Risky Intraday Order Flow and Equity Option Liquidity

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Abstract

Consistent with models where liquidity providers engage in active inventory management, we find a strong positive relationship between intraday order flow volatility and illiquidity in short-maturity index and equity options. Delta-hedge rebalancing needs and daily order flow measures are secondary. The impact of order flow volatility decreases with maturity, highlighting the heightened liquidity sensitivity of ultra-short maturity options. Leveraging multi-exchange stock option trading, we separate direct trade absorption costs from indirect costs, finding indirect costs dominate as exchanges adjust based on aggregate order flow risk across venues. Our findings enhance understanding of transaction cost drivers in this relatively novel market.

1 Introduction

Investors are turning into short-maturity options, changing the standard trading dynamics in both the SPX options market and the market for individual stock options. In 2023, an impressive 80% of SPX options trading focused on options with expiration less than a month (Dim, Eraker, and Vilkov 2024; Bandi, Fusari, and Reno 2024). The increase in option market liquidity, the rise in investor sophistication, and the growing desire to hedge against specific events have all contributed to the shift towards option strategies with shorter maturities and more frequent rebalancing.[1] In response to this need, exchanges promptly introduced weekly options expiring every Friday for some individual stocks, and daily expirations for SPX options, the so-called 0DTE options.[2]

The surge in short-term options volumes has spurred new research exploring this novel market, its characteristics, and its implications for market stability. The main focus of these papers is, however, on the prices and returns of the options (Bandi, Fusari, and Reno 2024; Almeida, Freire, and Hizmeri 2024; Beckmeyer, Branger, and Gayda 2023), or on the impact of option trading on the underlying market (Dim, Eraker, and Vilkov 2024; Adams, Fontaine, and Ornthanalai 2024; Brogaard, Han, and Won 2023), with limited analysis on the quality of the market itself.

This paper aims to fill this gap by analyzing the effective trading costs in short maturity and ultra-short maturity U.S. options and their relationship with the intraday order flow distribution, aiming to identify risky patterns that could disrupt a market characterized by

[1] See, for example, *https://www.cboe.com/insights/posts/the-evolution-of-same-day-options-trading/*

[2] In 2010, CBOE introduced the first SPX Weeklys (SPXW) with Friday expirations. In 2016, CBOE expanded its listings by launching SPXW options that expired on Mondays and Wednesdays. By 2022, CBOE had further broadened its listings to include SPXW contracts expiring on every weekday from Monday through Friday.

exceptionally high trading volumes.

According to standard market microstructure models (Glosten and Milgrom 1985; Stoll 1978), trading patterns that increase risks and costs for liquidity providers should be reflected in the bid-ask spread.[3] Inventory models that explicitly account for the stochastic nature of the order flow (e.g., Bogousslavsky and Collin-Dufresne 2023) emphasize the critical role of unbalanced order flow distribution in the stock market and its positive relationship with illiquidity. In this model, liquidity providers actively rebalance inventory throughout the day, aiming to balance buy and sell orders and maintain a small inventory. Intraday volatile order flow increases the inventory risk they face while awaiting offsetting trades, leading to wider spreads for investors. In the options market, liquidity providers can also manage inventory risk by delta-hedging their option positions in the underlying market. Inventory models in the options market that account for delta-hedging suggest that trading costs should reflect the risks and costs of discrete delta-hedge rebalancing (Jameson and Wilhelm 1992; Stoikov and Sağlam 2009; Cho and Engle 1999). However, recent empirical evidence by Hu, Kirilova, Muravyev, and Ryu (2024), based on market-makers accounts in the Korean options and futures markets, shows that liquidity providers primarily engage in active inventory management and trade matching, using delta-hedging only as a secondary risk management tool. If U.S. option liquidity providers exhibit similar behavior, we would expect intraday order flow volatility to be a primary determinant of spreads, outweighing the influence of variables related to delta-hedging needs.

Our empirical analysis encompasses the sample of options with a maximum maturity of seven weeks, including S&P500 index options (SPX options) and options on the constituents of the S&P500 index, spanning the period from 2004 to 2021.

[3] See Foucault, Pagano, and Röell (2013) for a review of market microstructure models where the bid-ask spread is endogenously set by liquidity providers to compensate for asymmetric information risk and/or inventory and order processing costs.

We begin by documenting that, while daily order imbalances are relatively small in absolute value (as documented by Dim, Eraker, and Vilkov 2024), the intraday distribution of order flow has been highly volatile since the years following the financial crisis. Examining the distribution of order flow on days characterized by high trading costs versus those with low trading costs reveals that illiquidity is associated with a very high order-flow volatility. This suggests that more dispersed orders are risky for liquidity providers and detrimental to overall liquidity, consistent with active intraday inventory management by liquidity providers. Formal time-series and panel regressions confirm this pattern: high intraday order flow volatility on day t is positively associated with trading costs on the same day. The positive relationship between order flow volatility and spreads persists across all maturities but is particularly strong for ultra-short maturities (0DTE and 1–6 days). This underscores the sensitivity of bid-ask spreads for these ultra-short maturity options to risky intraday trading patterns. Intuitively, for very short-term options, like 0DTE, liquidity providers do not have time to earn a premium on their inventory (as in e.g., Fournier and Jacobs 2020) and must quickly adjust to order flow, incorporating the required premium immediately into the spread.

Overall, our analysis demonstrates that the positive relationship between order flow volatility and illiquidity is highly robust and significant. It applies to both the SPX options market and the market for individual stock options (in both the time-series and cross-sectional dimensions) and survives the inclusion of numerous controls, including daily measures of volume, order imbalance, volatility, option Greeks, stock characteristics, past spread levels, and variables capturing market-makers' rebalancing needs. Importantly, all our regressions include time-fixed effects, such as day-of-the-week, month-of-the-year, and year dummies, to account for strong seasonalities in the spread.

Of special interest among the controls are the variables that specifically measure the hedging needs of market participants, particularly those engaged in delta-hedging. Using data from the CBOE Open-Close database, we analyze the positions of market-makers in the SPX options market, who are key liquidity providers and the participants most likely to delta-hedge their inventory. Following Dim, Eraker, and Vilkov (2024) and Ni, Pearson, Poteshman, and White (2021), we measure, for each day t in the sample, the gamma of their inventory (measured at $t-1$) and the delta of the new order flow they absorb on day t. These variables capture the extent of delta-hedge rebalancing for prior positions and the delta-hedging of new positions, respectively. We find a positive relationship between these measures and trading costs, consistent with options theory (Jameson and Wilhelm 1992). However, when intraday order flow volatility is included in the regression, the significance of these variables disappears, indicating that the positive relationship is relatively weak and overshadowed by the stronger link between volatile order flow and trading costs. This finding is suggestive of liquidity providers who primarily focus on active inventory management and trade matching, with delta-hedging serving as a secondary inventory management tool.

We next analyze more closely the role of direct and indirect inventory costs in driving the relationship between order flow volatility and illiquidity. Volatile order flow imposes costs on liquidity providers that are directly related to trade absorption (direct costs), such as order processing and inventory rebalancing, as well as costs not directly tied to trade absorption (indirect costs), such as heightened monitoring and greater uncertainty about future liquidity provision.[4] Since options on individual stocks trade across sixteen exchanges, we can conduct a more granular exchange-level analysis by leveraging the exchange flag in our data that identifies where each trade occurred. This unique feature of the dataset allows us to study heterogeneous exchange-specific liquidity and the role of trade absorption and

[4]For a detailed list of all inventory costs incurred by liquidity providers, see Foucault, Pagano, and Röell (2013).

direct costs in the volatile order flow-illiquidity relationship. Intuitively, the exchange that absorbs the trades and experiences an inventory shock faces both direct and indirect costs of providing liquidity, while other exchanges are only subject to indirect costs. Moreover, if trade absorption costs are the primary driver of the volatile order flow-illiquidity relationship, then exchange-specific liquidity should be more closely related to exchange-specific order flow volatility. Conversely, if liquidity providers' aversion to order flow volatility extends beyond trade absorption, i.e., due to indirect costs, exchange-specific liquidity should be more associated with total order flow volatility.

To test these hypotheses, we conduct two distinct analyses: one at the intraday level and another at the daily level. At the intraday level, we find that after a trade, the exchange where the trade took place raises the spread by approximately 1%, while other exchanges lower their spreads by around 22 basis points. This result suggests that direct costs of liquidity provision are significant and quickly reflected in the spread, while the spread reductions on other exchanges may reflect efforts to attract trading volume. In contrast, past order flow volatility (measured up to the time of trade) positively impacts spread changes across all exchanges, regardless of where the trade occurred. This indicates that the relationship between volatile order flow and illiquidity is largely driven by indirect costs from one trade to the next. At the daily level, we examine whether exchange-specific liquidity is more closely associated with the volatility of total order flow or exchange-specific order flow volatility. The results reveal that, although both factors are significant, total order flow volatility has a higher magnitude and significance. Overall, these findings suggest that indirect costs play a more substantial role in the relationship between order flow volatility and liquidity, and that exchanges learn from the total order flow across all exchanges.

Our paper contributes to different strands of literature. It is primarily related to the recent literature that studies the novel market of short-maturity options and ultra-short maturity options (Almeida, Freire, and Hizmeri 2024; Bandi, Fusari, and Reno 2024; Dim, Eraker, and Vilkov 2024; Beckmeyer, Branger, and Gayda 2023; Adams, Fontaine, and Ornthanalai 2024). The novel aspect of our investigation is the focus on option liquidity and its relation to the order flow. In a closely related paper on option liquidity, Christoffersen, Goyenko, Jacobs, and Karoui (2018) document a substantial illiquidity premium in the option market for longer maturity options. They also analyze the determinants of the bid-ask spread in the cross-section of options and find that the daily absolute value of the order imbalances from non market-makers are positively related to illiquidity. Unlike Christoffersen, Goyenko, Jacobs, and Karoui (2018), we focus on the intraday distribution of the order flow and its impact on liquidity in the time-series and cross-section dimensions of short-term options. We find that intraday order flow volatility is a more significant determinant of the spread than the absolute daily order imbalance. More generally, our paper provides a novel comprehensive analysis of trading costs in the index and equity options market (which are substantially higher than those observed in the stock market), and their relationship to daily and intraday measures of order flow, both market-wide and at the exchange level.[5]

2 Theoretical Framework and Literature Review

According to standard models of inventory management (e.g., Ho and Stoll 1983; Grossman and Miller 1988), liquidity providers set the bid-ask spread in the market to maximize their utility based on their final wealth. This wealth is determined by the cash earned from the

[5] Additional related literature has examined order-flow measures of trading and their impact on option prices, e.g., Bollen and Whaley (2004); Garleanu, Pedersen, and Poteshman (2008); Muravyev (2016); Cao, Jacobs, and Ke (2024); and Fournier and Jacobs (2020). Unlike these studies, which focus on the first moment of the order flow distribution, our research centers on the second moment and its impact on liquidity. There is also an extensive literature investigating the impact of the order flow on stock returns. A non exhaustive list is e.g., Chordia and Subrahmanyam (2004); Kelley and Tetlock (2013); Brogaard, Hendershott, and Riordan (2014); Chordia, Hu, Subrahmanyam, and Tong (2019).

bid-ask spread and their inventory position. These models typically assume utility functions that reflect an aversion to inventory variance, leading to wider bid-ask spreads as inventory risk increases. This aversion stems from the preference of liquidity providers to maintain a minimal and balanced inventory throughout the day, as holding a non-zero position between offsetting trades is risky.

This is best formalized in the model proposed by Bogousslavsky and Collin-Dufresne (2023). In their model, liquidity providers actively manage their inventory in the stock market by matching buy and sell orders to minimize imbalances. The bid-ask spread compensates these risk-averse liquidity providers for the inventory risk they face while awaiting offsetting order flow. If the arrival rates of buy and sell orders temporarily diverge during the day, it creates an unbalanced order flow, increasing inventory risk for liquidity providers. Consequently, holding trade volume constant, the equilibrium bid-ask spread rises with intraday volatility in order flow. Intuitively, in this framework, a large volume of shares bought in one period and sold in another entails more risk than smaller, continuous transactions spread evenly throughout the day.

In the options market, liquidity providers can manage inventory risk in two primary (non mutually exclusive) ways: i) by actively managing inventory and matching trades, as described above, or ii) by delta-hedging their option positions in the underlying stock market. Hu, Kirilova, Muravyev, and Ryu (2024), who analyze account-level data for market-makers in options and futures on the Korean Composite Stock Price Index (KOSPI 200), find that most market-makers do not delta-hedge their option inventory. Instead, they rely on active inventory reversal strategies (i), eliminating undesired positions within minutes. In such scenarios, intraday order flow volatility is expected to be a primary determinant of bid-ask spreads.

The first hypothesis tested in our analysis is whether the volatility of order flow is positively related to the effective spread. Acceptance of this hypothesis would suggest active inventory management by liquidity providers in the U.S. options market. However, this would not preclude the possibility that liquidity providers also utilize other inventory management tools, such as delta-hedging (ii). In such cases, additional factors are expected to influence the bid-ask spread, particularly when perfect inventory hedging is unattainable.[6] The risk associated with discrete delta-hedge rebalancing is best represented by the inventory's gamma, which measures the sensitivity of the delta position to price changes, thereby reflecting the rebalancing needs of liquidity providers (Jameson and Wilhelm 1992; Ni, Pearson, Poteshman, and White 2021; Dim, Eraker, and Vilkov 2024). Gamma also accounts for errors in discrete rebalancing caused by changes in the delta position. We hypothesize that if market-makers actively engage in inventory management, as observed in Hu, Kirilova, Muravyev, and Ryu (2024), inventory gamma will play a secondary role compared to order flow volatility in driving bid-ask spreads.

3 Data

We obtain options trade data from the CBOE's LiveVol, including timestamp down to milliseconds, trade price and size in contracts, the prevailing NBBO prices, and the contemporaneous best bid and offer prices of underlying security for each trade reported by the Options Price Reporting Authority (OPRA). The dataset spans the intraday trading activity of all equity and index options from January 01, 2004, to July 16, 2021. We merge the LiveVol data with the Center for Research in Securities Prices (CRSP), from which we obtain daily stock returns, trading volumes, prices, and the number of outstanding shares. Additionally,

[6] Traditional models of liquidity providers in the option market (e.g., Stoikov and Sağlam 2009; Cho and Engle 1999) suggest that order flow imbalances and inventory should not impact spreads if perfect delta-hedging is achievable.

we combine the intraday trade data with OptionMetrics, allowing us to access daily implied volatility and Greeks for option series. For each day, option series are required to be present in all three data sources.

We focus on S&P 500 index options and options on individual stocks which are the constituents of the S&P500 index. We track S&P 500 constituents on a monthly basis following the historical components file from CRSP. A stock is included in our cross-sectional sample for a given month if it was part of the S&P500 index in the previous month.

Our focus lies on short-term options with maturities of up to one month, as these have seen the most significant growth in trading activity over time (Almeida, Freire, and Hizmeri 2024), raising questions about the stability of the option market. Among these options, at-the-money (ATM) options are of special interest, as they have the highest decline in value as maturity approaches, and the highest value of gamma, which is particularly relevant for delta-hedgers liquidity providers (see Ni, Pearson, Poteshman, and White 2021). Moreover, the prices and spreads of ATM options are less affected by market microstructure noise than out-of-the-money (OTM) options (Duarte, Jones, and Wang 2024).[7] Our main sample is thus composed by ATM options, defined by an absolute delta between 0.375 and 0.625, with up to 48 days to maturity. The delta of each option series is assessed at the close of the preceding business day; for example, an option on day t is considered at-the-money if its absolute delta, as recorded by OptionMetrics at the close of day $t-1$, falls between 0.375 and 0.625.

We examine all options trades recorded by OPRA between 9:30 a.m. and 4:00 p.m US Eastern time. The OPRA database encompasses trades occurring across the sixteen exchanges where investors can trade options. SPX index options are specifically traded only

[7] In the robustness Section 5, we analyze out-of-the-money options and find results consistent with those observed for the at-the-money options in the baseline analysis.

on the CBOE exchange, with regular trading hours concluding at 4:15 p.m. Additionally, they are available for trading during global trading hours before the market opens and after it closes, with this time frame gradually expanding over time.[8] To ensure consistency in coverage across various securities and over time, we concentrate on the standard trading hours of 9:30 a.m. to 4:00 p.m. for all underlying stocks and the S&P500 index.

Following the literature, we apply filters to the intraday trade data to clean obvious errors and outlying records. We filter out the following observations: (1) cancelled trades; (2) trades with zero or negative price, size, and/or bid-ask spread; (3) trades whose sizes are higher than 100,000 contracts; (4) trades whose prices are below bid minus spread or above ask plus spread; and (5) trades whose prices are below \$0.10.

4 Empirical Results

This section explores the characteristics of intraday order flow distribution in short-term at-the-money options and its relation with illiquidity. Sections 4.1, 4.2, 4.3, and 4.4 focus on the order flow of SPX options, while Section 4.5 examines the cross-section of options on individual stocks. The analyses show that in all samples higher variance in intraday order flow is associated with increased trading costs in the time-series and in the cross-section. Section 4.6 performs an exchange-specific analysis to investigate the role of direct and indirect costs of inventory management.

[8] In 2015, CBOE extended trading hours for SPX options to include 3 a.m. to 9:15 a.m. In 2021, the start time moved to 8 p.m. of the day before, and in 2022, CBOE added the 'Curb' session from 4:15 p.m. to 5 p.m.

4.1 Order Flow and Daily Statistics

Our primary focus is on analyzing the distribution of intraday order flow. To achieve this, we first need to flag every trade as buy (i.e., buyer-initiated) versus sell (i.e. seller-initiated), since the OPRA data does not explicitly provide this information.

Following the literature on high-frequency data of trades and quotes of stocks (Lee and Ready 1991; Bogousslavsky and Collin-Dufresne 2023), trades are categorized as buys or sells based on the quote rule and tick rule. Specifically, if a trade price is closer to the National Best Offer, it is classified as a buy; otherwise, it is classified as a sell. If a trade price falls at the NBBO quote midpoint, we follow Bryzgalova, Pavlova, and Sikorskaya (2023), and apply the quote rule to the Best Bid and Offer (BBO) prices from the exchange where the trade was executed. In cases where the trade price equals the BBO mid price, the tick rule is applied: if the current trade price exceeds the price of the last trade in the same option, the current trade is classified as a buy; conversely, it is classified as a sell.

In the stock market, it is well-known that the quote rule effectively classify trades that occur without any price improvements, resulting in buyer-initiated (seller-initiated) trade prices that are very close to the quoted ask (bid) prices. However, when a trade receives significant price improvement, the trade classification may be prone to misclassification (Ellis, Michaely, and O'Hara 2000). To validate our quote rule on this critical sample, we obtain a sample of about one million option trades executed on 2024-02-02 through auctions.[9] These trades are mostly retail orders which have been automatically routed into auctions to receive the best price improvement. Within the auction database, we have access to the actual trade direction (buy versus sell) along with the prevailing bid and ask quotes of the exchange where the trade occurred. Analysis reveals that, in this sample, the quote rule successfully classifies

[9]We thank SpiderRock Data & Analytics for providing this auction data.

approximately 85% of the trades.[10]

We then partition the trading day into equispaced time-intervals, and calculate the option order flow on day t in each interval d by subtracting the trade size of seller-initiated trades of all options i from that of buyer-initiated trades:

$$\text{Order Flow}_{t,d} = \sum_i \text{Trade Size of Buys}_{i,t,d} - \sum_i \text{Trade Size of Sells}_{i,t,d}. \tag{1}$$

Several choices for the length of the time intervals are possible. The optimal choice balances the need for high frequency data and option liquidity; if the intervals are too short, we risk having many empty intervals due to insufficient trading activity. While this might not be an issue for SPX options, it could be problematic for some individual stock tickers. Therefore, we opt for a 5-minute interval, which provides a suitable balance as an intermediate high frequency. The first interval spans from 9:30 am to 9:35 am, while the final interval spans from 3:55 pm to 4:00 pm, and in total we have 78 intervals per day.

To obtain the daily order flow, which we label order imbalance and denote it with the variable OI_t, we sum the order flows across the intra-day intervals:

$$OI_t = \sum_d \text{Order Flow}_{t,d}. \tag{2}$$

The order flow measures the buy versus sell pressure in the market. It is positive when investors are, overall, buying more options than selling them, and negative otherwise.

Finally, we calculate the daily options volume by summing the number of contracts traded

[10] Another potential source of misclassification could occur with trades that are components of multi-leg strategies. Li et al. (2020) propose an heuristic approach to classify such trades. However, this methodology, relying on manual trade matching, cannot be verified without a sample containing the actual trade direction. Additionally, Li et al. (2020) find that in their sample, 70% of vertical spreads and 60% of straddles can be classified using the quote rule. Therefore, we opt to adhere to the standard quote rule for trade classification.

across all option series:

$$\text{Volume}_t = \sum_i \text{Trade Size}_{i,t}. \tag{3}$$

[Figure 1 here]

Figure 1 displays the average daily volume and order imbalance for at-the-money put and call options in each year of the sample period. Panel A1 confirms the well-known upward trend in SPX option volumes since the years 2012-2013, observed in both call and put options. Panel A2 documents some important characteristics of the daily order imbalances. On average, the order flow is positive for SPX put options and negative for SPX call options, displaying some variability across the years; this trend corresponds with findings from Chen, Joslin, and Ni (2019) and Jacobs, Mai, and Pederzoli (2024), among others. In the aftermath of the financial crisis, the order flow size surged, reaching an average of 2000 contracts as net order flow per day in 2010 (positive for put options and negative for call options). Post-crisis, the daily order flow size remained relatively stable with occasional deviations. For instance, during the years 2015 or 2018, we observe a modest average daily order flow in both call and put options. Particularly noteworthy are the last two years of our sample, 2020 and 2021, where we document an average negative order flow for both call and put options, with a magnitude around 2000.

Overall, the graph illustrates that, despite the surge in option volumes, buy and sell orders remain relatively balanced throughout the day, resulting in no significant increase in the overall size of the daily net order flow, consistent with results documented by exchange analysts and recent literature.[11] The next section will offer a new perspective on order flow patterns by analyzing the intraday distribution, revealing that even when the daily order flow is small, there can be substantial intraday variation.

[11]See, for example, *https://www.cboe.com/insights/posts/volatility-insights-evaluating-the-market-impact-of-spx-0-dte-options/*

4.2 Intraday Order Flow Distribution

In this section, we start our novel analyzes of the intraday distribution of the order flow. Every day we calculate mean, standard deviation, skewness, and quartiles ($q_{0.25}$, $q_{0.5}$, and $q_{0.75}$) of the seventy-eight 5-minute intervals order flows calculated according to Equation 1.

[Table 1 here]

Panels A1 and B1 of Table 1 present the average of the daily statistics over the years for ATM SPX call and put options. Figure 2 complements Table 1 by illustrating the time-series of the average 5-minute order flow with intraday confidence intervals.[12]

[Figure 2 here]

The intraday buy and sell orders are largely balanced over the sample period, with the average 5-minute order flow across years being -6 for ATM call options and 9 for ATM put options. These averages vary across years, ranging from a minimum of -28.8 (recorded in 2020 for ATM calls) to a maximum of 32.7 (recorded in 2016 for ATM puts). However, as shown in Figure 2, the mean 5-minute order flow does not exhibit any discernible time trend. Low skewness estimates across all years further highlight the overall symmetry of the intraday order flow distribution, which is confirmed by the median and 0.25–0.75 quartiles. Standard deviations, in contrast, are quite large, ranging from 229.7 (in 2004 for ATM calls) to 1764.7 (in 2011 for ATM puts). This results in wide confidence intervals for the average 5-minute order flow. For example, in 2011, the average 5-minute order flow for put options is 6.2 contracts, but with a standard deviation of 1764.7, the confidence interval spans

[12]Specifically, for every day in the sample, we compute the average intraday 5-minute order flow, μ_t, with its confidence interval $\mu_t \pm Z\frac{\sigma_t}{\sqrt{n}}$, where σ_t is the standard deviation of the intraday 5-minute order flows. The figure displays the monthly averages of these daily quantities.

$[-385, 398]$ contracts, reflecting substantial variability in intraday order flow. Examining the time-series of the average standard deviation by year, depicted in Figure 2, we find that the distribution initially exhibited a higher degree of concentration in the early years of the sample. Subsequently, it became more dispersed during the financial crisis in 2007, and, for ATM call options, it then stabilizes with some notable spikes around 2018. For ATM puts, the pattern is similar, with notable spikes in 2011 (concurrent to the European financial crisis), and 2018 (concurrent with the Volmageddon incident).

In summary, this analysis shows that, beginning with the financial crisis in 2007, the distribution of intraday order flow has remained stable over the years. It exhibits high symmetry but also a very high level of standard deviation. Notably, in the ATM put market, this standard deviation peaks during years marked by significant turbulence in volatility markets.

To gain a preliminary insight into the relationship between intraday order flow distribution and option market quality, we compare the distribution of intraday order flow during days characterized by high transaction costs with those characterized by low transaction costs. Our goal is to identify the distribution characteristics that are significant for liquidity.

In accordance with Christoffersen, Goyenko, Jacobs, and Karoui (2018) and Bogousslavsky and Collin-Dufresne (2023), we measure the cost of trading options with the effective spread incurred by option traders. Specifically, for each trade i on day t, we define the percent effective spread as:

$$\text{Effective Spread}_i = 2|\ln P_i - \ln M_i| \tag{4}$$

where P_i is the price of the trade i and M_i is the prevailing midpoint of the NBBO. For each day, the daily effective spread is the volume-weighted average of effective spreads across trades within the same option category (ATM calls and puts).

[Figure 3 here]

Panel A of Figure 3 displays the time series of the daily effective spread (ES_t) and daily changes in effective spread (ΔES_t) across the entire sample period for our samples of ATM SPX call and put options. The graph illustrates a downward trend in the spread throughout the sample period, along with recurrent spikes that may suggest seasonal patterns in both the spread and the daily changes in the spread. We will account for seasonalities and time-trends in the regression analysis of Sections 4.3 and 4.5.

We compare the intraday distribution of order flow on days characterized by low and high trading costs as follows: for each year in the sample, we identify the days falling in the bottom 10% and top 10% based on their ΔES_t values.[13] We then calculate the summary statistics (mean, standard deviation, skewness, and quartiles) shown in Table 1 for each of these subsamples. Panels A2 and B2 of Table 1 present the difference in these statistics between days with low and high transaction costs, segmented by year.

The results are qualitatively similar across the years for both call and put options markets. Days with low transaction costs have a distribution of intraday order flow that consistently shows lower standard deviation and smaller interquartile range compared to days with high transaction costs. Meanwhile, the distribution remains symmetric and with a small mean in both subsamples, as evidenced by the minimal change in skewness and mean values. The table also reports the results of testing whether the differences reported are statistically significant within each year. Although these statistical tests have limited power, we find that for half of the years, the differences in standard deviations and first and third quartiles

[13]Similar results are obtained when splitting the sample according to ES_t instead of ΔES_t. Results are provided in Table IA.1 in the Online Appendix.

are statistically significant. None of the other statistics show the same consistent pattern. The table also reveals no time-trend in the difference between the standard deviation of order flow on days with low and high trading costs, indicating that extreme distribution days have not become more pronounced over time. However, the current high levels of volumes in the option market represent a mass of traders which could potentially generate a very volatile order flow. This underscores the importance of understanding the implications of volatile intraday order flow distributions.

In summary, the findings of this section suggest that the distribution of intraday order flow holds significant economic implications for market liquidity. Specifically, days in which the average 5-minute order flow is more volatile, as measured by the standard deviation of the distribution and the interquantile range, appear to coincide with days with low option market liquidity. Next section formally tests this pattern through a regression analysis.

4.3 Volatile Order Flow and Option Market Liquidity

In this section, we conduct a formal examination of the relationship between option market liquidity and the standard deviation of the intraday order flow distribution, which were shown to be highly related in the previous section.

We conduct separate time-series regressions for SPX calls and put options using the following specification:

$$\Delta ES_t = \alpha + \beta_1 log(SD_t) + \beta_2 log(\text{Volume}_t) + \beta_3 |OI_t| + \text{Time Controls} + \text{Other Controls} + \epsilon_t, \tag{5}$$

where ΔES_t measures the daily change in the effective spread paid by investors for trading options on day t,[14] $log(SD_t)$ denotes the logarithm of the standard deviation of the intraday

[14] An alternative measure of trading costs commonly used in the literature is the absolute spread, defined as

order flow distribution on day t, $log(\text{Volume}_t)$ is the logarithm of the daily volume calculated according to Equation 3, and $|OI_t|$ is the absolute value of the daily order imbalance calculated according to Equation 2.[15] Time controls include day-of-the-week, month-of-year, and year dummies, while other controls include the market return and VIX level on day t,[16] the absolute value of the average delta, vega and gamma of the options on day t, and one-day and two-day lags of ΔES_t.[17] We further segment call and put option samples into maturity buckets with one-week intervals, ranging from options expiring on the same day (zero days to maturity or 0DTE), to options expiring in one week (1-6 days), and up to options expiring in seven weeks (42-48 days to maturity). All variables are calculated separately for ATM calls and put options in each maturity bucket on day t[18], and standard errors are calculated using Newey-West with the optimal lag suggested by Andrews and Monahan (1992).

[Table 2 here]

Table 2 presents the summary statistics of the dependent and independent variables included in the regressions. The average daily change in the spread is generally small and negative, ranging from a maximum (in absolute value) of -2.72 basis points for 0DTE put options to a minimum of -0.10 basis points for call options with 7-13 and 35-41 days to maturity. Trading volumes decrease with maturity, while order imbalances increase with

the spread in dollar terms rather than as a percentage of the mid-price. The robustness section 5.1 presents the results using the absolute spread, which are qualitatively similar to those from the baseline analysis.

[15]We use the absolute value of the order imbalance, following the findings of Christoffersen, Goyenko, Jacobs, and Karoui (2018), who demonstrated that this measure is strongly related to illiquidity through a market-maker inventory channel.

[16]Qualitatively similar results are obtained when using maturity-specific implied volatility in place of the VIX index. Results are available upon request.

[17]Section 5.3 reports the results using the spread in levels rather than changes and $log(SD_t)$ scaled by volumes. The findings are qualitatively similar to those from our baseline specification.

[18]For 0DTE options we considered the greeks recorded on day $t-1$.

maturity, indicating that the higher trading activity in ultra-short-term options is, on average, less directional compared to longer-term options.

[Table 3 here]

Panels A1 and B1 of Table 3 presents the regression results segmented by option maturity buckets. The results consistently reveal a positive and statistically significant relationship between the intraday volatility of order flow $log(SD_t)$ and the effective cost of trading, indicating that days characterized by greater volatility of intraday order flow correspond to lower liquidity. This result holds across various maturity buckets and put call samples, and remains robust after accounting for numerous controls. The breakdown of results into maturity buckets reveals a significant trend in the coefficient of $log(SD_t)$: the coefficient is higher for short-term options and decreases almost monotonically with option maturity. We formally test for differences in coefficients between the ultra-short maturity sample, including 0DTE options, and other maturities, by performing a pooled regression of ΔES_t on $log(SD_t)$, with dummies identifying each maturity bucket. Specifically, we introduce seven dummies, D_{1-6}, D_{7-13}, D_{14-20}, D_{21-27}, D_{28-34}, D_{35-41}, and D_{42-48}, representing each maturity bucket except 0DTE. The coefficient of $log(SD_t)$ measures the sensitivity of illiquidity to volatile order flow in 0DTE options, while interactions of $log(SD_t)$ with these dummies assess whether the coefficient differs in other maturity buckets compared to the 0DTE bucket. Panels A2 and B2 of Table 3 present the results. The $log(SD_t)$ coefficient is positive and significant, with a magnitude consistent with the estimate for the 0DTE sample alone. The interaction term coefficients are all negative and significant, confirming the lower sensitivity to order flow volatility in options with longer maturities.

The coefficients in Table 3 related to the absolute value of order imbalance also offer important insights and connection with the literature. The measure has been utilized in the literature as a measure of demand pressure (Bollen and Whaley 2004; Garleanu, Pedersen, and Poteshman 2008) or as an indicator of changes in option market-maker positions and their associated inventory risk (Muravyev 2016; Christoffersen, Goyenko, Jacobs, and Karoui 2018). While highly significant in univariate regressions, its significance weakens considerably in the full specifications, remaining significant only in a few subsamples.[19] Importantly, it does not overshadow the significance of order flow volatility. Essentially, these two variables gauge distinct aspects of order flow and are not interchangeable. For instance, a day could witness balanced buy and sell orders, resulting in a very low absolute value of order imbalance, yet the orders may be distributed in a highly dispersed manner throughout the day.

Altogether, the results of this section reveal a strong positive relationship between intraday order flow volatility and trading costs, particularly for ultra-short-maturity options. This finding aligns with market microstructure models incorporating stochastic order flow dynamics and suggests that liquidity providers actively manage their inventories throughout the trading day.

4.4 Market Makers Delta-Hedge Rebalancing Needs

Liquidity providers in the options market can also manage inventory risk by delta-hedging their positions in the underlying market. This involves selling an amount of shares equal to the delta (Δ) of their option position to neutralize exposure to movements in the underlying asset. However, this strategy carries its own risks: it incurs transaction costs proportional to the size of the inventory being hedged and requires continuous monitoring due to the rapid changes in the delta of their inventory. These changes, measured by gamma (Γ) are

[19] Table IA.5 in the Online Appendix presents the regression results of illiquidity on the absolute value of order imbalance, both in the univariate regression and together with log(SD).

especially pronounced as options approach expiration. Models of inventory management in the option market, which assume a market maker providing liquidity while discretely maintaining a delta-hedged inventory, show that transaction costs should be proportional to the delta-hedging costs incurred by the market-maker (Jameson and Wilhelm 1992).

In this section, we analyze the relationship between market-makers' delta-hedging needs in the SPX options market and transaction costs. Market-makers are employed by exchanges to ensure continuous liquidity and are the most likely market participants to engage in delta-hedging. The CBOE Open-Close database provides the daily number of buy and sell orders by end-users (non market-makers) in the SPX options market, which cumulatively measure (minus) the daily inventory of market-makers.[20] We merge the CBOE Open-Close database with Optionmetrics[21] and measure the delta-hedging needs of market-makers using the following two variables. For each day t, we measure the gamma of market-makers' inventory at time $t-1$, calculated as the sum of their inventory across all option series ($Inv_{t-1,j}$) weighted by their gamma:

$$GammaInv_{t-1} = |\sum_j Inv_{t-1,j}\Gamma_{t-1,j}S^2_{t-1}|.$$

This variable quantifies the extent to which market-makers must rebalance their delta-hedge in response to changes in the options' delta, which is more significant when gamma is high. Additionally, we measure the delta-hedging needs arising from new order flows absorbed by market-makers on day t, defined as the sum of order flows across all option series scaled by

[20]The OPRA database used in the main analysis does not identify traders, preventing the computation of inventory of liquidity providers.

[21]See Jacobs, Mai, and Pederzoli (2024) for a detailed description of the Open-Close database along with filtering and merging procedure.

the options' delta:

$$DeltaOI_t = |\sum_j OI_{t,j}\Delta_{t,j}S_t|.$$

Following Dim, Eraker, and Vilkov (2024), both variables are expressed in index units: the inventory gamma is scaled by S_{t-1}^2, and the delta of new positions is scaled by S_t, where S_t is the index value at time t.

[Table 4 here]

Table 4 presents the results of regressing our main variable measuring trading costs (ΔES_t) on $GammaInv_{t-1}$ (Panel A) and $DeltaOI_t$ (Panel B). The results are broken down by maturity categories as in Table 2. In the univariate specifications, $GammaInv_{t-1}$ and $DeltaOI_t$ are always positively related to transaction costs for all maturity categories, as indicated in the first column of each subsample. This is consistent with option inventory models (Jameson and Wilhelm 1992) and suggests that the bid-ask spread incorporates market-makers' delta-hedging costs.

We then introduce the volatility of the order flow in the regressions and test whether the previously documented positive relationship between log(SD) and illiquidity is subsumed by these delta-hedging variables or whether it remains a dominant factor. The second columns of each subsample document that, when log(SD) is included in the regression, most coefficients of $GammaInv_{t-1}$ and $DeltaOI_t$ become insignificant or even switch sign. The third specifications, which include log(SD) alongside all other controls from the baseline analysis, further confirm the insignificance or negative signs of the delta-hedging variables. Meanwhile, log(SD) consistently remains positive and significant.

Altogether, these results confirm that the volatility of the order flow is a key determinant of the spread and suggest that liquidity providers actively manage their inventories throughout the day, with delta-hedging costs playing a secondary role in influencing trading costs.

4.5 Volatile Order Flow and Option Market Liquidity in Individual Stock Options

The previous sections document a strong positive relationship between the time-series of the cost of trading SPX options and the volatility of the intraday order flow distribution. This section documents that the same relationship also holds in the market for options on individual stocks.

We consider the constituents of the S&P 500, tracking them monthly from the beginning of our sample. A stock-day is included in our sample if the stock was part of the S&P 500 index in the preceding month.[22] Panel B of Figure 1 displays the average daily volumes and order imbalances of at-the-money equity options with up to 48 days to maturity. Unlike SPX options, we find that investors trade more call options than put options on individual stocks, with the difference in volumes significantly increasing from 2020 onwards. Panel B2 indicates that the daily order imbalance is, on average, positive for both call and put options. Our findings are novel but qualitatively align with the summary statistics provided by Bryzgalova, Pavlova, and Sikorskaya (2023) and Bogousslavsky and Muravyev (2024) on retail trading, which accounts for a substantial portion of volumes in options on individual stocks in recent years.

Our primary variable of interest, $log(SD_{s,t})$, is the logarithm of the daily standard devi-

[22]Figure IA.1 in the Online Appendix shows the number of individual stocks in our sample over time. In the early years, the count ranges from 100 to 200, eventually stabilizing between 300 and 400 from 2009 onward. The sample size aligns with that used by Christoffersen, Goyenko, Jacobs, and Karoui (2018). As a robustness check, we verified that our findings remain robust even when excluding the early years of the sample. Results are available upon request.

ation of the seventy-eight 5-minute order imbalances. It is constructed separately for each stock s using the same procedure as for SPX outlined in section 4.1. Since options on individual stocks may not be traded as frequently as SPX options, we include a stock-day option type (call/put) in the sample if the option group has at least ten non-empty intervals out of the seventy-eight. The other variables related to daily volumes, order imbalance, and effective cost of trading are also constructed separately of each stock-day option-type following equations 3, 2, and 4, respectively.

We perform a panel regression of $\Delta ES_{s,t}$ on $log(SD_{s,t})$ with stock-fixed effect, controlling for volumes and the absolute value of the order imbalance on day t.[23] Other controls include the average implied volatility of options on stock s and day t, $IV_{s,t}$, and the average of the options greeks, i.e., gamma, vega, and the absolute value of delta on stock s and day t.[24] We also control for stock characteristics, as stock return, firm size and stock volume. Time fixed-effects include day-of-the-week, month-of-the-year, and year controls. Standard errors are double clustered at the day and stock level.

[Table 5 here]

Table 5 presents the results for call options (Panel A) and put options (Panel B). The samples are further divided into options with maturities of up to 24 days and those with maturities between 25 and 48 days. The results are robust, showing a strong positive relationship between the standard deviation of the order flow and illiquidity for both call and put samples. Additionally, the coefficient is higher for very-short maturity options (up to 24 days to expiration), confirming that shorter maturity options display a higher sensitivity of trading cost to intraday order flow volatility.

[23]Qualitatively similar results are obtained using a cross-sectional Fama-MacBeth regression instead of the panel regression, and they are presented in Table IA.4 in the Online Appendix.

[24]For 0DTE options, we use the greeks recorded on day $t-1$.

4.6 An Analysis by Exchange

The previous sections document a robust positive relationship between volatile order flow and illiquidity in the time series of SPX options and options on individual stocks. This section explores the role of inventory shocks in this relationship. Inventory management costs include costs directly related to trade absorption and inventory shocks, such as transaction costs and inventory rebalancing costs, as well as indirect costs, such as monitoring and anticipatory inventory management. If costs related to inventory shocks are driving the relationship, liquidity providers absorbing more trades would quote higher spreads when order flow is volatile. Conversely, if liquidity providers' aversion to order flow volatility extends beyond actual trade absorption, the relationship between liquidity and volatile order flow would remain consistent across providers.

To obtain heterogeneity across liquidity providers, we exploit the fact that individual stock options are traded simultaneously across sixteen exchanges. The OPRA database provides the exchange identifier for each trade, along with the contemporaneous best bid and offer quotes across all exchanges. Every exchange designates a primary market-maker for each ticker, which generally differs across exchanges.[25] As long as liquidity providers are heterogeneous across exchanges, exchanges are heterogeneously exposed to inventory shocks, allowing us to isolate the role of inventory shocks in the observed relationship.[26]

We conduct two separate analyses: (i) a trade-by-trade analysis that investigates the differential change in spread after a trade between the exchange that absorbed the trade and the other exchanges, and (ii) a daily analysis that tests whether changes in effective

[25] The current list of designated market makers for each ticker on CBOE and NASDAQ, for example, is publicly available on the website of the exchanges.

[26] Muravyev (2016) utilizes a similar multi-exchange setting to quantify the inventory and non-inventory components of a trade's price impact. In contrast, our focus is on the spread and its relation to the standard deviation of the order flow.

spread across exchanges are more closely linked to the volatility of the total order flow or to exchange-specific order flow volatility. For these analyses at the exchange level we focus on the constituents of the Dow Jones which have been part of the index since the start of our sample period, January 2004. Our sample comprises the following sixteen tickers: AXP, BA, CAT, DIS, DOW, HD, IBM, INTC, JNJ, JPM, KO, MMM, MRK, MSFT, PG, WMT. As in the main analysis, we consider the sample of one-month (up to 48 days to maturity) at-the-money call and put options, with moneyness determined by the delta recorded by OptionMetrics at the end of the preceding day.

For the trade-by-trade analysis, we track, for every ticker and trade, the change in the quoted spread across all exchanges.[27] We analyze an average of ten million trades for call options and six million trades for put options per stock. Microsoft (MSFT) has the largest option market, with forty million records in the call option sample and eighteen million records in the put option sample. DOW and 3M (tickers DOW and MMM) have the smallest option markets, but their sample still encompass approximately two million records in the call market and one million records in the put market.

We perform the following pooled regression separately for each stock:

$$\Delta Spread_{i,j,\tau} = \alpha + \beta_1 Dummy_{i,j,\tau-1} + \beta_2 log(SD_{0,\tau}) + \beta_3 log(SD_{0,\tau}) Dummy_{i,j,\tau-1} + \epsilon_\tau, \quad (6)$$

where $\Delta Spread_{i,j,\tau}$ is the change in the quoted spread in exchange i for option j from the trade time $\tau - 1$ to the next trade time τ. We measure the quoted spread as the difference between the quoted ask and bid prices on the exchange, divided by the exchange mid price.

[27]For simultaneous trades occurring on the same option and exchange, we consolidate them into a single observation. This aggregated observation has a trade size equal to the signed sum of the individual trade sizes and a trade price that is the average of the individual trade prices. All other filters align with those previously applied in the daily analysis.

$Dummy_{i,j,\tau-1}$ is a dummy variable which equals one for exchange i where the trade in option j occurred at time $\tau - 1$. It is zero for all other exchanges. The dummy variable thus captures the differential liquidity response between the exchange that absorbed the trade versus the others. $log(SD_{0,\tau})$ measures the logarithm of the standard deviation of the order flow from the start of the day until time τ.[28] The primary measure considers the order flow across all exchanges, though we will also examine an exchange-specific measure later. Finally, the variable $log(SD_{0,\tau})Dummy_{i,j,\tau-1}$ is the interaction between the standard deviation of the order flow and the dummy.

[Table 6 here]

Table 6 presents the results by stock and option type (Panel A for calls and Panel B for puts), with all coefficients multiplied by 100.[29]

The first specification includes only a constant and the dummy, and thus tests if the change in spread after a trade is the same between the exchange where the trade occured and all the other exchanges. We find consistent and robust results across stocks, as well as across call and put samples, indicating that the constant is negative while the coefficient of the dummy variable is positive. Following a trade, the spread decreases by ten to twenty basis points across all exchanges, while it increases in the exchange where the trade was recorded. The actual change in spread in the trading exchange is the sum of these two coefficients, approximately amounting to 1%. Thus, the primary impact of a trade on illiquidity stems

[28] The first trades of the day lack sufficient trading history to calculate $log(SD_{0,\tau})$ using the 5-minute order flow as done in the daily analysis. Therefore, we will only consider trades recorded after 10 a.m. Additionally, we implement a higher frequency version of $log(SD_{0,\tau})$ by considering the standard deviation of all signed trade sizes from the start of the day until time τ. Similar results are obtained by calculating $log(SD_{0,\tau})$ using 1-minute order flow and are available upon request.

[29] All regressions include day fixed effect, and the standard errors are clustered at the day and exchange levels. $\Delta Spread_{i,j,\tau}$ are also winsorized at the 1% and 99% levels to eliminate instances of apparently unrealistic quotes reported by OPRA.

from inventory costs, while the non-inventory impact is smaller and negatively related to illiquidity. This last result might indicate an effort from the exchanges that did not absorbed the trades to attract volumes.

In the second specification, we augment the regression with the addition of the standard deviation of the order flow up to time τ. We introduce the variable $log(SD_{0,\tau})$ and its interaction with the dummy variable. The hypothesis we test is whether volatile order flow, previously shown to be positively associated with illiquidity in the main analysis, plays a more significant role in the liquidity of the exchange that just experienced an inventory shock. The results consistently document a positive coefficient for $log(SD_{0,\tau})$ and an insignificant coefficient for the interaction, indicating that all exchanges are affected similarly by order flow volatility, with no distinction for the exchange that just absorbed the trade.

In the third specification, we re-estimate the panel regressions using an exchange-specific measure of volatile order flow, $log(SD_{i,0,\tau})$. Specifically, for each exchange, we calculate the standard deviation of the order flow up to time τ by considering only the trades that occurred on that exchange. Similar to before, our hypothesis to test is that if volatile order flow is primarily related to illiquidity through an inventory shock channel, we would expect exchanges with the highest levels of $log(SD_{i,0,\tau})$ to revise their spreads more. Moreover, this effect should be more pronounced for the trading exchange. Specification 3 in Table 6 presents the results, documenting that both the coefficients of $log(SD_{i,0,\tau})$ and its interaction with the dummy are insignificant, indicating that it is the volatility of total order flow, rather than exchange-specific order flow, that correlates with illiquidity.

Finally, we examine the role of trade absorption at the daily level by analyzing the heterogeneous changes in daily effective spreads across exchanges ($\Delta ES_{i,s,t}$) and their relationship with $log(SD_{s,t})$ (total order flow volatility) and $log(SD_{s,i,t})$ (exchange-specific order flow volatility). As expected, these two variables are positively correlated, though moderately, with an average correlation of approximately 40% and a maximum correlation of 60%.

[Table 7 here]

Table 7 shows that, for both call and put options, the strongest relationship, in terms of both magnitude and significance, is between the spread and $log(SD_{s,t})$. The coefficient for $log(SD_{s,i,t})$ is also significant, indicating that at the daily level the distribution of exchange-specific order flow has also an impact on the exchange liquidity, however the coefficient is nearly ten times smaller than that for $log(SD_{s,t})$.

In summary, the results of this section show that exchange-specific liquidity is mainly driven by the volatility of the total order flow, regardless of whether the order flow was absorbed by the exchange or by others. While exchange-specific order flow dynamics are significant in the daily regressions, their impact is smaller compared to the effect of global order flow. These findings suggest that volatile order flow imposes costs and risks on liquidity providers that extend beyond those solely related to trade absorption, and exchanges are revising their spread based on the distribution of the total order flow.

5 Additional Analysis and Robustness

This section presents the findings from various robustness analyses. Section 5.1 demonstrates that the results also hold when using the dollar spread instead of the relative spread. Section 5.2 adds option return volatility to the regression. Section 5.3 reports results using the spread in levels rather than changes, as well as the volatility of order flow scaled by volume. Section 5.4 shows that the results remain robust in the out-of-the-money options sample. Finally, Section 5.5 provides additional analysis, showing that the relationship between volatile order flow and illiquidity is not driven by (i) retail trading, (ii) market opening and closing sessions, and that it remains robust even when time fixed effects are excluded. The tables for Sections 5.3, 5.4, and 5.5 are reported in the Online Appendix.

5.1 Dollar Spread

The main measure of trading costs used in our analysis is the effective spread, calculated according to Equation 4. This measure expresses the spread in log terms, providing a relative measure of trading costs with respect to the option price. It captures the reduction in option returns that traders incur due to transaction costs. Our choice aligns with the existing literature (Bogousslavsky and Collin-Dufresne 2023; Christoffersen, Goyenko, Jacobs, and Karoui 2018) and reflects our goal of understanding how trading costs faced by traders are influenced by potentially risky patterns in the order flow distribution.

As a robustness check, we test our results using an alternative measure of trading costs: the spread expressed in dollar terms. This measure quantifies the dollar gain a liquidity provider earns by supplying liquidity in a trade and immediately reversing the position with another trade of the opposite sign. Specifically, for each trade i, the dollar spread is defined as:

$$\text{Dollar Spread}_i = |P_i - M_i|$$

where P_i is the trade price and M_i is the prevailing midpoint of the NBBO. On each day, the daily dollar spread is calculated as the volume-weighted average of the dollar spreads across trades, scaled by the value of the underlying asset on day t, S_t.

[Table 8 here]

[Table 9 here]

Panel A of Tables 8 and 9 present the regression results for SPX options and equity options, respectively. In these regressions, we use the first difference of the dollar spread as the dependent variable instead of our baseline measure of spread, ΔES. All other controls remain consistent with those used in Tables 3 and 5. The results consistently show a positive and robust relationship between the volatility of the order flow and the dollar spread for both call and put options, as well as for SPX and equity options. Panel A of Table 8 documents that for SPX options, the magnitude of the coefficients is particularly high for ultra-short-term options (0DTE and 1-6 days to maturity), confirming that liquidity is more sensitive to volatile order flow for these very short maturity categories. For equity options, Panel A of Table 9 shows that the difference in coefficients between medium and short maturity options is noticeable only for call options, while the effect is less apparent for put options. This likely occurs because the differing impact is primarily driven by ultra-short-term options (with maturities of less than a week), which investors predominantly trade using call options on single-name stocks. Nonetheless, even a small difference in the absolute spread can result in a substantial difference in the relative spread and trading costs for investors (as documented in Table 5), given the lower option prices for shorter maturities options.

5.2 Relation with Realized Option Volatility

All market microstructure models of inventory and asymmetric information (see Foucault, Pagano, and Röell 2013 for a review) predict that transaction costs should be positively related to asset volatility. This section formally tests this hypothesis and assesses the robustness of our results to the inclusion of a variable that measures the realized intraday volatility of options. This addresses the potential concern that order flow volatility might act as a proxy for the underlying volatility of the options themselves.

We compute the realized option volatility (ORV_t) for day t by summing the squared average 5-minute option returns across the seventy-eight 5-minute intervals throughout the day. Panel B of Tables 8 and 9 present the regression results for SPX options and equity options, respectively. The results confirm a robust positive relationship between ORV_t and illiquidity, consistent with theoretical predictions. However, the significance of the volatility of the order flow (log(SD)) is not subsumed by ORV_t, as shown in the second specification of each subsample. This indicates that, while the two variables are generally correlated (ranging from a minimum of -10% to a maximum of 30%, depending on the sample), they convey distinct information about transaction costs and liquidity.

5.3 Spread in Levels and Scaled $log(SD_t)$

In this section, we first assess the robustness of our findings by using the daily effective spread ES_t instead of ΔES_t as the dependent variable. Table IA.1 provides the preliminary analysis and the descriptive statistics for ES_t. Tables IA.2 and IA.3 present time-series regressions for SPX options and panel regressions for individual stock options using ES_t as the dependent variable. The main results and conclusions remain consistent with our baseline analysis.

We further test the robustness of our results by scaling the volatility of order flow and order imbalance by daily volume, resulting in $\log(SD/volume)_t$ and $|OI/volume|_t$ variables. Tables IA.6 and IA.7 report the time-series regression for SPX options and the panel regression for individual stock options using these scaled variables. The findings confirm a positive relationship between the intraday volatility of order flow $log(SD/volume)_t$ and illiquidity, consistent with our baseline results.

5.4 Out-of-the-money (OTM) Option Sample

In this section, we assess the robustness of our findings by varying the moneyness of the sample used in the baseline analysis, specifically examining out-of-the-money (OTM) options with up to 48 days to maturity instead of at-the-money (ATM) options. An option on day t is classified as OTM if its absolute delta, as recorded by OptionMetrics at the close of day $t-1$, lies between 0.125 and 0.375. Tables IA.8 and IA.9 present the time-series regression for SPX options and the panel regression for individual stock options using OTM options, respectively. The results align with those of our main analysis, showing a positive and statistically significant relationship between the intraday volatility of order flow and trading costs. The effect is even stronger than in the ATM sample, with coefficients decreasing as option maturity increases.

5.5 Additional Robustness

In this section, we further examine if there is any bias in our main results due to controlling for day-of-week, month-of-year, and year fixed effects (see Jennings, Kim, Lee, and Taylor (2024)). Tables IA.10 and Table IA.11 report the time-series regression for SPX options and the panel regression for individual stock options excluding day-of-week and month-of-year controls. While the adjusted R^2 values mildly decrease after removing these time controls, the primary results and inferences remain consistent.

Finally, we assess to which extent our results are due to: i) retail trading, and ii) the opening and closing trading sessions. Tables IA.12 and IA.13 present the results of Table 3 re-estimated by excluding retail trades (identified with the 'SLAN' flag following Bryzgalova, Pavlova, and Sikorskaya 2023) and excluding the first and last half an hour of trading, respectively. The results consistently demonstrate a positive relationship between intraday order flow volatility and illiquidity, indicating that retail trading and the opening and closing trading sessions are not the main drivers of this effect.

6 Conclusion

The recent surge in volumes in option contracts with increasingly shorter expirations has raised concerns among academics and regulators about the stability of this expanding market. A key characteristic of the options market is its high level of transaction costs, leaving an open question as to how effectively liquidity providers can further absorb large, potentially imbalanced order flows while maintaining an efficient and well-functioning market.

Our analysis documents economically and statistically significant positive relationship between intraday order flow volatility and illiquidity in options market, particularly for ultra-short term options. The effect is pervasive: it holds in the time-series and cross-sectional dimension, and it outweighs the significance of more traditional daily first-moment measures of order flow dynamics, such as volumes or absolute order imbalances. Furthermore, it also outweighs the significance of traditional measures capturing the delta-hedging needs of market makers. These findings suggest that liquidity providers rely primarily on active inventory rebalancing and trade matching throughout the day, with the main source of inventory risk arising from providing liquidity to unbalanced order flows. An exchange-specific analysis further shows that liquidity providers are averse to volatile order flows even when they do not directly absorb them, highlighting the role of indirect costs and future liquidity provision risk in the observed relationship.

Our findings underscore the potential risks posed by high volumes in short-term option contracts, which can amplify intraday order flow volatility and challenge market stability. We show that as intraday order flow volatility rises, liquidity providers widen bid-ask spreads to manage the elevated risk, resulting in higher hedging costs for investors increasingly dependent on short-term rollover strategies over long-term hedges. This spread widening, in turn, can impair market efficiency by reducing liquidity and price discovery, which may in turn elevate systemic risk. These dynamics highlight critical aspects that regulators should consider to maintain stability and market quality in financial markets. An interesting direction for future research would be to explore the broader implications of unbalanced order flow in the options market, including its impact on investors' portfolios, hedging strategies, and, more generally, on risk premia in financial markets.

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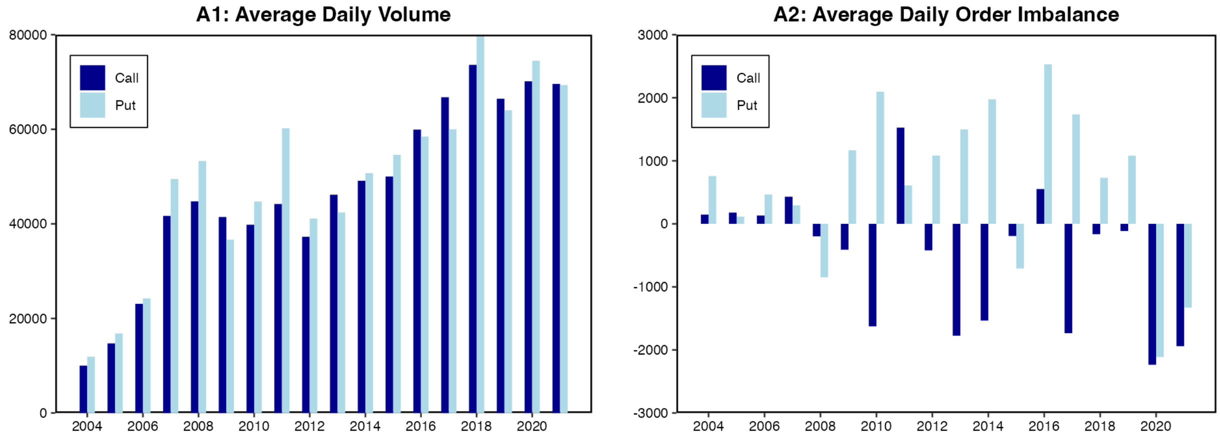
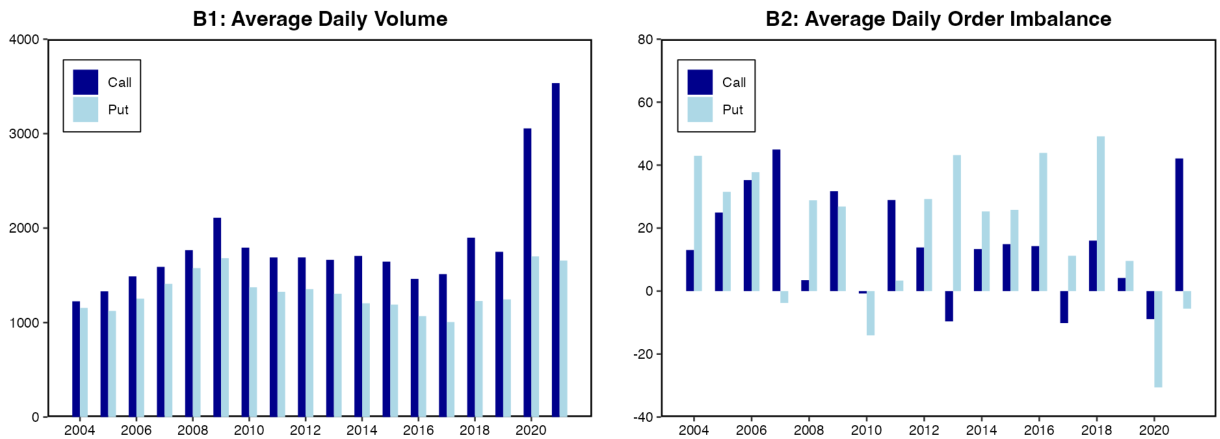
Figure 1: Daily Volumes and Order Imbalances

Panel A: SPX options

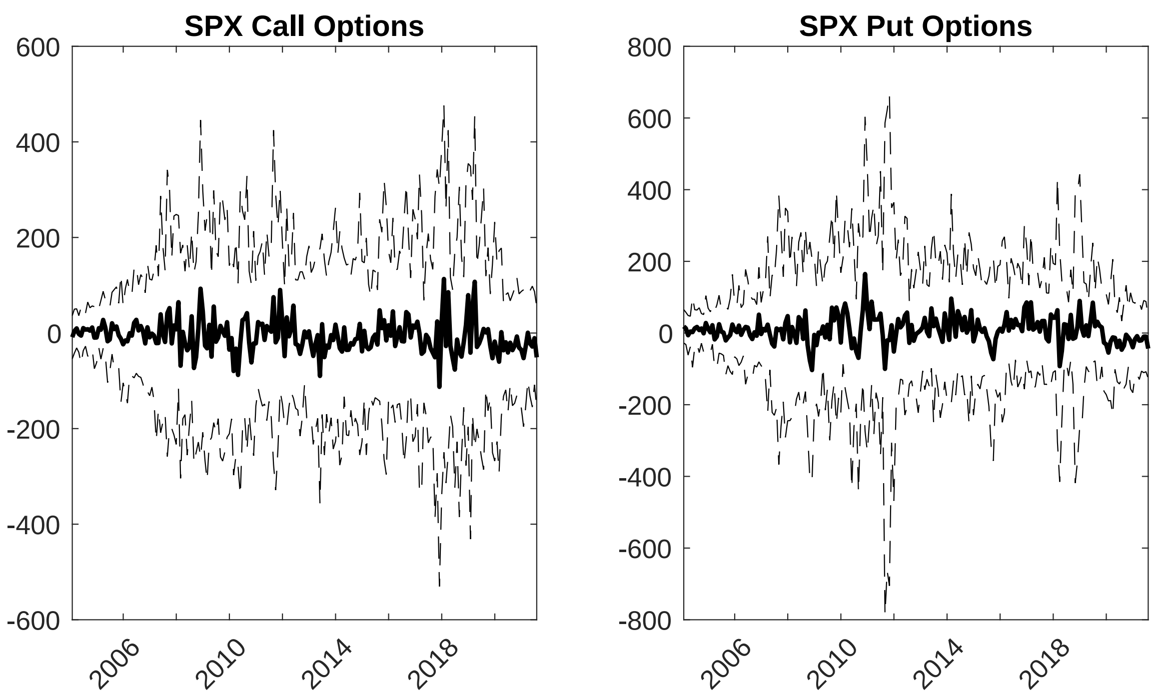


Panel B: Individual Stock Options



This figure displays the average daily volumes and order imbalance for at-the-money (ATM) options with maturities up to one month (48 days), across each year in our sample period. Daily volume is the total number of contracts traded, and daily order imbalance is the difference between buy and sell initiated trades. Panel A displays the average daily volumes (A1) and order imbalance (A2) for SPX call and put options. Panel B plots for call and put options written on the stocks which are part of the S&P500 index, where we compute average daily volume and order imbalance for each stock-year, and then we take the cross-sectional averages for each year.

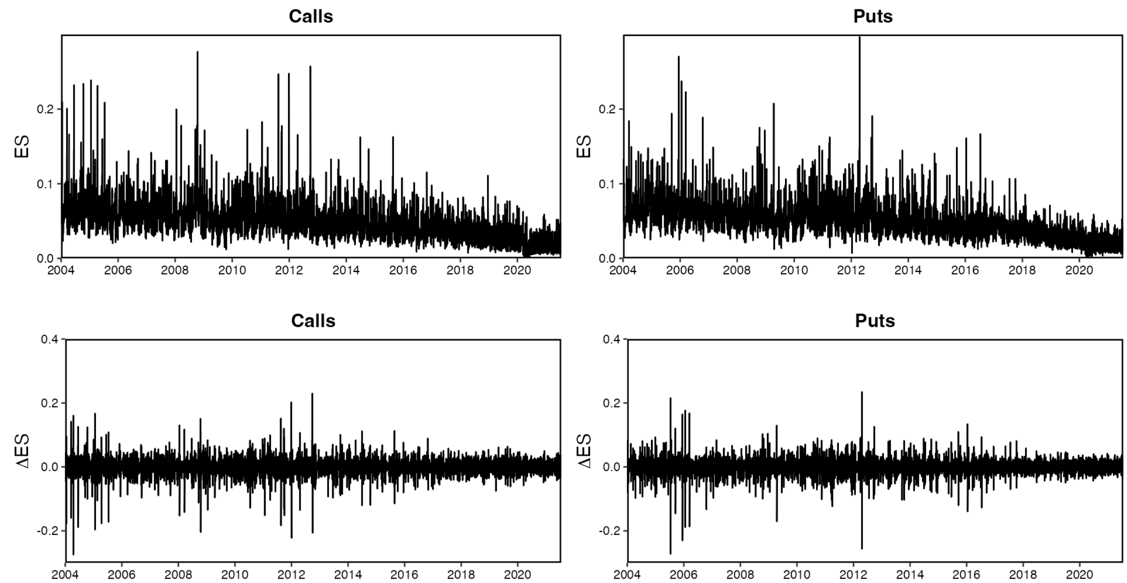
Figure 2: **Intraday Order Flow Distribution Over the Years**



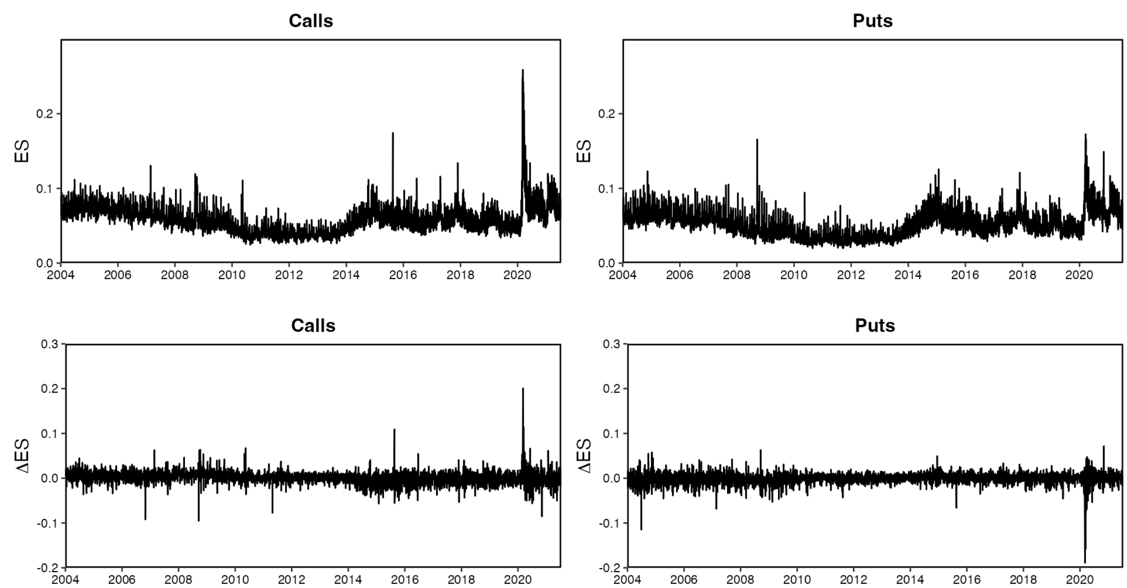
This figure displays the time-series of the average intraday 5-minute order flow for SPX ATM call and put options with confidence intervals. The graph is obtained by dividing each trading day into seventy-eight equal intervals, each covering five minutes, and calculating the order flow (buys minus sells) of put and call options within each interval. The solid lines display the daily average of these 5-minute order flows, μ_t, while the dotted lines depict the 95% confidence intervals, calculated as $\mu_t \pm \frac{Z\sigma_t}{\sqrt{n}}$, where σ_t is the intraday standard deviation of the seventy-eight order flows. For readability, the graph displays the monthly averages of these daily quantities.

Figure 3: Time-Series of ES_t and ΔES_t

Panel A: SPX Options



Panel B: Individual Stock Options



The figure presents the time-series of the daily effective spread and the daily changes in effective spread for ATM call and put options. Panel A presents the graph for SPX options while Panel B presents the graphs for individual stocks options, where a stock-day is included in our sample if the stock was part of the S&P 500 index in the preceding month.

Table 1: Intraday Order Flow Distribution Over the Years

Panel A: SPX Calls

	A1: Five-minute Order Flow Summary Statistics						A2: Difference in Distribution Between Low and High ΔES Days					
Year	**Mean**	**Std**	**Skewness**	**Q25**	**Q50**	**Q75**	**ΔMean**	**ΔStd**	**ΔSkew**	**ΔQ25**	**ΔQ50**	**ΔQ75**
2004	2.3	229.7	-0.2	-31.4	3.0	41.9	-20.03	-75.14	0.17	-1.56	-3.70**	-19.54**
2005	3.0	350.2	0.2	-48.6	-0.2	48.5	22.72	-147.68**	1.24	34.85***	2.10	-22.01
2006	1.2	510.3	-0.2	-68.3	2.0	82.3	0.55	-49.53***	0.17	33.18*	-2.77	-27.08
2007	5.0	917.1	-0.2	-129.8	3.2	148.6	-17.52	-400.03	-0.36	65.30	-6.31	-111.37*
2008	-3.4	969.6	-0.5	-128.0	3.1	153.9	-21.21	-290.95	-0.43	53.27	-4.38	-69.80
2009	-6.9	1047.3	-0.1	-113.1	1.3	111.8	-47.94	-217.78	-0.29	4.13	3.06	-16.14
2010	-21.3	971.2	-0.6	-119.9	1.6	125.0	-76.44	-149.49	-0.80	20.41	5.21	-63.75
2011	18.7	922.0	-0.2	-127.6	6.9	151.9	-10.13	-198.46	-0.62	47.00	7.71	-73.89
2012	-6.9	723.4	-0.2	-121.6	3.9	125.0	16.16	-139.37	0.52	18.35	-1.80	-13.82
2013	-24.0	875.9	-0.1	-152.2	-6.6	121.3	-61.56*	-329.71***	-1.43**	31.05	-8.69	-39.49
2014	-19.3	846.8	-0.2	-152.2	-4.9	135.0	-11.94	-200.53**	-0.74	77.78**	9.69	-59.50**
2015	-3.1	792.5	-0.3	-133.6	3.2	140.5	-8.54	-273.39**	-0.07	29.65	0.04	-63.61
2016	6.9	852.8	-0.1	-164.5	2.1	179.9	-68.78**	-94.13	-0.55	23.68	-7.52	-106.34**
2017	-22.2	1157.6	-0.3	-179.1	-4.4	160.3	106.68*	-419.93	1.46	108.29***	8.35	-49.64
2018	-1.6	1121.6	0.0	-196.3	-1.6	189.7	36.70	-716.95*	0.54	125.31***	2.38	-154.20***
2019	-2.1	1020.2	0.1	-161.0	-2.2	148.3	39.55	-501.96*	0.20	81.86***	-7.81	-95.55***
2020	-28.8	597.3	-0.4	-155.8	-12.9	124.1	111.31***	-214.14	0.84	152.23***	48.21***	29.88

Panel B: SPX Puts

	B1: Five-minute Order Flow Summary Statistics						B2: Difference in Distribution Between Low and High ΔES Days					
Year	**Mean**	**Std**	**Skewness**	**Q25**	**Q50**	**Q75**	**ΔMean**	**ΔStd**	**ΔSkew**	**ΔQ25**	**ΔQ50**	**ΔQ75**
2004	10.9	267.7	0.4	-34.2	3.4	50.5	-19.29	-90.45**	0.02	0.16	-1.08	-14.05
2005	0.8	385.8	-0.1	-54.1	2.4	62.7	10.43	-144.95**	-0.28	38.44**	3.94	-16.07
2006	6.7	486.3	0.1	-76.5	1.3	87.6	56.71**	-67.53	1.70**	57.95**	3.25	-14.99
2007	3.9	1011.2	0.0	-163.0	2.3	178.7	-43.73	-279.26*	-0.47	74.28*	-7.63	-106.35***
2008	-12.1	1071.0	-0.3	-186.4	-1.3	180.0	29.80	-406.20**	1.24*	144.97	10.06	-149.65**
2009	15.6	980.6	0.1	-90.8	4.9	111.0	-19.59	-298.88	-0.19	41.76	0.21	-61.96*
2010	28.8	1279.4	0.4	-111.4	9.4	143.7	60.99	-635.74*	1.02	58.80*	-15.13	-85.95*
2011	6.2	1764.7	-0.1	-143.4	10.4	183.5	19.82	-313.39	0.26	52.75	15.90	-71.73
2012	13.5	864.5	0.0	-122.6	3.8	140.2	-89.85**	59.02	-1.25	-4.61	-5.32	-49.92
2013	19.6	811.9	0.2	-118.5	7.2	145.2	-25.11	-305.34**	-1.29	9.17	1.62	-40.78
2014	25.5	858.4	0.3	-131.9	11.3	179.5	-36.73	-154.60	-0.81	70.44**	-11.87	-92.18**
2015	-8.6	803.4	-0.2	-154.0	4.5	161.2	-5.02	-405.08***	0.43	119.59***	-6.44	-143.34***
2016	32.7	756.7	-0.1	-145.8	14.2	214.9	-47.87	-185.71*	0.24	91.71***	-17.73**	-185.39***
2017	22.6	678.1	-0.1	-155.8	8.5	194.3	-19.72	-123.96	-0.59	68.61*	8.17	-83.64***
2018	9.7	1027.6	0.1	-197.5	7.9	232.5	9.52	-197.15	0.77	82.91	13.65	-96.30
2019	14.0	662.5	0.1	-158.1	2.6	171.0	-18.03	-199.89***	0.14	102.56***	-4.87	-121.63***
2020	-27.1	563.1	-0.1	-180.1	-22.9	129.0	30.80	-120.59	-0.94	134.09***	47.06***	-27.03

This table displays averages of intraday order flow distribution statistics for SPX ATM call (Panel A) and put options (Panel B). We divide each trading day into seventy-eight equal intervals, each covering five minutes, and we compute the order flow (buy minus sell orders) within each interval. Panels A1 and B1 display the daily mean, standard deviation (*Std*), skewness, first quartile (*Q25*), median (*Q50*), and third quartile (*Q75*) of the five-minute order flow distribution. Panels A2 and B2 display differences in these average statistics (mean, std, skewness, and quantiles) between high and low liquidity days, classified annually into low liquidity (top 10%) and high liquidity (bottom 10%) days based on ΔES values. Significance levels are denoted by *, **, and ***, representing the 10%, 5%, and 1% levels, respectively.

Table 2: Descriptive Statistics of ΔES, log(SD), Volume and Order Imbalance. SPX Options

Panel A: Calls

	ΔES								log(volume)							
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**	**0**	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
Mean	-0.16	-0.24	-0.10	-0.18	-0.19	-0.16	-0.10	-0.26	9.07	8.62	8.77	8.40	8.21	8.36	7.86	7.62
Std	798.58	996.08	275.24	206.24	167.58	173.54	153.62	162.16	1.14	1.59	1.03	1.25	1.38	1.58	1.92	1.98
Skewness	0.20	-0.33	-0.27	0.07	0.04	-0.28	-0.09	-0.07	-0.72	-1.18	-0.68	-0.33	-0.15	-0.15	-0.06	-0.13
Kurtosis	23.21	404.46	16.94	6.15	3.77	12.80	5.11	8.27	0.82	1.03	1.61	0.31	-0.35	-0.54	-1.08	-1.09
ρ	-0.46	-0.49	-0.44	-0.45	-0.40	-0.46	-0.43	-0.48	0.21	0.56	0.42	0.53	0.56	0.58	0.64	0.60
N	1038	2990	2899	2797	2735	2596	2362	2165	1038	2990	2899	2797	2735	2596	2362	2165

	log(SD)								|OI|							
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**	**0**	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
Mean	4.79	4.89	5.18	5.05	5.00	5.22	4.86	4.70	1.52	1.87	2.24	2.24	2.14	2.93	2.88	2.37
Std	0.85	1.21	0.98	1.14	1.20	1.29	1.63	1.71	2.01	2.95	3.64	3.82	3.80	5.18	5.37	4.35
Skewness	-0.42	-0.60	-0.17	-0.19	-0.18	-0.34	-0.22	-0.32	3.02	3.97	5.25	4.86	4.22	3.66	3.43	3.48
Kurtosis	0.51	0.47	0.38	-0.11	-0.32	-0.12	-0.72	-0.74	13.68	24.02	46.83	41.30	24.84	17.15	15.82	16.33
ρ	0.06	0.41	0.32	0.41	0.36	0.41	0.50	0.47	0.03	0.17	0.18	0.23	0.20	0.26	0.27	0.25
N	1038	2990	2899	2797	2735	2596	2362	2165	1038	2990	2899	2797	2735	2596	2362	2165

Panel B: Puts

	ΔES								log(volume)							
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**	**0**	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
Mean	-2.72	-0.19	-0.15	-0.18	-0.14	-0.17	-0.18	-0.12	9.23	8.69	8.78	8.41	8.18	8.27	7.88	7.69
Std	681.15	649.04	251.79	198.32	172.47	149.13	154.74	150.78	1.12	1.54	1.08	1.28	1.40	1.57	1.86	1.92
Skewness	-0.29	-0.35	-0.18	-0.05	-0.10	-0.11	0.00	-0.21	-0.82	-1.11	-0.64	-0.20	0.06	0.02	-0.04	-0.04
Kurtosis	7.43	12.52	4.97	12.59	8.74	4.46	18.85	5.26	1.03	1.00	1.62	0.17	-0.45	-0.57	-0.94	-0.98
ρ	-0.48	-0.47	-0.43	-0.46	-0.43	-0.44	-0.45	-0.44	0.32	0.56	0.41	0.55	0.61	0.66	0.67	0.63
N	1038	2960	2903	2791	2738	2618	2374	2216	1038	2960	2903	2791	2738	2618	2374	2216

	log(SD)								|OI|							
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**	**0**	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
Mean	4.88	4.94	5.19	5.06	4.97	5.11	4.82	4.67	1.78	1.91	2.22	2.20	2.20	2.77	2.47	2.43
Std	0.84	1.16	0.98	1.12	1.21	1.30	1.55	1.68	2.17	3.15	3.84	4.67	4.59	6.00	5.20	5.79
Skewness	-0.73	-0.60	-0.20	-0.12	-0.12	-0.15	-0.31	-0.19	2.34	5.77	5.95	7.60	5.90	5.88	5.35	6.21
Kurtosis	1.23	0.60	0.76	0.13	-0.27	-0.07	-0.58	-0.73	7.35	67.03	53.34	85.58	52.17	50.96	42.34	56.23
ρ	0.12	0.37	0.33	0.42	0.45	0.50	0.55	0.54	0.16	0.16	0.21	0.34	0.24	0.33	0.37	0.26
N	1038	2960	2903	2791	2738	2618	2374	2216	1038	2960	2903	2791	2738	2618	2374	2216

The table reports the time-series mean, standard deviation, skewness, excess kurtosis, AR(1) coefficient (ρ), and total number of observations (N) of daily difference in effective spread (ΔES), logarithm of daily volume ($log(volume)$), logarithm of volatility of order-flow ($log(SD)$), and absolute value of daily order flow ($|OI|$) across option maturity buckets. Panel A presents the results for SPX call options while Panel B presents the results for SPX put options. Absolute value of daily order-flow is divided by 1000 while ΔES is in basis points.

Table 3: Time-series Regressions of ΔES_t on log(SD_t) for SPX Options

Panel A: Calls

A1: Subsample Regressions

Days to Maturity	**0**	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD$_t$)	0.021***	0.018***	0.006***	0.004***	0.004***	0.005***	0.003***	0.002***
	(4.22)	(5.48)	(5.52)	(5.36)	(6.8)	(8.22)	(5.63)	(4.76)
log(volume$_t$)	0.001	-0.012***	0.002*	0.001	0.0002	-0.002***	-0.0003	0.0001
	(0.21)	(-3.21)	(1.87)	(0.73)	(0.46)	(-3.85)	(-0.91)	(0.25)
|OI$_t$|	-0.013	0.002	-0.00001	-0.0001	0.002*	0.001	0.002***	0.004***
	(-1.59)	(0.36)	(-0.01)	(-0.06)	(1.71)	(1.47)	(2.62)	(3.83)
R$_{M,t}$	-1.955***	0.046	0.006	0.001	0.006	-0.109	0.012	-0.0003
	(-4.13)	(0.24)	(0.05)	(0.02)	(0.14)	(-1.09)	(0.3)	(-0.01)
VIX$_t$	-0.077*	-0.053***	-0.045***	-0.02***	-0.018***	-0.02**	-0.008	-0.004
	(-1.96)	(-2.59)	(-4.03)	(-2.86)	(-3.01)	(-2.41)	(-0.99)	(-0.55)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1038	2990	2899	2797	2735	2596	2362	2165
Adj. R^2	0.48	0.43	0.395	0.342	0.31	0.383	0.338	0.364

A2: Pooled Regression with Maturity Dummies

log(SD$_t$)	0.028***
log(SD$_t$) D$_{1-6}$	-0.0202***
log(SD$_t$) D$_{7-13}$	-0.0194***
log(SD$_t$) D$_{14-20}$	-0.0221***
log(SD$_t$) D$_{21-27}$	-0.0228***
log(SD$_t$) D$_{28-34}$	-0.0233***
log(SD$_t$) D$_{35-41}$	-0.0242***
log(SD$_t$) D$_{42-48}$	-0.0243***
Maturity Dummies	Yes
Time Controls	Yes
Other Controls	Yes
N	19582
Adj. R^2	0.388

Panel B: Puts

B1: Subsample Regressions

Days to Maturity	**0**	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD$_t$)	0.024***	0.018***	0.007***	0.005***	0.003***	0.003***	0.003***	0.003***
	(5.65)	(6.27)	(6.11)	(6.07)	(5.45)	(5.18)	(5.42)	(5.85)
log(volume$_t$)	-0.011**	-0.01***	0.0004	0.001	0.001	0.0002	-0.0001	-0.0003
	(-2.56)	(-3.7)	(0.38)	(0.93)	(1.3)	(0.41)	(-0.22)	(-0.62)
|OI$_t$|	-0.005	0.009**	0.002	-0.0002	0.004**	-0.0005	0.000002	0.001
	(-0.48)	(2.56)	(1.39)	(-0.13)	(2.21)	(-0.6)	(0.003)	(0.58)
R$_{M,t}$	1.661***	-0.054	0.148	0.045	-0.044	0.04	0.157	0.023
	(4.13)	(-0.44)	(1.59)	(0.97)	(-0.88)	(0.45)	(1.5)	(0.62)
VIX$_t$	0.03	-0.024	-0.024**	-0.007	-0.005	-0.017*	0.005	0.01
	(0.96)	(-1.49)	(-2.56)	(-0.94)	(-0.73)	(-1.67)	(0.75)	(1.26)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1038	2960	2903	2791	2738	2618	2374	2216
Adj. R^2	0.47	0.461	0.345	0.348	0.341	0.352	0.316	0.313

B2: Pooled Regression with Maturity Dummies

log(SD$_t$)	0.022***
log(SD$_t$) D$_{1-6}$	-0.0116***
log(SD$_t$) D$_{7-13}$	-0.0138***
log(SD$_t$) D$_{14-20}$	-0.0157***
log(SD$_t$) D$_{21-27}$	-0.0162***
log(SD$_t$) D$_{28-34}$	-0.0178***
log(SD$_t$) D$_{35-41}$	-0.0177***
log(SD$_t$) D$_{42-48}$	-0.0179***
Maturity Dummies	Yes
Time Controls	Yes
Other Controls	Yes
N	19638
Adj. R^2	0.367

Panels A1 and B1 present the time series regressions of ΔES_t on *log(SD_t)* for SPX ATM call (A1) and put options (B1), performed separately for different maturity buckets. ΔES_t is the daily change in the effective spread on day t, *log(SD_t)* is the logarithm of the standard deviation of the intraday order flow distribution on day t, $log(volume_t)$ is the logarithm of the daily options volume, and $|OI_t|$ is the absolute value of the daily order imbalance divided by 10,000. $R_{M,t}$ is daily return on SPX on day t and VIX_t is the level of VIX divided by 100 on day t. Panels A2 and B2 present the results of pooled regressions of ΔES_t on *log(SD_t)* and the interaction of *log(SD_t)* with dummies that identify the different maturity buckets. Time controls include day-of-the-week, month-of-year, and year dummies. Other controls contain one-day and two-day lags of ΔES_t, absolute value of the average delta, vega and gamma of the options on day t. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table 4: Regressions of ΔES_t on Market Makers Delta-Hedging Variables

Panel A: Market Makers Gamma Inventory

	0			1-6			7-13			14-20			21-27			28-34			35-41			42-48		
Calls																								
$\log(\mathrm{SD})_t$		0.026***	0.02***		0.009***	0.015***		0.008***	0.006***		0.004***	0.004***		0.004***	0.004***		0.004***	0.006***		0.002***	0.003***		0.003***	0.002***
		(8.79)	(3.96)		(7.76)	(4.63)		(12.9)	(5.1)		(11.57)	(5.19)		(13.87)	(6.82)		(12.13)	(8.67)		(10.59)	(5.96)		(11.67)	(4.78)
$GammaInv_{t-1}$	0.189**	0.113	0.042	0.068***	-0.001	0.028	0.065***	0.005	0.006	0.044***	0.005	-0.01	0.048***	0.011	0.008	0.041***	-0.022*	0.016	0.044***	-0.018	0.012	0.019	-0.06***	-0.035**
	(2.3)	(1.5)	(0.82)	(2.8)	(-0.04)	(1.24)	(5.18)	(0.37)	(0.42)	(4.26)	(0.52)	(-0.93)	(4.84)	(1.17)	(0.7)	(3.96)	(-1.77)	(1.3)	(3.52)	(-1.27)	(0.84)	(1.54)	(-4.12)	(-2.31)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
N	1037	1037	1035	3153	3153	3151	2901	2901	2899	2799	2799	2797	2737	2737	2735	2598	2598	2596	2364	2364	2362	2167	2167	2165
Adj. R^2	-0.004	0.068	0.475	0.04	0.05	0.403	0.003	0.072	0.38	0.007	0.049	0.335	0.001	0.051	0.307	-0.004	0.048	0.379	-0.002	0.042	0.332	-0.011	0.036	0.361
Puts																								
$\log(\mathrm{SD})_t$		0.02***	0.024***		0.01***	0.016***		0.008***	0.007***		0.005***	0.005***		0.004***	0.003***		0.003***	0.003***		0.002***	0.003***		0.003***	0.003***
		(8.81)	(5.64)		(8.43)	(5.53)		(10.76)	(6.08)		(11.5)	(6.3)		(11.27)	(5.65)		(10.03)	(4.96)		(7.98)	(5.4)		(9.38)	(5.84)
$GammaInv_{t-1}$	0.072	-0.021	0.004	0.089***	-0.013	0.035	0.059***	-0.032**	0.015	0.04**	-0.026*	0.003	0.054***	-0.008	0.008	0.012	-0.041***	-0.015	0.021	-0.042**	0.005	0.034***	-0.05***	-0.002
	(1.15)	(-0.35)	(0.07)	(2.97)	(-0.47)	(1.13)	(3.43)	(-2.01)	(0.77)	(2.52)	(-1.71)	(0.18)	(4.68)	(-0.7)	(0.64)	(0.98)	(-3.14)	(-1.04)	(1.38)	(-2.38)	(0.28)	(2.61)	(-3.1)	(-0.12)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
N	1037	1037	1035	3136	3136	3134	2905	2905	2903	2793	2793	2791	2740	2740	2738	2620	2620	2618	2376	2376	2374	2218	2218	2216
Adj. R^2	0.002	0.056	0.469	0.101	0.132	0.422	0.004	0.076	0.34	0.013	0.06	0.345	0.005	0.055	0.339	-0.002	0.031	0.352	-0.009	0.023	0.315	-0.007	0.038	0.312

Panel B: Market Makers Inventory Change

	0			1-6			7-13			14-20			21-27			28-34			35-41			42-48		
Calls																								
$\log(\mathrm{SD})_t$		0.027***	0.021***		0.01***	0.016***		0.009***	0.006***		0.005***	0.004***		0.004***	0.004***		0.004***	0.006***		0.002***	0.003***		0.002***	0.002***
		(8.29)	(4.12)		(8.06)	(4.8)		(13.29)	(5.5)		(11.78)	(5.3)		(13.11)	(6.81)		(11.24)	(8.59)		(9.19)	(5.86)		(9.54)	(5.12)
$DeltaOI_t$	0.048***	-0.006	-0.002	-0.0001	-0.015***	-0.005	0.006***	-0.01***	-0.006***	0.006***	-0.004**	-0.002	0.006***	-0.002	-0.001	0.005***	-0.003**	-0.001	0.006***	0.001	0.001	0.007***	0.0001	-0.001
	(4.03)	(-0.56)	(-0.18)	(-0.01)	(-4.93)	(-1.62)	(3.55)	(-4.86)	(-3.76)	(3.91)	(-2.29)	(-1.34)	(4.74)	(-1.25)	(-0.94)	(4.4)	(-2.06)	(-0.74)	(5.94)	(0.57)	(0.6)	(5.09)	(0.24)	(-0.95)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
N	1037	1037	1035	3153	3153	3151	2901	2901	2899	2799	2799	2797	2737	2737	2735	2598	2598	2596	2364	2364	2362	2167	2167	2165
Adj. R^2	0.004	0.066	0.474	0.039	0.051	0.403	0	0.078	0.382	0.008	0.05	0.335	0.003	0.051	0.307	0.001	0.049	0.379	0.009	0.042	0.332	0.002	0.033	0.36
Puts																								
$\log(\mathrm{SD})_t$		0.021***	0.025***		0.011***	0.016***		0.007***	0.007***		0.005***	0.005***		0.004***	0.003***		0.002***	0.003***		0.002***	0.003***		0.002***	0.003***
		(8.08)	(5.77)		(8.29)	(5.53)		(9.62)	(5.97)		(11.76)	(6.25)		(10.8)	(5.57)		(9.04)	(5.2)		(7.61)	(5.33)		(7.99)	(5.87)
$DeltaOI_t$	0.028***	-0.007	-0.013*	0.01***	-0.007*	-0.003	0.009***	-0.001	0.001	0.006***	-0.003*	-0.001	0.007***	-0.002	0.0001	0.005***	0.0001	0.002	0.005***	-0.0001	0.001	0.007***	0.002	0.001
	(3.76)	(-0.94)	(-1.86)	(2.9)	(-1.92)	(-0.82)	(5.59)	(-0.29)	(0.38)	(3.1)	(-1.81)	(-0.62)	(4.47)	(-1.01)	(0.02)	(3.14)	(0.27)	(1.28)	(3.99)	(-0.23)	(0.49)	(4.04)	(0.96)	(0.45)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
N	1037	1037	1035	3136	3136	3134	2905	2905	2903	2793	2793	2791	2740	2740	2738	2620	2620	2618	2376	2376	2374	2218	2218	2216
Adj. R^2	0.009	0.056	0.470	0.100	0.132	0.422	0.010	0.075	0.34	0.016	0.061	0.345	0.010	0.056	0.339	0.005	0.028	0.353	-0.003	0.021	0.315	0.006	0.037	0.312

The table presents time-series regressions of ΔES_t on the market maker inventory variables $GammaInv_{t-1}$ (Panel A) and $DeltaOI_t$ (Panel B) for at-the-money SPX options. The regressions are performed separately for different maturity buckets. ΔES_t is the daily change in the effective spread, and $GammaInv_{t-1}$ is the gamma of the market-makers inventory at the end of $t-1$, calculated as the sum of market-makers inventory in each option series scaled by their gamma. $DeltaOI_t$ is the sum of the order flows absorbed by market makers in each option series on day t scaled by their delta. The other variables are analogous to those analyzed in the baseline regression in Table 3. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table 5: **Panel Regressions of $\Delta ES_{s,t}$ on log($SD_{s,t}$) for Individual Stock Options**

	Panel A: Calls		**Panel B: Puts**	
	0-24	**25-48**	**0-24**	**25-48**
log(SD)$_{s,t}$	0.008***	0.004***	0.007***	0.004***
	(46.58)	(48.97)	(39.04)	(41.77)
log(volume)$_{s,t}$	-0.005***	-0.004***	-0.004***	-0.003***
	(-29.22)	(-44.01)	(-21.55)	(-35.42)
$\|$OI$\|_{s,t}$	-0.003***	0.005***	-0.003***	0.003***
	(-4.75)	(7.78)	(-3.99)	(5.44)
Return$_{s,t}$	-0.209***	-0.056***	0.098***	0.038***
	(-38.34)	(-24.20)	(17.27)	(15.80)
IV$_{s,t}$	0.012***	-0.008***	0.014***	-0.006***
	(19.08)	(-18.48)	(22.17)	(-14.16)
Stock FE	Yes	Yes	Yes	Yes
Time Controls	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes
Adj. R^2	0.431	0.389	0.446	0.356

This table presents the results of panel regressions of $\Delta ES_{s,t}$ on *log($SD_{s,t}$)* for ATM call options (Panel A) and put options (Panel B) written on the stocks that are the constituents of the S&P500. The results are presented for two maturity buckets: 0-24 days to maturity and 25-48 days to maturity. $\Delta ES_{s,t}$ is the daily change in the effective spread on day t for options on stock s. *log($SD_{s,t}$)* is the logarithm of the standard deviation of the intraday order flow distribution on day t for options on stock s, $log(volume_{s,t})$ is the logarithm of the daily options volume, and $|OI_{s,t}|$ is the absolute value of the daily order imbalance (scaled by 10,000). $Return_{s,t}$ is the return of underlying stock on day t, and $IV_{s,t}$ is the average implied volatility of the options on stock s on day t. Other controls include firm size, stock volume, one-day and two-day lags of $\Delta ES_{s,t}$, and absolute values of the average delta, vega and gamma of the options on day t. Time controls include day-of-the-week, month-of-year, and year dummies. Standard errors are clustered at the day and stock level. The corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table 6: Intraday Change in Spread After a Trade

Regression of $\Delta Spread_{i,j,\tau}$

Panel A: Call Options

		Specification 1		Specification 2				Specification 3			
Ticker	**N obs**	α	$D_{i,j,\tau-1}$	α	$D_{i,j,\tau-1}$	$log(SD_{0,\tau})$	$log(SD_{0,\tau})\times D_{i,j,\tau-1}$	α	$D_{i,j,\tau-1}$	$log(SD_{i,0,\tau})$	$log(SD_{i,0,\tau})\times D_{i,j,\tau-1}$
AXP	3,326,546	-0.22***	1.15***	-0.63***	1.52*	0.15***	-0.13	-0.16*	1.09**	-0.01	0
BA	25,018,432	-0.14**	2.03**	-0.26***	2.12*	0.05***	-0.03	-0.04	2.08*	-0.06*	0.01
CAT	9,699,156	-0.15***	0.89***	-0.40***	1.80**	0.09***	-0.32.	-0.10**	0.84***	-0.01	0
DIS	16,290,675	-0.14***	1.77**	-0.41***	2.11*	0.10***	-0.12	-0.09***	1.78*	-0.02	0
DOW	2,035,970	-0.32***	1.38***	-0.65***	2.32**	0.11**	-0.28*	-0.30***	1.30***	0	0
HD	7,114,453	-0.18***	1.58**	-0.57***	2.97.	0.15***	-0.48	-0.15*	1.82*	-0.02	0
IBM	9,188,497	-0.13***	1.03***	-0.33***	1.21*	0.07**	-0.06	-0.07.	0.88***	-0.02*	0
INTC	15,281,754	-0.13***	0.85***	-0.42***	1.40**	0.08***	-0.14	-0.13***	0.87***	0	0
JNJ	4,250,672	-0.19***	1.57***	-0.65***	2.29*	0.17***	-0.25	-0.20**	1.83**	0.01	0
JPM	15,712,097	-0.10***	0.69***	-0.28***	1.31*	0.05***	-0.17	-0.05*	0.63***	-0.01.	0
KO	4,091,749	-0.22***	1.59***	-0.62***	2.31*	0.13***	-0.22	-0.23**	2.07**	0	0
MMM	1,972,024	-0.29***	1.58***	-0.77***	2.74*	0.21***	-0.43	-0.32*	1.93**	0.01	-0.01
MRK	2,991,683	-0.22***	1.86***	-0.66***	3.13*	0.14***	-0.37	-0.36.	2.40**	0.01	0
MSFT	41,399,546	-0.07***	1.12***	-0.32***	2.05*	0.08***	-0.27	-0.04.	1.19**	-0.01*	0
PG	3,051,203	-0.19***	1.14***	-0.63***	1.56.	0.15***	-0.14	-0.17.	1.16**	0.01	0
WMT	10,666,867	-0.15***	1.42*	-0.45***	2.24.	0.10***	-0.27	-0.08.	1.54*	-0.02	0

Panel B: Put Options

		Specification 1		Specification 2				Specification 3			
Ticker	**N obs**	α	$D_{i,j,\tau-1}$	α	$D_{i,j,\tau-1}$	$log(SD_{0,\tau})$	$log(SD_{0,\tau})\times D_{i,j,\tau-1}$	α	$D_{i,j,\tau-1}$	$log(SD_{i,0,\tau})$	$log(SD_{i,0,\tau})\times D_{i,j,\tau-1}$
AXP	2,420,146	-0.23***	1.14***	-0.60***	1.32*	0.14***	-0.07	-0.13*	0.88***	-0.02	0
BA	12,972,646	-0.15***	2.08*	-0.33***	2.49*	0.07***	-0.15	-0.13*	2.36*	-0.02.	0
CAT	7,212,261	-0.15***	0.85***	-0.36***	1.19**	0.07***	-0.11	-0.09***	0.71***	-0.01	0
DIS	7,507,297	-0.15***	1.80*	-0.52***	2.46.	0.14***	-0.23	-0.11	1.87.	-0.02	0
DOW	1,152,225	-0.38***	1.26***	-0.83***	1.86*	0.17**	-0.2	-0.08	0.85***	-0.06	0
HD	4,137,262	-0.18***	1.34**	-0.47***	2.12.	0.11***	-0.26	-0.16*	1.31*	0	0
IBM	7,006,937	-0.13***	1.01***	-0.36***	1.27*	0.08***	-0.09	-0.07.	0.80***	-0.02.	0
INTC	8,912,057	-0.14***	0.83***	-0.44***	1.09***	0.08***	-0.07	-0.12***	0.79***	0.01	0
JNJ	2,382,666	-0.18***	1.28***	-0.69***	1.27*	0.19***	0	-0.13	1.08*	0.01	0
JPM	9,725,906	-0.11***	0.65***	-0.25***	1.01*	0.04***	-0.11	-0.05*	0.54***	-0.01	0
KO	2,172,693	-0.24***	1.29***	-0.63***	1.95*	0.14***	-0.21	-0.27*	1.54*	0.02.	0
MMM	1,341,136	-0.31***	1.46***	-1.08***	2.17**	0.34***	-0.26	-0.19*	1.18***	-0.02	0
MRK	1,657,527	-0.21***	1.55***	-0.72***	2.07.	0.19***	-0.15	-0.25.	1.27***	0.01	0
MSFT	18,485,005	-0.07***	1.08***	-0.38***	1.82*	0.10***	-0.22	-0.07.	1.14**	0	0
PG	2,070,349	-0.20***	1.01***	-0.64***	1.10.	0.16***	-0.04	-0.08	0.68**	-0.01	0
WMT	5,080,495	-0.16***	1.06**	-0.53***	1.51.	0.13***	-0.15	-0.11	0.93*	0	0

The table presents the results of panel regressions of the changes in spread after each trade across exchanges. The dependent variable, $\Delta Spread_{i,j,\tau}$, measures the change in the quoted spread for option j in exchange i from trade $\tau-1$ to the next trade τ. The change in spread is regressed on the following variables and their interactions: a constant (coefficient α), a dummy variable $D_{i,j,\tau-1}$, which is equal to one if the trade of option j at time $\tau-1$ was executed on exchange i, and the variables $log(SD_{0,\tau})$ and $log(SD_{i,0,\tau})$ which measure the volatility of the order flow from the start of the day up to trade τ across all exchanges or only for exchange i, respectively. The regressions are computed separately for each ticker and for calls (Panel A) and put options (Panel B). All regressions include day fixed effect, and standard errors are clustered at the day and exchange level. Coefficients are multiplied by 100.

Table 7: Panel Regressions of Exchange-Specific $\Delta ES_{i,s,t}$ on log(SD)

	Daily regressions of $\boldsymbol{\Delta ES_{i,s,t}}$					
	Panel A: ATM Calls			**Panel B: ATM Puts**		
	(1)	(2)	(3)	(1)	(2)	(3)
log(SD$_{s,t}$)	0.0016***	0.0015***	0.0016***	0.0017***	0.0016***	0.0017***
	(10.05)	(8.88)	(9.75)	(9.37)	(7.91)	(9.72)
log(SD$_{s,i,t}$)	0.0002*	0.0002**	0.0002*	0.0003***	0.0002***	0.0002***
	(2.31)	(2.62)	(2.25)	(4.03)	(3.95)	(3.99)
log(Volume$_{i,s,t}$)	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002
	(1.06)	(1.23)	(1.2)	(1.13)	(0.87)	(0.96)
$\|$OI$\|_{s,t}$	-0.0011*	-0.0008	-0.0011*	-0.0018*	-0.0018*	-0.0018*
	(-2.23)	(-1.46)	(-2.22)	(-2.11)	(-2.40)	(-2.04)
Stock Return$_{s,t}$	-0.1476***	-0.0790*	-0.1476***	0.0288	0.0645*	0.0295
	(-3.66)	(-2.36)	(-3.66)	(1.21)	(2.43)	(1.22)
IV$_{s,t}$	0.0027	0.0003	0.0027	0.0044	0.0012	0.0047.
	(0.85)	(0.1)	(0.84)	(1.63)	(0.37)	(1.73)
Stock FE	Yes	Yes	Yes	Yes	Yes	Yes
Day FE	No	Yes	No	No	Yes	No
Exchange FE	No	No	Yes	No	No	Yes
Time Controls	Yes	No	Yes	Yes	No	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.06	0.12	0.06	0.04	0.09	0.04

This table presents the results of panel regressions of exchange-specific $\Delta ES_{i,s,t}$ for ATM call and put options with one-month to maturity written on the constituents of the Dow Jones analyzed in Table 6. $\Delta ES_{i,s,t}$ is the daily change in the effective spread on day t for options on stock s in exchange i, *log($SD_{s,t}$)* is the logarithm of the option order flow volatility on day t for stock s, and *log($SD_{s,i,t}$)* is the logarithm of the option order flow volatility using only trades recorded in exchange i. $log(Volume_{i,s,t})$ is the logarithm of the daily options volume for stock s in exchange i, $|OI_{s,t}|$ is the absolute value of the daily option order imbalance (scaled by 10,000), *Stock Return*$_{s,t}$ is the return of underlying stock on day t, and $IV_{s,t}$ is the average implied volatility of options on stock s on day t. Other controls include firm size, stock volume, and absolute value of the average delta, vega and gamma of the options on stock s on day t. Time controls include day-of-the-week, month-of-year, and year dummies. Standard errors are clustered at the day, stock and exchange level. The corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table 8: Robustness: Dollar Spread and Realized Option Volatility for SPX Options

Panel A: ΔDollar Spread$_t$ and log(SD)$_t$

SPX Calls

Maturity	**0**	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD)$_t$ ×1000	0.036***	0.043***	0.019***	0.018***	0.019***	0.033***	0.016***	0.010***
	(7.27)	(6.56)	(3.98)	(3.85)	(4.82)	(7.52)	(3.90)	(2.39)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1035	2990	2899	2797	2735	2596	2362	2165
Adj. R^2	0.544	0.405	0.333	0.265	0.245	0.336	0.266	0.304

SPX Puts

Maturity	**0**	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD)$_t$ ×1000	0.044***	0.063***	0.033***	0.030***	0.021***	0.028***	0.025***	0.033***
	(5.16)	(6.88)	(4.44)	(5.14)	(3.84)	(3.93)	(5.20)	(4.48)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1035	2960	2903	2791	2738	2618	2374	2216
Adj. R^2	0.506	0.462	0.346	0.361	0.292	0.313	0.294	0.313

Panel B: ΔES_t and ORV_t

SPX Calls

Maturity	**0**		**1-6**		**7-13**		**14-20**		**21-27**		**28-34**		**35-41**		**42-48**	
log(SD)$_t$		0.028***		0.020***		0.006***		0.004***		0.004***		0.005***		0.003***		0.002***
		(4.78)		(6.02)		(5.46)		(5.36)		(6.85)		(8.15)		(5.77)		(5.01)
ORV$_t$	0.009***	0.007***	0.053***	0.046***	0.019***	0.016***	0.011***	0.009***	0.007***	0.009***	0.010***	0.007**	0.01***	0.009***	0.016***	0.013***
	(8.33)	(4.58)	(7.84)	(5.64)	(3.13)	(3.02)	(5.24)	(3.97)	(3.56)	(4.26)	(3.1)	(2.12)	(4.11)	(2.82)	(4.56)	(3.44)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	1037	1035	3153	2990	2901	2899	2799	2797	2737	2735	2598	2596	2364	2362	2167	2165
Adj. R^2	0.054	0.501	0.114	0.464	0.009	0.401	0.010	0.345	-0.002	0.314	-0.002	0.384	0.001	0.340	-0.005	0.368

SPX Puts

Maturity	**0**		**1-6**		**7-13**		**14-20**		**21-27**		**28-34**		**35-41**		**42-48**	
log(SD)$_t$		0.027***		0.019***		0.007***		0.005***		0.003***		0.003***		0.003***		0.003***
		(5.31)		(6.75)		(6.30)		(6.24)		(5.50)		(5.17)		(5.59)		(6.09)
ORV$_t$	0.004***	0.002*	0.040***	0.032***	0.015***	0.017***	0.005***	0.008***	0.004**	0.007***	0.005***	0.007**	0.008***	0.010***	0.008***	0.007***
	(4.33)	(1.92)	(5.72)	(4.08)	(4.81)	(5.47)	(3.24)	(4.76)	(2.52)	(4.21)	(2.97)	(3.77)	(3.79)	(4.09)	(3.09)	(2.67)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	1037	1035	3136	2960	2905	2903	2793	2791	2740	2738	2620	2618	2376	2374	2218	2216
Adj. R^2	0.017	0.472	0.165	0.494	0.011	0.356	0.013	0.352	0.001	0.344	0.001	0.356	-0.007	0.319	-0.005	0.315

Panel A of the table presents time-series regressions of ΔDollar Spread$_t$ on the volatility of the order flow log(SD)$_t$ for SPX call and put options. ΔDollar Spread$_t$ is the daily change in the effective dollar spread. Panel B presents time-series regressions of ΔES_t on the realized option volatility ORV_t, which is calculated as the sum of squared 5-minute average option returns on day t. The other variables are analogous to those analyzed in the baseline regression in Table 3. Dollar Spread$_t$ is winsorized at 99.5% and 0.5% levels. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table 9: Robustness: Dollar Spread and Realized Option Volatility for Individual Stock Options

Panel A: ΔDollar Spread$_{s,t}$ and log(SD)$_{s,t}$

	Calls		Puts	
	0-24	**25-48**	**0-24**	**25-48**
log(SD)$_{s,t}$ × 1000	0.081***	0.076***	0.077***	0.076***
	(66.81)	(60.25)	(54.32)	(46.95)
Stock FE	Yes	Yes	Yes	Yes
Time Controls	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes
Adj. R^2	0.351	0.298	0.392	0.343

Panel B: $\Delta ES_{s,t}$ and $ORV_{s,t}$

	Calls				Puts			
	0-24		**25-48**		**0-24**		**25-48**	
log(SD)$_{s,t}$		0.009***		0.004***		0.009***		0.004***
		(49.78)		(50.26)		(46.99)		(42.91)
ORV$_{s,t}$	0.013***	0.012***	0.006***	0.005***	0.022***	0.022***	0.008***	0.007***
	(104.92)	(118.99)	(45.38)	(50.82)	(118.33)	(152.54)	(39.78)	(47.25)
Stock FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	No	Yes	No	Yes	No	Yes	No	Yes
Adj. R^2	0.026	0.444	0.003	0.391	0.037	0.471	0.004	0.360

Panel A of the table presents panel regressions of ΔDollar Spread$_{s,t}$ on the volatility of the order flow log(SD)$_{s,t}$ for individual stock options. ΔDollar Spread$_{s,t}$ is the daily change in the effective dollar spread for options on stock s. Panel B presents panel regressions of $\Delta ES_{s,t}$ on the realized option volatility $ORV_{s,t}$, which is calculated as the sum of squared 5-minute average option returns for stock s on day t. The other variables are analogous to those analyzed in the baseline regression in Table 5. Dollar Spread$_{s,t}$ is winsorized at 99.5% and 0.5% levels, and standard errors are clustered at the day and stock level.

Internet Appendix for "Risky Intraday Order Flow and Equity Option Liquidity"

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Table IA.1: Robustness: Effective Spread in Levels

	Panel A: Order Flow Distribution Difference Between Low and High ES Days											
	SPX Calls						SPX Puts					
Year	**ΔMean**	**ΔStd**	**ΔSkew**	**ΔQ25**	**ΔQ50**	**ΔQ75**	**ΔMean**	**ΔStd**	**ΔSkew**	**ΔQ25**	**ΔQ50**	**ΔQ75**
2004	0.07	-161.01***	1.26*	27.71***	-3.89***	-47.39***	-17.00	-212.60***	0.05	37.64***	-2.58	-58.54***
2005	5.26	-192.33***	1.47*	40.72***	-0.73*	-44.67***	-10.69	-176.65**	-0.72	48.77***	0.23	-47.26***
2006	-13.14	-194.95**	-1.18	64.62***	-8.48	-79.90***	20.75	-379.08***	0.69	136.96***	-0.21	-119.62***
2007	-11.60	-576.35***	-0.55	181.26***	-9.25	-209.77***	28.27	-626.54**	0.20	221.08***	0.00	-176.56***
2008	-4.78	-839.85***	0.33	193.27***	-11.25	-237.30***	31.17	-812.08***	0.19	240.27***	19.12	-193.55***
2009	-65.60	-688.48***	0.23	110.09***	-3.67	-140.46***	28.41	216.04	0.31	94.70***	-4.83	-104.77***
2010	-98.65*	-433.04**	-0.02	41.36	-8.29	-164.81***	-25.71	-882.59***	-0.43	134.30***	-24.06	-186.24***
2011	-46.19	-504.00***	0.72	131.10***	-19.40*	-232.99***	-18.90	621.62	-0.69	52.68	-13.58	-99.52
2012	-20.33	-319.20***	0.92	54.68**	-12.80*	-98.56**	-25.65	-48.27	0.43	63.59*	-4.46	-85.96**
2013	-1.15	-235.64	-1.07	111.62***	0.65	-85.40***	-13.85	-411.24***	-0.85	64.64**	-6.88	-106.55***
2014	-51.44	-331.51***	-0.99	111.41***	11.08	-119.74***	-64.61	-226.12	-0.80	67.27***	-12.63	-117.03***
2015	-42.43	-295.73**	-0.67	78.23***	-14.79***	-150.11***	-35.68	-277.74*	-0.74	113.06***	-8.81	-149.88***
2016	-83.11**	-213.61	-0.30	97.11***	-18.15*	-238.61***	-79.38***	-370.18***	-0.03	110.07***	-18.50***	-266.76***
2017	86.38**	-432.59**	1.33	142.88***	4.00	-110.86***	-39.82	-276.82***	-0.41	63.30*	-13.06	-130.88***
2018	-84.13*	-247.49	-1.02	170.82***	7.46	-212.99***	16.17	-606.49*	0.96	120.97**	-17.25	-218.55**
2019	10.19	-431.08	0.25	98.98***	-1.27	-74.80***	-20.84	-291.76***	-0.97	95.88***	-2.85	-105.40***
2020	92.75***	-407.61***	0.41	199.41***	64.9***	-48.01	70.45***	-290.05***	-0.87	171.84***	66.88***	0.11

	Panel B: ES Summary Statistics							
	SPX Calls							
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
Mean	0.09	0.06	0.04	0.03	0.02	0.02	0.02	0.02
Std	0.07	0.08	0.03	0.02	0.02	0.02	0.02	0.02
Skewness	3.18	14.96	1.89	1.57	1.32	1.64	1.48	1.74
Kurtosis	26.06	459.05	6.57	3.02	1.68	5.17	2.91	5.93
ρ	0.28	0.26	0.6	0.63	0.67	0.61	0.68	0.65
N	1040	2992	2901	2799	2737	2598	2364	2167
	SPX Puts							
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
Mean	0.09	0.06	0.04	0.03	0.02	0.02	0.02	0.02
Std	0.06	0.06	0.03	0.02	0.02	0.02	0.02	0.02
Skewness	1.97	2.67	1.47	1.58	1.48	1.38	1.49	1.44
Kurtosis	8.15	11.53	2.59	4.58	2.98	2.18	3.57	1.88
ρ	0.35	0.44	0.62	0.66	0.66	0.69	0.68	0.71
N	1040	2962	2905	2793	2740	2620	2376	2218

Panel A displays differences in mean, standard deviation, skewness, and quantiles of the intraday order flow distribution between high and low liquidity days, classified annually into low liquidity (top 10%) and high liquidity (bottom 10%) days based on values of the effective spread (ES). Significance levels are denoted by *, **, and ***, representing the 10%, 5%, and 1% levels, respectively. Panel B reports the time-series mean, standard deviation, skewness, excess kurtosis, AR(1) coefficient (ρ), and total number of observations (N) of the effective spread (ES). The results are presented separately for SPX call and put options.

Table IA.2: **Robustness: Regressions of ES_t on log(SD_t) for SPX Options**

Panel A: Calls

	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD_t)	0.02^{***}	0.02^{***}	0.007^{***}	0.003^{***}	0.003^{***}	0.004^{***}	0.001^{***}	0.001
	(4.11)	(7.3)	(7.01)	(3.81)	(5.47)	(6.71)	(3.08)	(1.34)
log($volume_t$)	0.001	-0.013^{***}	0.002^{**}	0.003^{***}	0.002^{***}	-0.0001	0.002^{***}	0.002^{***}
	(0.19)	(-4.89)	(2.29)	(4.95)	(4.13)	(-0.45)	(4.39)	(5.64)
$\|OI_t\|$	-0.016^{**}	0.002	0.001	0.001	0.002	0.001^{*}	0.002^{***}	0.004^{***}
	(-2.06)	(0.5)	(0.81)	(1.15)	(1.47)	(1.73)	(3.49)	(4.91)
$R_{M,t}$	-1.939^{***}	-0.007	-0.03	-0.012	-0.001	-0.084	0.022	-0.031
	(-3.77)	(-0.04)	(-0.3)	(-0.27)	(-0.05)	(-1.15)	(0.75)	(-0.95)
VIX_t	-0.028	0.039	-0.011	-0.005	-0.002	0.021^{**}	0.046^{***}	0.026^{**}
	(-0.92)	(1.63)	(-0.86)	(-0.69)	(-0.05)	(1.98)	(4.21)	(2.15)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1036	2991	2900	2798	2736	2597	2363	2166
Adj. R^2	0.484	0.304	0.64	0.664	0.681	0.629	0.703	0.675

Panel B: Puts

	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD_t)	0.023^{***}	0.019^{***}	0.008^{***}	0.004^{***}	0.003^{***}	0.002^{***}	0.002^{***}	0.002^{***}
	(6.2)	(7)	(7.94)	(5.19)	(4.34)	(3.87)	(3.64)	(4.29)
log($volume_t$)	-0.01^{**}	-0.012^{***}	0.001	0.003^{***}	0.003^{***}	0.002^{***}	0.002^{***}	0.001^{***}
	(-2.57)	(-4.69)	(0.41)	(3.91)	(4.65)	(4.97)	(3.91)	(3.52)
$\|OI_t\|$	-0.005	0.008^{**}	0.002	0.001	0.004^{**}	0.001	-0.001	0.001
	(-0.56)	(2.54)	(1.03)	(0.26)	(2.36)	(0.92)	(-0.24)	(1.55)
$R_{M,t}$	1.442^{***}	-0.07	0.083	0.015	-0.034	0.058	0.12	-0.029
	(3.67)	(-0.61)	(1.08)	(0.4)	(-1.03)	(0.77)	(1.32)	(-0.72)
VIX_t	-0.054	-0.015	-0.015	-0.01	0.014	0.015	0.032^{**}	0.017^{*}
	(-1.65)	(-0.74)	(-1.21)	(-1.48)	(1.44)	(1.49)	(2.53)	(1.8)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1036	2961	2904	2792	2739	2619	2375	2217
Adj. R^2	0.513	0.528	0.633	0.666	0.674	0.685	0.685	0.727

The table presents the time series regressions of ES_t on *log(SD_t)* for SPX ATM call (Panel A) and put options (Panel B), performed separately for different maturity buckets. ES_t is the daily effective spread on day t, *log(SD_t)* is the logarithm of the standard deviation of the intraday order flow distribution on day t, $log(volume_t)$ is the logarithm of the daily options volume, and $|OI_t|$ is the absolute value of the daily order imbalance divided by 10,000. $R_{M,t}$ is daily return on SPX on day t and VIX_t is the level of VIX divided by 100 on day t. Time controls include day-of-the-week, month-of-year, and year dummies. Other controls contain one-day and two-day lags of ES_t, absolute value of the average delta, vega and gamma of the options on day t. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.3: **Robustness: Panel Regressions of $ES_{s,t}$ on log($SD_{s,t}$) for Individual Stock Options**

	Panel A: Calls		Panel B: Puts	
	0-24	25-48	0-24	25-48
log($SD_{s,t}$)	0.015***	0.007***	0.014***	0.006***
	(70.8)	(63.59)	(41.89)	(46.75)
log($volume_{s,t}$)	-0.016***	-0.007***	-0.013***	-0.006***
	(-71.52)	(-71.67)	(-32.32)	(-41.98)
$\|OI_{s,t}\|$	-0.001	0.003***	0.00005	0.002***
	(-1.27)	(6.13)	(0.05)	(3.79)
$Return_{s,t}$	-0.153***	-0.016***	0.116***	0.028***
	(-17.46)	(-3.12)	(14.29)	(5.96)
$IV_{s,t}$	0.033***	0.01***	0.021***	-0.002***
	(63.57)	(26.21)	(38.8)	(-4.93)
Stock FE	Yes	Yes	Yes	Yes
Time Controls	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes
Adj. R^2	0.238	0.282	0.192	0.233

This table presents the results of panel regressions of $ES_{s,t}$ on *log($SD_{s,t}$)* for ATM call options (Panel A) and put options (Panel B) written on the stocks that are the constituents of the S&P500. The results are presented for two maturity buckets: 0-24 days to maturity and 25-48 days to maturity. $ES_{s,t}$ is the daily effective spread on day t for options on stock s. *log($SD_{s,t}$)* is the logarithm of the standard deviation of the intraday order flow distribution on day t for options on stock s, $log(volume_{s,t})$ is the logarithm of the daily options volume, and $|OI_{s,t}|$ is the absolute value of the daily option order imbalance (scaled by 10,000), where daily order imbalance is the difference between buy and sell initiated trades. $Return_{s,t}$ is the return of underlying stock on day t, and $IV_{s,t}$ is the average implied volatility of the options on stock s on day t. Other controls include firm size, stock volume, one-day and two-day lags of $ES_{s,t}$, and absolute values of the average delta, vega and gamma of the options on day t. Time controls include day-of-the-week, month-of-year, and year dummies. Standard errors are clustered at the day and stock level. The corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.4: **Fama-MacBeth Regressions of $\Delta ES_{s,t}$ on log($SD_{s,t}$) for Individual Stock Options**

	Panel A: Calls		Panel B: Puts	
	0-24	25-48	0-24	25-48
log(SD$_{s,t}$)	0.008***	0.004***	0.008***	0.004***
	(29.62)	(34.03)	(28.37)	(26.23)
log(volume$_{s,t}$)	-0.006***	-0.004***	-0.006***	-0.004***
	(-20.26)	(-29.91)	(-20.2)	(-24.43)
|OI$_{s,t}$|	0.005***	0.013***	0.003*	0.013***
	(3.88)	(5.87)	(1.69)	(3.89)
Return$_{s,t}$	-0.158***	-0.076***	0.215***	0.094***
	(-9.69)	(-10.46)	(12.19)	(10.65)
IV$_{s,t}$	-0.018***	-0.018***	-0.018***	-0.02***
	(-9.89)	(-16.46)	(-8.5)	(-15.28)
Other Controls	Yes	Yes	Yes	Yes
Adj. R^2	0.475	0.448	0.463	0.448

This table presents the results of Fama-MacBeth regressions of $\Delta ES_{s,t}$ on *log($SD_{s,t}$)* for ATM call options (Panel A) and put options (Panel B) written on the stocks that are the constituents of the S&P500. The results are presented for two maturity buckets: 0-24 days to maturity and 25-48 days to maturity. $\Delta ES_{s,t}$ is the daily change in the effective spread on day t for options on stock s. *log($SD_{s,t}$)* is the logarithm of the standard deviation of the intraday order flow distribution on day t for options on stock s, $log(volume_{s,t})$ is the logarithm of the daily options volume, and $|OI_{s,t}|$ is the absolute value of the daily option order imbalance (scaled by 10,000), where daily order imbalance is the difference between buy and sell initiated trades. $Return_{s,t}$ is the return of underlying stock on day t, and $IV_{s,t}$ is the average implied volatility of the options on stock s on day t. Other controls include firm size, stock volume, one-day and two-day lags of $\Delta ES_{s,t}$, and absolute values of the average delta, vega and gamma of the options on day t. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992). The corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.5: Additional: Regressions of ΔES_t on log(SD_t) for SPX Options

Panel A: SPX Call Options

Maturity	0			1-6			7-13			14-20			21-27			28-34			35-41			42-48		
log(SD_t)		0.026***	0.021***		0.008***	0.018***		0.007***	0.006***		0.004***	0.004***		0.003***	0.004***		0.003***	0.005***		0.001***	0.003***		0.001***	0.002***
		(7.72)	(4.22)		(5.53)	(5.48)		(11.32)	(5.52)		(10.53)	(5.36)		(9)	(6.8)		(8.37)	(8.22)		(6.31)	(5.63)		(6.05)	(4.76)
log($volume_t$)			0.001			-0.012***			0.002*			0.001			0.0002			-0.002***			-0.0003			0.0001
			(0.21)			(-3.21)			(1.87)			(0.73)			(0.46)			(-3.85)			(-0.91)			(0.25)
$\|OI_t\|$	0.056***	-0.008	-0.013	0.023***	0.005	0.002	0.012***	0	-0.00001	0.006***	-0.001	-0.0001	0.007***	0.002	0.002*	0.005***	0.001	0.001	0.005***	0.002**	0.002***	0.006***	0.003***	0.004***
	(5.52)	(-0.75)	(-1.59)	(5.15)	(1.01)	(0.36)	(6.26)	(-0.22)	(-0.01)	(6.13)	(-0.6)	(-0.06)	(8.21)	(1.6)	(1.71)	(9.22)	(0.77)	(1.47)	(7.02)	(2.19)	(2.62)	(7.59)	(3.17)	(3.83)
$R_{M,t}$			-1.955***			0.046			0.006			0.001			0.006			-0.109			0.012			-0.0003
			(-4.13)			(0.24)			(0.05)			(0.02)			(0.14)			(-1.09)			(0.3)			(-0.01)
VIX_t			-0.077*			-0.053***			-0.045***			-0.02***			-0.018***			-0.02**			-0.008			-0.004
			(-1.96)			(-2.59)			(-4.03)			(-2.86)			(-3.01)			(-2.41)			(-0.99)			(-0.55)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1040	1040	1038	3153	3153	2990	2901	2901	2899	2799	2799	2797	2737	2737	2735	2598	2598	2596	2364	2364	2362	2167	2167	2165
Adj. R^2	0.018	0.068	0.48	0.005	0.01	0.43	0.024	0.068	0.395	0.014	0.042	0.342	0.027	0.052	0.31	0.021	0.047	0.383	0.027	0.041	0.338	0.027	0.038	0.364

Panel B: SPX Put Options

Maturity	0			1-6			7-13			14-20			21-27			28-34			35-41			42-48		
log(SD_t)		0.019***	0.024***		0.007***	0.018***		0.006***	0.007***		0.004***	0.005***		0.003***	0.003***		0.002***	0.003***		0.002***	0.003***		0.002***	0.003***
		(7.29)	(5.65)		(5.05)	(6.27)		(7.28)	(6.11)		(9.85)	(6.07)		(6.35)	(5.45)		(8.21)	(5.18)		(7.1)	(5.42)		(6.8)	(5.85)
log($volume_t$)			-0.011**			-0.01***			0.0004			0.001			0.001			0.0002			-0.0001			-0.0003
			(-2.56)			(-3.7)			(0.38)			(0.93)			(1.3)			(0.41)			(-0.22)			(-0.62)
$\|OI_t\|$	0.044***	0.003	-0.005	0.026***	0.011**	0.009**	0.011***	0.001	0.002	0.004**	-0.001	-0.0002	0.007***	0.003*	0.004**	0.002**	-0.001	-0.0005	0.003***	0	0.000002	0.003***	0.001	0.001
	(5.98)	(0.38)	(-0.48)	(5.67)	(2.45)	(2.56)	(6.48)	(0.29)	(1.39)	(2.53)	(-1.02)	(-0.13)	(5.99)	(1.71)	(2.21)	(2.32)	(-1.43)	(-0.6)	(3.61)	(-0.11)	(0.003)	(3.68)	(0.51)	(0.58)
$R_{M,t}$			1.661***			-0.054			0.148			0.045			-0.044			0.04			0.157			0.023
			(4.13)			(-0.44)			(1.59)			(0.97)			(-0.88)			(0.45)			(1.5)			(0.62)
VIX_t			0.03			-0.024			-0.024**			-0.007			-0.005			-0.017*			0.005			0.01
			(0.96)			(-1.49)			(-2.56)			(-0.94)			(-0.73)			(-1.67)			(0.75)			(1.26)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1040	1040	1038	3136	3136	2960	2905	2905	2903	2793	2793	2791	2740	2740	2738	2620	2620	2618	2376	2376	2374	2218	2218	2216
Adj. R^2	0.018	0.051	0.47	0.017	0.029	0.461	0.025	0.064	0.345	0.008	0.043	0.348	0.031	0.051	0.341	0.003	0.023	0.352	0.007	0.025	0.316	0.013	0.036	0.313

The table presents the time series regressions of ΔES_t on *log(SD_t)* for SPX ATM call (Panel A) and put options (Panel B), performed separately for different maturity buckets. ΔES_t is the daily change in the effective spread on day t, *log(SD_t)* is the logarithm of the standard deviation of the intraday order flow distribution on day t, $log(volume_t)$ is the logarithm of the daily options volume, and $|OI_t|$ is the absolute value of the daily order imbalance divided by 10,000. $R_{M,t}$ is daily return on SPX on day t and VIX_t is the level of VIX divided by 100 on day t. Time controls include day-of-the-week, month-of-year, and year dummies. Other controls contain one-day and two-day lags of ΔES_t, absolute value of the average delta, vega and gamma of the options on day t. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.6: Robustness: Regressions of ΔES_t on log($SD/volume$)$_t$ for SPX Options

Panel A: Calls								
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD/volume)$_t$	0.022***	0.013**	0.006***	0.003***	0.003***	0.005***	0.002***	0.001**
	(4.83)	(2.51)	(5.32)	(3.97)	(4.98)	(7.39)	(3.95)	(2.31)
log(volume)$_t$	0.021***	0.006***	0.009***	0.005***	0.004***	0.004***	0.003***	0.003***
	(6.44)	(3.94)	(16.3)	(14.87)	(17.52)	(14.82)	(14.49)	(14.68)
|OI/volume| $_t$	-0.016	0.032	0.001	0.005**	0.004***	0.004**	0.003***	0.005***
	(-0.73)	(1.43)	(0.45)	(2.22)	(2.62)	(2.5)	(2.6)	(3.66)
$R_{M,t}$	-1.952***	0.044	0.006	0.003	0.004	-0.107	0.012	0.007
	(-4.14)	(0.23)	(0.05)	(0.06)	(0.11)	(-1.08)	(0.29)	(0.14)
VIX$_t$	-0.077**	-0.052**	-0.045***	-0.02***	-0.018***	-0.018**	-0.008	-0.004
	(-1.99)	(-2.48)	(-4.05)	(-2.84)	(-2.94)	(-2.28)	(-1.03)	(-0.5)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1038	2990	2899	2797	2735	2596	2362	2165
Adj. R^2	0.48	0.432	0.395	0.344	0.311	0.384	0.337	0.363

Panel B: Puts								
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD/volume)$_t$	0.021***	0.015***	0.007***	0.004***	0.003***	0.002***	0.002***	0.003***
	(5.09)	(5.98)	(5.51)	(4.24)	(4.73)	(3.04)	(4.19)	(4.21)
log(volume)$_t$	0.012***	0.009***	0.008***	0.006***	0.005***	0.003***	0.003***	0.003***
	(5.42)	(7.52)	(13.4)	(13.79)	(14.88)	(12.07)	(12.47)	(13.57)
|OI/volume| $_t$	0.02	0.021***	0.004	0.006***	0.003*	0.004***	0.002*	0.003*
	(0.99)	(2.73)	(1.27)	(2.68)	(1.87)	(2.9)	(1.96)	(1.82)
$R_{M,t}$	1.652***	-0.046	0.155	0.045	-0.04	0.036	0.155	0.024
	(4.1)	(-0.38)	(1.64)	(0.95)	(-0.82)	(0.41)	(1.48)	(0.65)
VIX$_t$	0.031	-0.021	-0.023**	-0.006	-0.005	-0.017*	0.005	0.01
	(0.96)	(-1.3)	(-2.44)	(-0.89)	(-0.67)	(-1.72)	(0.69)	(1.25)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1038	2960	2903	2791	2738	2618	2374	2216
Adj. R^2	0.47	0.462	0.345	0.351	0.336	0.354	0.317	0.314

This table presents the time series regressions of ΔES_t on *log($SD/volume$)$_t$* for SPX ATM call and put options for different maturity buckets. ΔES_t is the daily change in the effective spread on day t. *log($SD/volume$)$_t$* is the logarithm of the standard deviation of the intraday order flow distribution scaled by daily volume on day t, $log(volume)_t$ is the logarithm of the daily options volume, and $|OI/volume|_t$ is the absolute value of the daily order imbalance scaled by daily volume where daily order imbalance is the difference between buy and sell initiated trades. $R_{M,t}$ is daily return on SPX on day t. VIX_t is the level of VIX divided by 100 on day t. Time controls include day-of-the-week, month-of-year, and year dummies. Other controls contain one-day and two-day lags of ΔES_t, absolute value of the average delta, vega and gamma of the options on day t. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.7: Robustness: Panel Regressions of $\Delta ES_{s,t}$ on log$(SD/volume)_{s,t}$ for Individual Stock Options

	Panel A: Calls				Panel B: Puts			
	0-24		25-48		0-24		25-48	
log(SD/volume)$_{s,t}$	0.006***	0.008***	0.004***	0.004***	0.005***	0.007***	0.003***	0.004***
	(35.46)	(46.58)	(47.92)	(48.97)	(29.33)	(39.04)	(40.3)	(41.77)
log(volume)$_{s,t}$		0.004***		0.001***		0.004***		0.001***
		(33.72)		(11.92)		(30.6)		(11.04)
|OI/volume| $_{s,t}$	0.006***	-0.003***	0.004***	0.003***	0.008***	-0.003***	0.003***	0.002***
	(9.44)	(-4.75)	(14.58)	(7.78)	(10.68)	(-3.99)	(11.24)	(5.44)
Stock Return$_{s,t}$	-0.207***	-0.209***	-0.055***	-0.056***	0.097***	0.098***	0.037***	0.038***
	(-37.97)	(-38.34)	(-23.83)	(-24.2)	(17.06)	(17.27)	(15.65)	(15.8)
IV$_{s,t}$	0.013***	0.012***	-0.008***	-0.008***	0.015***	0.014***	-0.006***	-0.006***
	(20.67)	(19.08)	(-18.59)	(-18.48)	(24.12)	(22.17)	(-14.27)	(-14.16)
Stock FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.43	0.431	0.389	0.389	0.445	0.446	0.356	0.356

This table presents the results of panel regressions of $\Delta ES_{s,t}$ on *log(SD/volume)*$_{s,t}$ for ATM call options (Panel A) and put options (Panel B) written on the stocks that are the constituents of the S&P500. The results are presented for two maturity buckets: 0-24 days to maturity and 25-48 days to maturity. $\Delta ES_{s,t}$ is the daily change in the effective spread on day t for options on stock s. *log(SD/volume)*$_{s,t}$ is the logarithm of the standard deviation of the intraday order flow distribution scaled by daily volume on day t for options on stock s, $log(volume)_{s,t}$ is the logarithm of the daily options volume, and $|OI/volume|_{s,t}$ is the absolute value of the daily option order imbalance scaled by daily volume, where daily order imbalance is the difference between buy and sell initiated trades. *Return*$_{s,t}$ is the return of underlying stock on day t, and $IV_{s,t}$ is the average implied volatility of the options on stock s on day t. Other controls include firm size, stock volume, one-day and two-day lags of $\Delta ES_{s,t}$, and absolute values of the average delta, vega and gamma of the options on day t. Time controls include day-of-the-week, month-of-year, and year dummies. Standard errors are clustered at the day and stock level. The corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.8: Robustness: SPX OTM Options

Panel A: Calls								
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD$_t$)	0.032***	0.034***	0.013***	0.012***	0.007***	0.009***	0.009***	0.007***
	(4.29)	(7.39)	(6.34)	(7.18)	(5.88)	(8.49)	(8.94)	(7.4)
log(volume$_t$)	-0.05***	-0.031***	-0.001	-0.004**	-0.001	-0.002***	-0.003***	-0.002**
	(-8.65)	(-6)	(-0.64)	(-2.05)	(-0.88)	(-2.6)	(-3.58)	(-2.3)
|OI$_t$ |	0.054***	0.002	-0.002	0.001	0.004***	0.001	0.001	0.003**
	(5.8)	(0.38)	(-1.18)	(0.38)	(4.14)	(0.34)	(0.93)	(2.15)
R$_{M,t}$	-2.396***	-0.112	-0.095	-0.106	0.009	0.011	-0.063	-0.09
	(-7.48)	(-0.5)	(-0.68)	(-0.94)	(0.12)	(0.13)	(-0.93)	(-0.85)
VIX$_t$	-0.111	-0.104***	-0.039***	-0.034**	0.007	-0.006	-0.007	0.008
	(-1.4)	(-4.12)	(-2.64)	(-2.42)	(0.53)	(-0.7)	(-0.46)	(0.56)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1010	3102	2925	2825	2778	2698	2464	2362
Adj. R^2	0.514	0.464	0.354	0.376	0.372	0.39	0.36	0.372
Panel B: Puts								
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD$_t$)	0.057***	0.024***	0.016***	0.009***	0.007***	0.008***	0.007***	0.007***
	(7.41)	(5.1)	(4.59)	(6.2)	(6.85)	(7.9)	(9.06)	(9.2)
log(volume$_t$)	-0.062***	-0.018***	-0.005	-0.003*	-0.002**	-0.002**	-0.004***	-0.003***
	(-12.85)	(-5.03)	(-1.3)	(-1.83)	(-2.04)	(-2.09)	(-5.01)	(-4.06)
|OI$_t$|	0.012	0.003	0.001	0.002	0.001	-0.001	0.003***	0.001
	(1.46)	(0.81)	(0.78)	(1.62)	(1.6)	(-0.19)	(2.64)	(1.38)
R$_{M,t}$	1.333***	0.214	0.277*	0.027	0.003	0.001	0.115	-0.12*
	(5.69)	(0.84)	(1.73)	(0.5)	(0.05)	(0.02)	(1.62)	(-1.96)
VIX$_t$	0.009	-0.011	-0.001	-0.015*	0.005	0.001	0.01	0.018
	(0.21)	(-0.52)	(-0.03)	(-1.75)	(0.54)	(0.03)	(1.1)	(1.64)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1019	3220	2934	2830	2791	2729	2509	2416
Adj. R^2	0.562	0.436	0.349	0.289	0.354	0.33	0.372	0.382

This table presents the time series regressions of ΔES_t on *log(SD$_t$)* for SPX out-of-the-money (OTM) call (Panel A) and put options (Panel B) performed separately for different maturity buckets. ΔES_t is the daily change in the effective spread on day t, *log(SD$_t$)* is the logarithm of the standard deviation of the intraday order flow distribution on day t, $log(volume_t)$ is the logarithm of the daily options volume, and $|OI_t|$ is the absolute value of the daily order imbalance divided by 10,000. $R_{M,t}$ is daily return on SPX on day t and VIX_t is the level of VIX divided by 100 on day t. Time controls include day-of-the-week, month-of-year, and year dummies. Other controls contain one-day and two-day lags of ΔES_t, absolute value of the average delta, vega and gamma of the options on day t. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.9: **Robustness: Individual Stock OTM Options**

	Panel A: Calls		**Panel B: Puts**	
	0-24	25-48	0-24	25-48
$\log(\text{SD}_{s,t})$	0.015^{***}	0.009^{***}	0.012^{***}	0.007^{***}
	(51.37)	(48.17)	(45.59)	(43.15)
$\log(\text{volume}_{s,t})$	-0.012^{***}	-0.007^{***}	-0.009^{***}	-0.006^{***}
	(-43.98)	(-41.57)	(-36.81)	(-36.07)
$\lvert\text{OI}_{s,t}\rvert$	0.002^{**}	0.005^{***}	0.001	0.005^{***}
	(2.13)	(7.48)	(0.48)	(8.75)
$\text{Return}_{s,t}$	-0.393^{***}	-0.108^{***}	0.155^{***}	0.026^{***}
	(-47.2)	(-21.66)	(18.79)	(5.48)
$\text{IV}_{s,t}$	0.024^{***}	-0.008^{***}	0.032^{***}	-0.002^{***}
	(21.28)	(-7.56)	(36.35)	(-2.6)
Stock FE	Yes	Yes	Yes	Yes
Time Controls	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes
Adj. R^2	0.484	0.428	0.473	0.391

This table presents the results of panel regressions of $\Delta ES_{s,t}$ on *log(*$SD_{s,t}$*)* for out-of-the-money (OTM) call options (Panel A) and put options (Panel B) written on the stocks that are the constituents of the S&P500. The results are presented for two maturity buckets: 0-24 days to maturity and 25-48 days to maturity. $\Delta ES_{s,t}$ is the daily change in the effective spread on day t for options on stock s. *log(*$SD_{s,t}$*)* is the logarithm of the standard deviation of the intraday order flow distribution on day t for options on stock s, $log(volume_{s,t})$ is the logarithm of the daily options volume, and $|OI_{s,t}|$ is the absolute value of the daily option order imbalance (scaled by 10,000). $Return_{s,t}$ is the return of underlying stock on day t, and $IV_{s,t}$ is the average implied volatility of the options on stock s on day t. Other controls include firm size, stock volume, one-day and two-day lags of $\Delta ES_{s,t}$, and absolute values of the average delta, vega and gamma of the options on day t. Time controls include day-of-the-week, month-of-year, and year dummies. Standard errors are clustered at the day and stock level. The corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.10: Robustness: Regressions of ΔES_t on log(SD_t) for SPX Options, without Time Controls

Panel A: Calls								
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD$_t$)	0.021***	0.016***	0.006***	0.004***	0.003***	0.005***	0.002***	0.002***
	(4.26)	(5.43)	(5.58)	(4.19)	(5.98)	(7.8)	(4.89)	(3.78)
log(volume$_t$)	0.001	-0.011***	0.002*	0.002**	0.001**	-0.001***	0.001	0.001
	(0.14)	(-2.6)	(1.88)	(2.17)	(1.99)	(-2.91)	(0.09)	(1.6)
|OI$_t$ |	-0.013*	0.004	-0.001	0.001	0.002*	0.001	0.002***	0.004***
	(-1.68)	(0.61)	(-0.03)	(0.03)	(1.91)	(1.34)	(2.64)	(3.92)
$R_{M,t}$	-1.903***	0.099	0.012	0.011	0.017	-0.128	0.007	0.027
	(-4.03)	(0.55)	(0.12)	(0.2)	(0.45)	(-1.25)	(0.15)	(0.67)
VIX$_t$	-0.049	-0.062***	-0.042***	-0.017**	-0.017***	-0.016**	-0.01	-0.01
	(-1.24)	(-3.25)	(-3.95)	(-2.41)	(-2.76)	(-1.99)	(-1.25)	(-1.15)
Day-of-Week Dummies	No	No	No	No	No	No	No	No
Month-of-Year Dummies	No	No	No	No	No	No	No	No
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1038	2990	2899	2797	2735	2596	2362	2165
Adj. R^2	0.47	0.403	0.377	0.343	0.314	0.361	0.322	0.355
Panel B: Puts								
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD$_t$)	0.024***	0.015***	0.007***	0.005***	0.003***	0.003***	0.002***	0.003***
	(5.27)	(5.27)	(5.68)	(5.81)	(4.12)	(5)	(4.31)	(5.51)
log(volume$_t$)	-0.011**	-0.008***	0.001	0.001**	0.002***	0.001	0.001	0.001
	(-2.57)	(-2.71)	(0.54)	(2.13)	(2.85)	(1.31)	(1.03)	(0.41)
|OI$_t$|	-0.004	0.007**	0.003*	-0.001	0.004**	-0.001	-0.001	0.001
	(-0.43)	(2.06)	(1.75)	(-0.16)	(2.42)	(-0.64)	(-0.16)	(0.79)
$R_{M,t}$	1.694***	-0.052	0.146*	0.056	-0.043	0.025	0.153	0.034
	(4.14)	(-0.4)	(1.71)	(1.2)	(-0.89)	(0.28)	(1.44)	(0.8)
VIX$_t$	0.066**	-0.02	-0.022**	-0.009	-0.003	-0.016**	-0.003	0.002
	(2.4)	(-1.28)	(-2.27)	(-1.3)	(-0.38)	(-2.07)	(-0.38)	(0.31)
Day-of-Week Dummies	No	No	No	No	No	No	No	No
Month-of-Year Dummies	No	No	No	No	No	No	No	No
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1038	2960	2903	2791	2738	2618	2374	2216
Adj. R^2	0.431	0.452	0.327	0.339	0.33	0.298	0.314	0.324

This table presents the time series regressions of ΔES_t on *log(SD_t)* for SPX ATM call and put options for different maturity buckets. ΔES_t is the daily change in the effective spread on day t. *log(SD_t)* is the logarithm of the standard deviation of the intraday order flow distribution on day t, $log(volume_t)$ is the logarithm of the daily options volume, and $|OI_t|$ is the absolute value of the daily order imbalance divided by 10,000 where daily order imbalance is the difference between buy and sell initiated trades. $R_{M,t}$ is daily return on SPX on day t. VIX_t is the level of VIX divided by 100 on day t. Other controls contain one-day and two-day lags of ΔES_t, absolute value of the average delta, vega and gamma of the options on day t. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.11: Robustness: Panel Regressions of $\Delta ES_{s,t}$ on log($SD_{s,t}$) for Individual Stock Options, without Time Controls

	Panel A: Calls		Panel B: Puts	
	0-24	25-48	0-24	25-48
log(SD$_{s,t}$)	0.008***	0.004***	0.007***	0.004***
	(45.69)	(49.95)	(37.6)	(41.86)
log(volume$_{s,t}$)	-0.005***	-0.004***	-0.003***	-0.003***
	(-27.49)	(-44.97)	(-18.97)	(-35.61)
|OI$_{s,t}$|	-0.003***	0.003***	-0.004***	0.002***
	(-4.61)	(7.66)	(-4.36)	(5.57)
Return$_{s,t}$	-0.215***	-0.057***	0.096***	0.038***
	(-39.15)	(-24.4)	(16.84)	(15.82)
IV$_{s,t}$	0.007***	-0.009***	0.009***	-0.007***
	(11.63)	(-19.02)	(14.84)	(-15.03)
Day-of-Week Dummies	No	No	No	No
Month-of-Year Dummies	No	No	No	No
Year Dummies	Yes	Yes	Yes	Yes
Stock FE	Yes	Yes	Yes	Yes
Adj. R^2	0.423	0.388	0.437	0.356

This table presents the results of panel regressions of $\Delta ES_{s,t}$ on *log($SD_{s,t}$)* for ATM call options (Panel A) and put options (Panel B) written on the stocks that are the constituents of the S&P500. The results are presented for two maturity buckets: 0-24 days to maturity and 25-48 days to maturity. $\Delta ES_{s,t}$ is the daily change in the effective spread on day t for options on stock s. *log($SD_{s,t}$)* is the logarithm of the standard deviation of the intraday order flow distribution on day t for options on stock s, $log(volume_{s,t})$ is the logarithm of the daily options volume, and $|OI_{s,t}|$ is the absolute value of the daily option order imbalance (scaled by 10,000), where daily order imbalance is the difference between buy and sell initiated trades. *Return$_{s,t}$* is the return of underlying stock s on day t. $IV_{s,t}$ is the average implied volatility of options series on stock s on day t. Other controls contain one-day and two-day lags of $\Delta ES_{s,t}$, natural logarithm of size (price of stock s multiplied by its number of outstanding shares) and number of shares traded for stock s on day t, absolute value of the average delta, vega and gamma of the options on day t. Standard errors are clustered at the day and stock level. The corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.12: Robustness: Regressions of ΔES_t on log(SD_t) for SPX Options, without SLAN Trades

Panel A: Calls

	0	1-6	7-13	14-20	21-27	28-34	35-41	42-48
log(SD_t)	0.021***	0.015***	0.006***	0.004***	0.003***	0.005***	0.003***	0.002***
	(4.25)	(5.08)	(5.41)	(5.39)	(6.19)	(7.73)	(6.06)	(4.65)
log($volume_t$)	0.001	-0.006	0.002*	0.001	0.001	-0.001***	-0.0001	0.0001
	(0.29)	(-1.62)	(1.66)	(0.92)	(1.61)	(-2.82)	(-0.55)	(0.92)
$\lvert OI_t \rvert$	-0.014*	0.002	0.001	0.001	0.002*	0.0001	0.001**	0.003***
	(-1.71)	(0.29)	(0.5)	(0.88)	(1.65)	(0.47)	(2.08)	(3.43)
$R_{M,t}$	-1.916***	-0.052	-0.008	-0.009	-0.017	-0.125	-0.007	0.016
	(-4.01)	(-0.31)	(-0.07)	(-0.16)	(-0.44)	(-1.16)	(-0.13)	(0.39)
VIX_t	-0.075*	-0.07***	-0.043***	-0.017**	-0.013**	-0.016*	-0.012	-0.006
	(-1.91)	(-4.65)	(-4.03)	(-2.51)	(-2.14)	(-1.92)	(-1.56)	(-0.71)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1038	2748	2686	2591	2524	2382	2144	1959
Adj. R^2	0.473	0.49	0.383	0.354	0.321	0.369	0.331	0.358

Panel B: Puts

	0	1-6	7-13	14-20	21-27	28-34	35-41	42-48
log(SD_t)	0.023***	0.016***	0.007***	0.005***	0.003***	0.003***	0.003***	0.003***
	(5.44)	(5.41)	(5.7)	(6.5)	(4.7)	(4.97)	(4.63)	(5.92)
log($volume_t$)	-0.011**	-0.006**	0.0001	0.001	0.001**	0.0001	0.0001	0.0001
	(-2.53)	(-2.11)	(0.24)	(1.12)	(2.08)	(1.05)	(0.59)	(-0.19)
$\lvert OI_t \rvert$	-0.005	0.007**	0.003*	-0.0001	0.004**	-0.001	-0.0001	0.001
	(-0.52)	(2.15)	(1.75)	(-0.29)	(2.21)	(-0.7)	(-0.16)	(0.68)
$R_{M,t}$	1.667***	0.084	0.163*	0.063	-0.057	0.044	0.168	0.04
	(4.18)	(0.64)	(1.79)	(1.36)	(-1.21)	(0.48)	(1.56)	(0.89)
VIX_t	0.03	-0.038***	-0.023**	-0.007	-0.003	-0.011	0.0001	0.002
	(0.97)	(-2.96)	(-2.54)	(-0.99)	(-0.39)	(-1.29)	(0.06)	(0.28)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1038	2731	2688	2584	2527	2404	2157	2008
Adj. R^2	0.451	0.46	0.321	0.332	0.331	0.295	0.317	0.353

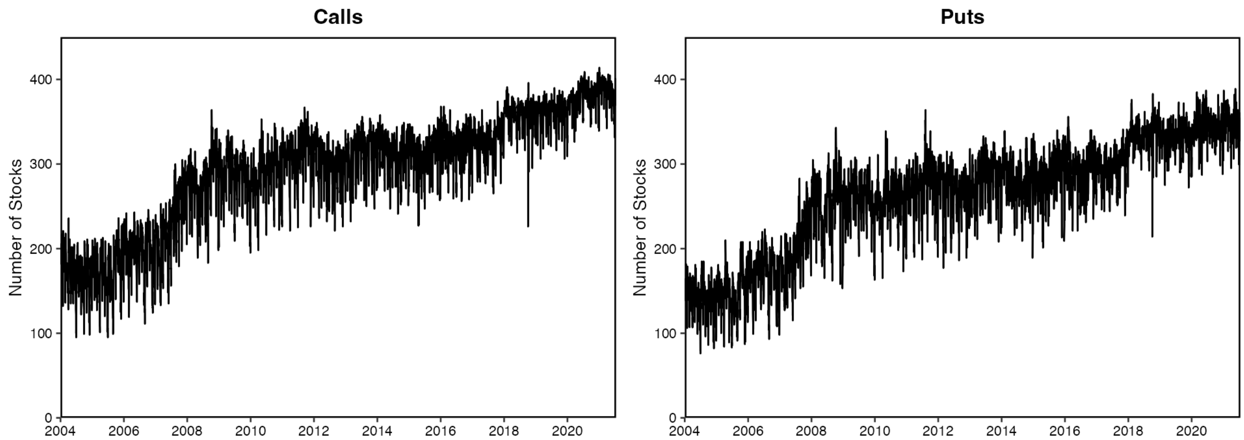
This table presents the time series regressions of ΔES_t on *log(SD_t)* for SPX ATM call and put options for different maturity buckets. We exclude trades with trade condition id of 114, corresponding to Single Leg Auction Non Intermarket Sweep Orders (SLAN). ΔES_t is the daily change in the effective spread on day t. *log(SD_t)* is the logarithm of the standard deviation of the intraday order flow distribution on day t, $log(volume_t)$ is the logarithm of the daily options volume, and $|OI_t|$ is the absolute value of the daily order imbalance divided by 10,000 where daily order imbalance is the difference between buy and sell initiated trades. $R_{M,t}$ is daily return on SPX on day t. VIX_t is the level of VIX divided by 100 on day t. Other controls contain one-day and two-day lags of ΔES_t, absolute value of the average delta, vega and gamma of the options on day t. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Table IA.13: Robustness: Regressions of ΔES_t on log(SD_t) for SPX Options, without the First and Last Half an Hour of Trading

Panel A: Calls								
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD_t)	0.026***	0.016***	0.005***	0.004***	0.004***	0.005***	0.003***	0.003***
	(5.63)	(5.41)	(4.43)	(4.7)	(6.56)	(7.89)	(5.11)	(5.08)
log($volume_t$)	-0.007	-0.01***	0.003**	0.001	0.0001	-0.002***	-0.0001	-0.0001
	(-1.57)	(-3.22)	(2.13)	(1.51)	(0.5)	(-3.2)	(-0.7)	(-0.29)
$\lvert OI_t \rvert$	-0.024**	0.006	0.001	0.001	0.003*	0.002*	0.002**	0.004***
	(-2.33)	(0.98)	(0.68)	(0.68)	(1.74)	(1.84)	(2.53)	(3.09)
$R_{M,t}$	-2.447***	0.179	0.03	-0.01	0.01	-0.108	0.001	0.003
	(-3.79)	(0.94)	(0.29)	(-0.17)	(0.21)	(-1.24)	(0.01)	(0.06)
VIX_t	-0.063	-0.047**	-0.049***	-0.015*	-0.017***	-0.014*	-0.006	0.001
	(-1.39)	(-2.07)	(-4.04)	(-1.91)	(-2.69)	(-1.8)	(-0.79)	(0.16)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1033	2910	2881	2771	2679	2512	2239	2023
Adj. R^2	0.507	0.439	0.389	0.365	0.324	0.375	0.351	0.373
Panel B: Puts								
	0	**1-6**	**7-13**	**14-20**	**21-27**	**28-34**	**35-41**	**42-48**
log(SD_t)	0.031***	0.017***	0.006***	0.005***	0.004***	0.003***	0.003***	0.003***
	(5.33)	(5.99)	(5.4)	(5.74)	(6.24)	(5.98)	(7.05)	(5.56)
log($volume_t$)	-0.022***	-0.01***	0.001	0.001	0.001	-0.0001	-0.0001	-0.0001
	(-3.85)	(-3.28)	(0.74)	(1.43)	(1.05)	(-0.53)	(-0.9)	(-0.53)
$\lvert OI_t \rvert$	-0.005	0.007**	0.004*	-0.001	0.002	-0.0001	-0.0001	-0.001
	(-0.35)	(2.1)	(1.96)	(-0.73)	(0.93)	(-0.04)	(-0.39)	(-0.5)
$R_{M,t}$	2.413***	-0.064	0.131	0.054	0.007	0.006	0.143	0.028
	(3.98)	(-0.44)	(1.41)	(0.84)	(0.17)	(0.08)	(1.45)	(0.73)
VIX_t	0.078*	-0.027	-0.026***	-0.004	-0.002	-0.015*	0.003	0.008
	(1.83)	(-1.61)	(-2.65)	(-0.57)	(-0.32)	(-1.88)	(0.47)	(0.97)
Time Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1036	2902	2888	2765	2692	2533	2271	2104
Adj. R^2	0.485	0.449	0.347	0.346	0.328	0.343	0.31	0.282

This table presents the time series regressions of ΔES_t on *log(SD_t)* for SPX ATM call and put options for different maturity buckets. The first and last half an hour of trading are excluded from the sample. The sample covers trades from 10:00 am to 3:30 pm. ΔES_t is the daily change in the effective spread on day t. *log(SD_t)* is the logarithm of the standard deviation of the intraday order flow distribution on day t, $log(volume_t)$ is the logarithm of the daily options volume, and $|OI_t|$ is the absolute value of the daily order imbalance divided by 10,000 where daily order imbalance is the difference between buy and sell initiated trades. $R_{M,t}$ is daily return on SPX on day t. VIX_t is the level of VIX divided by 100 on day t. Other controls contain one-day and two-day lags of ΔES_t, absolute value of the average delta, vega and gamma of the options on day t. Standard errors are computed using Newey-West with the optimal lag suggested by Andrews and Monahan (1992), and corresponding t-statistics are presented in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Figure IA.1: **Daily Number of Stocks in the Sample**



This figure plots the daily number of stocks in the equity options sample for ATM call options and ATM put options. A stock-day is included in our sample if the stock was part of the S&P 500 index in the preceding month. We include equity options with maturities between 0 and 48 days.