinkorswim platform on January 22, 2018.[20] U.S. broker E*Trade announced nocturnal trading in the same 12 exchange traded funds on February 20, 2018.[21] Nocturnal trading by U.S. retail clients was slow to take off (Figure 1), and it was not until May 11, 2023 that the next major U.S. retail broker, Robinhood, announced it was starting nocturnal trading in 43 symbols (ETFs and individual names) for active traders, with plans to gradually expand access to all users by June, 2023.[22] On July 25, 2023, Interactive Brokers announced that they have partnered with BOATS for supplemental liquidity.[23] U.S. retail broker TradeUP started offering nocturnal trading to its U.S. clients on June 25, 2024. More recently,

[19] https://bit.ly/3PEF1SL
[20] https://bwnews.pr/42lH4Td
[21] https://bwnews.pr/42jQ4YU
[22] https://on.wsj.com/3PGYxOl
[23] https://bit.ly/4apAoW8

Schwab said on October 30, 2024, it plans a slow roll-out of nocturnal trading starting with its most active traders and a limited list of 24 ETFs. The rollout is expected to be completed midway through the first quarter of 2025, when clients will have access to nocturnal trading in all stocks listed on the Dow Jones Industrial Average, the Standard & Poor's 500 Index, the Nasdaq 100 Index, and hundreds of ETFs.[24] Finally, Webull announced the launch of nocturnal trading, powered by BOATS on November 12, 2024.

A major target audience for the nocturnal Blue Ocean session is retail investors in the Asia-Pacific region that want to trade U.S. securities during Asian business hours, and BOATS has gradually built this clientele through strategic partnerships. BOATS announced a strategic partnership with a Korean brokerage firm Samsung Securities to offer U.S. equity trading during local Asia-Pacific business hours on February 8, 2022.[25] And by now, at least 18 Korean retail brokers, e.g., Kiwoom Securities, Korea Investment & Securities, Mirae Asset Securities, and NH Investment & Securities, offer trading of U.S. stocks on BOATS during Asian business hours. A partnership between BOATS and Hong Kong based Futu Clearing Inc. to provide Futubull clients real-time trading of U.S. equities was announced on February 14, 2023.[26] BOATS and the Tokyo Stock Exchange (TSE) announced a strategic partnership on August 7, 2023.[27] In 2024, additional partnerships were announced, e.g., with the global broker GTN to launch extended trading hours trading for U.S. stocks from clients in the Asia-Pacific and Middle East markets, and the U.S. broker TradeUP started offering nocturnal trading through its overseas affiliate, Tiger Brokers, to its clients throughout the Asia-Pacific region (Auckland, Beijing, Singapore, and Sydney).

Several institutional agency brokers are also partnering with BOATS, including Cantor Fitzgerald, Clear Street, Eugene Investment & Securities (South Korea, retail and institutional), Instinet, Velocity Clearing, and Vision Financial Markets (active traders, retail and institutional). These

[24] https://reut.rs/3PDETmu
[25] https://bit.ly/4anAKwo
[26] https://bit.ly/4h0sapY
[27] https://bit.ly/3E2Vyxa

are not just providing sponsored access, but also using BOATS to execute block trades according to BOATS leadership.

IA1.2 Interactive Brokers EOS ATS (IBEOS)

Interactive Brokers announced on November 21, 2022, that they were offering nocturnal trading for the same list of widely-held U.S. ETFs as TD Ameritrade and E*Trade.[28] However, instead of joining the other brokers using BOATS, Interactive Brokers developed their own platform, the IBKR Eos ATS (IBEOS). Interactive Brokers already operated their own ATS for pre-open, regular market trading, and after-hours trading, so they had the technology in house. Moreover, Interactive Brokers has affiliates all over the world, including the Asia-Pacific region (Australia, Hong Kong, Japan, Singapore), that were given access to IBEOS for trading U.S. stocks during the overnight period, aiming to build a large pool of liquidity.

IBEOS offers trading from 8 p.m. to 3:50 a.m. with the week's first session starting on Sunday at 8 p.m. and the last session ending Friday at 3:50 a.m.[29] The IBEOS only accepts regular limit orders with the following time-in-force (TIF) instructions: (i) "day" (i.e., good for the duration of the trading session), (ii) immediate or cancel, and (iii) good-til-time (orders submitted with TIF instructions of longer than day are treated as day orders by the ATS and are canceled at the end of the trading session). Resting orders execute based on the following factors in order: price, time, and size. Trades executed in IBEOS are reported by 8:15 a.m. following the end of the relevant trading session to either the NASDAQ TRF Carteret and the NASDAQ TRF Chicago. IBEOS does not route orders out.

The following information is made available by IBEOS to brokerage customers and liquidity providers on a security-by-security basis during the ATS' regular trading hours: (i) highest resting bid price, lowest resting offer price, and aggregate size at such price level ("Top of Book Data")

[28] https://bwnews.pr/3EbUIOx
[29] https://bit.ly/4h0giEu

and (ii) price and size of the last sale within the ATS ("Last Sale Data"). This information is also made available to the IBKR Smart Order Router (SOR), although the SOR does not use such information for routing purposes. ATS market data is made available to brokerage customers and liquidity providers at no charge.

IBEOS exchange fees for Interactive Broker clients are as follows:[30]

1. For adding liquidity, there is a rebate of $.0000

2. For taking liquidity, the charge is $.0010.

Interactive Brokers has expanded the list of securities over time, and on July 25, 2023 announced that it is offering nocturnal trading for over 10,000 symbols. On the same date, it announced a partnership with BOATS for supplemental liquidity.[31] In addition to Interactive Broker's own foreign affiliates, the Taiwanese broker Sinopac started using IBEOS to access U.S. markets during Asian business hours for their clients on February 16, 2023.[32]

IA1.3 Retail Brokers

As discussed above, there are now at least six U.S. retail brokers that allow clients to trade in the nocturnal period. These include E*Trade, Interactive Brokers, Robinhood, Schwab (TD Ameritrade), TradeUP, and Webull. The current offerings differ slightly as summarized for major retail brokers in Figure 2. Interactive Brokers has the broadest security coverage offering trading in all NMS securities, E*Trade, Robinhood, and Schwab offer nocturnal trading for select but growing list of securities, and so far Fidelity does not offer nocturnal trading at all. Note also that retail brokers define the pre-open period as between 7 a.m. and open, even though the SIP opens at 4 a.m.

[30] https://bit.ly/3Cf4W06
[31] https://bit.ly/4apAoW8
[32] https://bit.ly/3WoAveK

[Figure 2]

Figure 3 illustrates the U.S. retail broker phase-in of securities for which nocturnal trading is allowed. In 2018, the list comprised 12 liquid ETFs, and this list was augmented to 24 liquid ETFs by TD Ameritrade and E*Trade in 2019. Interactive Brokers adopted the same list when they launched their IBEOS ATS in 2022. Nocturnal trading for select mega-cap stocks did not begin until May 2023, and it was initially limited to Robinhood clients. Robinhood rapidly expanded its offerings to roughly 900 securities, and Interactive Brokers went even further when they announced nocturnal trading for 10,000 NMS securities just two months later. Meanwhile, both E*Trade and TD Ameritrade (now part of Schwab) maintained their original lists, although Schwab announced in October 2024 that it will expand its offerings to cover index stocks and additional liquid ETFs.

[Figure 3]

BOATS has announced large partnerships with several foreign brokers, including Samsung, Futubull, GTN, and Tiger Brokers. However, many more foreign brokers can be accessing BOATS through a U.S. registered sponsoring broker. It is unclear which U.S. NMS securities Asian brokers allow their retail investors to trade on the BOATS and IBEOS platforms, but it appears to have been a significantly broader list than the one offered by U.S. brokers. When Samsung Securities starts offering trading on BOATS in February 2022, the number of securities traded on the platform increases from 31 to 524. However, trading remains highly concentrated in a few popular symbols, with the number of actively traded symbols far lower than the total number of NMS securities. Additionally, Asia-focused leveraged ETFs are particularly popular. For example, trading activity for two Direxion Daily FTSE China 50 Index (3X) Leveraged ETFs – YINN (Bull) and YANG (Bear) – both exceeded the 5% of consolidated volume in December 2024, forcing BOATS to disable trading for these symbols for the month of January 2025, because of

the SEC Regulation ATS' Fair Access Rules.[33] In practice, BOATS peaked at 4,222 unique symbols traded the week of July 15, 2024, while IBEOS peaked at 1,220 unique symbols traded the week of November 4, 2024 (the week of the U.S. Presidential election) based on weekly FINRA ATS Transparency data.

Most U.S. retail brokers charge zero commissions, and this applies also for nocturnal trading at E*Trade, Robinhood, Schwab (TD Ameritrade), TradeUP, and Webull. Thus, these retail brokers have to cover the BOATS trading fees some other way (see next subsection). Interactive Brokers offer nocturnal trading to its IBKR PRO Clients who pay commissions either at a tiered or a fixed rate. In addition to commissions per share, IBKR Pro-Tiered clients pay exchange fees and thus pay the BOATS and IBEOS fees for nocturnal trading. By contrast, IBKR Pro-Fixed clients do not pay exchange fees, and thus the regular commission of $0.005 per share has to cover the BOATS/IBEOS fees.[34]

We do not have detailed information on commissions for trading U.S. securities through retail brokers in the Asia-Pacific region, but it appears to be a mix of zero commissions and commissions and platform fees charged. Tiger Brokers Singapore charges a commission of $0.005 per share and a platform fee of $0.005 per share (presumably to cover the BOATS fees).[35] By contrast, Webull Singapore charges zero commissions also for trading U.S. securities on BOATS. In Hong Kong, Futubull charges commissions for trading U.S. securities, but Webull Hong Kong does not. As expected, Interactive Brokers' Asia-Pacific affiliates charge commissions for trading U.S. securities during Asian business hours. South Korean retail brokers like Kiwoon, Mirae, and Samsung charged commissions for retail trading in U.S. securities in 2022. However, a virtual marketing war broke out in South Korea in the summer of 2023 as brokers tried to court retail investors that were trading U.S. securities by offering commissions discounts (until year-end) and

[33] https://bit.ly/4h6FGZ9
[34] https://bit.ly/3Cf4W06
[35] https://bit.ly/4hoAHTx

other incentives.[36]

IA1.4 Liquidity Providers

BOATS and IBEOS both invite professional liquidity providers to their platforms. Virtu Financial and Jane Street are explicitly mentioned as partners on BOATS' website (https://blueocean-tech.io/), and the role of liquidity providers is frequently mentioned by BOATS representatives as being crucial for the success of the platform.[37] IBEOS Form ATS-N states "Only market-makers and other principal trading firms willing to provide significant liquidity to IBKR's customers may, subject to the approval of IBKR management, access the ATS as Liquidity Providers." Hence, OTC market makers (wholesalers) such as Virtu and Jane Street are likely active liquidity providers on both these platforms. It is our understanding that other major OTC market makers such as Citadel have so far elected not to participate in nocturnal trading.

In addition, OTC market makers act as executing brokers for zero commission U.S. retail brokers such as Robinhood and Webull. Therefore, these brokers do not route to BOATS and IBEOS directly, instead relying on wholesalers to either execute the nocturnal orders on a principal basis or route them to the BOATS platform. For example, Robinhood's customer agreement states:[38]

If Robinhood 24 Hour Market trading is available to you and you enter a limit order that is eligible for execution during the Robinhood 24 Hour Market, you understand that [...] (5) Robinhood will route such orders to a market center (a "24H Market Maker"), which may execute the order on a principal basis or route the order for execution to another market center; (6) between 8 p.m. and 4 a.m. ET ("Overnight Hours"), Robinhood will route such orders to a single 24H Market Maker, which may execute the order on a principal basis or route the order for execution to a single alternative trading system (the "24H ATS"); (7) the 24H ATS is not

[36] https://bit.ly/4jjGlIf
[37] https://bit.ly/4apFMIQ
[38] https://bit.ly/3PJfI1Y

required to display prices publicly and may have very limited liquidity and/or high volatility; (8) such an order may not be price protected and so may be executed by a market center at a price that is worse than prices available at other execution venues; (9) if the order is unexecuted as of the beginning of, or shortly before, the next Overnight Hours session, the order will be canceled and, subject to the order's time-in-force instructions, re-routed to a single 24H Market Maker, which may execute the order on a principal basis or route the order for execution to the 24H ATS; (10) if the order is unexecuted as of the end of, or shortly before the end of, the Overnight Hours session, the order will be canceled and, subject to the order's time-in- force instructions, re-routed to a 24H Market Maker, which may execute the order on a principal basis or route the order for execution to another market center; and (11) if the order is canceled and re-routed as described in (9) or (10) above, the order will not be eligible for execution during the period of time between the cancellation of the order and its re-routing.

Similarly, Webull states in their Extended Hour Trading Disclosure:[39]

Webull's extended hours trading offering allows you to place limit orders outside of regular trading hours. These orders are sent to a market maker, who may fill the order directly or pass it to another trading venue. During overnight hours (8 p.m. to 4 a.m. ET) ("overnight trading"), Webull works with a single market maker who may execute orders themselves or send them to an alternative trading system (ATS). This ATS doesn't publicly display prices and may have low liquidity and high price volatility. Webull may decide to add or remove market makers or modify this order processing.

It is unclear whether OTC market makers pay for nocturnal order flow. However, given that retail brokers charge zero commissions and have no other revenue sources for these orders, it is likely that they do.

[39] https://bit.ly/4h1lyaH

IA1.5 SEC Rule 606(a) Reports

SEC Rule 606(a) requires reporting of routing of held orders both during and outside regular trading hours. As far as we have been able to discern, the only broker that reports order routing to BOATS is Interactive Brokers. Rule 606(a) does not require brokers to report every venue they route to, as long as the total reported flow exceeds 90%, and all venues receiving at least 5% of order flow are disclosed.

Interactive Brokers started reporting routing to BOATS for non-S&P 500 stocks in January 2024 and for S&P 500 stocks in August 2024 based on their Rule 606(a) filings, as their usage of the platform started to grow.

Figure IA1.2 shows Interactive Brokers' routing to BOATS for non-S&P 500 stocks, which quickly grew to reach 10.22% of all non-directed and a notable 13.52% of all non-directed limit orders (Panel A) and 7 million shares. Recall that BOATS does not accept market orders.

[Figure IA1.2]

Figure IA1.3 shows Interactive Brokers' routing to BOATS for S&P 500 stocks, which, as we mentioned, did not trigger reporting until August 2024 yet quickly grew to reach 7.74% of all non-directed orders and 10.90% of all non-directed limit orders (Panel A) and 38 million shares.

[Figure IA1.3]

Interactive Brokers so far has only reported routing to its own nocturnal ATS IBEOS in its Rule 606(a) report for August 2024, when the platform received a drastic increase in order flow due to the service interruption at BOATS. For that month, they report that 3.43% (5.04%) of all non-directed flow for S&P 500 (non-S&P 500) securities was routed to IBEOS.

It is clear from Figure IA1.2 and Figure IA1.3 that nocturnal trading has quickly become a significant fraction of Interactive Brokers' retail business. We have less information about BOATS usage by other U.S. retail brokers, as they may not yet have reached levels of routing that would

require reporting. E*Trade appears to route directly to BOATS based on their Extended Hours Agreement:[40]

During the overnight extended-hours trading session, we route orders to a single alternative trading system ("ATS"). During the overnight session, there is no consolidated quote and the ATS that we use is not required to display its orders to the public. In addition, ATSs are not required to provide orders "price protection" which means that you are not guaranteed execution at top-of-book prices, and other orders may execute at prices not available to you.

TD Ameritrade also used to route directly to BOATS based on their January 21, 2018 Extended-Hours Session Rules. It is unclear if Schwab continues the historical practice of TD Ameritrade to route directly to BOATS, or if they route to an OTC market maker. Neither TD Ameritrade nor Schwab reports their routing on their Rule 606(a) reports, possibly because it does not reach a level which would be reportable.

Other brokers appear to view nocturnal orders as not-held and thus not reportable for Rule 606(a) purposes. For example, Robinhood's customer agreement states:[41]

If Robinhood 24 Hour Market trading is available to you and you enter a limit order that is eligible for execution during the Robinhood 24 Hour Market, you understand that ... (4) Robinhood deems each such order to be a "not held" order, i.e., an order with respect to which you have granted Robinhood discretion with respect to the price and time of execution...

The reason may to be that they characterize nocturnal orders as 24-hour orders (Robinhood 24 Hour Market and Schwab EXTO orders). These orders can be submitted from 8 p.m. and 4 a.m. and remain active until 8 p.m. on the following day. An unexecuted 24-hour order from the overnight session, will be re-routed back to the market maker for execution, and the market maker in turn may rout to a pre-open venue, and subsequently possibly to another venue for the regular market session. It appears that these brokers believe that since discretion is involved, it

[40] https://bit.ly/3CiwmCn
[41] https://bit.ly/3PJfI1Y

becomes a not-held order. We have an indication that nocturnal trading is of growing importance at Robinhood based on a March 6, 2024, statement by its CEO Vlad Tenev on X:

"Since we launched Robinhood 24 Hour Market last year, we've executed $10B in trading volume in overnight hours. On our busiest days, we've seen as much as 25% of the total daily trading volume come from outside regular trading hours."

IA2. Nocturnal Market Quality using Trades Data

In this section, we measure nocturnal market quality using the DTAQ and prior-day records data, which includes trades but not quotes. These market quality measures include:

- Roll measure of percent effective spread, motivated by Roll (1984) is computed based on intra-subperiod tick-by-tick data. This measure treats positive stock return autocovariance estimates as 0 (Goyenko, Holden, and Trzcinka, 2009).

- EDGE Day measure, computed at a daily frequency, and EDGE Min, computed at a one-minute frequency. Ardia, Guidotti, and Kroencke (2024) (AGK) show that the EDGE measures provide an efficient, asymptotically unbiased estimators of the effective bid-ask spread by incorporating discretely observed prices and optimizing estimation variance. AGK's analyses reveal that the measures outperform traditional spread estimators, especially in periods of infrequent trading, such as overnight sessions.

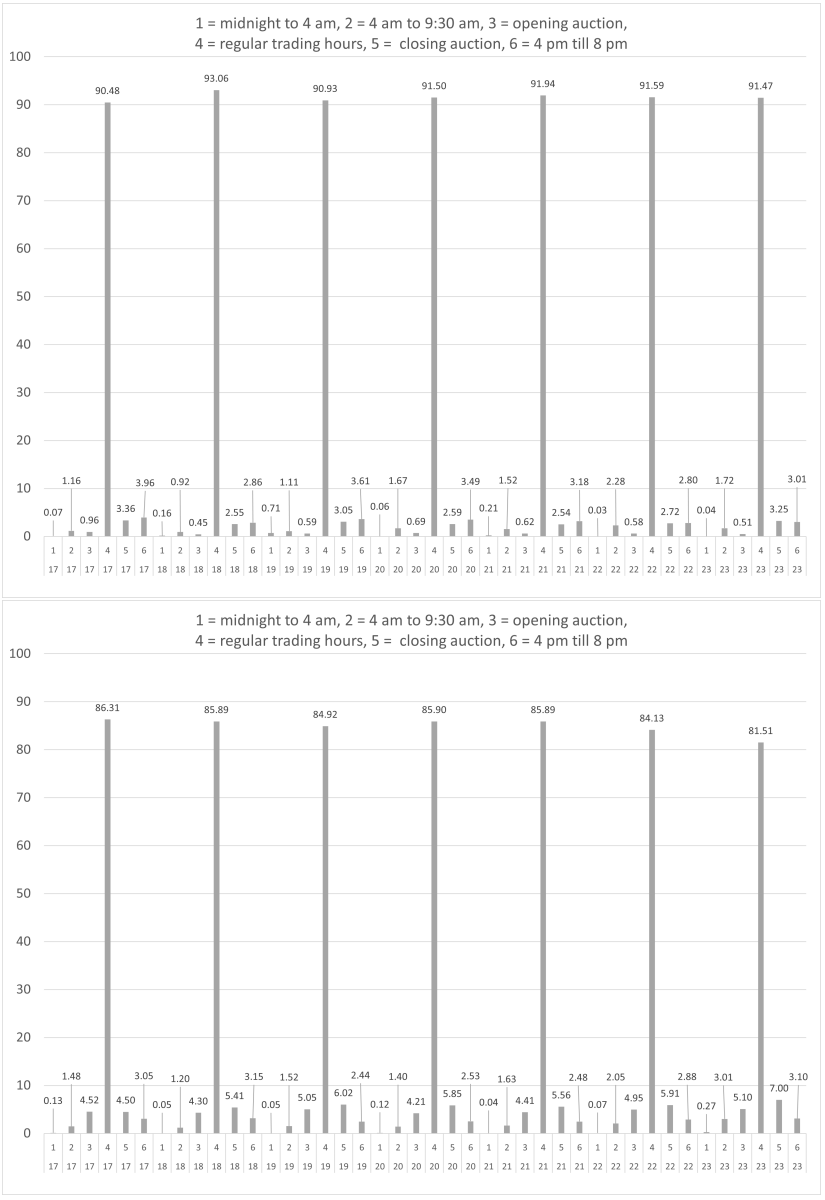

Figure IA1.1. Intraday Trading Periods

The figure reports percent of total share volume reported during different intraday periods: 1 = midnight to 4 a.m., 2 = 4 a.m. to 9:30 a.m., 3 = opening auction, 4 = regular trading hours, 5 = closing auction, 6 = 4 p.m. till 8 p.m. The source for the data is the DTAQ for 24 ETFs in the top panel (FXI, SPY, EEM, GLD, SLV, DIA, UNG, TLT, IWM, QQQ, USO, SH, RWM, PSQ, AGG, DOG, EWA, EFA, EWJ, IJH, VTI, XLF, XLE, and XLK), and for All NMS securities in the bottom panel. Source: DTAQ. Note that DTAQ does not report trades occurring in the 8 pm to midnight period.

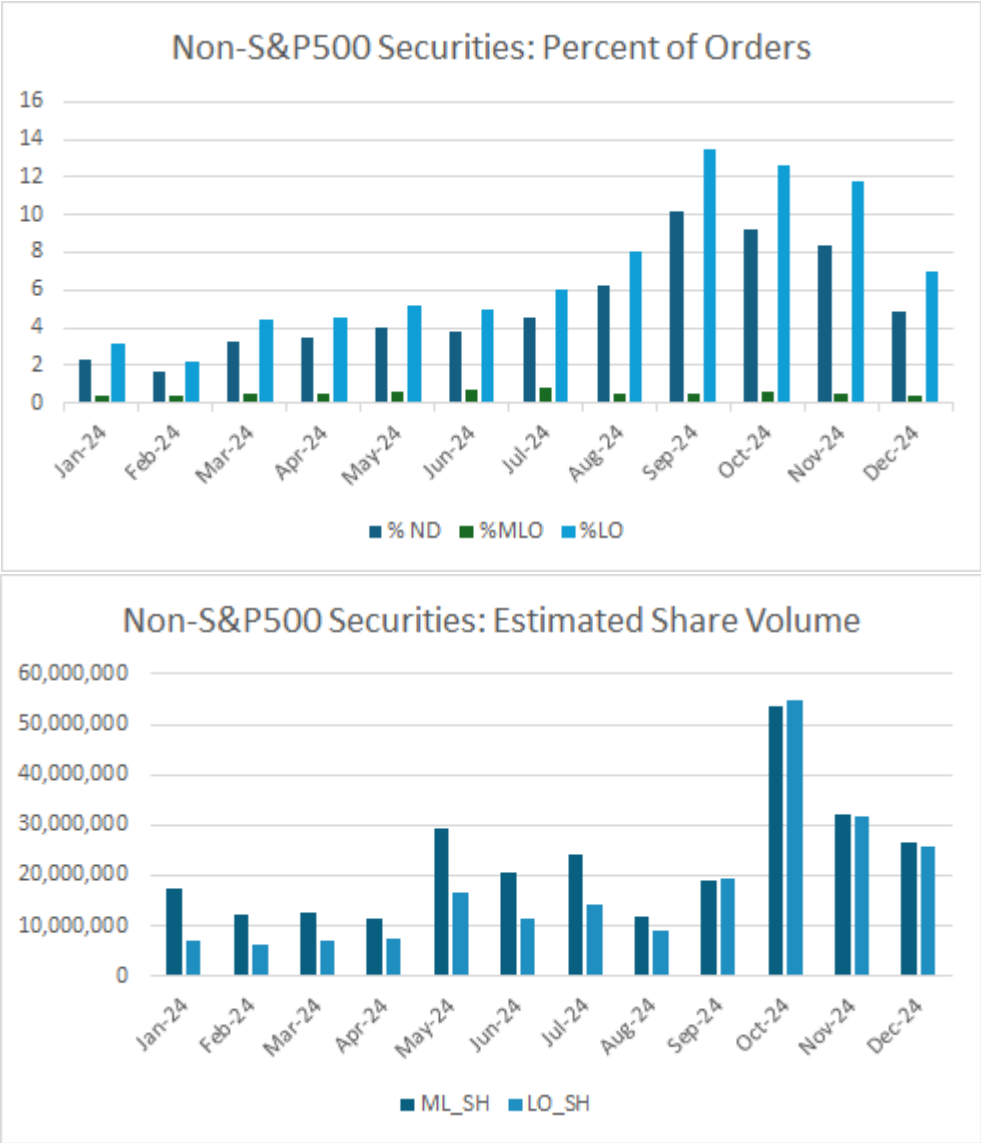

Figure IA1.2. Interactive Brokers Routing Non-S&P 500 securities to BOATS

This figure shows the percent of all Interactive Brokers non-directed held orders for Non-S&P 500 shares that are routed to BOATS by month for 2024 in Panel A, and the estimated share volume routed to BOATS in Panel B. %ND, %MLO, and %LO indicate the percent of all non-directed orders, marketable limit orders, and limit orders respectively. The estimated share volume is calculated based on the reported total dollar payments, divided by the cents per share. ML_SH and LO_SH are the estimated share volume for marketable limit orders and limit orders, respectively. Source: Rule 606 Reports.

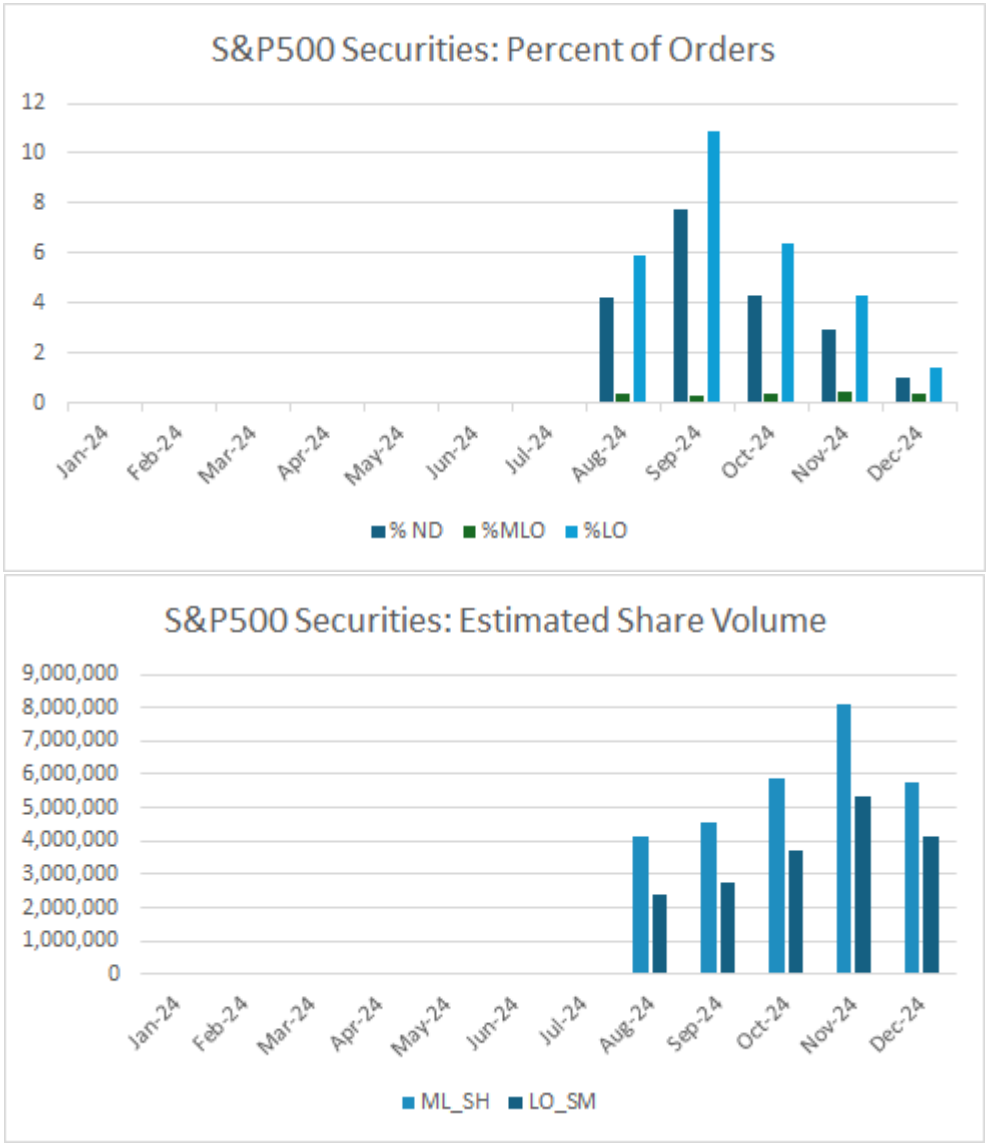

Figure IA1.3. Interactive Brokers Routing S&P 500 securities to BOATS

This figure shows the percent of all Interactive Brokers non-directed held orders for S&P 500 shares that are routed to BOATS by month for 2024 in Panel A, and the estimated share volume routed to BOATS in Panel B. %ND, %MLO, and %LO indicate the percent of all non-directed orders, marketable limit orders, and limit orders respectively. The estimated share volume is calculated based on the reported total dollar payments, divided by the cents per share. ML_SH and LO_SH are the estimated share volume for marketable limit orders and limit orders, respectively. Source: Rule 606 Reports.

Table IA2.1
Measures of Percent Effective Spread using Trades Data

The table reports percent effective spreads for a pilot sample of 484 NMS securities based on DTAQ and CTS data for January 2024-May 2024. Roll is calculated based on intra sub-period tick-by-tick data. The EDGE trading cost measure is calculated once per sub-period at the daily (EDGE Day) and one-minute frequency (EDGE Min) following Ardia, Guidotti, and Kroencke (2024). The measures are equally-weighted.

Panel A: Full Sample				
Time Period	# Stocks	Roll	EDGE Day	EDGE Min
4 p.m. to 8 p.m.	484	0.51%	1.57%	0.87%
8p.m. to Midnight	484	0.61%	2.32%	2.48%
Midnight to 4a.m.	484	0.42%	1.89%	1.14%
4a.m. to 9:30a.m.	484	0.45%	1.86%	0.74%
Open	484			
Regular Hours	484	0.10%	1.08%	0.16%
Close	484			
Panel B: Stocks and ADRs				
Time Period	# Stocks	Roll	EDGE Day	EDGE Min
4p.m. to 8p.m.	347	0.62%	1.84%	1.04%
8p.m. to Midnight	347	0.73%	2.61%	2.86%
Midnight to 4a.m.	347	0.53%	2.29%	1.39%
4a.m. to 9:30a.m.	347	0.50%	2.16%	0.88%
Open	347			
Regular Hours	347	0.12%	1.24%	0.21%
Close	347			
Panel C: All Other Security Types (Mainly ETFs)				
Time Period	# Stocks	Roll	EDGE Day	EDGE Min
4p.m. to 8p.m.	132	0.25%	0.88%	0.44%
8p.m. to Midnight	132	0.32%	1.60%	1.49%
Midnight to 4a.m.	132	0.15%	0.91%	0.50%
4 a.m. to 9:30 a.m.	132	0.32%	1.08%	0.38%
Open	132			
Regular Hours	132	0.03%	0.66%	0.05%
Close	132			