Nocturnal Trading*

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Abstract. Although relatively new, nocturnal trading in U.S.-listed equities, defined as trading between 8:00 p.m. and 4:00 a.m., has grown rapidly. This activity is predominantly retail-driven and concentrates in a relatively small subset of securities. A single trading platform dominates the nocturnal session, with liquidity supplied by only two market makers. Using unique transaction-level data, we show that despite limited liquidity-provider participation, trading costs remain relatively low. Moreover, despite the retail dominance, nocturnal trading contributes economically significant price discovery, particularly for non-U.S. firms and macro-oriented exchange-traded funds. While nocturnal traders appear to trade on price-relevant information, transaction costs leave average net profitability close to zero unless positions are held over longer horizons.

Key words: Nocturnal Trading, Retail Investors, Execution Quality, Price Discovery

JEL: G20; G24; G28

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1 Introduction

Nocturnal trading of U.S. equities, defined as trading between 8:00 p.m. and 4:00 a.m. the following day, is a relatively recent phenomenon that is rapidly gaining momentum.[1] Such trading was virtually non-existent as recently as late 2022, before experiencing rapid growth throughout 2023 and 2024 (Figure 1). Trading volume during nocturnal hours is predominantly retail, and nocturnal activity often accounts for more than 10% of total daily retail volume for securities that actively trade overnight.

[Figure 1]

Whether nocturnal trading represents a valuable addition to the range of options available to retail investors is an open question. The absence of institutional competition during these hours may create an environment in which retail investors have greater opportunity to trade on price-relevant information such as global and firm-specific extended hours news.[2] However, the nocturnal market may also be susceptible to frictions commonly associated with retail trading, including attention-driven behavior and herding (Barber, Huang, Odean, and Schwarz, 2022, Eaton, Green, Roseman, and Wu, 2022). During regular trading hours, such retail behaviors are likely tempered by the presence of sophisticated institutional traders who contribute to price discovery and help maintain price efficiency. It is unknown whether similar mechanisms operate effectively during nocturnal hours.[3]

Furthermore, it remains unclear whether the nocturnal market is capable of providing retail participants with liquidity that is competitively priced. To our knowledge, only two proprietary

[1] "Overnight Trading Gains Traction with the NYSE on Board," by I. Schmerken, Flextrade, November 21, 2024 (`https://bit.ly/4joe9UI`).

[2] "Momentum Is Building Toward Round-the-Clock Equity Trading," by J. Hintze, TabbFORUM, July 10, 2025 (`https://bit.ly/4rzJveT`).

[3] An additional concern is impaired decision-making due to reduced mental alertness documented by Han, Hirshleifer, Sheng, and Sun (2025). This is unlikely to be a first-order issue for our results, however, because a large share of nocturnal market participants in our sample are retail investors from the Asia-Pacific region, who trade during their daytime hours.

trading firms (wholesalers), Jane Street and Virtu, make markets during the nocturnal session over our sample period. The number of active wholesalers is three to four times larger during regular trading hours (Ernst, Malenko, Spatt, and Sun, 2025, Dyhrberg, Shkilko, and Werner, 2025), and whether their limited participation during the nocturnal session is sufficient to sustain a competitive liquidity environment is unclear. It is worth noting that during regular trading hours, wholesalers predominantly intermediate retail market and marketable limit orders off-exchange, while primarily routing non-marketable limit orders to exchanges (Battalio and Jennings, 2025, Anand, Samadi, Sokobin, and Venkataraman, 2025). During the nocturnal session, both marketable and non-marketable retail orders tend to be sent directly to the nocturnal venues.

Until very recently, nocturnal trading was confined to two Alternative Trading Systems (ATSs): Blue Ocean (BOATS) and Interactive Brokers' IBKR EOS (IBEOS). However, several additional venues are entering, or plan to enter, the overnight trading space, including major exchanges such as Nasdaq and the NYSE, along with other ATSs. During our sample period from January to May 2024, virtually all nocturnal trading volume occurs on BOATS.[4] Trading activity is also highly concentrated cross-sectionally: roughly 50% of dollar volume is generated by just 10 stocks, and approximately 90% by the top 100. Virtually all BOATS volume originates from retail traders, with about 80% coming from the Asia-Pacific region, despite the venue's continued efforts to attract institutional participation.[5]

To study the nocturnal market and compare it with other parts of the 24-hour trading cycle, we construct a sample of frequently traded stocks that have activity in all three sessions: nocturnal, extended, and regular hours, on every day of the sample period, which spans January through May 2024.[6] Given the concentrated nature of overnight trading in a small set of actively traded names,

[4]Nocturnal trading volumes declined in the third quarter of 2024 due to a temporary service interruption on BOATS. Korean brokerages, reportedly a significant source of trading volume on the platform prior to the disruption, did not return to BOATS until November 2025.

[5]"Blue Ocean's Brian Hyndman Talks Overnight Trading & Tokenization," by B. Morris, TabbFORUM, November 20, 2025 (https://bit.ly/48A7YIj).

[6]Extended hours include pre-open and post-close periods; respectively, 4:00 a.m. to 9:30 a.m. and 4:00 p.m. to 8:00 p.m. Regular hours include the main trading session from 9:30 a.m. to 4:00 p.m..

this sample captures the vast majority of nocturnal volume. We find that quoted and effective spreads during the nocturnal session are comparable to those observed during extended hours. Compared to regular trading hours, nocturnal spreads are roughly twice as wide.

Realized spreads, which reflect trading costs net of adverse selection, offer a more nuanced view. While realized spreads during the nocturnal session are positive and exceed those observed during regular hours at very short horizons, they fall below regular-hours levels at longer horizons and even become negative. This suggests that, unless a nocturnal liquidity provider is able to exit their position quickly, which is a challenge given the relatively low frequency of nocturnal order flow and the directional imbalances it often exhibits, they may not be adequately compensated for the risks and costs of liquidity provision. Given that wholesalers supply liquidity during the nocturnal session, it may appear puzzling that they would do so at a loss. The key to interpreting the realized spread result is that a substantial fraction of nocturnal liquidity is supplied by retail investors themselves; BOATS representatives estimate this share to be approximately 50%. In such an environment, wholesalers can earn positive realized spreads while retail traders earn negative spreads, producing the negative average we observe.

Why are nocturnal realized spreads negative? Trade price impacts during the nocturnal window are two to fifteen times larger than during regular trading hours. This flow is also persistent, generating order imbalances more than three times those observed during the day. In contrast, nocturnal quotes are considerably less informative. To assess their informational content, we follow Muravyev and Pearson (2020) and Hagströmer (2021) and compare depth-imbalance-weighted midquotes to unweighted midquotes. The results show that nocturnal limit orders are relatively uninformed, as weighted midquotes point in the direction opposite of actual future price movements.

This finding is noteworthy for two reasons. First, even if wholesalers tend to submit informed quotes during the nocturnal session, as one might expect from sophisticated liquidity providers with access to market indicators from around the globe, their information appears to

be overwhelmed by the predominance of uninformed retail limit orders. Second, the structure of the nocturnal market is difficult to reconcile with modern models of dynamic limit order books (Goettler, Parlour, and Rajan, 2009, Roşu, 2020, Bhattacharya and Saar, 2021, Riccò, Rindi, and Seppi, 2024), which assume that informed traders submit both marketable and non-marketable orders and often prefer the latter. Instead, nocturnal trading more closely resembles the environment assumed in earlier models, where informed traders primarily rely on market orders (Glosten, 1994, Rock, 1996, Seppi, 1997), raising the question of why the nocturnal market has evolved toward this equilibrium.

To provide further evidence on nocturnal price movements, we assess price discovery by constructing a Weighted Price Contribution (WPC) measure to quantify the relative impact of different trading sessions over the 24-hour cycle. We find that the nocturnal session contributes an economically and statistically significant 10% to overall price discovery over the full trading day. The effect is even more pronounced for the most actively traded securities; for example, nocturnal trading in the top ten securities accounts for over 21% of 24-hour price discovery.

What drives the price discovery observed during the nocturnal session? Our results show that for U.S.-headquartered stocks, nocturnal trading contributes only about 4% to total price discovery, indicating that overnight information incorporation is unlikely to be fueled primarily by earnings announcements or other U.S.-centric idiosyncratic news events. In contrast, for firms headquartered outside the U.S., nocturnal trading contributes over 20% to total price discovery. Many of these firms are based in Asia, consistent with the view that overnight price movements reflect the incorporation of news released during business hours in the Asia-Pacific region.

We also examine index securities, including equity index ETFs and what we refer to as macro ETFs, those tied to U.S. Treasuries, gold, and other broad macroeconomic exposures. While equity index ETFs exhibit nocturnal price discovery of just over 11%, this figure is not significantly different from that of U.S. stocks during the same period. In contrast, macro ETFs display substantially greater nocturnal price discovery, approaching 24%, which is both economically and

statistically distinct from the U.S. stock benchmark. These findings suggest that global macroeconomic information is being incorporated into prices during the overnight session. Finally, we examine a group of securities primarily consisting of leveraged ETFs on indices and individual stocks in the U.S. and Asia. These ETFs represent nearly a quarter of our sample. The nocturnal WPC for this group is both statistically significant and sizable, at nearly 20%, indicating that investors actively trade these instruments and move prices during the nocturnal session.

One might question whether the observed nocturnal price discovery reflects the incorporation of long-lived information or merely transitory price pressure, caused by herding coupled with imperfect arbitrage, that persists briefly and then partially reverses over subsequent days or weeks (Barber, Huang, Odean, and Schwarz, 2022, Hendershott, Menkveld, Praz, and Seasholes, 2022). While this question is inherently difficult to answer, especially given the ambiguity around the appropriate information horizon, we find that liquidity demanders' profits earned during the nocturnal period do not reverse for at least 90 days. These profitability figures are however gross of trading costs. Once these costs, which, as previously discussed, are substantial, are taken into account, the profitability of nocturnal positions declines considerably. At most investment horizons we examine, these positions appear to merely break even unless held for more than three months. This suggests a market equilibrium. While retail investors do appear to trade on price-relevant information during the nocturnal session, trading costs appear to absorb much of these rents. As a result, for the average investor, the profitability of nocturnal trading is largely neutral unless positions are held for extended periods.

This study is related to the literature on quote and trade activity and price discovery during the pre-open and after-hours periods. Biais, Hillion, and Spatt (1999) examine price discovery during the pre-open on the Paris Bourse, whereas Cao, Ghysels, and Hatheway (2000) investigate price discovery via quotes on Nasdaq during its pre-open. Barclay and Hendershott (2008) also analyze price discovery during the Nasdaq pre-open and find that increased pre-open trading volume enhances the efficiency of opening prices. Moreover, they document a shift in price discovery

from the opening trade to the pre-open period, though this effect is concentrated among the highest-volume stocks. By the end of their sample period, pre-open trading reached 4% of share volume, exceeding after-hours trading volume.

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 extended-hours trading costs and liquidity externalities, for Nasdaq stocks. The former study finds that about 10% of daily price discovery occurs between 8:00 a.m. and 9:30 a.m., while price discovery for the remaining extended hours periods is insignificant. These studies also 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 relative to regular hours, 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 (Berkman and Truong, 2009, deHaan, Shevlin, and Thornock, 2015, Cunat and Groen-Xu, 2017). 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 (2012) 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. 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. Finally, Gregoire and Martineau (2022) find that quotes reflect information quicker than trade prices following earnings announcements during extended hours. We find that nocturnal price discovery is relatively low for U.S. stocks compared to ETFs and international stocks, suggesting that price movements from 8 p.m. to 4 a.m. are not driven by U.S. earnings announcements.

2 Background

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

Continuous nocturnal trading in U.S. equities dates back at least to 2018 via tZERO Group. Initially, tZERO operated through its broker-dealer subsidiary, PRO Securities, before taking over an alternative trading system in 2019 under the Market Maker ID (MMID) PROS. Around the same time, tZERO acquired the assets of Blue Ocean Financial Technology and formed Blue Ocean Technologies, which subsequently established a new subsidiary, Blue Ocean ATS (BOATS), with the goal of operating an overnight trading venue.

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 also states that institutional investors do not currently have a very large presence on their platform. BOATS operates as a limit order market, accepting both marketable and non-marketable limit orders. All order sizes are fully displayed, and the platform does not permit hidden or reserve orders.

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, such as MOON ATS (MOON) and Bruce ATS (BOSS), have very recently launched overnight trading platforms. IBEOS executes a relatively small share of nocturnal volume, while the other platforms have captured a trivial amount of volume thus far.

After a gradual ramp-up, many major U.S. retail brokers such as E*Trade, Interactive Brokers, Robinhood, and Schwab now offer nocturnal trading for a broad cross-section of securities. 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, which overlaps with the Asia-Pacific business day. These brokers either have partnerships with the ATSs, such as BOATS or IBEOS, or access the platforms through a U.S. registered sponsoring broker.

3 Data

We obtain data from a variety of sources. To measure trading and quoting activity during extended and regular hours, we use Daily TAQ (DTAQ). In the current regulatory reporting framework, DTAQ reports only the nocturnal trades and quotes that occur between midnight and 4:00 a.m. Activity between 8:00 p.m. and midnight is reported via "as-of/prior-day" messages the next morning, and those records are not included in Daily TAQ. To capture the full nocturnal session, we obtain comprehensive BOATS trade and quote data directly from the Intercontinental Exchange (ICE), which distributes these data as a separate product. 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.

Our analysis covers January through May 2024. According to weekly FINRA ATS Transparency data, 6,495 unique symbols trade on BOATS during this period. As shown in Figure 2, trading activity is highly uneven: 942 symbols (14.5%) trade in only one week, and the majority trade in fewer than eight of the 22 weeks. Moreover, eight percent of symbol-week observations consist of a single trade for a single share. At the same time, a meaningful subset of symbols trade regularly, with 1,112 symbols (17.1%) trading in every week of the sample, though not necessarily every day.[7] For comparison, among the same 6,945 symbols, 85.6% trade every week during the pre-open, 94.0% during regular trading hours, and 83.5% during the after-hours session.

[Figure 2]

To analyze BOATS and TAQ trade and quote data, we apply many of the filters recommended by Holden and Jacobsen (2014). However, because our focus is on a trading period that can be

[7] A total of 1,772 unique symbols trade on IBEOS during the sample period. Of these, 47.0% trade for only one week and 63.3% trade for at most two weeks, while just 49 symbols trade in every week of the sample.

relatively illiquid, we relax certain filters typically used for regular trading hours. For example, given the wider spreads observed outside regular hours, we do not impose an upper bound on quoted spreads.

To ensure sufficient data for assessing market quality, we require each security to have at least ten trades per nocturnal session (i.e., per night). We also require that the average nocturnal trade price exceeds $1 and that the security appears in CRSP with a non-missing share code. The resulting sample includes 2,905 securities that trade on BOATS and also trade in the U.S. pre-open, regular trading, and after-hours sessions on at least one day during the sample period. We further partition this sample into 174 securities that trade nocturnally on every night of the sample period (the frequently traded sample) and a non-overlapping remainder (the less frequently traded sample).

3.1 Top Ten Securities

To begin discussing nocturnal trading activity, it is useful to focus first on the securities that trade most frequently during the nocturnal session. Table 1 summarizes the top ten symbols traded both overall and by month. Panel A lists the top ten symbols by share volume and shows that nocturnal traders favor leveraged ETFs on semi-conductor indices such as the Direxion Daily Semiconductor Bear 3X Shares (SOXS) and the Direxion Daily Semiconductor Bull 3X Shares (SOXL), and on U.S. market indices such as ProShares UltraPro Short QQQ (SQQQ) and ProShares UltraPro QQQ (TQQQ) which are leveraged 3X. They also actively trade leveraged ETFs of Chinese market indices, including the Direxion Daily FTSE China Bull 3x Shares (YINN) and the Direxion Daily FTSE China Bear 3X Shares (YANG). Furthermore, nocturnal traders favor leveraged single name ETFs such as Direxion Daily TSLA Bull 2X Shares (TSLL) and T-Rex 2x Long Tesla Daily Target ETF (TSLT), and single stocks focusing on electric vehicles (NIO and FFIE), AI (SOUN), and crypto (COIN). While many symbols appear consistently

in the top ten by share volume, there is quite a bit of variation across the months suggesting that individual securities experience bursts of trading activity possibly related to news (LUNR, MARA, IBIT, LICY, and NKLA). In May 2024, we even see the meme stock GameStop (GME) appearing as number three in terms of share volume.

[Table 1]

Panel B repeats the analysis based on dollar volume and includes many more single name securities such as Nvidia (NVDA), Tesla (TSLA), Microsoft (MSFT), and Apple (AAPL). Dollar volumes are significant in the top ten symbols: almost $6 billion for Nvidia and more than $3 billion for Tesla over our five-month sample period. The difference between symbols comparing the panels is a reflection of the fact that single name securities such as these trade at higher stock prices than the leveraged ETFs. However, note that there is significant overlap in terms of top-ten presence for leveraged ETFs such as SOXL, TQQQ, and YINN. By dollar volume, index ETFs such as Invesco QQQ Trust (QQQ) and the SPDR S&P 500 ETF Trust (SPY) are also heavily traded overnight. Across the months, other semiconductor- and technology-related stocks appear intermittently (AMD, META, MSTR, SMCI, and TSM), and in May the meme stock GameStop (GME) also emerges among the top ten.

We briefly explore patterns of nocturnal trading activity by day of the week and time of day in Figures 3 and 4, respectively. Monday includes activity from Sunday 8 p.m. through Monday 4 a.m., Tuesday includes activity from Monday 8 p.m. through Tuesday 4 a.m., and so on. Many observers have told us that nocturnal activity peaks on Sunday evening leading into Monday as Asian traders react to news that has arrived over the weekend. Instead, Figure 3 shows that dollar volume is close to evenly distributed throughout the week.

[Figures 3 and 4]

In terms of time of night, Figure 4 shows that the highest share of dollar volume on Blue Ocean, about 12% of the ATS' volume, occurs right after the nocturnal trading session starts at

8 p.m. ET. This peak is at 9 a.m. in Hong Kong, Shanghai, and Singapore, 10 a.m. in Korea and Japan, and 12:00 p.m. in Sydney, Australia. There is also an increase in trading in the penultimate half hour of nocturnal trading, 3:00-3:30 a.m. About 7-8% of nocturnal dollar volume occurs during this window. This increase coincides with European market open at 9 a.m. Central European Time.

3.2 Concentration

We next consider concentration in nocturnal trading symbols, and how it compares to concentration in other periods of the trading day. This analysis sheds light on whether the significant nocturnal trading volume we find in the top ten lists for stocks such as NVDA and TSLA is representative of the universe of securities that are traded on Blue Ocean. Figure 5 compares the cumulative percent of dollar volume for the 400 stocks with the highest dollar volume on Blue Ocean to cumulative percent of dollar volume for all stocks trading during the rest of the 24-hour cycle.

[Figure 5]

The figure shows that approximately 50% of nocturnal dollar volume is concentrated in just ten symbols. More than 80% of volume is concentrated in 50 symbols, over 90% in 100 symbols, and nearly all nocturnal volume is accounted for by 300 securities. Pre-open trading is also highly concentrated, though the accumulation of volume is somewhat less steep. Regular-hours trading exhibits substantially less concentration: only about 25–30% of dollar volume is accounted for by the ten most actively traded symbols. The top 400 securities during regular trading hours account for about 75% of total volume, compared with nearly 100% during the nocturnal period. After-hours trading largely mirrors regular hours, though its cumulative volume rises more quickly, indicating greater concentration. In the trade and quote analysis that follows, we focus much of

our attention on a frequently traded sample of fewer than 200 securities. These concentration patterns indicate that this sample captures the vast majority of nocturnal trading volume.

3.3 Transition Matrices

Having documented the degree of concentration across sub-periods of the 24-hour trading day, we next examine whether the same stocks trade consistently on Blue Ocean over time. Table 1 has provided some indication that the composition of the top ten symbols varies across months. Another approach to this question is to examine the stability of trading activity on Blue Ocean over time. Figure 6 reports transition matrices for all securities traded on Blue Ocean, grouped into dollar-volume deciles. The top panel reports transitions from one night to the next, while the bottom panel shows transitions from one week to the next. If trading activity is stable, such that a security tends to remain in the same decile over time, we would expect the transition matrix to exhibit mass concentrated along the diagonal, with relatively little off-diagonal movement.

[Figure 6]

While securities do transition across deciles over time, predominantly between adjacent categories, trading activity exhibits substantial persistence among the most actively traded securities. In particular, the highest volume decile shows pronounced stability both on a night-to-night basis (0.71) and from week to week (0.73). More moderate persistence is also observed in the second-highest decile (0.39 night to night and 0.45 week to week) and the third-highest decile (0.27 and 0.32, respectively). In contrast, securities with lower trading activity experience significantly greater mobility across dollar-volume deciles.

We repeat this analysis in Figure 7 by comparing nocturnal trading with subsequent trading activity in the same-day pre-open and regular sessions to assess whether nocturnal traders concentrate on the same securities as traders in later periods. There is substantial overlap at the top of the distribution; securities in the highest nocturnal dollar-volume decile remain in the top decile

with probability 0.60 during the pre-open and 0.45 during regular trading hours. As one moves down the nocturnal dollar-volume deciles, the degree of overlap with subsequent trading activity rankings declines markedly.

[Figure 7]

In summary, while retail investors trading nocturnally tend to concentrate on largely the same securities across consecutive days and weeks, their trading preferences appear to differ somewhat from those of market participants active outside the nocturnal session. This pattern is consistent with prior evidence showing that retail investors' stock selection preferences systematically differ from those of institutional investors (e.g., Barber and Odean (2008), Laarits and Sammon (2025)).

4 Market Quality

What is the nature of nocturnal market quality, and how competitive is liquidity provision in this market? This section addresses these questions by first examining nocturnal trading activity and transaction costs in subsection 4.1. It then estimates liquidity provider profits and losses (and, by extension, those of liquidity demanders) during the nocturnal session in subsection 4.2. Finally, subsection 4.3 compares nocturnal trading costs with those observed during other segments of the trading day.

4.1 Nocturnal Period

We evaluate nocturnal activity and market quality using trade and quote data for BOATS from January through May 2024. We consider two sub-samples: a frequently traded (FT) sample consisting of the 174 symbols that trade every day in each of the nocturnal, pre-open, regular trading, and after-hours sessions during our sample period; and a less frequently traded (LFT) sample which consists of the remaining 2,731 symbols that trade on BOATS at least one day

(and each intraday session within that day) during the sample period but are not part of the FT sample. The statistics for the LFT sample cover only the nights when there is nocturnal trading for a particular stock.

We report nocturnal quote and trade statistics in Table 2. The statistics are dollar-volume weighted across firms within each day and then averaged across trading days. For the frequently traded (FT) sample, the nocturnal period exhibits substantial trading and quoting activity. There are 15,852 (1,982) quote updates per night (hour) with an average time-weighted quoted depth of 1,358 shares. Average trade size is 47 shares and there are 5,724 (716) trades per night (hour) on average for a quote-to-trade ratio of 2.8. The average nocturnal price is $309.34, which means that the average trade is for $14,539. Stocks in the LFT sample have a lower price on average ($92.74), and it is therefore not surprising that the quoted depth at 3,807 shares is greater than for the FT sample. Quoting activity for these stocks is quite high with 10,388 (1,292) quote updates per night (hour) resulting in a quote-to-trade ratio of 3.4. Average trade size is 123 shares, which translates into an average trade size in dollars of $11,407.

[Table 2]

Next, we summarize nocturnal market quality for our two sub-samples in Table 3. Measures are again value-weighted across stocks and then averaged across days. For the frequently traded stocks, which we saw in Figure 5 make up the vast majority of BOATS volume, quoted and effective spread are not too large, at 7.56 and 9.55 basis points, respectively. As expected, the spreads are wider for the LFT sample at 36.16 bps for quoted and 41.22 bps for effective spreads. Furthermore, quoted spreads are narrower than effective spreads for both sub-samples, resulting in an effective-to-quoted spread ratio (E/Q) of 1.26 for the FT sample and 1.14 for the LFT sample. BOATS operates as a pure limit order market in which all order sizes are fully displayed, and hidden or reserve orders are not permitted. Although wholesalers such as Virtu and Jane Street are active on BOATS, they do not provide the price improvement typically observed during

regular trading hours. Consequently, no price improvement mechanisms operate in this market, and the E/Q ratio is greater than 1.0 because orders that exceed displayed depth must walk the book.

[Table 3]

Table 3 also provides an alternative measure of effective spread following Hagströmer (2021). This measure, the "weighted midpoint effective spread," captures the difference between the price of a trade and an adjusted midquote that reflects depth imbalances. For example, if the bid depth Q_B is larger than the ask depth Q_A, the weighted midquote between the bid P_B and the ask P_A is $(P_B \cdot Q_A + P_A \cdot Q_B)/(Q_B + Q_A)$, which is greater than the midquote $(P_B + P_A)/2$. For both subsamples, the Hagströmer effective spreads are larger than the traditional effective spreads, showing that the BOATS limit order book is relatively uninformed about future price movements.

Panel B reports price impacts and realized spreads at different horizons: 5 seconds, 60 seconds, and 5 minutes. For the FT sample, price impact at the 5-second horizon already consumes 40% of the effective spread and realized spreads turn negative (-3.11 bps) at the 60-second horizon and beyond. The price impact continues increasing, resulting in a sizable negative realized spread of -18.54 basis points at the 5-minute horizon. The evidence for the LFT sample is similar, but the larger effective spreads leave more room for the price impact, resulting in positive albeit declining realized spreads out to 60 seconds. Hence, on average, liquidity providers would need to exit their positions in less than 60 seconds (5 minutes) to make money in the FT (LFT) sample. Is this possible given the nocturnal trading activity? If we assume buys and sells are equally likely, and that trades arrive smoothly throughout the night, Table 2 suggests that liquidity providers as a group can, under ideal circumstances, expect to exit a position in 10 seconds for FT stocks and 20 seconds for stocks in the LFT sample. Granted, trade clustering and herding would imply that it likely takes longer than this to complete a round-trip. Further, there is likely heterogeneity, as professional liquidity providers are likely to move faster than retail traders providing liquidity.

Finally, we compare conventional and Hagströmer measures of price impacts and realized spreads as both heavily rely on the midquote. Specifically, we replace the midquote with the weighted midquote defined above. Hagströmer price impacts are uniformly larger for both subsamples and across all horizons, reinforcing the notion that nocturnal limit order book imbalances contain relatively little information about future price movements. Hagströmer realized spreads are also uniformly larger because Hagströmer effective spreads are sufficiently wider than conventional effective spreads.

4.2 BOATS Liquidity Provider Profits

The realized spread analysis in the previous section provides an approximation for liquidity providers' revenue net of adverse selection costs over alternative short horizons. We next extend the analysis by estimating liquidity provider profits, accounting for all intranight purchases and sales and valuing any residual inventory both at the end of the nocturnal session and at later times. This analysis serves multiple purposes. One, the inverse of liquidity provider profits are liquidity demander profits, so this analysis also provides estimates of profits over longer horizons for the trade initiator. Two, as previously discussed, in addition to the HFT firms, retail investors also provide liquidity in the nocturnal market. Thus, assuming longer horizons for closing out a position may be reasonable for some liquidity providers in our data.

To perform this analysis, we track the liquidity providers' trades each night, starting from a zero position and cumulating the dollar value of their sells minus their buys. This gives us a measure of the profits from liquidity provision, buying at the bid and selling at the ask. At the end of each nocturnal period, we keep track of the liquidity providers' net long or short position. We then calculate the value of the net closing position if it is closed out in the future at different horizons: the adjacent pre-open volume-weighted-average-price (VWAP), the following opening auction price, the VWAP during the following regular trading hours, the following closing auction

price, and closing prices 10, 30, 60, and 90 days out.

Table 4 summarizes the results of this analysis. Liquidity providers' profits on intranight buys and sells are positive, reflecting gains from the bid-ask spread. However, if they hold inventory until the market open or longer, those gains are completely wiped out by the negative closing inventory profits. This pattern is consistent with the price impact results in Table 3 that saw larger price impacts over longer holding horizons. The net effect of the gains from the spreads and the losses from closing out inventory at the end of the session or longer is an overall profit that is not significantly different from zero. This effect persists through a holding horizon of 60 days (assuming a 90-day horizon leads to negative liquidity provider profits). This evidence suggests that, on average, price pressure in the nocturnal market is sufficiently strong to wipe out liquidity provider profits unless the holding period is very short. It should be noted that we do not observe liquidity provider holding periods, and that there is likely heterogeneity across groups. The HFTs providing liquidity may make money, while retail liquidity provision may not be profitable.

[Table 4]

As we note earlier, the inverse of these estimates corresponds to profits earned by liquidity demanders. The results indicate that nocturnal liquidity demanders initially incur trading costs by paying the spread, but these losses are gradually offset over longer horizons as prices continue to move in the direction of their trades. At a 90-day holding horizon, nocturnal liquidity demanders earn positive net profits, which remain positive even after market adjustment.

4.3 Nocturnal Trading, Other Extended Hour Periods, and Regular Hours

A natural question is how nocturnal trading compares to regular and extended hours. To shed light on this issue, we use DTAQ to measure trading activity and market quality for the pre-open (4:00 a.m. to 9:30 a.m.), regular trading hours, and after-hours (4:00 p.m. to 8 p.m.) periods and compare these statistics to the evidence from the nocturnal period. We exclude open and closing

auctions and market-on-close orders from the analysis on market quality, though we do include them when assessing price discovery in Section 5. For this analysis, we focus on the frequently traded sample of 174 stocks to ensure comparability across trading periods, as these securities trade consistently during each nocturnal session.

Prior research documents that pre-open and after-hours trading sessions are characterized by a small number of relatively large trades. For example, Jiang, Likitapiwat, and McInish (2012) study S&P 500 stocks during 2004-2008 and document on average 267 (194) quotes, 44 (20) trades, and an average trade size of $304,069 ($574,681) during pre-open (after-hours). Barclay and Hendershott (2003, 2004) document similar findings for the largest Nasdaq stocks in 2000. These patterns still hold during the after-hours session based on more recent data. Cui, Gozluklu, and Haykir (2024) rely on data for S&P 1500 stocks from 2004-2022 to calculate value-weighted average trading activity and find 153 trades on average and dollar average trade size of $177,931 during the after-hours period. The activity has risen over time based on their data, but trading activity after-hours is modest with roughly 190 trades on a given day even at the end of their sample period. Similarly, Gregoire and Martineau (2022) study data for S&P 1500 stocks from 2011-2015 and document a median (75 percentile) number of trades on a given day for S&P 500 stocks during the after-hours period to be 17 (31). Trading in S&P 400 (Mid Caps) and S&P 600 (Small Caps) is even more sparse based on their data. After-hours trades are larger also in their sample, with 19% of trades exceeding $50,000.

Is this pattern of sparse quote and trading activity but very large trades documented in prior work for the pre-open and after-hours periods still evident? And, how does the nocturnal period compare to extended hours?

The results for continuous trading during each sub-period of the 24-hour trading cycle are in Table 5. We repeat some of the results for the nocturnal period for convenience. Despite its rapid growth, nocturnal quoting and trading activity is still relatively modest. Between 5 and 6 million shares trade a day for sample stocks during the nocturnal period, making up 0.22% of

daily volume. The nocturnal share of daily number of trades is a little higher at 0.67%. Pre-open (after-hours) share is about 3-4% (2%) of daily volume. We also find that there has been a substantial increase in quoting and trading activity during both the pre-open and after-hours periods compared to what prior research has documented based on earlier sample periods. On a per hour basis, the average number of quotes and trades in the pre-open period are 11,236 and 5,932 respectively. Similarly, the average number of quotes and trades in the after-hours period are 6,134 and 5,951 on average. Trading and quoting activity during nocturnal and extended hours still however pales in comparison to regular hours trading, with on average 159,231 quotes and 69,859 trades per hour.

[Table 5]

Table 5 also shows that nocturnal traders favor lower price stocks ($309) compared to traders that are active during other periods of the day ($379 to $415 depending on period), and the trade size in terms of shares is 47 compared to 90 and 104 for pre-open and regular hours, respectively. The relatively low nocturnal trade size is unsurprising, given that retail traders dominate the nocturnal market. Echoing findings in the prior literature, we find much larger average trade size in the after-hours period (746). Finally, the quote-to-trade ratio is actually highest for the nocturnal period at 2.77, followed by the regular trading hours at 2.28 and pre-open at 1.89. Quoting activity relative to trades is much lower for the after-hours period (1.03). It is worth mentioning that we only observe best quote updates, and we do not observe new orders further down the book.

Prior research has documented poor market quality outside of regular trading hours. For example, Barclay and Hendershott (2004) and Jiang, Likitapiwat, and McInish (2012) find quoted, effective, and realized spreads during pre-open and after-hours trading to be at least five to ten times the size of spreads during regular trading hours. Based on more recent data, Cui, Gozluklu, and Haykir (2024) document value-weighted quoted and effective spreads of 162.6 and 71.2 bps

during after hours compared to 4.9 and 5.1 bps during regular trading hours. They find that five-minute price impacts are larger during after-hours (5.6 compared to 3.2 bps), but the difference is not nearly large enough to wipe out the differences in effective spreads. As a result, after-hours realized spreads in their data are much larger at 54.5 bps compared to realized spreads of 1.9 bps during regular trading hours.

This evidence raises the concern that market quality during the nocturnal period may be substantially worse than during regular trading hours, given the relatively thin trading activity and limited competition among professional liquidity providers. It also raises the question of whether market quality during extended trading hours has improved relative to regular trading hours, as off-hours trading activity is now considerably greater than in the sample periods studied in earlier work.

Table 6 summarizes our findings. Panels A and B show the results for the conventional market quality measures that reference the algebraic midquote. Panel A reveals that quoted spreads are a little more than two times wider during the nocturnal period (7.56 bps) than during regular trading hours (3.42 bps), but they are actually lower than quoted spreads during the pre-open (8.43) and roughly equal to the quoted spreads observed during the after-hours period (7.18). E/Q ratios are larger than one for three out of the four sub-periods, including regular hours trading. In fact, the ratios are remarkably similar for the nocturnal and regular trading periods. This shows that large orders also walk the book during regular trading hours, creating slippage. The E/Q ratio is less than one (0.89) for the pre-open period, suggesting that hidden and reserve orders, as well as odd-lot limit orders are prevalent during the pre-open. The E/Q ratio is particularly large (1.81) for the after-hours trading period, as a result of the large trades we see coupled with lower depth documented earlier in Table 5.

[Table 6]

Panel A also reports absolute order imbalances defined as the absolute difference in buy

and sell share volume, scaled by total share volume, where trade direction is signed with the Lee-Ready algorithm. Order imbalances are large for the nocturnal period (0.17) suggesting that nocturnal traders tend to herd. They are even larger for the after-hours period (0.31), but here part of the explanation can be earnings releases after the close. By comparison, order imbalances are smaller for pre-open (0.09) and regular hours trading (0.05). The last column shows that mid-quote volatility is actually lowest for nocturnal (1.32) followed by after-hours trading (1.65), suggesting relatively smooth adjustment of quotes to trading activity. By contrast, mid-quote volatility is more than twice as high for regular trading hours (2.89) which is to be expected given that the bulk of the price discovery likely takes place during this period, a topic we will return to in Section 5 below.

We consider price impacts and realized spreads at different horizons in Panel B. Nocturnal trade price impacts are on par with pre-open price impacts at the 5-second horizon, but are much larger than price impacts from the other periods at longer horizons. The nocturnal period is also the only period with negative realized spreads, and they turn negative at the 60-second horizon (-3.11 bps) before dropping down to -18.45 bps after 5-minutes. For all other periods, the effective spreads are wide enough to cover the adverse selection cost all the way out to the 5-minute horizon, resulting in positive realized spreads throughout. These are particularly large for the after-hours period (8.17 bps), but meaningful also for the pre-open (1.46) and regular (2.31) trading periods. Coupled with the evidence on order imbalances, these findings are consistent with herding behavior and active price discovery during the nocturnal period, which we analyze in more detail in the following section.

Table 7 reports regression results for trading cost measures across the different sessions of the 24-hour trading cycle. Each trading cost measure is regressed on indicator variables for the trading cycle sessions, with regular trading hours serving as the omitted category. Thus, the regressions tests for significant differences between regular hours and the other hours of the day. Since analysis earlier in this section shows cross-sectional variation across periods, some spec-

ifications control for lagged dollar volume, price volatility, and average trade price. We also include firm-day fixed effects. The regressions are weighted by dollar volume. The conclusions are qualitatively similar to the univariate evidence from Table 6. Quoted and effective spreads are significantly greater for the nocturnal period compared to regular hours, but realized spreads at horizons longer than 5 seconds are significantly lower.

[Table 7]

5 Price Discovery

We next consider to what extent the nocturnal period contributes to price discovery over the 24-hour trade cycle. Given the relatively small share of nocturnal volume and the paucity of U.S. news releases, one could reasonably expect a trivial amount of price discovery in the nocturnal period. On the other hand, given that information in all its forms now disseminates around the clock, it is possible that the nocturnal period significantly contributes to price discovery.

To perform the analysis, we compute the weighted price contribution, or WPC, across the close-to-close window. The WPC measures the average percentage share that each period (nocturnal, pre-open, regular hours, and after-hours) contributes to price changes over the 24 hour trading period. Because the open and close auctions can also contribute to price discovery, we do not exclude them; instead, we incorporate them into regular trading hours. We do not report auction results separately for consistency with the rest of the paper, where they are omitted, because trading costs cannot be reliably estimated for auctions. We follow Barclay and Hendershott (2003) in constructing the WPC, which is computed across stocks each period-day, then averaged across days. We focus on the frequently traded sample of 174 securities, which makes up over 90% of nocturnal dollar volume.

We report our findings in Table 8. We find substantial price discovery in the nocturnal period. For the full sample of frequently traded stocks, over 10% of close-close returns occurs between

8 p.m. and 4 a.m., which is striking given that less than 1% of daily volume occurs nocturnally (Table 5). This result is particularly strong for the list of top 10 securities by nocturnal dollar volume (from Table 1). For this sample, a substantial 21% of daily price discovery occurs overnight. These values are statistically significant at the 1% level.

[Table 8]

We also document notable patterns in price discovery during other hours of the day. Prior research, e.g., Barclay and Hendershott (2003), reports price discovery of about 11% in the pre-open period but does not find significant price discovery during other periods outside of regular trading hours. Consistent with an expanded news cycle and increased liquidity, our findings suggest price discovery has also increased in the non-nocturnal extended hours, as we find a significant percentage of price discovery, at over 19% in the pre-open period and 6% in the after-hours window.

A natural question is: What is the source of this price discovery, particularly during the nocturnal period? To dig deeper, we assign the sample securities to various groups, such as individual stocks and various ETF groupings. We begin with individual stocks, which we group into U.S. stocks and ADRs or stocks with international headquarters (which we call ADRs for short). At about 4% WPC, the nocturnal price discovery for U.S. stocks is relatively modest compared to the full sample. We also compare tech versus non-tech U.S. stocks and find a similar amount of nocturnal price discovery across the two sub-groups. This evidence suggests that the significant nocturnal price discovery we document cannot be explained by overnight trading on earnings announcements that take place after the U.S. market close. In contrast, nocturnal price discovery in ADRs is quite large, at about 20.5%. Many of these companies, for example Alibaba, are headquartered in Asia, which is consistent with price movements reflecting news released during the daytime in the Asia-Pacific region.

We next turn to index securities such as stock market index ETFs like the Invesco QQQ

Trust (QQQ) and the SPDR S&P 500 ETF Trust (SPY) or macro ETFs, such as the iShares 7-10 Year Treasury ETF (IEF). Our evidence suggests that market-wide information is incorporated overnight also for these securities. For the market index ETFs, over 11% of price discovery occurs nocturnally. The findings are particularly strong for what we refer to as the macro ETFs, as nearly 24% of price discovery for these securities occurs nocturnally. Given the increased noise from splitting the sample into security groupings, for example the market index ETFs consist of only 9 securities while the macro ETFs consist of 5, we test whether the sub-samples of securities listed in Panel B of Table 8 have period-level WPCs that are significantly different from the associated WPCs for U.S. stocks. We find that the nocturnal WPCs for the market index ETFs are not significantly different, but the nocturnal WPCs from the macro ETFs are large enough to be different than those from U.S. stocks. Thus, it would appear that the nocturnal period offers an important time for markets to incorporate macroeconomic information, such as information reflected in Treasuries, into prices.

We also consider a group that makes up an important number of nocturnal trading symbols (44 of the 174), the remaining ETFs, which we refer to as Other ETFs. These securities are mainly levered ETFs on indices and individual stocks based in the U.S. such as the Direxion Daily Semiconductor Bull 3X Shares (SOXL) and the ProShares UltraPro QQQ (TQQQ) and Asia such as Direxion Daily FTSE China Bull 3x Shares (YINN) and Direxion Daily FTSE China Bear 3X Shares (YANG) (see Table 1). Nocturnal WPCs are quite large for the group of Other ETFs, at nearly 20%, suggesting that the Asia-based investors actively trade these securities and move prices overnight. Finally, we consider the REITs and MLPs that are popular overnight and find about 10% of price discovery occurs nocturnally.

An important question is whether the substantial price discovery we document during the nocturnal period reflects the incorporation of fundamental information or merely uninformed price pressure that subsequently reverses. Taken together with our analysis of liquidity provider inventory valuations over longer horizons in Table 4, the evidence indicates that prices continue

to move in the direction of nocturnal liquidity demand for up to 90 days. This persistence suggests that, even if nocturnal price movements are partly transitory, any subsequent reversal occurs only over relatively long horizons rather than over short-term intervals.

6 Conclusions

Nocturnal trading in U.S. equities has grown rapidly since 2022 and now constitutes a meaningful share of retail trading activity, particularly for a set of actively traded securities. Using comprehensive transaction-level data from Blue Ocean ATS, we provide novel evidence on this new market. Despite thinner trading and limited participation by professional liquidity providers, quoted and effective spreads during the nocturnal session are comparable to those observed during extended hours, though substantially wider than during regular trading hours. Once adverse selection is accounted for however, realized spreads are often negative, indicating that liquidity during nocturnal hours is supplied at relatively favorable terms for liquidity demanders.

While nocturnal trade flow moves prices, as evidenced by large and persistent price impacts, standing limit orders are relatively uninformed. A substantial fraction of liquidity is provided by retail limit orders, which dilutes the informational content of quotes and helps explain the negative realized spreads observed at longer horizons. Nocturnal price movements do not quickly reverse, as we find that overnight trading contributes an economically and statistically significant share of daily price discovery, roughly 10% on average, and more than 20% for the most actively traded securities. Price discovery during nocturnal hours is especially pronounced for non-U.S.-headquartered firms and for macro-oriented ETFs, consistent with the incorporation of information from around the globe. While nocturnal traders appear to trade on price-relevant information, transaction costs leave average net profitability close to zero unless positions are held over longer horizons.

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Table 1
What is Traded on Blue Ocean?

The table reports the top ten symbols traded on Blue Ocean by share volume in Panel A and by dollar volume in Panel B. The sample period in column (1) is January through May 2024, while column (2)-(6) reports results for each month separately. Units are in million shares (dollars).

All		Jan		Feb		Mar		Apr		May	
Symbol	Volume	Symbol	Volume	Symbol	Volume	Symbol	Volume	Symbol	Volume	Symbol	Volume
Panel A: Top Ten by Share Volume											
SOXS	123	SOXS	26	SOXS	22	SOXS	52	SOXS	18	FFIE	20
SQQQ	52	YINN	11	LUNR	12	SOXL	11	SQQQ	14	YANG	12
SOXL	52	SOXL	11	YINN	11	SQQQ	10	SOXL	13	GME	11
YINN	40	SQQQ	10	SOXL	8	YINN	8	TSLL	13	SQQQ	10
TSLL	35	TQQQ	5	SOUN	8	SOUN	7	TQQQ	8	SOXL	9
YANG	34	TSLL	5	SQQQ	8	IBIT	5	YANG	5	TSLL	9
TQQQ	25	NIO	5	YANG	6	YANG	5	TSLT	5	AMC	8
NIO	23	YANG	4	NIO	5	TSLT	5	TSLA	5	YINN	5
FFIE	20	TSLA	3	MARA	4	NIO	5	YINN	5	NVDL	5
SOUN	19	MARA	3	TSLL	4	LICY	5	NKLA	4	SOXS	5
Panel B: Top Ten by Dollar Volume											
NVDA	5,847	TSLA	726	NVDA	1,113	NVDA	1,632	NVDA	1,101	NVDA	1,505
TSLA	3,087	NVDA	497	TSLA	530	TSLA	620	TSLA	792	TSLA	419
SOXL	2,060	SOXL	336	SOXL	297	SOXL	520	SOXL	505	SOXL	403
TQQQ	1,444	TQQQ	284	SMCI	236	MSTR	317	TQQQ	432	GME	400
QQQ	1,214	QQQ	277	QQQ	213	TQQQ	268	QQQ	330	NVDL	272
SPY	964	MSFT	215	TQQQ	210	SMCI	264	SPY	263	TQQQ	251
MSFT	863	AMD	197	YINN	190	COIN	243	SOXS	190	AAPL	206
AAPL	806	SPY	190	MSFT	178	QQQ	227	META	180	QQQ	168
YINN	758	YINN	172	SPY	167	NVDL	200	TSM	173	SPY	161
COIN	745	AAPL	171	COIN	151	AMD	196	MSFT	170	YINN	153

Table 2
BOATS Quoting and Trading Activity

The table presents summary statistics on quoting and trading activity on Blue Ocean ATS (BOATS) from January through May 2024. Results are reported for two samples: (i) 174 stocks that trade on BOATS every day of the sample period (frequently traded sample), and (ii) the remaining 2,731 sample stocks that trade on BOATS at least once during the sample period (less frequently traded sample). The reported statistics include the following stock-night averages: (i) number of quotes, (ii) time-weighted average best quoted depth (in shares), (iii) number of trades, (iv) trade size, (v) trade price, and (vi) the ratio of quotes to trades (Q/T). These statistics are dollar volume averaged across stocks and then averaged across days.

	# Quotes	Quoted depth	# Trades	Trade size	Price	Q/T
Frequently traded (FT)	15,852	1,358	5,724	47	309.34	2.77
Less frequently traded (LFT)	10,338	3,807	3,055	123	92.74	3.38

Table 3
BOATS Trading Costs

The table presents trading costs on Blue Ocean ATS (BOATS) from January through May 2024. Results are reported for two samples: (i) 174 stocks that trade on BOATS every day of the sample period (frequently traded sample), and (ii) the remaining 2,731 sample stocks that trade on BOATS at least once during the sample period (less frequently traded sample). The reported trading cost measures include 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 at a future time; and the realized spread, which is the difference between the effective spread and the price impact. The future midquote times we use to compute price impact are 5 seconds, 60 seconds, or 5 minutes ahead. In addition to the conventional effective spread measure, we also construct the Hagströmer measure, which captures the difference between the price of a trade and an adjusted midquote that reflects depth-imbalances. Trades are signed using the Lee-Ready algorithm. The statistics are volume-weighted within firm-day, dollar volume averaged across stocks, and then averaged across days. The trading costs are percentage measures reported in basis points.

Panel A: Quoted and Effective Spreads

	Conventional		Hagströmer
	Quoted spread	Effective spread	Effective spread
Frequently traded (FT)	7.56	9.55	10.83
Less frequently traded (LFT)	36.16	41.22	48.71

Panel B: Price Impact and Realized Spread

	Conventional		Hagströmer	
	Price impact	Realized spread	Price impact	Realized spread
Frequently traded (FT), 5 seconds	3.85	5.70	4.67	6.16
Frequently traded (FT), 60 seconds	12.66	-3.11	13.83	-3.00
Frequently traded (FT), 5 minutes	28.09	-18.54	29.18	-18.34
Less frequently traded (LFT), 5 seconds	11.54	29.68	14.20	34.51
Less frequently traded (LFT), 60 seconds	32.31	8.91	36.65	12.06
Less frequently traded (LFT), 5 minutes	59.88	-18.66	65.56	-16.85

Table 4
Liquidity Provider Profits

The table reports estimates of liquidity provider profits for full sample of BOATS securities. To do so, we track the liquidity providers' trades each night, starting from a zero position and cumulating the dollar value of their sells minus their buys, which is labeled Intranight Buy-Sell. Additionally, at the end of each nocturnal period, we keep track of the liquidity providers' net long or short position. We then calculate the value of the net closing position (labeled Closing Inventory) if it is closed out in the future at different horizons: the adjacent pre-open volume-weighted-average-price (VWAP), the following opening auction price, the VWAP during the following regular trading hours, the following closing auction price, and closing prices 10, 30, 60, and 90 days out. Profit is the sum of the Intranight Buy-Sell and Closing Inventory profits.

	Intranight Buy-Sell		Closing Inventory		Profit		
Close-Out	Dollars	p-value	Dollars	p-value	Dollars	p-value	Profit/Inventory %
Pre-open	5,519	(0.02)	-5,615	(0.02)	67	(0.34)	0.01
Opening Call	5,519	(0.02)	-5,611	(0.02)	71	(0.50)	0.01
Day (VWAP)	5,519	(0.02)	-5,561	(0.02)	120	(0.32)	0.02
Closing Call	5,519	(0.02)	-5,606	(0.02)	76	(0.52)	0.01
Close t=10	5,519	(0.02)	-5,768	(0.02)	-68	(0.81)	-0.01
Close t=30	5,519	(0.02)	-5,584	(0.03)	164	(0.71)	0.03
Close t=60	5,519	(0.02)	-6,554	(0.02)	-776	(0.16)	-0.14
Close t=90	5,519	(0.02)	-7,698	(0.01)	-1,898	(0.01)	-0.34

Table 5
Quoting and Trading Activity Across the Trading Day

The table presents summary statistics on quoting and trading activity across the trading day from January through May 2024. Results are reported for the 174 stocks that trade in each of the four daily periods (nocturnal, pre-open, regular, and after-hours). Panel A reports the following stock-day-period averages: (i) number of quotes, (ii) time-weighted average best quoted depth (in shares), (iii) number of trades, (iv) trade size, (v) trade price, and (vi) the ratio of quotes to trades (Q/T). These statistics are dollar volume averaged across stocks and then averaged across days. Panel B report alternative volume metrics for each period. The totals, in millions, are summed across firms each day then averaged across days. Percent is each period's market share of daily volume.

Panel A: Mean Statistics

	# Quotes	Quoted depth	# Trades	Trade size	Price	Q/T
Nocturnal	15,852	1,358	5,724	47	309.34	2.77
Pre-open	61,800	1,929	32,629	90	394.25	1.89
Regular	1,034,999	2,620	454,082	104	378.91	2.28
After-hours	24,536	1,296	23,804	746	414.84	1.03

Panel B: Daily Volume Totals and Percentages

	Daily dollar volume		Daily share volume		Daily # Trades	
	Total (mil)	Percent	Total (mil)	Percent	Total (mil)	Percent
Nocturnal	313.59	0.12%	5.68	0.22%	0.12	0.67%
Pre-open	6,211.71	2.44%	72.13	2.85%	0.68	3.74%
Regular	241,982.32	94.93%	2,403.94	94.88%	17.13	93.85%
After-hours	6,401.23	2.51%	51.98	2.05%	0.32	1.73%

Table 6
Trading Costs Across the Trading Day

The table reports trading cost variables across the trading day for a sample of 174 frequently traded securities from January through May 2024. The reported trading cost measures include 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 best midquote; the price impact, measured as twice the signed difference between the midquote at the time of the trade and the midquote at a future time; and the realized spread, which is the difference between the effective spread and the price impact. The future midquote times we use to compute price impact are 5 seconds, 60 seconds, or 5 minutes ahead. Other statistics include the E/Q ratio, which is effective spread over quoted spread and order imbalances (OIB) defined as the absolute difference in buy and sell share volume, scaled by total share volume. The statistics are volume-weighted within firm-day, dollar volume averaged across stocks, and then averaged across days. Unless specified otherwise, the trading costs are percentage measures reported in basis points.

Panel A: Conventional Spread and Volatility Measures

	Quoted spread	Effective spread	E/Q	OIB	Midquote vola	Quoted spread ($c)
Nocturnal	7.56	9.55	1.26	0.17	1.32	17.80
Pre-open	8.43	7.50	0.89	0.09	2.02	36.83
Regular	3.42	4.18	1.22	0.05	2.89	17.69
After-hours	7.18	13.01	1.81	0.31	1.65	29.17

Panel B: Conventional Price Impact and Realized Spread

	5-second horizon		60-second horizon		5-minute horizon	
	Price impact	Realized spread	Price impact	Realized spread	Price impact	Realized spread
Nocturnal	3.85	5.70	12.66	-3.11	28.09	-18.54
Pre-open	3.94	3.39	5.26	2.06	5.86	1.46
Regular	1.58	2.50	1.73	2.33	1.75	2.31
After-hours	2.93	9.91	3.93	8.92	4.67	8.17

Table 7
Regression Analysis of Trading Costs Across the Trading Day

The table presents regression analysis of trading costs variables across the trading day for a sample of 174 frequently traded securities from January through May 2024. The key x-variables are dummy variables representing alternative trading periods, where regular trading hours are the excluded group. The alternative y-variables are trading cost measures that include 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 best midquote; and the realized spread, which is the difference between the effective spread and the price impact. The future midquote times we use to compute realized spreads are 5 seconds, 60 seconds, or 5 minutes ahead. The regressions are weighted by dollar volume. Some specifications include dollar volume, price volatility, and average trade price for controls, which are measured for each stock-day-period and lagged by one day. The trading costs are percentage measures reported in basis points. Standard errors are reported in parentheses and clustered by firm-day. Statistical significance is reported at the 1% (***), 5% (**), or 10% (*) levels.

	Quoted spread		Effective spread		5-min Realized spread		60-sec Realized spread		5-sec Realized spread	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nocturnal dummy	1.98***	3.98***	4.74***	7.84***	-22.72***	-20.52***	-5.62***	-3.33***	3.52***	5.95***
	(0.23)	(0.45)	(0.18)	(0.36)	(2.11)	(2.11)	(0.86)	(0.96)	(0.19)	(0.37)
Pre-open dummy	3.66***	6.11***	2.20***	5.99***	-1.53***	0.94*	-0.90***	1.83***	0.33	3.31***
	(0.54)	(0.85)	(0.29)	(0.51)	(0.37)	(0.56)	(0.28)	(0.47)	(0.25)	(0.44)
After-hours dummy	4.24***	6.93***	8.40***	12.57***	4.96***	7.55***	5.57***	8.53***	6.58***	9.90***
	(0.24)	(0.49)	(0.64)	(0.67)	(0.71)	(0.75)	(0.63)	(0.64)	(0.62)	(0.61)
Lagged Volume		0.18***		0.28***		0.16***		0.20***		0.23***
		(0.02)		(0.03)		(0.03)		(0.03)		(0.03)
Lagged Volatility		-0.17***		-0.26***		-0.01		-0.14**		-0.24***
		(0.05)		(0.07)		(0.08)		(0.07)		(0.07)
Lagged Price		0.02		0.03*		-0.02		0.01		0.02
		(0.01)		(0.02)		(0.03)		(0.02)		(0.02)
Obs.	73,080	72,384	73,080	72,384	73,080	72,384	73,080	72,384	73,080	72,384
Within R^2	0.08	0.11	0.10	0.15	0.06	0.07	0.05	0.08	0.07	0.10
Firm x Day FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 8
Price Discovery Across the Trading Day

The table estimates how much each trading period contributes to price discovery over the close-to-close window for various samples. We compute WPC for a full (FT) sample of 174 symbols, the top 10 symbols by nocturnal dollar volume, the 95 U.S. stocks in the full sample, the 34 non-tech and 61 tech U.S. stocks, the 18 ADRs or internationally headquartered stocks, the 9 stock market index ETFs (such as SPY), the 5 macro ETFs (such as treasury-linked funds), the 44 symbols labeled Other ETFs (such as levered ETFs tied to an Asian index or individual stock), and the 3 REITs/MLPs. WPC is computed across stocks each period-day, then averaged across days. We report whether the WPC is significantly different from 0 at the 1% (***), 5% (**), or 10% (*) significance levels. Panel B also reports whether the WPC for each group-period is significantly different from the associated WPC for U.S. stocks at the the 1% (*a*), 5% (*b*), or 10% (*c*) significance levels.

Panel A: WPC for Full Sample, Top 10 List, and U.S. Stocks

	Full	Nocturnal Top 10	U.S. stocks	U.S. stocks (non-tech)	U.S. stocks (tech)
Nocturnal	10.38%***	21.41%***	4.14%***	3.24%***	4.40%***
Pre-open	19.13%***	17.88%***	18.04%***	17.65%***	17.92%***
Regular	64.12%***	50.95%***	70.56%***	75.53%***	69.76%***
After-hours	6.05%***	9.26%***	6.85%***	3.51%***	7.44%***

Panel B: WPC for ADRs and ETFs

	ADRs	Market index ETFs	Macro ETFs	Other ETFs	REITs/MLPs
Nocturnal	20.51%^{b}***	11.41%**	23.65%^{a}***	19.83%^{c}***	10.27%**
Pre-open	18.09%***	36.82%^{c}***	37.16%^{b}***	20.74%***	1.68%
Regular	59.01%***	46.07%^{a}***	38.44%^{a}***	53.45%^{c}***	84.13%***
After-hours	2.09%**	5.57%	0.78%	5.77%***	4.02%

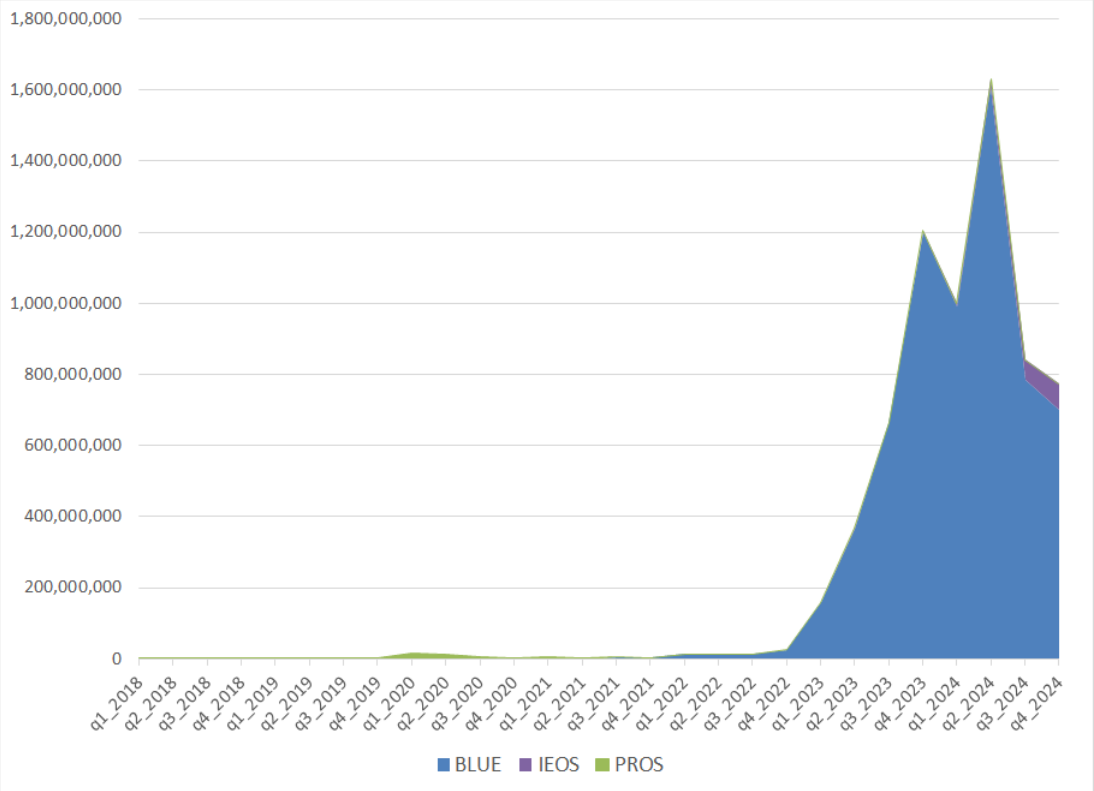

Figure 1. Nocturnal Trading

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.

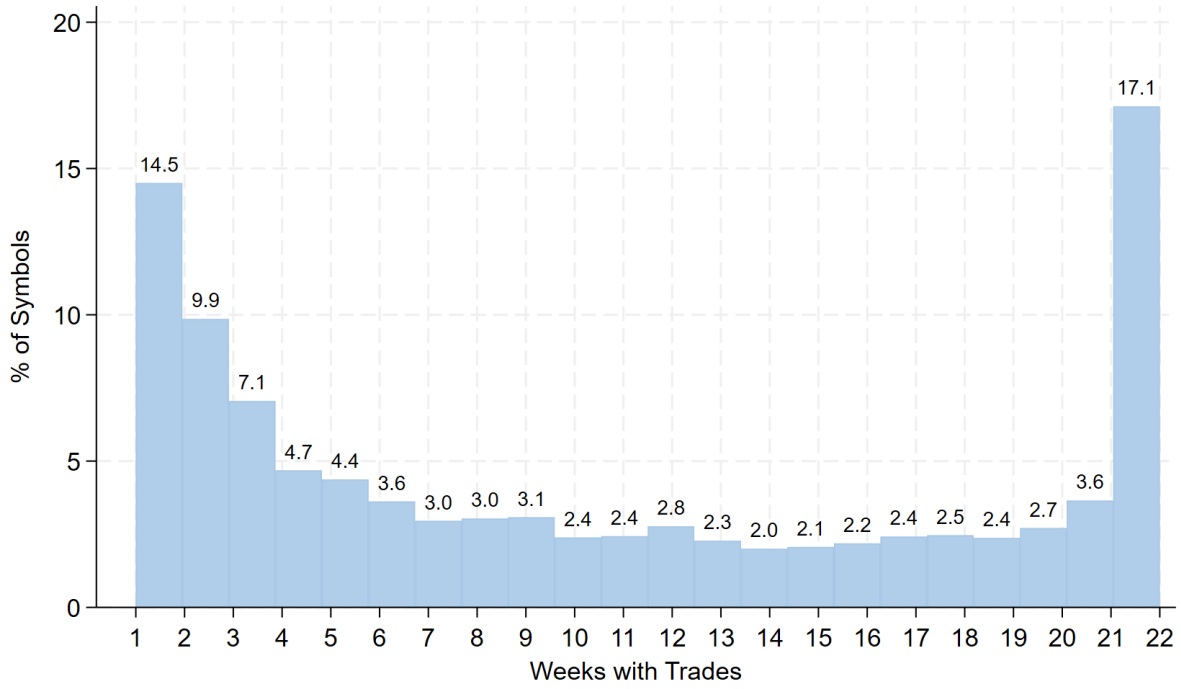

Figure 2. Nocturnal Trading

The figure reports the frequency distribution of the 6,495 unique symbols trading on Blue Ocean ATS (BOATS) by the number of weeks that there is nocturnal trading during the period January through May 2024. The source for the data is the FINRA ATS Transparency data for all NMS securities.

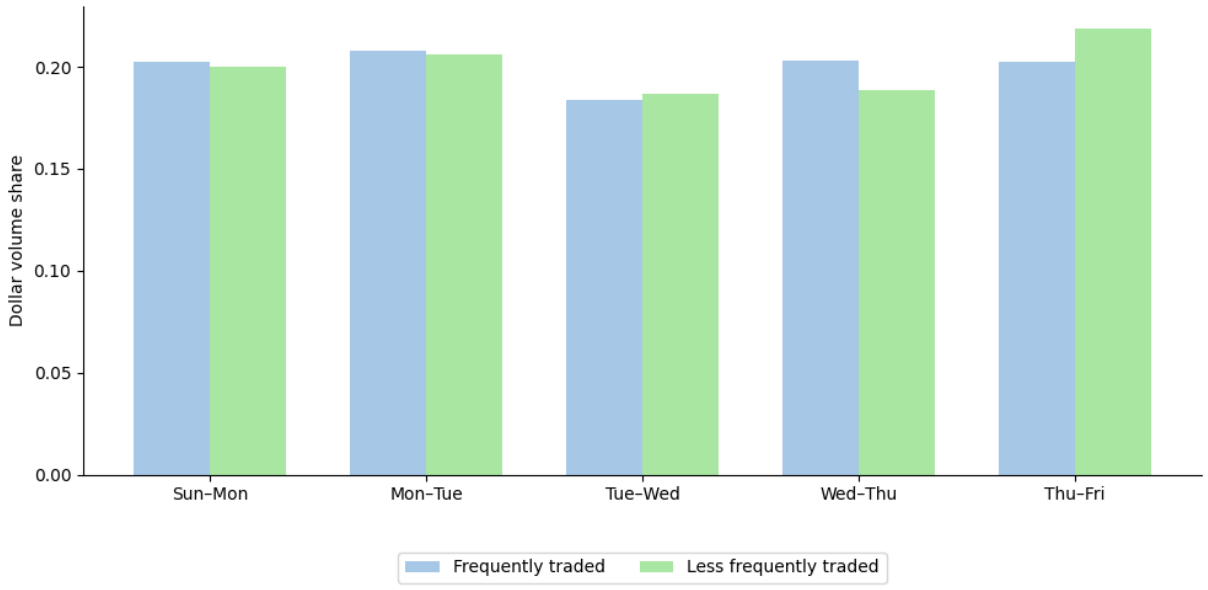

Figure 3. Intraweek Dollar Volume

The figure reports the distribution of nocturnal dollar volume on the Blue Ocean ATS (BOATS) across weeknights. Sunday-Monday (Sun-Mon) includes activity from Sunday 8 p.m. through Monday 4 a.m., Mon-Tue includes activity from Monday 8 p.m. through Tuesday 4 a.m., and so on. The dollar volume shares, defined as each night's dollar volume divided by that week's total nocturnal dollar volume, are shown separately for the frequently traded sample (blue bars) and the remaining stocks (green bars). All statistics are dollar-volume-weighted across stocks.

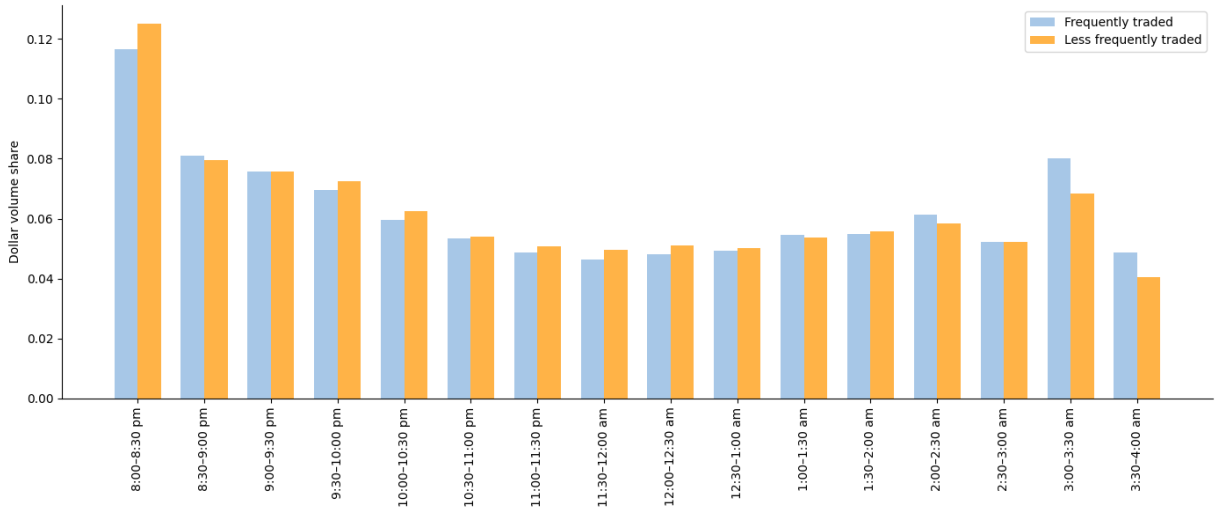

Figure 4. Intranight Dollar Volume

The figure reports the distribution of nocturnal dollar volume on the Blue Ocean ATS (BOATS) across half-hour intervals from 8 p.m. to 4 a.m. The shares, defined as each interval's dollar volume divided by total intranight volume, are shown separately for the frequently traded sample (blue bars) and the remaining stocks (orange bars). All statistics are dollar-volume-weighted across stocks.

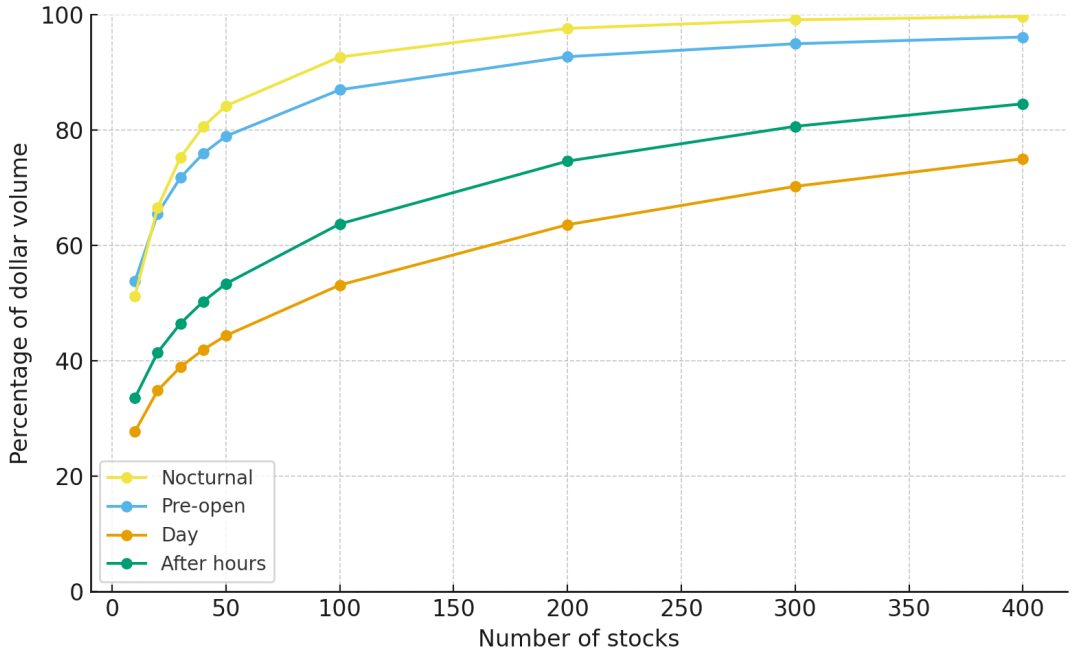

Figure 5. Concentration

The figure shows the cumulative distribution of dollar volume by sub-period of the day for the 400 stocks with highest dollar volume on the Blue Ocean ATS (BOATS).

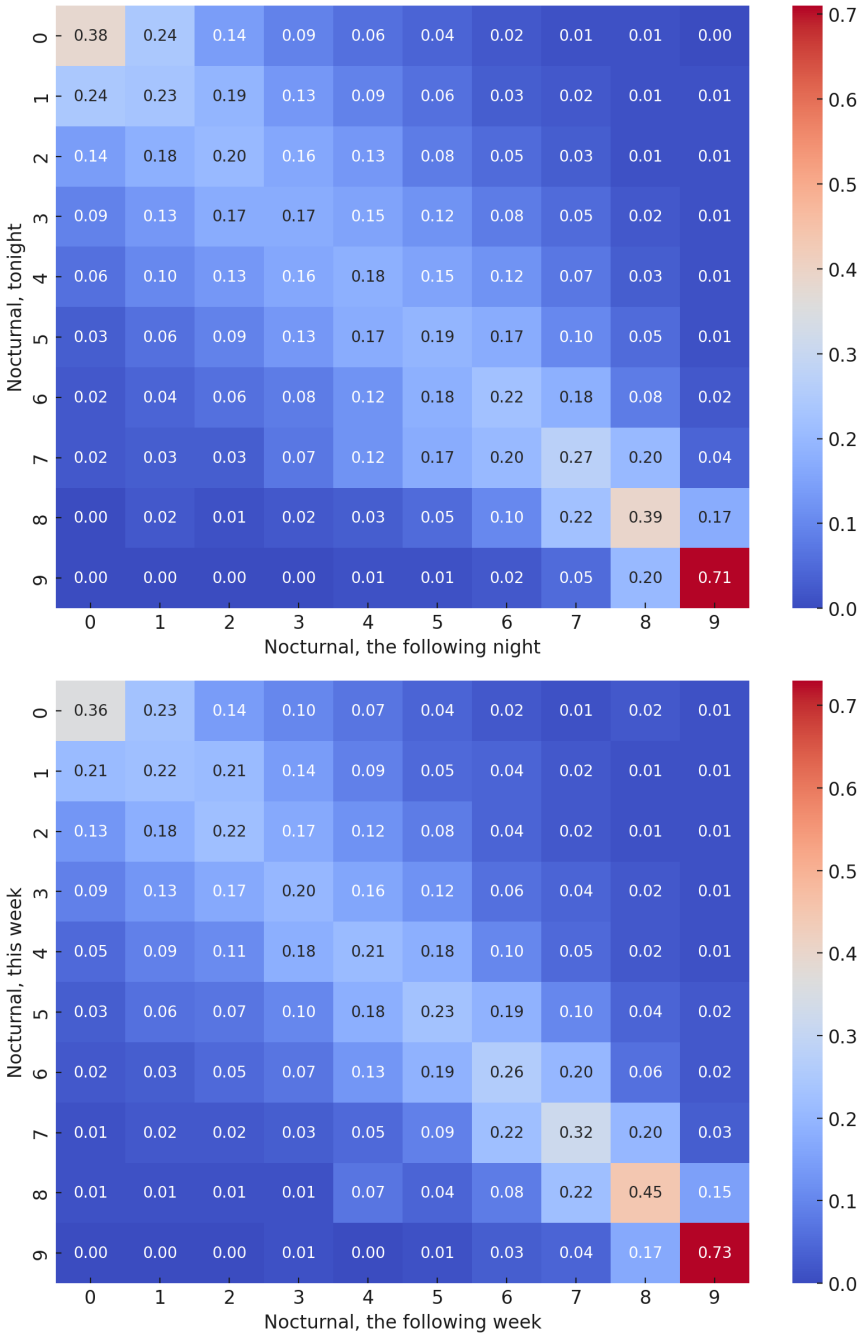

Figure 6. Transition Matrix Blue Ocean to Blue Ocean
This figure displays the transition matrix between Blue Ocean ATS (BOATS) trading tonight/tomorrow night (top) and this week/next week (bottom).

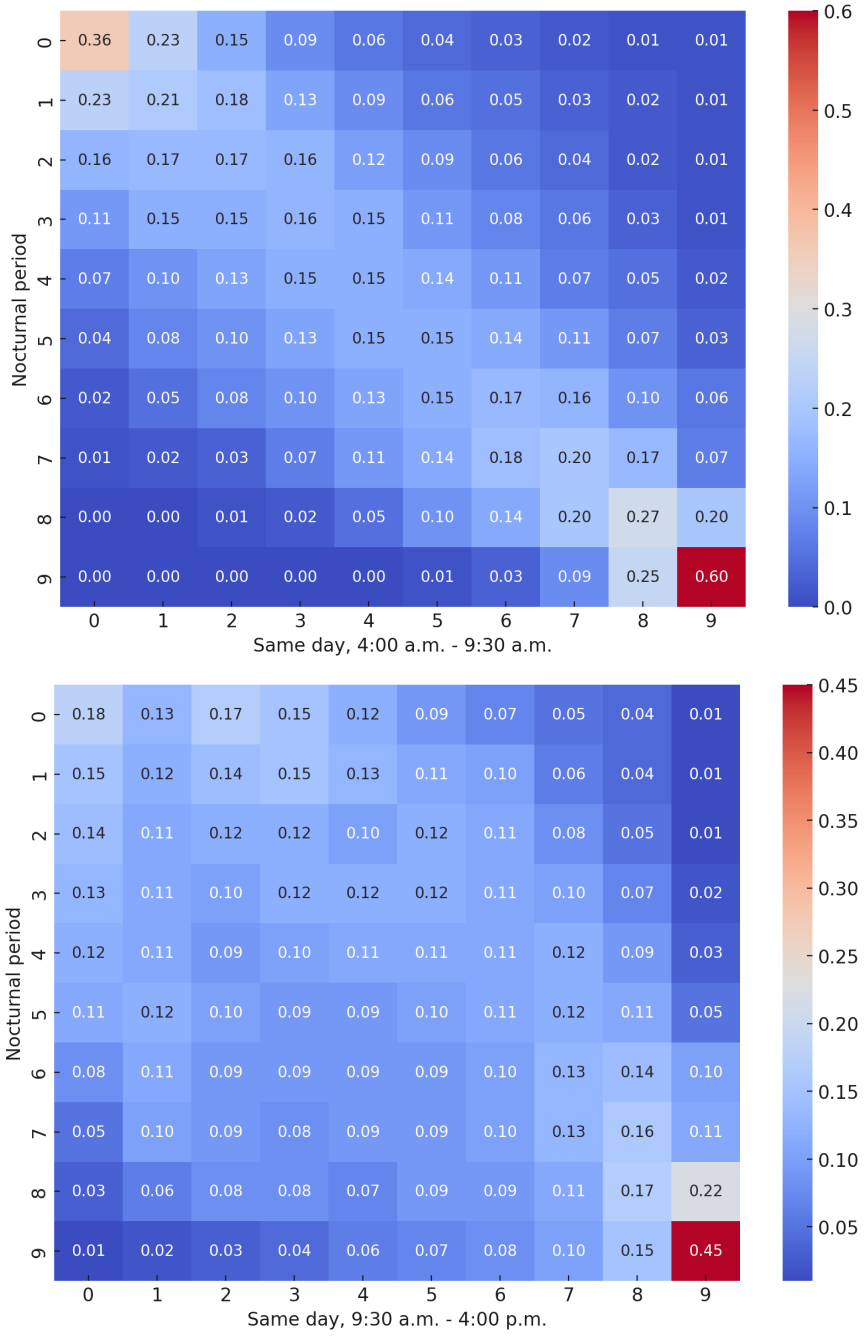

Figure 7. Transition Matrix Blue Ocean to Subsequent Periods

This figure displays the transition matrix between Blue Ocean ATS (BOATS) trading tonight and subsequent periods; pre-open (top) and regular trading hours (bottom).

Internet Appendix to "Nocturnal Trading"

Gregory W. Eaton, Andriy Shkilko, Ingrid M. Werner

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Internet Appendix to "Nocturnal Trading"

Gregory W. Eaton, Andriy Shkilko, Ingrid M. Werner

IA1 Extended Discussion of Institutional Details

This section provides further discussions of the institutional details of nocturnal trading. The New York Stock Exchange (NYSE) introduced after-hours trading in June 1991 by extending trading hours by an hour in response to overseas competition, and the after-hours trading period has gradually been extended to cover the period 4 p.m. to 8 p.m. In 1999, Nasdaq moved its opening hour to 7 a.m. The NYSE, facing increased competition, countered in 2005 by allowing traders to start at 4 am. Nasdaq did the same in 2013. However, it was not until 2018 that the concept of nocturnal trading for retail investors was introduced to the U.S. public when TD Ameritrade promoted "All Night Long" trading with a February 4, 2018, Superbowl ad featuring Lionel Richie.[8] Hence, nocturnal trading actually dates back to at least early 2018.

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

[8] https://bit.ly/3PI086E

Singaporean firm Blue Ocean Financial Technology, Pte. Ltd. to facilitate trading in certain NMS stocks and ETFs after U.S. markets had closed.[9]

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:[10]

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 marketplace 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.

[9] https://bit.ly/4h2udK8
[10] https://bit.ly/40lBY6Y

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.[11] At this point, BOATS starts reporting under MMID BLUE, and takes over the business of nocturnal trading in NMS securities from tZERO ATS which has been reporting under MMID PROS.[12]

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.

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

[12] Based on FINRA ATS Transparency data, tZERO LLC ATS continues trading OTC securities.

BOATS charges subscribers a per-executed-share fee based on the following schedule:[13]

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
   (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.[14]

As illustrated in Figure IA3.5, 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 IA3.4). BOATS' first U.S. retail broker client was TD Ameritrade that started offering nocturnal trading

[13] https://bit.ly/4hmKg5f
[14] https://bit.ly/3PEF1SL

in 12 exchange traded funds on its Thinkorswim platform on January 22, 2018.[15] U.S. broker E*Trade announced nocturnal trading in the same 12 exchange traded funds on February 20, 2018.[16] 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.[17] On July 25, 2023, Interactive Brokers announced that they have partnered with BOATS for supplemental liquidity.[18] U.S. retail broker TradeUP started offering nocturnal trading to its U.S. clients on June 25, 2024.

More recently, 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.[19] 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.[20] 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

[15] https://bwnews.pr/42lH4Td
[16] https://bwnews.pr/42jQ4YU
[17] https://on.wsj.com/3PGYxOl
[18] https://bit.ly/4apAoW8
[19] https://reut.rs/3PDETmu
[20] https://bit.ly/4anAKwo

real-time trading of U.S. equities was announced on February 14, 2023.[21] BOATS and the Tokyo Stock Exchange (TSE) announced a strategic partnership on August 7, 2023.[22] 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 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.[23] 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.[24] The IBEOS only accepts regular

[21] https://bit.ly/4h0sapY
[22] https://bit.ly/3E2Vyxa
[23] https://bwnews.pr/3EbUIOx
[24] https://bit.ly/4h0giEu

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") 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:[25]

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.[26] 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.[27]

[25] https://bit.ly/3Cf4W06
[26] https://bit.ly/4apAoW8
[27] https://bit.ly/3WoAveK

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 IA3.5. 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.

[Figure IA3.5]

Figure IA3.4 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 IA3.4]

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.[28] 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.[29]

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 commis-

[28] https://bit.ly/4h6FGZ9
[29] https://bit.ly/3Cf4W06

sions 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).[30] 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 other incentives.[31]

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.[32] 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

[30] https://bit.ly/4hoAHTx
[31] https://bit.ly/4jjGlIf
[32] https://bit.ly/4apFMIQ

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:[33]

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 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:[34]

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

[33] https://bit.ly/3PJfI1Y
[34] https://bit.ly/4h1lyaH

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.

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 IA3.2 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 IA3.2]

Figure IA3.3 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 IA3.3]

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 IA3.2 and Figure IA3.3 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:[35]

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:[36]

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) Robin-

[35] https://bit.ly/3CiwmCn
[36] https://bit.ly/3PJfI1Y

hood 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 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 Growth in Nocturnal Trading

Using FINRA ATS Transparency Data, Figure IA3.6 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. Korean brokers started using BOATS again in November of 2025.

[Figure IA3.6]

Figure IA3.7 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 IA3.7]

IA3 Prior-Day Trades Data

Our main analysis of market quality and price discovery relies on data from the BOATS platform, which represents the vast majority of nocturnal activity as illustrated in Figure 1 of the

paper. In order to verify that are results are robust to including also the IBEOS platform, we use a different dataset that we describe 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.[37] 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).[38] 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, 2023, although the NYSE continues to produce them.[39] 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.

[37] https://www.finra.org/rules-guidance/notices/09-52
[38] Ibid.
[39] https://bit.ly/4joqRTq

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.

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.

IA3.1 Market Quality

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.

Table IA3.1 reports the three spread measures for each sub-period of the 24 hour trading day based on the sample of 484 securities for January-May 2024. Trading costs during the nocturnal period are significantly greater than the average during regular trading hours. Using Roll to measure liquidity, we find costs of 0.61% from 8 p.m. to midnight and 0.42% from midnight to 4 a.m., at least four times greater than the 0.10% observed during regular hours. However, Ardia, Guidotti, and Kroencke (2024) argue that traditional metrics like Roll underestimate true trading costs in periods of infrequent trading, while their EDGE metric provides a more accurate estimate. Using EDGE Day (EDGE Min), we estimate costs at 2.32% (2.48%) in the first half of the night and 1.89% (1.14%) in the second half, which is several times greater than the 0.16% observed during regular hours.[40]

[Table IA3.1]

We next consider how these spread measures vary by security type. In Panels B and C, 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. Generally, spreads are higher for Stocks and ADRs than they are for ETFs and this is true for all sub-periods.

[40] Ardia, Guidotti, and Kroencke (2024) explain that EDGE Min significantly outperforms EDGE Day, and we therefore focus on the EDGE Min measure.

IA3.2 Trading Activity and Price Discovery

We next analyze trading activity and price discovery during the nocturnal hours. Table IA3.2 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 IA3.2]

We next consider how these measures vary by security type. In Table IA3.3, 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 IA3.3]

To further understand cross-sectional variation, Table IA3.4 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 IA3.4]

IA3.2.1 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 IA3.5). 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 after-hours 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.

[Table IA3.5]

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 after-hours announcements.

Table IA3.1
Measures of Percent Effective Spread using Prior Day 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			

Table IA3.2
Nocturnal Trading Activity and Price Discovery using Prior Day Trades Data

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 IA3.3
Trading Period Statistics Grouped by Security Type using Prior Day Trades Data

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 IA3.4
Trading Period Statistics Sorted by Total Volume or Nocturnal Volume Share using Prior Day Trades Data

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 IA3.5
Earnings Announcements using Prior Day Trades Data

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 after-hours 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 After-Hours 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%

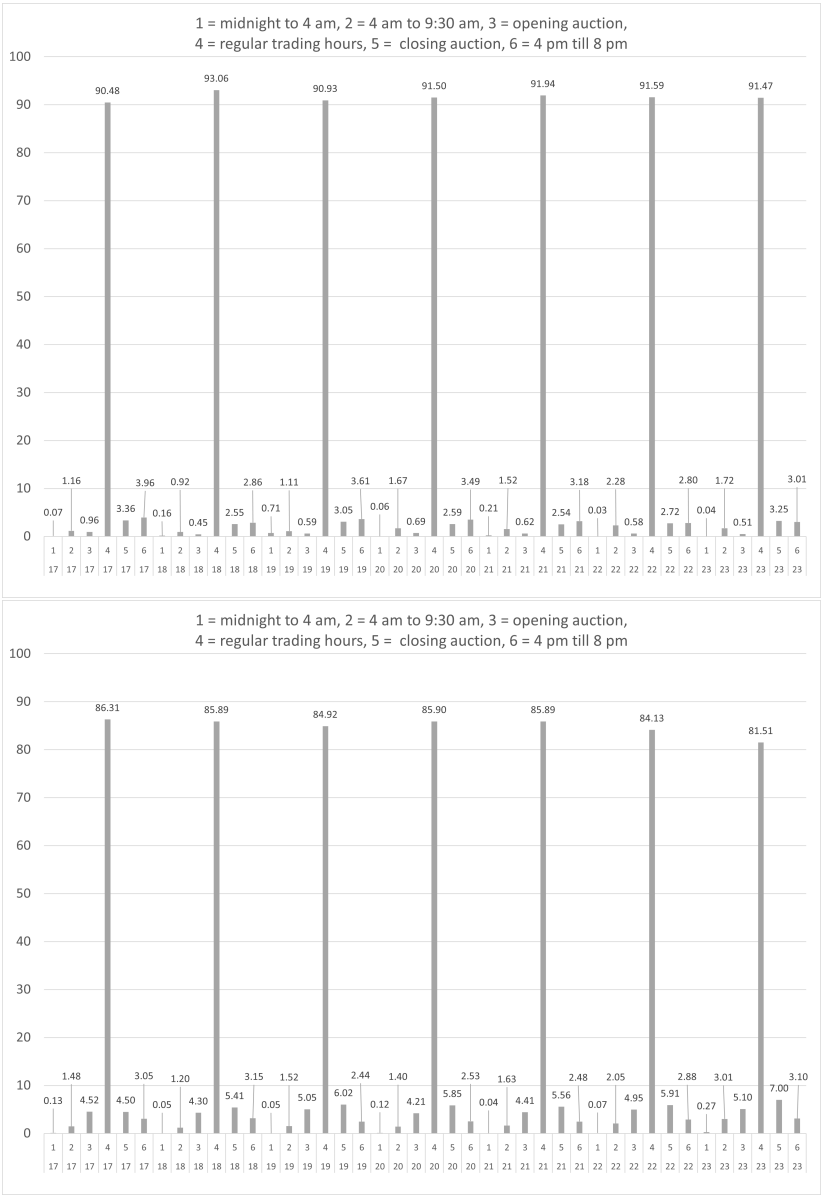

Figure IA3.1. Intraday Trading Periods

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.

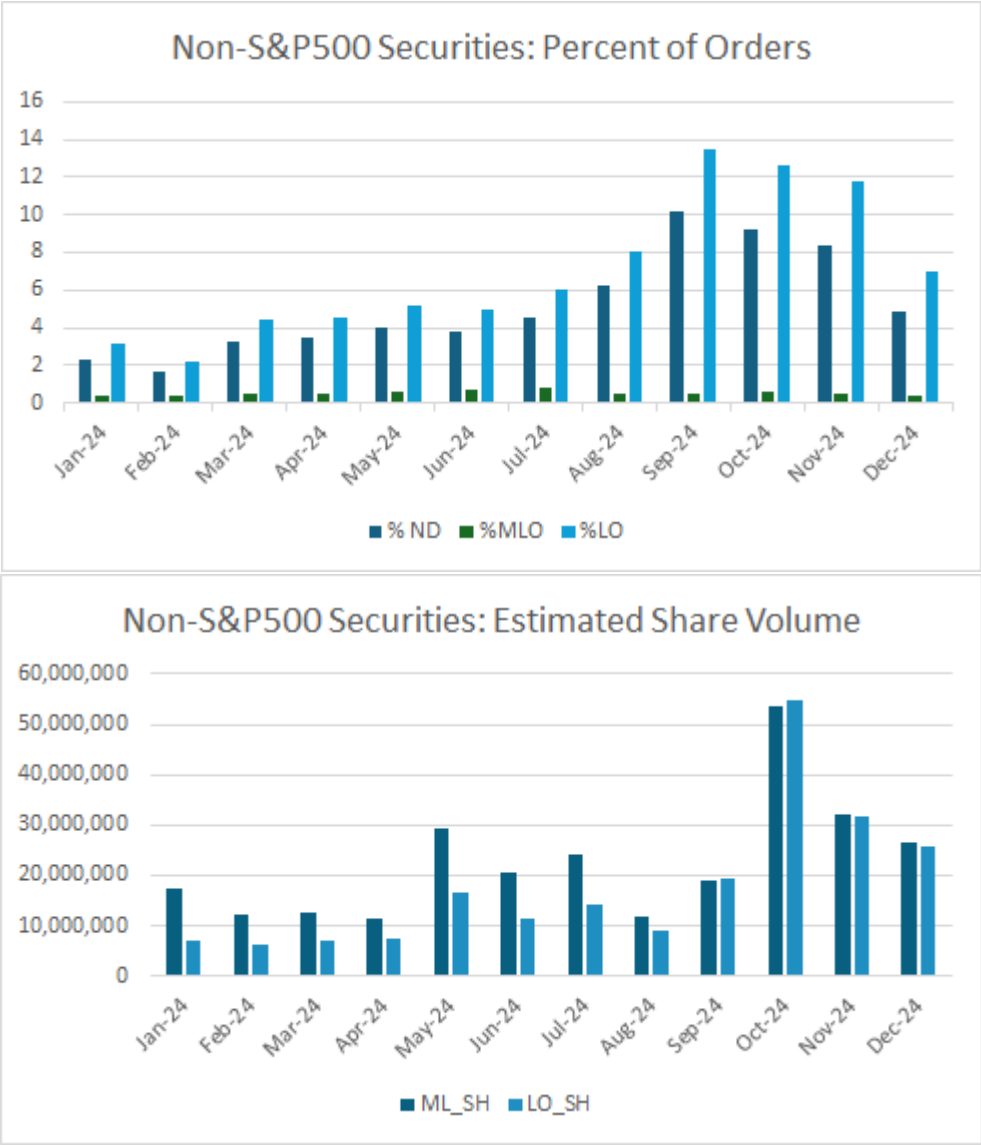

Figure IA3.2. Interactive Brokers Routing Non-S&P 500 securities to BOATS

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.

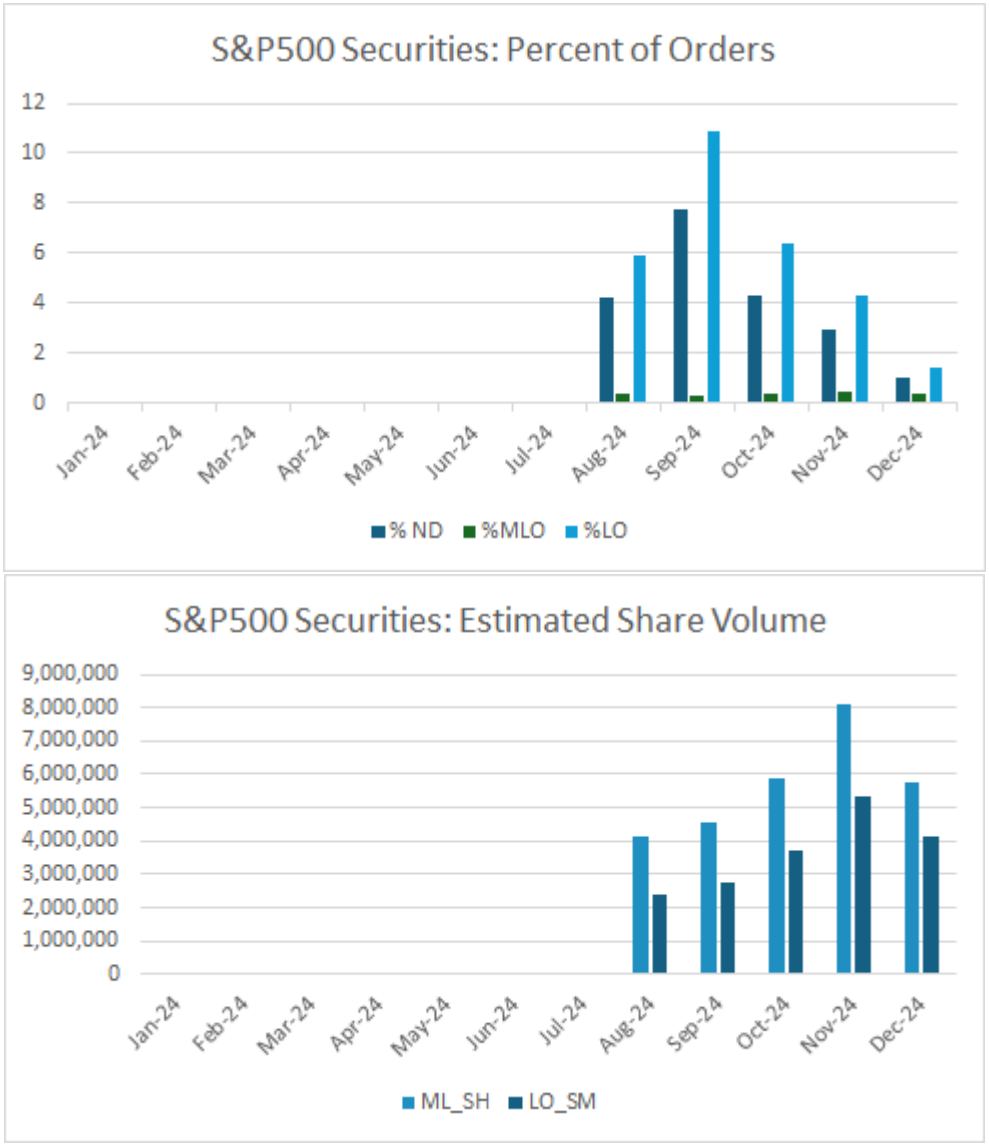

Figure IA3.3. Interactive Brokers Routing S&P 500 securities to BOATS

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.

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 IA3.4. List of Nocturnal Securities for U.S. Retail Brokers
Source: Web search for announcements.

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 IA3.5. Major Retail Broker Overnight Offerings
Source: Investopedia.

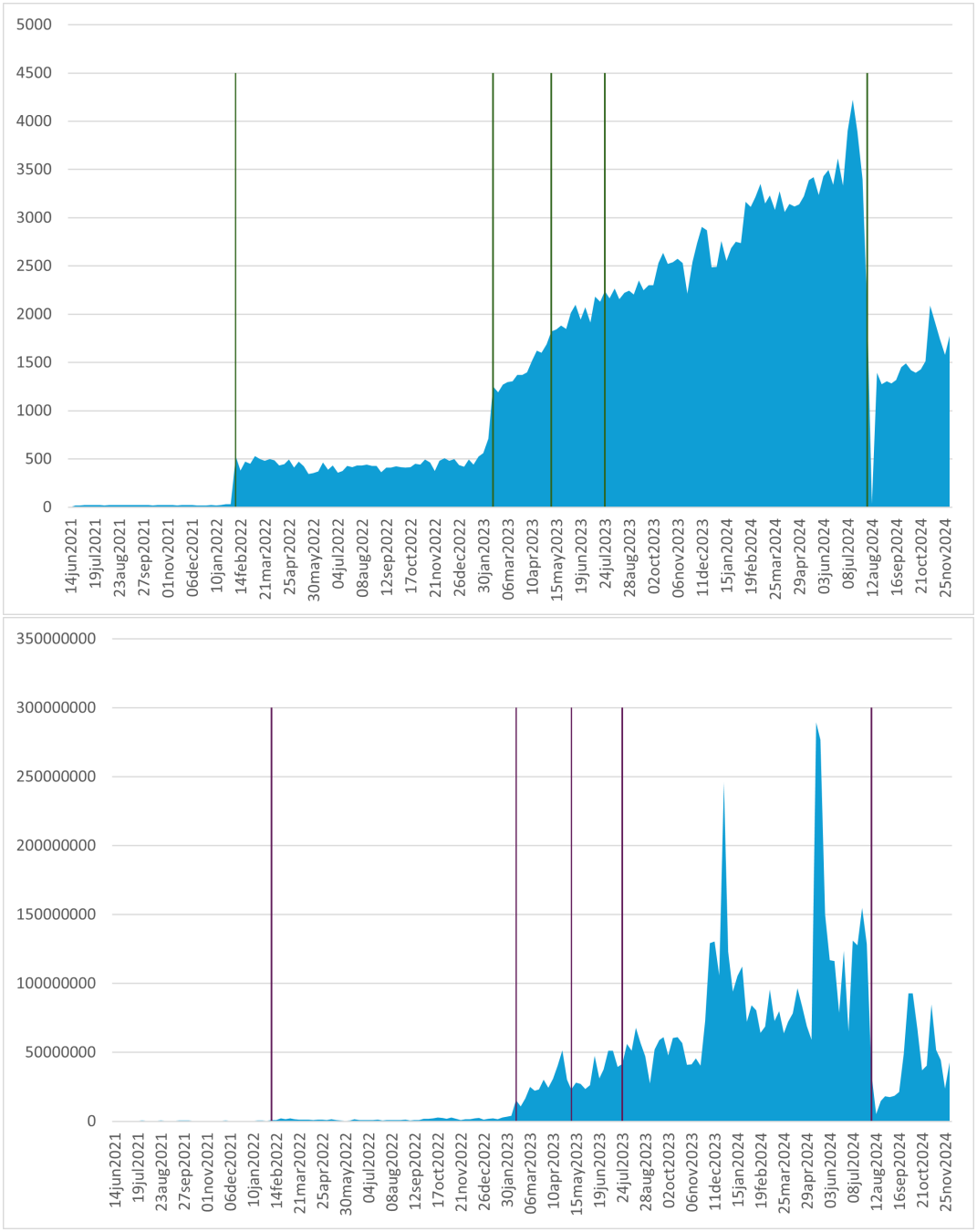

Figure IA3.6. Nocturnal Trading Activity on BOATS

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.

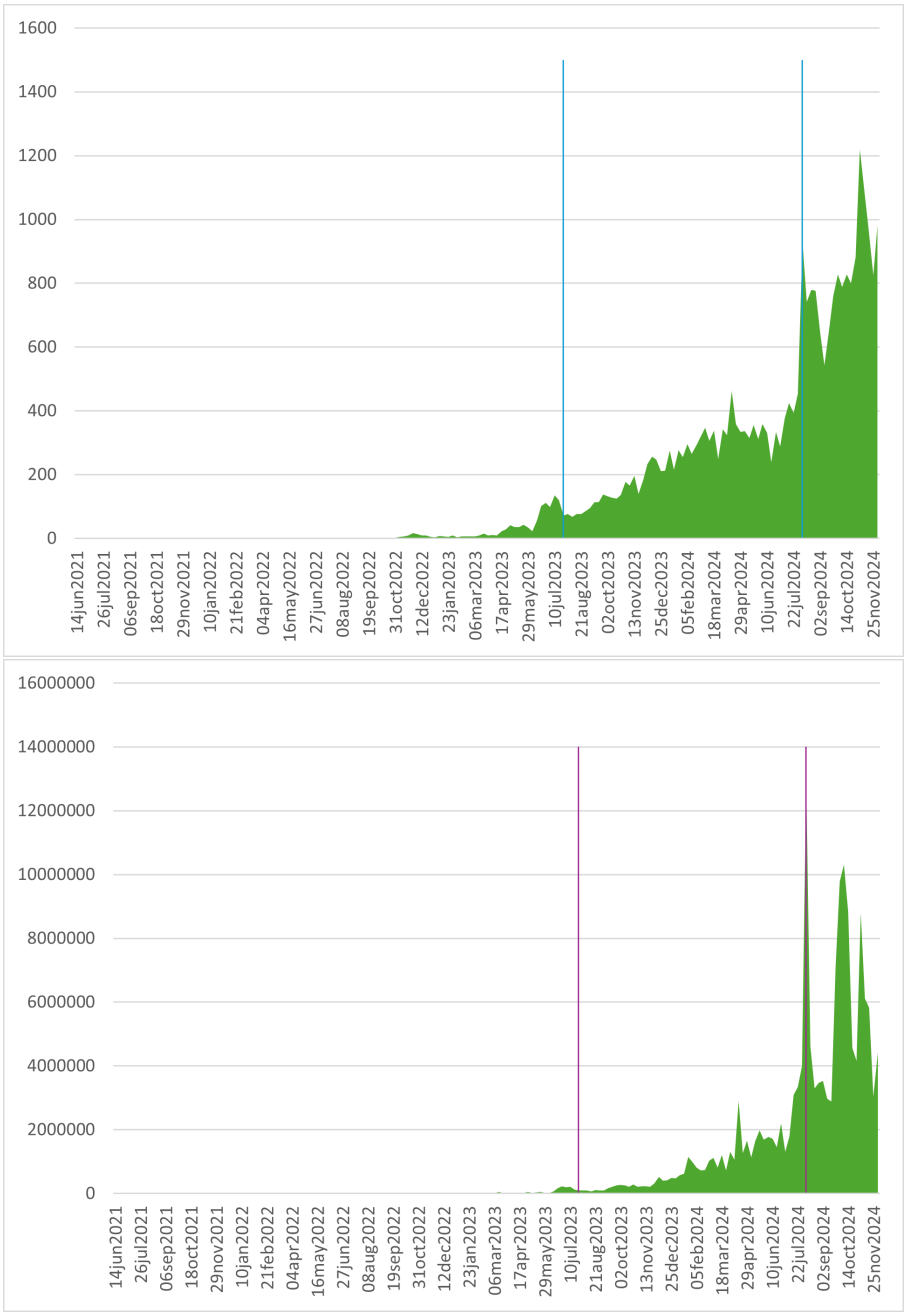

Figure IA3.7. Nocturnal Trading Activity on IBEOS

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.