Demystify the Surge in VIX[1]

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Abstract

On August 5, 2024, the CBOE Volatility Index (VIX) surged from 23.9 to over 65 during pre-market hours, while VIX futures remained below 35. This paper examines the factors behind this spike using intraday options trades and quotes data. Our analysis reveals two key findings: (1) more out-of-the-money (OTM) put options were included in the VIX calculation compared to a typical trading day (e.g., August 2, 2024 when the VIX was in the range between 20 and 21.5 during pre-market hours), while fewer OTM call options met the criteria to be included during this period; and (2) the surge was primarily driven by a sharp increase in the mid-quote prices of OTM put options, not the broader range of strikes. These results highlight the role of market illiquidity during extreme VIX movements.

Keywords: Volatility Index; VIX; index options; pre-market hours; OPRA

JEL Codes: G12, G13, G23

Introduction

The CBOE VIX, often referred to as the market's "fear gauge," measures the market's expectation of 30-day volatility in U.S. equities. Derived from real-time mid-quote prices of S&P 500 index options (SPX and SPXW), CBOE Global Indices, LLC (CBOE) calculates and updates the VIX value every 15 seconds during both pre-market and regular trading hours. The methodology relies on selecting a broad range of out-of-the-money (OTM) call and put options while ensuring that only actively quoted strikes contribute to the index.

On August 5, 2024, the VIX experienced an unprecedented surge during pre-market trading. Specifically, at 3:15 AM Eastern Standard Time on August 5, the CBOE initially broadcast the prior day's closing VIX value of 23.9. However, within 15 seconds, the index surged to 42. By 8:30 AM, the VIX had skyrocketed to over 65—representing a 180% increase from the previous close.[2] This extreme move occurred while front-month VIX futures remained below 35, signaling a significant dislocation between implied spot volatility and futures pricing (Figure 1). This disparity is important since, under normal market conditions, the VIX and its corresponding futures prices tend to move in tandem. A divergence of this magnitude suggests the CBOE calculation predicted high volatility while VIX futures market participants appeared to generally believe the heightened implied volatility was transitory and would fall within a month.

Concerns emerged regarding the fragility of the VIX amid uncertainties surrounding macro events and the exact cause of its spike. Larry Summers highlighted one potential explanation, suggesting that the inclusion of further OTM options in the VIX calculation may have mechanically, or even artificially, inflated its value.[3] As he argued, “because there are some illiquid instruments that go into the calculation of the VIX, the VIX had a somewhat artificial move on Monday.”, and “I think [that] should be studied by the relevant parties in the industry and the regulator — the SEC.” This paper investigates the expansion of the range of strikes included in the VIX calculation on August 5, quantifies the contribution of those additional strikes to the overall index movement, and looks for additional factors that might have contributed the spike in the VIX.

Replicating The Disseminated VIX

The data used in this paper consists of intraday trades and quotes from the Options Price Reporting Authority (OPRA), obtained through the SEC's Market Information Data Analytics System (MIDAS) platform. Specifically, we first downloaded all quote records for the near-term and next-term S&P 500 index options and then created snapshots of the bid and ask prices for each option series at 15-second intervals.

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[2] According to Ahmed (2024), this represents the largest ever intraday jump in the VIX.

[3] Please see Anstey (2024). Other explanations include large trades in SPX and VIX options during pre-market hours (Kilburn and Bartholomew (2024)).

We follow the methodology outlined in the CBOE Volatility Index (VIX) Methodology paper (Cboe Global Indices LLC, 2024) to replicate the VIX calculation. For each expiration, we first determine the forward price F by identifying the strike price where the absolute difference between the call and put mid-quote prices is smallest, and the at-the-money (ATM) strike, K_0, is set as the strike price at or immediately below F.[4] Next, we apply the zero-bid rule, which excludes strikes once two consecutive options have zero-bid prices. This ensures that only actively quoted OTM options are included in the calculation. After establishing the eligible strikes, we compute the implied variance separately for the near-term and next-term options. The final VIX value is then equal to the square root of the time-weighted average of these implied variances, ensuring a 30-day constant maturity estimate.

In cases where the VIX cannot be calculated due to missing forward price data or abrupt negative jumps, we apply the filtering algorithm specified in the CBOE volatility index mathematics methodology (Cboe, 2025) to use the most recently available valid VIX value. The filtering algorithm operates by first establishing a baseline value and then comparing each subsequent calculated VIX value against it over a defined threshold period—2 minutes during regular trading hours or 5 minutes during pre-market hours. If a new VIX value exceeds the baseline or falls by less than 0.5 points, the new value is published and becomes the updated baseline. If instead the new value drops by more than or equal to 0.5 points, the algorithm republishes the existing baseline as the current VIX value instead of the new lower value. Additionally, if the VIX cannot be calculated due to a missing K_0, the most recent baseline is republished as the VIX value. This filtering mechanism can smooth fluctuations in the VIX by filtering out sudden negative drops and ensuring that instances of failing to find the ATM strike do not introduce unnecessary noise into the index value.[5,6]

In Figure 2, we present our replicated VIX alongside CBOE's disseminated VIX. Panel A displays the unfiltered VIX which represents our replicated VIX without applying the filtering algorithm, while Panel B shows the filtered VIX, which applies the filtering approach described in CBOE's mathematical methodology paper. For the unfiltered VIX, if the ATM strike K_0 cannot be determined for either the front-term or next-term contracts–making the VIX calculation impossible–we set the unfiltered VIX value to be zero.

From Panel A, we observe that during pre-market hours, there are instances where K_0 cannot be determined–resulting in a VIX value of zero–as well as sharp and temporary negative jumps in the

[4] Only options with two-sided quotes (i.e., bid greater than 0) are selected to derive K_0.

[5] Large negative jumps often occur when two consecutive, relatively liquid OTM options suddenly have zero bids, leading to a sharp reduction in the range of options included in the VIX calculation according to the zero-bid rule and, consequently, a lower VIX value.

[6] Another potential approach to filtering out VIX jumps caused by random shifts in the range of included strikes was proposed by Andersen, Bondarenko and Gonzzalez-Perez (2011). Their method uses the forward price and ATM implied volatility to determine the strike range.

value of VIX.[7] The inability to derive K_0 corresponds to short periods when most call or put options lack two-sided quotes. For example, at 06:38:15 AM, all next-term put options had zero bids, making it impossible to determine the next-term K_0, which in turn prevented a VIX calculation. The sharp and temporary negative jumps occur when market makers suddenly withdraw bids for a few consecutive OTM put options, reducing the range of strikes–because of the zero-bid rule–included in the VIX calculation. For example, at 06:25:45 AM, the next-term put options with strikes ranging from 3400 to 4875 had zero bids. As a result, the lowest strike price included in the VIX calculation jumped at 06:26:30 AM from 2000 to 48780 significantly reducing the range of strikes considered in the calculation. This led to a sharp drop in the VIX value to 34.58, significantly lower than both the previously published VIX and the baseline VIX of 48.34. If the filtering algorithm is applied, the baseline value would be published instead.

From Panel B, we observe that the filtered VIX is generally smooth and aligns well with the CBOE disseminated VIX, except for an extended period around 5 AM. The cause of this gap remains unclear. For instance, at 05:00:15 AM, our calculated VIX is 37.64, whereas the CBOE VIX is 41.33. If we include all options, even those with zero bids, the calculated VIX increases to 38.3. This may suggest that differences between our replication and the CBOE's disseminated VIX may reflect nuances in implementation or additional steps consistent with the CBOE's stated methodology but not fully specified in publicly available documentation. We recognize the potential for some level of ambiguity when seeking to replicate complex mathematical models in real world applications and believe there is value in CBOE continuing to periodically review its published methodologies for how it calculates VIX to ensure that they continue to accurately describe the process it follows with sufficient detail to allow others to replicate that process.

Range of Strikes in VIX Calculation

The CBOE calculates the VIX using a bucket approach that incorporates both near-term and next-term options. Near-month options refer to Friday contracts with 23 to 30 days until expiration, while next-term options are the next Friday contracts with less than 37 days remaining.[8] In essence, the VIX is the square root of the time-weighted average between the implied variance of the near-term contracts and next-term contracts. For August 5, the near-term options are those expiring on August 30 and the next-term options are those expiring on September 6. In calculating the implied variance for a given expiration date, only OTM calls and puts with non-zero bid prices are considered. A zero-bid rule is applied to ensure liquidity, and the selection process stops once two consecutive strikes with zero bids are encountered, thereby excluding highly illiquid contracts.

[7] To be exact, during pre-market hours, there were 12 instances where K_0 could not be determined and 262 instances where the unfiltered VIX fell more than 0.5 points below the baseline. In these cases, the filtered VIX used the baseline instead.

[8] Friday contracts refer to the options which expire on a Friday.

Market distress often leads to wider bid-ask spreads, which can affect the range of strikes included in the VIX calculation. If these wider spreads cause more OTM options to have a one-sided quote (for example, a zero bid), fewer options might be incorporated. On the other hand, increased demand for put options as a hedge against further declines can help maintain non-zero bids for additional OTM strikes, potentially broadening the strike range. To assess the net effect, we compared the lowest strike prices used in the VIX calculation between August 2 and August 5. Panel A in Figure 3 illustrates that for the near-term put options the lowest strikes on August 2 before 9:15 AM generally fell between 2,700 and 2,800 most of the time. In contrast, on August 5, the lowest strike included in the calculation initially remained around 3,500 for an extended period, occasionally jumping to 5,000 or dropping to 2,000. After 4:32:30 AM, it consistently fell below 2000, eventually reaching as low as 1,400. Panel B of Figure 3 shows that for next-term put options, the lowest strikes on August 2 remained around 2,400 for most of the pre-market trading session. In contrast, on August 5, the lowest strikes initially stood at 3,750 from 3:15 AM to 5:20 AM but quickly dropped below 2,000, eventually stabilizing at 1,750 before the market opened.

In addition, while the inclusion of deeper OTM put options expanded on August 5, the range of call options contracted. As Figure 4 illustrates, on August 2 the highest call strikes incorporated in the VIX calculation were approximately 6,300 for near-term options and 6,400 for next-term options. On August 5, however, both categories saw their highest strike levels drop to about 5,800. This narrowing suggests that fewer OTM call options met the liquidity criteria during the volatile market conditions, potentially due to reduced participation of liquidity providers at these strike levels.

Contributions from Further OTM Put Options

Next, we aim to assess the impact of including additional, further OTM put options in the VIX calculation. We begin by constructing two time series. The first series is the filtered VIX, as shown in Figure 2. The second series, referred to as filtered VIX 2800, is derived using only OTM put options with strike prices at or above 2800 and OTM call options, after applying the zero-bid rule and the filtering algorithm. The difference between the filtered VIX and filtered VIX 2800 can be interpreted as the contribution to VIX from OTM options with strikes below 2800.

Figure 5 illustrates the findings. The upper panel of the figure shows the CBOE VIX, and the bottom panel shows the difference between filtered VIX and filtered VIX 2800. The maximum contribution from further OTM put options amounts to a maximum of 6 points, or roughly 10% of the overall VIX value.

Widened Bid-Ask Spreads and Elevated Midpoint Prices

Since further OTM put options contributed only a small fraction of the VIX surge, we next investigate other factors that may have driven the spike. We begin by analyzing the quotes of an OTM put option contract that was actively traded on both August 2 and August 5. Figure 6 presents the bid, ask, and midpoint prices of ATM and 3500 strike put options with expiration on August 30 during pre-market hours on August 2 and August 5. Panels A and B show the prices for ATM options, while Panels C and D show those for 3500 strike options. The figure reveals a significant increase in the bid-ask spread on August 5 compared to August 2, where the spread rises from below one dollar on August 2 to $50 or more on August 5. For the 3500 strike put options, the spread surges from $0.2 to above $15. Also from Panel D, although the widened bid-ask spread initially led to zero bid quotes for an extended period around 4 AM, the bid price eventually rose consistently above zero, thereby ensuring that this option was included in the VIX calculation.

In addition, the midpoint of the 3500 strike options shows a consistent value $0.7 on August 2, while it increases to well above $10 on August 5, reaching $50.25 at 8:37 AM. The dramatic rise in midpoint prices – especially in OTM options – could have been a key factor in the spike in VIX during pre-market hours on August 5.

Per Unit Strike Increment Contribution to the VIX

According to CBOE's VIX methodology, the contribution to the implied variance from a given option with strike price K_i is calculated as:

$$\frac{\Delta K_i}{K_i^2} e^{RT} Q(K_i)$$

where K_i is the strike of the i^{th} OTM option, ΔK_i represents the interval between consecutive strike prices, R is the risk-free interest rate, and $Q(K_i)$ is the midpoint of the bid-ask spread of the option. If we scale the term by ΔK_i, we will have $e^{RT} Q(K_i)/K_i^2$, which reflects the contribution to the implied variance per unit strike increment.

Given that the unit of implied variance is T and the unit of implied volatility is $\sqrt{T}$, the contribution of a given option to the VIX per unit strike increment can be set as taking the square root of $e^{RT} Q(K_i)/K_i^2$.

Figure 7 illustrates the contribution to the VIX per unit strike increment from near-term and next-term options, plotted against K/K_0 for both August 2 and August 5 at 8:37 AM. While the lowest strike included in the VIX calculation on August 5 is approximately $0.27K_0$ ($0.35\ K_0$) for near-term (next-term) compared to $0.50K_0$ ($0.44\ K_0$) on August 2, the highest strike included dropped slightly (e.g., $1.16K_0$ to $1.14K_0$ for near-term options). This indicates that more OTM put options were incorporated while fewer OTM call options were included in the calculation on August 5, consistent with our earlier results illustrated in Figure 3 and Figure 4.

When $K/K_0 = 1$ (the ATM strike), the contribution on August 5th from the near-term ATM option is 0.003, which is 1.5 times larger than the contribution on August 2nd from the near-term ATM option. At $K/K_0 = 0.7$, the contribution on August 5th from the near-term OTM option is 0.002, which is 6.7 times larger compared to August 2nd. These results clearly show that the substantially elevated midpoints of the quotes for OTM put options were the primary drivers behind the surge in the VIX.

Conclusion

In replicating the VIX index during pre-market hours on August 5, 2024, we find instances where OTM options, particularly put options, had zero bids, making it impossible to determine the VIX index, or resulting in large temporary negative jumps in the unfiltered VIX value. We also observe that more illiquid OTM put options were incorporated in the VIX calculation whereas fewer OTM call options met the criteria. However, our analysis suggests that this expanded strike range on the put side was not the primary factor behind the surge. Instead, our results indicate that the significant elevation in midpoint prices of OTM options was the primary driver.

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Figure 1: There was a surge in VIX on August 5, 2024, while VIX futures did not rise alongside.

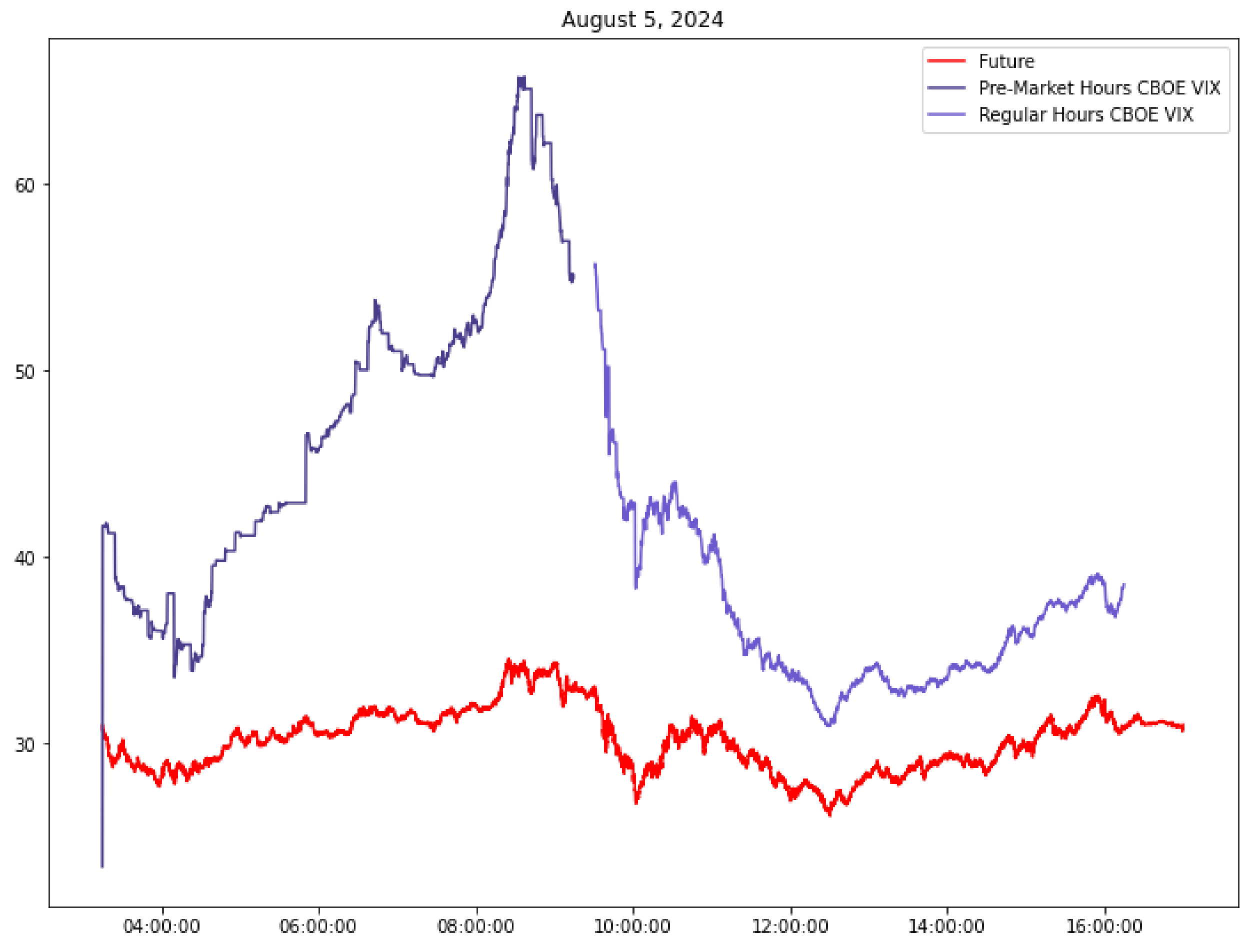

Figure 2: Replicating the VIX Index.

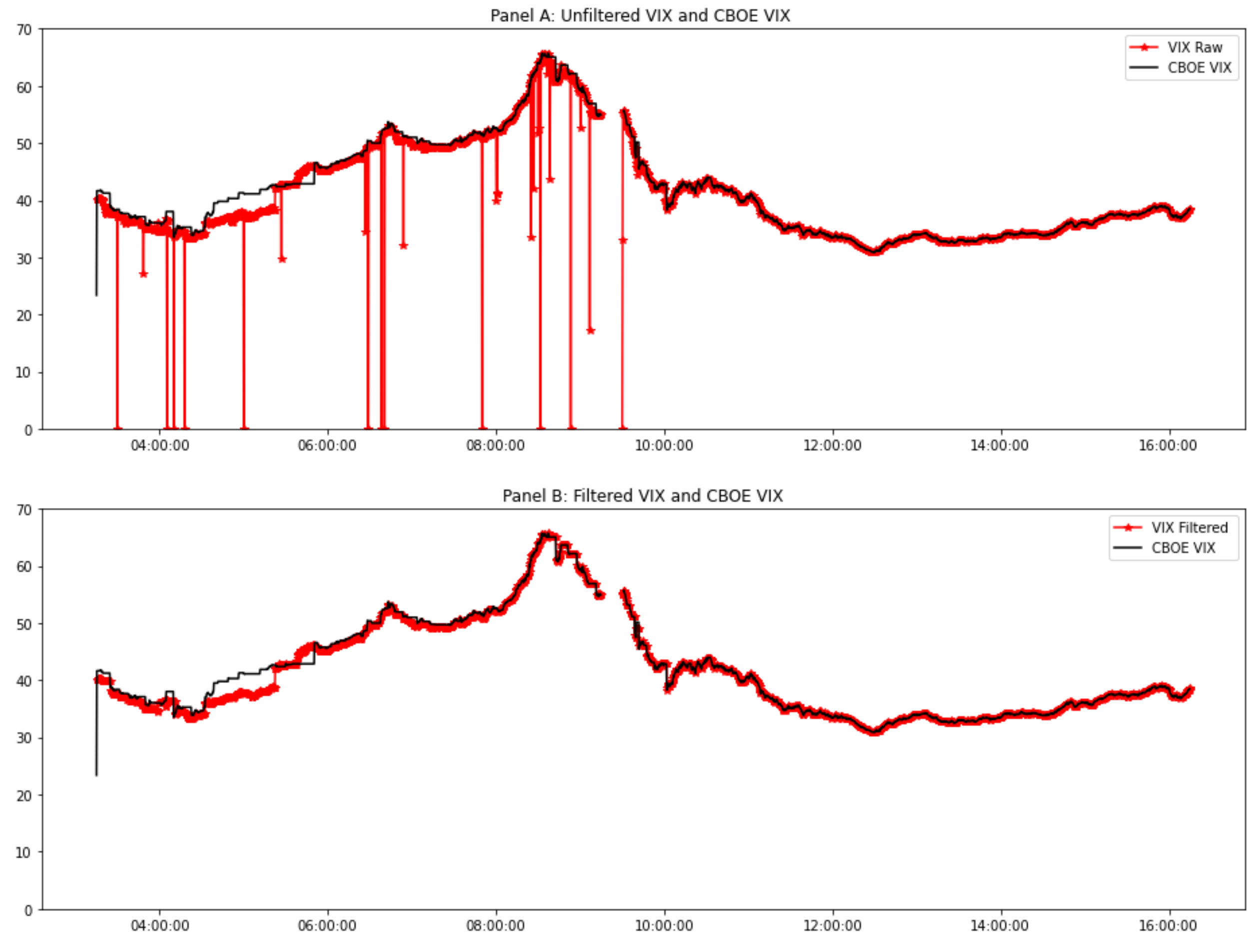

Figure 3: Lowest Strikes (OTM Put Options) Included in VIX Calculation on August 5 for Near-Term and Next-Term Options

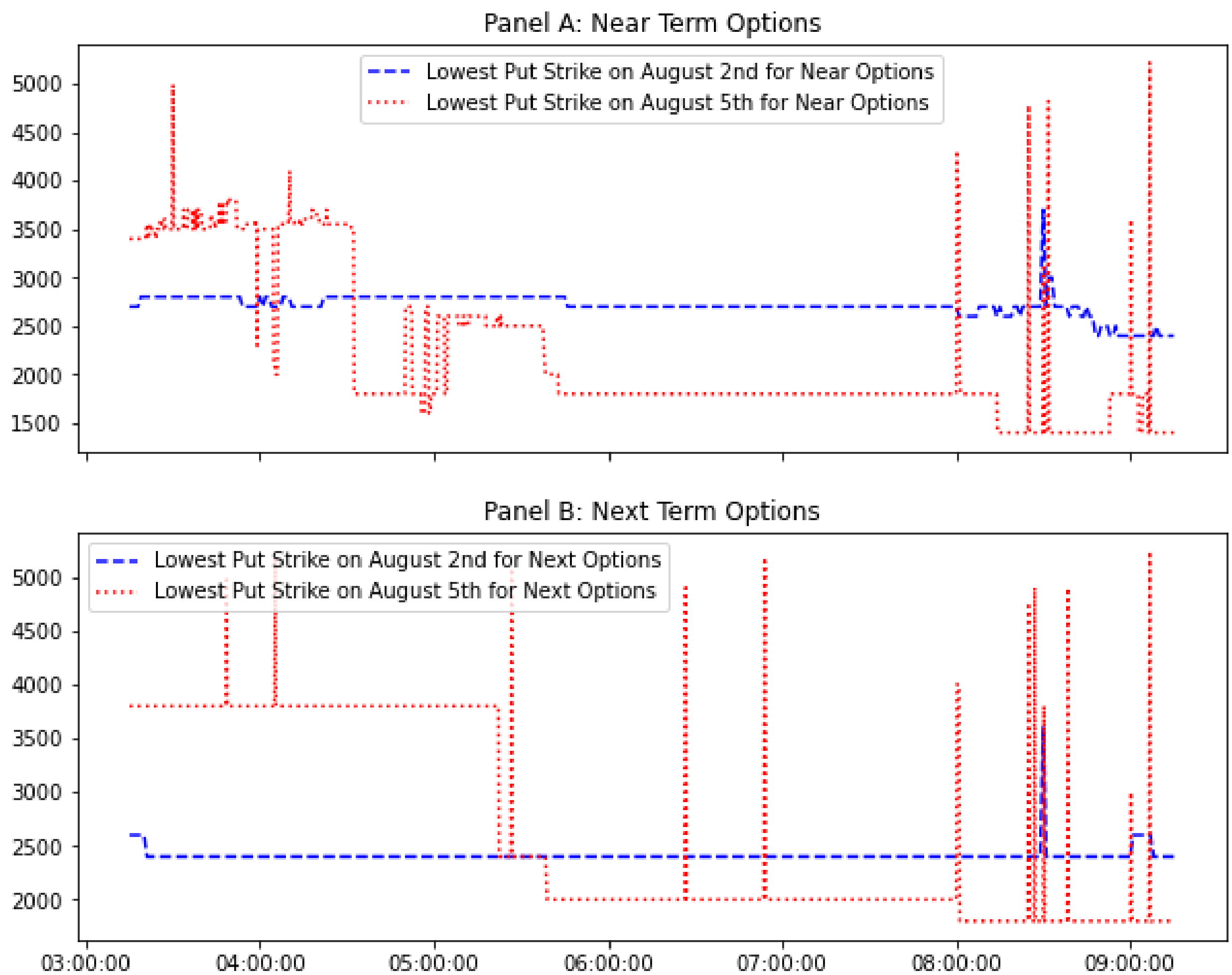

Figure 4: Highest Strikes (OTM Call Options) Included in VIX Calculation on August 5 for Near-Term and Next-Term Options

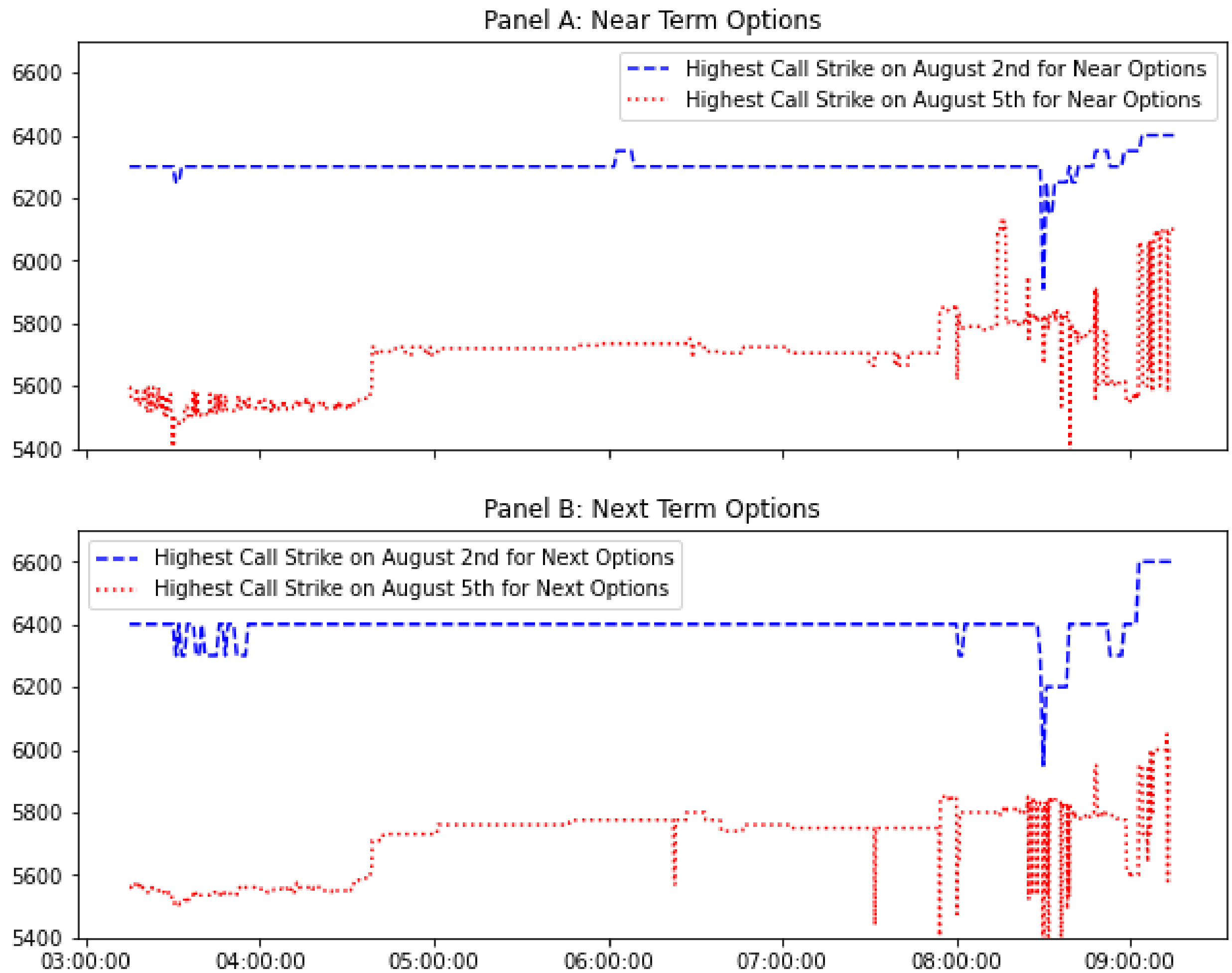

Figure 5: Contributions from Strikes Below 2800.

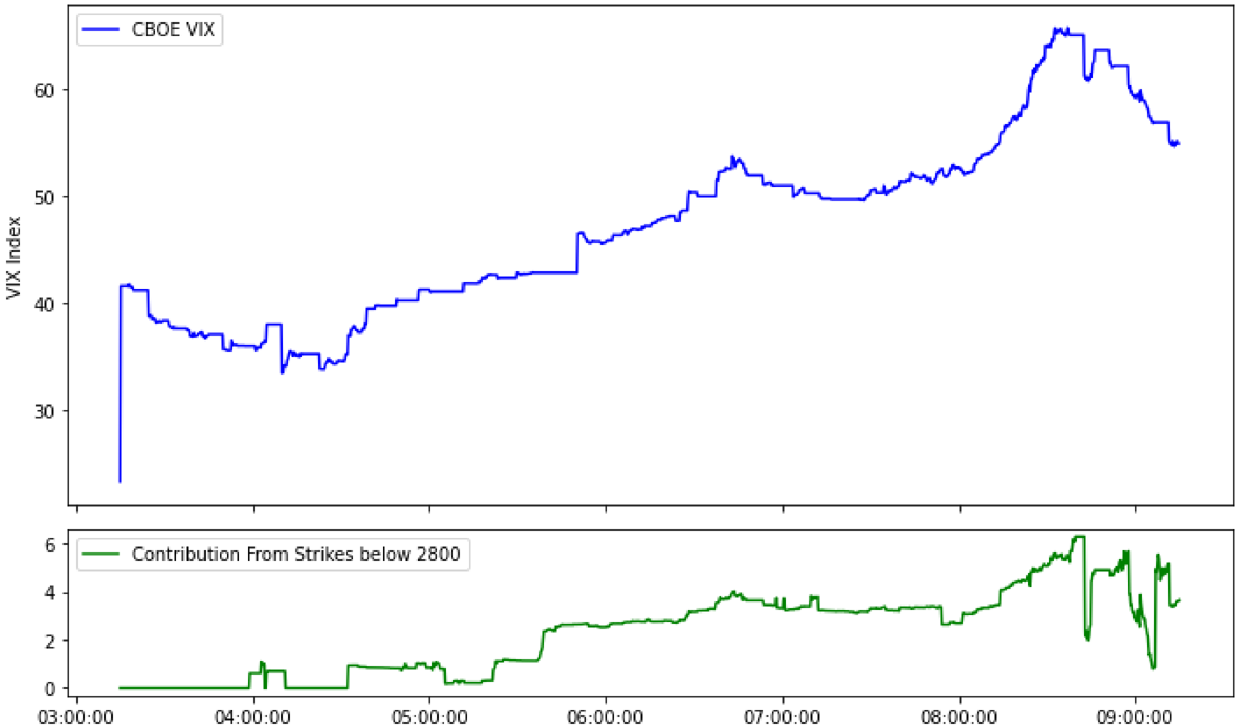

Figure 6: Price Dynamics of ATM and 3500 Strike Put Options during Pre-Market Hours on August 2 and 5.

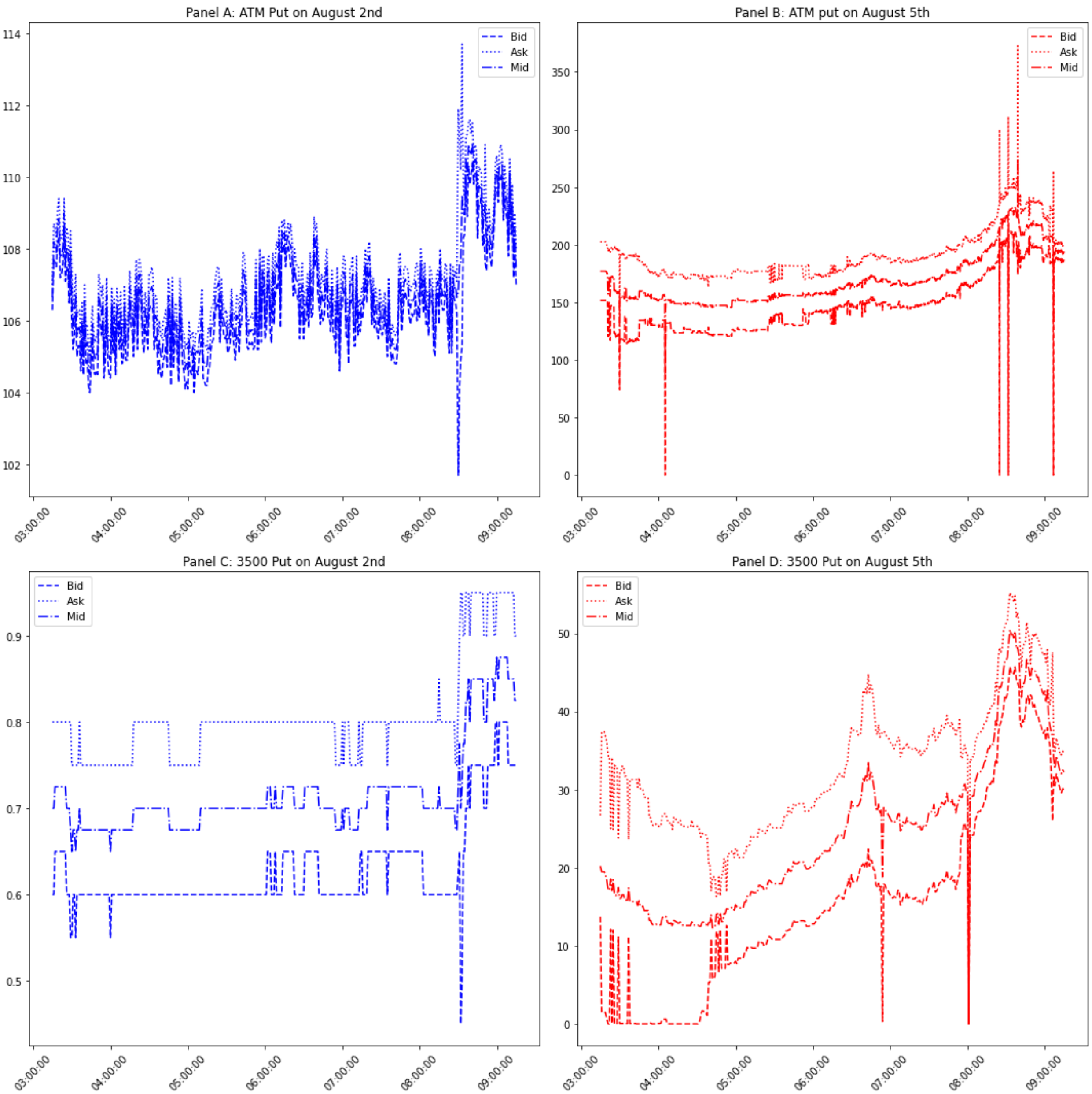

Figure 7: Per Unit Strike Increment Contribution to the VIX