MEMORANDUM

To: FILE
From: DIVISION OF ECONOMIC AND RISK ANALYSIS[1]
Date: February 2, 2021
Subject: CORNERSTONE ANALYSIS OF PM CASH-SETTLED INDEX OPTION PILOTS

The Division of Economic and Risk Analysis ("Division") contracted with Cornerstone Research, an economic and financial consulting firm, to study the effects of pilot programs ("Pilots") that allow the listing and trading of certain cash-settled index options settled using the closing index value on the expiration date ("PM cash-settled index options"). The amount of expiring PM cash-settled index derivatives may be associated with abnormal transitory volatility in the corresponding index futures, the underlying index, and index component securities around the market close on expiration dates. This report studies, employing multivariate regression models, whether and how expiring open interest in PM cash-settled index options is empirically related with the tendency of the corresponding index futures, the underlying index, or index components to experience increased short-term (transitory) volatility and price reversal around the time of market close. The report utilizes the level of expiring PM cash-settled index options open interest and the measure of volatility and price reversals for the corresponding index futures, the underlying cash index, and index component securities in the minutes leading up to and immediately following the market close to study the effects of the Pilots.

The report finds that there is a positive statistical relation between the level of expiring PM cash-settled index options open interest and the measure of volatility and price reversals for index futures, the underlying cash index, and index component securities in the minutes leading up to and immediately following the market close on expiration dates. However, the report suggests that the magnitude of the effect of expiring PM cash-settled index options open interest on the measure of volatility and price reversals for index futures, the underlying cash index, and index component securities is economically very small. The Division believes that the research and statistical methodologies employed in this report is appropriate in examining the Pilots and agrees with the conclusions drawn in this report.

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[1] This is a memo by the Staff of the Division of Economic and Risk Analysis of the U.S. Securities and Exchange Commission. The Commission has expressed no view regarding the analysis, findings, or conclusions contained herein.

MEMORANDUM

DATE: September 16, 2020

TO: Division of Economic and Risk Analysis, U.S. Securities and Exchange Commission

RE: PM Index Option Expiration Pilots

I. Executive Summary

The goal of this research is to provide evidence useful for the Commission staff in evaluating the impact of a series of Self-Regulatory Organization ("SRO") pilot rule changes under which certain option exchanges have listed cash-settled index options that settle based on the closing index value on the expiration date ("PM Option Expiration Pilots").[1]

Stock index futures and options, when they were first introduced in the 1980s, were designed to settle based on the closing index value on the expiration date. In the late 1980s, in response to concerns that trading activity associated with the expiration of futures and options may have contributed to excess volatility and reversals around the close, settlement of index futures and certain index options was changed to be based on a settlement value calculated at market open. In recent years, SRO pilot rule changes have allowed for certain index options to be based on the closing index values ("PM-settled options"). The prior history of PM-settled options suggests possible concerns that a high amount of expiring options may still be associated with abnormal volatility around the market close.

[1] This research was performed by Stewart Mayhew and D. Timothy McCormick, supported by the staff of Cornerstone Research, under the direction of Amy Edwards and other staff in the Division of Economic and Risk Analysis (DERA), pursuant to contract SECHQ1-16-C0024. The views and interpretations expressed in this memo do not necessarily represent the views of Cornerstone Research.

This research investigates the extent to which there is an empirical association between expiring open interest in index options settling at the close and the tendency of the underlying index or index constituents to experience increased short-term (transitory) volatility around the time of the close. In particular, multivariate regression methodology, with various alternative specifications, is employed to measure the degree to which higher expiring open interest of p.m.-settled options explains variation in measures of volatility and price reversals in the minutes leading up to and immediately following the close.

The broadest set of results pertains to the market for p.m.-settled options on the S&P 500 index, which is by far the largest p.m.-settled index option market on any U.S. securities exchange. Metrics evaluated for the S&P 500 include measures designed to measure volatility and short-term price reversals near the close, based on index futures prices, cash index values, and index constituent stock prices. The analysis is based on more than 11 years of data (from 2007 to 2018).

Based on a review of the data (Section IV) and the regression results (Section VII), the findings with respect to the S&P 500 market can be summarized as follows:

- Since 2007, the size of the market for p.m.-settled options on the S&P 500 index has grown from a trivial portion of the overall market to a substantial share (from around 0.1% of open interest in 2007 to 36% in 2018). Most of the largest expiration events for p.m.-settled options in the sample occurred in the last year of the sample.
- Open interest on expiring p.m.-settled options, as compared to a.m.-settled options, is spread out across a greater number of expiration dates, so a smaller

percentage of open interest expires on any one date. A priori, this fragmentation across dates mitigates the concern that option expiration may have a disruptive effect on the market.

- Regression results are fairly consistent across specifications and metrics in showing a statistically significant, positive association between the level of expiring p.m.-settled options and measures of volatility and reversals near the close (after controlling for other factors that might contribute to volatility near the close). This effect is observed in metrics based on the futures market, the cash index, and the component stocks. These results are tabulated in Tables 5 through 24 and discussed in Section VII below.
- The fact that the regression methodology finds a statistically significant association does not necessarily mean that the economic magnitude of the effect is large. A discussion of the economic magnitude of relevant regression coefficients is provided in Section VII below to aid the reader in assessing the economic magnitude of the effect. As one example, based on one of the main specifications, the largest settlement event that occurred in the entire sample (a settlement of $100.4 billion of notional on December 29, 2017) had an estimated impact on the futures price of approximately 0.02% (a predicted impact of $0.54 relative to a closing futures price of $2,677).[2]
- When the same methodology is applied to evaluate whether there is a relationship between expiring open interest of a.m.-settled options and volatility near the open, no evidence of a statistically significant relationship is found.

[2] This example is based on the absolute return metric in the specification presented in Table 5.

- There is little evidence that there is greater volatility related to option settlements during an environment of high market volatility, as measured by the VIX index being in the top 10%.
- There is no evidence that less liquid securities experience a greater effect from p.m. settlements.

Index options expiring at the close were introduced on the Russell 2000 index in 2014 and on the Nasdaq 100 index in 2018. As illustrated in Section II below, the markets for both a.m.- and p.m.-settled options on these indices are very small compared to the size of that for S&P 500 index options. Compared to the results for the S&P 500 index, results for the Russell 2000 and Nasdaq 100 indices, summarized in Section VIII below, are less clear. Overall, for some of the regression specifications and metrics analyzed, the analysis finds statistically significant relationships between settling quantity and volatility at the close, yet not consistently for all metrics and specifications. There is also some evidence that higher settlement quantities for Nasdaq 100 index a.m.-settled options is associated with higher volatility around the open of trading. Especially the results for the Nasdaq 100 index p.m.-settled options should be treated more cautiously because the number of observations is much smaller than for the other indices.

The regression results indicate some evidence of a statistical association between metrics designed to measure abnormal transitory volatility surrounding index option settlement and expiring open interest in PM-settled index options. However, these results do not establish causality—that is, the results do not prove that increased volatility around the close was actually caused by the expiration of the PM-settled options. For example, it is possible that other unmodeled factors explain transitory volatility around the close and that these same factors lead to increased trading of PM-settled options. Therefore, the models discussed below should not be viewed as a reliable tool for predicting what the effect is likely to be if PM-settled options were introduced on other indices or to predict what might happen if the size of the PM-settled option market grows significantly larger. In particular, the model should not be used to extrapolate predictions of what might happen beyond the range of prior experience reflected in the data.

II. Background

Stock index futures and options markets first developed in the 1980s. Among other notable developments, in 1983 the Chicago Mercantile Exchange ("CME") introduced futures on the S&P 500 index and the Chicago Board Options Exchange ("Cboe") introduced options on the S&P 100 and S&P 500 indices. Futures and options on the Russell 2000 index, the Nasdaq 100 index, and various other indices have also been introduced over the years.[3]

Index futures and options are cash-settled, based on a computed value of the underlying index. When stock index futures and options were first introduced, settlement was based on the closing value of the underlying index on the option's expiration date. However, certain episodes of price reversals around the close on quarterly expiration dates attracted the attention of regulators to the possibility that the simultaneous expiration of index futures, futures options, and options might be inducing abnormal volatility in the index value around the close.[4]

Academic research at the time provided at least some evidence suggesting that futures and option expiration contributed to excess volatility and reversals around the close. For

[3] Options were introduced on the Russell 2000 index in 1992 (Release 34-31382), on the Nasdaq 100 index in 1994 (Release No. 34-33428), and on the Dow Jones Industrial Average in 1997. See "2016 CBOE Market Statistics," Cboe, p. 10.
[4] Stoll, Hans R, "Index futures, program trading, and stock market procedures," *The Journal of Futures Markets* 8, no. 4 (1988): 391–412 (Henceforth, Stoll (1988)).

example, a 1986 study by Hans Stoll and Robert Whaley found evidence that index values were more volatile near the close on quarterly expiration days compared to other days and had a greater tendency to reverse the next day.[5]

This regulatory focus in the mid-1980s on the effects of option expiration culminated in SRO rulemaking, overseen by the CFTC and SEC, modifying the terms of certain index futures and options to settle based on an underlying index value calculated from opening prices rather than closing prices. Contract specifications for the CME's S&P 500 futures and the New York Futures Exchange's ("NYFE") NYSE Composite index futures were modified to settle based on the opening prices of the index constituents on the day of expiration, beginning with the June 1987 contracts.[6] Cboe introduced a new class of S&P 500 options based on a.m. settlement in April 1987. For a few years, the original p.m.-settled S&P 500 classes continued to trade on the Cboe in parallel with the new a.m.-settled classes, but the p.m.-settled S&P 500 options were phased out in 1992–1993. However, p.m. settlement did not disappear altogether. In 1993, the SEC approved a rule allowing Cboe to list p.m.-settled options on certain broad-based indices expiring at the end of each calendar quarter ("Quarterly Index Expirations")[7] and S&P 100 options, which were American style (could be exercised any day before expiration) and continued to be settled at the market close. Subsequent cash-settled index options, including Russell 2000 and Nasdaq 100 index options, were introduced as a.m.-settled contracts.

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[5] Stoll, Hans R., and Robert E. Whaley, "Expiration day effects of index options and futures," *Monograph Series in Finance and Economics*, no. 3 (1986). See also Stoll, Hans R., and Robert E. Whaley, "Program trading and expiration-day effects," *Financial Analysts Journal* 43, no. 2 (1987): 16–28 (Henceforth, Stoll and Whaley (1987)); Stoll, Hans R., and Robert E. Whaley, "Expiration-day effects: what has changed?," *Financial Analysts Journal* 47, no. 1 (1991): 58–72 (Henceforth, Stoll and Whaley (1991)); Stoll (1988); Day, Theodore E., and Craig M. Lewis, "The behavior of the volatility implicit in the prices of stock index options," *Journal of Financial Economics* 22, no. 1 (1988): 103–122 (Henceforth, Day and Lewis (1988)).
[6] Release No. 34-24367.
[7] Release No. 34-62911; *see also* Release No. 31800.

Starting in 2006, the SEC approved numerous rule changes, on a pilot basis—the PM Option Expiration Pilots—permitting the option exchanges to introduce other index options with p.m. settlement. These include p.m.-settled S&P 500 index options expiring on the last business day of a calendar quarter (Cboe, 2006),[8] S&P 500 index options expiring weekly (other than the third Friday) and at the end of each month (Cboe, 2010),[9] S&P 500 index options expiring on the third Friday (Cboe C2, 2011),[10] options on the Mini-SPX index (Cboe, 2013),[11] options on broad-based indices with expirations weekly on Mondays and Wednesdays (Cboe, 2015 and 2016),[12] and options on the Nasdaq 100 index (Nasdaq ISE, 2018).[13]

Over the years, the PM Option Expiration Pilots have periodically been extended, and as of the time of this study some of them have not yet been adopted as permanent. The purpose of the present study is to provide evidence germane to the evaluation of these pilots, with a particular focus on investigating the extent to which the growth of the p.m.-settled index option markets in recent years has led to heightened transitory volatility or price reversals near the close. The remainder of this section provides an overview of how the size of the market for a.m.- and p.m.-settled index options on the S&P 500, Russell 2000, and Nasdaq 100 indices has evolved in recent years. The sources for the data underlying the figures and tables below are described in Section IV, below.

In the past decade or so, the size of the market for p.m.-settled S&P 500 options has grown from a small sliver of the overall market to a substantial portion of the market. This is

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[8] Release No. 34-54123; adopted as permanent on June 23, 2009; *see also* Release No. 34- 60164.
[9] Release No. 34-62911.
[10] Release No. 34-65256.
[11] Release No. 34-70087.
[12] Release No. 34-76529; Release No. 34-78132; Release No. 34-78531.
[13] Release No. 34-82612.

illustrated in Figure 1, which plots the notional value of open interest of a.m.- and p.m.-settled S&P 500 options over time. Notional open interest in p.m.-settled S&P 500 options increased from $1.5 billion (median) in 2007 to $34.5 billion in 2011, then to $1.3 trillion in 2018, an increase by a factor of more than 850 in 11 years.[14] Over the same time period, notional open interest of a.m.-settled S&P 500 options increased about 71%, from $1.4 trillion (median) in 2007 to $2.5 trillion in 2018. Between 2007 and 2018, open interest of p.m.-settled options as a percentage of all S&P 500 options, based on median notional value, grew from less than 0.2% to about 35%. Figure 2 provides a similar picture based on trading volume. Daily trading volume in p.m.-settled S&P 500 options has increased from a median of about 700 contracts in 2007 to nearly 1.7 million contracts in 2018, and now exceeds trading volume of the a.m.-settled S&P 500 options.

Another way to measure the size of the market is by the total notional value of contracts resulting in an in-the-money settlement at expiration. Table 1 reports the total notional settlement value of a.m.-settled and p.m.-settled S&P 500 options by year from 2006 to 2018. Unlike the open interest and volume graphs referred to above, which show snapshot and median values, this table reports a total settlement amount, aggregated by year. As the table indicates, the aggregated notional settlement value of p.m.-settled options has increased dramatically, to the point where it now exceeds the settlement value of a.m.-settled options. Worthy of note is that compared to a.m.-settled options, the settlements of p.m.-settled options have been spread more evenly across a considerably larger number of expiration dates since 2011, so the notional

[14] 2018 statistics for the S&P 500 are calculated through the last day of the futures regression time period, November 27, 2018. The cash index regression time period ends one month earlier, October 24, 2018.

amount expiring in-the-money on any one day tends to be lower. This is illustrated by Figure 3, which graphs notional values of settlement amount of p.m.- and a.m.-settled S&P 500 options.

By every metric examined, the cash-settled Russell 2000 and Nasdaq 100 index options markets are much smaller than the S&P 500 market. Aggregate open interest for cash-settled Russell 2000 index options in 2018 was approximately $84.1 billion (time series median) compared to $3.8 trillion for the S&P 500, making the Russell 2000 index options market about 2% of the size of the S&P 500 options market. As of 2018, the Nasdaq 100 options market was also about 2% of the size of the S&P 500 market.

The Russell 2000 index option market has been stagnant and even shrinking over time, as illustrated in Figures 4 and 5, which plot open interest and trading volume for the Russell 2000 index options. The trend in open interest and trading volume has been decreasing or flat since the size of the market peaked around 2007–2008. Russell 2000 index options with p.m. settlement were introduced in 2014, and since then the p.m.-settled market has grown to account for a substantial portion of the market. Open interest in p.m.-settled options in 2018 was $26.3 billion (time series median), accounting for roughly 31% of the total open interest. Trading volume in 2018 was 43,760 contracts, accounting for about 44% of the total.[15]

The market for cash-settled Nasdaq 100 options markets has also been stagnant, if not shrinking, since 2012 (for this study, data were available only back to 2012). This is illustrated in Figures 7 and 8, which plot open interest and trading volume for the Nasdaq 100 options. For a.m.-settled options, this decline is particularly pronounced, with both open interest and trading volume significantly lower now than in 2012. The median traded volume of a.m.-settled Nasdaq

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[15] *See also* Figure 6 and Table 2 for the notional values of expiring open interest of p.m.- and a.m.-settled Russell 2000 options, which confirm these trends.

100 options decreased from 32,075 contracts in 2012 to 6,522 contracts in 2018. Notional open interest of a.m.-settled Nasdaq 100 options decreased from $77.5 billion in 2012 to $61.6 billion in 2018.[16] As options on the Nasdaq 100 index settling at the close were introduced in 2018, there are not enough data to see a trend.

III. Economic Framework

Based on economic theory, there are various reasons why one might expect the expiration of index futures and options potentially to have a disruptive effect on the underlying index or on the markets for securities linked to the index, if the expiring open interest is sufficiently large.[17]

First, even though index futures and options contracts self-liquidate with cash settlement upon expiration, expiration might induce some market participants to engage in trading in the underlying market. For example, market makers and other market participants may be hedging positions in expiring contracts using other instruments linked to the underlying index, such as Exchange-Traded Funds ("ETFs"), baskets of stocks, or other (non-expiring) index derivatives. To the extent that these hedged positions in expiring options are not rolled over to a longer maturity prior to expiration, the hedged positions will abruptly change to unhedged positions upon expiration. Market participants might respond by seeking to trade rapidly to neutralize the risk of their position, for example by liquidating their positions in the hedging instruments.

To illustrate, suppose that a speculator holds a large purchased position in in-the-money S&P 500 call options, and the written position is held by a market maker, who has been hedging the short exposure of these written call positions by holding long positions in (physical) ETFs

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[16] *See also* Figure 9 and Table 3 for the notional values of expiring open interest of p.m.- and a.m.-settled Nasdaq 100 options, which confirm these trends.
[17] *See* Stoll (1988) for an early analysis of these effects.

tracking the S&P 500 index. Assuming the speculator continues to hold the long position in the call options through expiration (does not roll over the position), the market maker's written option position would terminate upon expiration and settlement. This would leave the market maker holding a long position in the ETFs. The market maker's position has transformed instantaneously from a hedged (market neutral) position to an unhedged long position. Assuming the market maker does not want to continue to hold this speculative position, the market maker would need to liquidate the position by selling the ETFs into the market.[18] If this happens simultaneously in the same direction for many large expiring positions, the cumulative effect could be for the selling pressure to exert temporary downward pressure on the index and the prices of the component stocks in the index.

Such trading could occur in either direction, depending on the side of the market of the positions that need to be liquidated. If there is a sufficiently large imbalance between buying and selling volume induced by hedgers liquidating their positions, it might result in a short-term price pressure in the market for the hedging instrument. Based on this theory, the potential price impact is likely to be largest where there is a large amount of expiring open interest for in-the-money options.[19] This theory is not limited to options that settle at the close. The same

[18] The selection of ETFs as the hedging instrument is for illustrative purposes. The same basic logic applies regardless of what hedging instruments are used. Because futures, options, ETFs, and the basket of component stocks are linked by arbitrage, the cumulative effect of extreme trading pressure across all of these instruments may be transmitted quickly across all these linked markets.

[19] The option's "delta" measures the risk exposure of the option price to changes in the underlying index, and can be used to determine how many units of the underlying index would be necessary to hedge a given option position. As options approach expiration, the option's delta approaches one for in-the-money call options and negative one for in-the-money put options. Thus, the underlying stock or index position required to hedge an expiring in-the-money option is roughly equal to the option's notional value. For out-of-the money options, delta approaches zero at expiration, so market participants do not need to hold significant stock or index positions to hedge, and the expiration of out-of-the-money options is not likely to generate additional trading.

argument potentially applies to expiring a.m.-settled and p.m.-settled open interest in futures or options.

In addition, large open interest in cash-settled index options may create an incentive for market manipulation.[20] Specifically, manipulators may seek to manipulate the underlying index in the time period immediately before settlement in an effort to move settlement prices of their option holdings in a direction that benefits their position. For instance, a manipulator with a large purchased call option position might seek to push the underlying index value up to push their option deeper in-the-money and to have a higher settlement value, while a manipulator with a large written call position might seek to push the index down to decrease the settlement value. This type of manipulation is more likely to be a concern for narrow-based indices, to the extent that narrower indices are easier to manipulate. This type of manipulation would likely be difficult for broad-based indices such as the S&P 500, Nasdaq 100, and Russell 2000. There is no evidence that such manipulation has occurred in broad-based indices. To the extent it does occur, one would expect it to manifest in the form of higher index movements immediately prior to settlement, and an increased likelihood of reversals surrounding the settlement time. These effects would be qualitatively similar to the effects of the unwinding of hedging trades, described above. This study does not propose any methodology for empirically distinguishing deliberate manipulation from benign behavior. It is mentioned here merely to emphasize there may be multiple interpretations of any observed effects.

IV. Data and Sample

[20] Dutt, Hans R., and Lawrence E. Harris, "Position limits for cash-settled derivative contracts," *Journal of Futures Markets* 25, no. 10 (2005): 945–965.

Option settlement quantity data for a.m.- and p.m.-settled options were obtained from the Cboe, including the number of contracts that settled in-the-money for each exchange-traded option series on the S&P 500 index and the Russell 2000 index on expiration days from January 20, 2006 through December 31, 2018.[21, 22] Daily open interest and volume data for each option series were also obtained from Cboe, including open interest data from January 3, 2006 through December 31, 2018 and trading volume data from January 3, 2006 through December 31, 2018.[23]

Options settlement quantity data for a.m.- and p.m.-settled Nasdaq 100 options were obtained from Nasdaq ISE. Data for a.m.-settled options cover the period from January 3, 2012 to February 27, 2019. Data for p.m.-settled options cover the period from January 4, 2018 through February 27, 2019, with the first settlement on February 2, 2018. Nasdaq ISE also provided daily open interest and volume data for the same time period.

Intraday cash index levels and intraday prices and trading volume for index futures were obtained from Tick Data.[24] Tick Data provides cash index prices (i.e., the level of the S&P 500 index and Nasdaq 100 index) at regular intervals throughout the day.[25] For the Russell 2000 index, intraday prices of the iShares Russell 2000 ETF, as reported by market participants to the consolidated feed, were obtained from Tick Data. Daily open interest data for futures on the

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[21] The data only include listed options, and do not include any over-the-counter options. Binary and range options are also not included.

[22] DERA staff is using the referenced data with Cboe's permission.

[23] DERA staff is using the referenced data with Cboe's permission.

[24] Tick Data licenses its U.S. equity data from the New York Stock Exchange; all its other data come from ICE Data or Morningstar.

[25] These regular intervals range from approximately one minute to approximately one second, depending on the year (the data become more granular beginning in 2015 for the S&P 500, and 2012 for the Nasdaq 100).

S&P 500 index and the Nasdaq 100 index were obtained from Thomson Reuters Refinitiv. Daily closing levels of the VIX index were obtained from the Cboe.

For the constituent analysis, the composition of the S&P 500 and Nasdaq 100 indices over time was obtained from Compustat. Constituent volume and market cap data were accessed through CRSP. TAQ provided NBBO and trades data for individual constituents.

V. Metrics

This section describes the metrics used to measure the extent to which the market experiences abnormal transitory volatility surrounding index option settlement. These include metrics derived from futures prices, described in Section V.A below, and metrics derived from the time series of computed index values, described in Section V.B below. Index values are computed under the direction of the index providers, and disseminated periodically to market participants during regular trading hours for the stock market, based on the most recent transaction prices of the component stocks. Index futures trade almost around the clock, including time periods outside of regular market hours for the equity markets.[26]

A. Futures Metrics

Since futures on cash indices trade frequently and are liquid both before and after the stock market opens and closes, they can be used to measure abnormal volatility in intervals surrounding the close, i.e., before and after the p.m. option settlement time. In addition, futures prices can be used to measure abnormal volatility surrounding the open. This allows to evaluate the degree to which abnormal volatility around the open is related to expiration of a.m.-settled

[26] Futures on the Mini-S&P 500 and Mini-Nasdaq 100 trade Sunday to Friday from 6:00 p.m. to 5:00 p.m. ET with a daily trading halt from 4:15 p.m. to 4:30 p.m. ET.

options, providing a useful benchmark for the results on p.m.-settled option expirations. The metrics described below are implemented using intraday futures data for the E-Mini S&P 500 index and the E-Mini Nasdaq 100 index.[27]

As a measure of volatility in the time period immediately after settlement of p.m.-settled options, the absolute value of the futures price return over a one-minute period following the stock market close, beginning with the index futures price immediately prior to the stock market close (i.e., prior to 4:00 p.m. ET), is computed.

Likewise, to measure abnormal volatility immediately after the open, the absolute return over a one-minute period from the last price observed before market open to the first price one minute after market open is computed.[28]

To measure volatility in the time period leading up to the close, the standard deviation of one-minute returns over the last 15 minutes of a trading day (typically 3:45 to 4:00 p.m. ET) is calculated. Volatility is normalized by the standard deviation of one-minute returns during regular hours on the same trading day, excluding the first and last 15 minutes of trading.[29] For example, if on a particular day the standard deviation of one-minute returns between 3:45 p.m. ET and 4:00 p.m. ET is 0.004 and the standard deviation of returns from 9:45 a.m. ET to 3:45 p.m. ET is 0.002, this metric would take on a value of 2 for that day, indicating that volatility

[27] Since futures on the E-Mini S&P 500 and the E-Mini Nasdaq 100 are more active and liquid, especially in recent years, and closely track futures on the underlying, it is more appropriate to construct these futures metrics using data for futures on the E-Minis. *See also* Hasbrouck, Joel, "Intraday price formation in US equity index markets," *The Journal of Finance* 58, no. 6 (2003): 2375–2400, for an analysis that shows that for the S&P 500 and Nasdaq 100 indices, most of the price discovery occurs in the E-mini market.
[28] A similar measure for the first minute of the trading day using the cash index data is not computed. Even though the cash index is computed and disseminated during this time period, there is generally a delay in the open on individual components of the index due to the time required to complete the opening auction process, and during this time period, the index calculation uses stale prices for index components that have not yet opened.
[29] The denominator of this metric is the standard deviation of all one-minute returns throughout the trading day, excluding the first and last 15 minutes.

during the last 15 minutes of the trading day was twice as high as it was during the rest of the trading day. This metric is referred to in the charts below as the "Standard Deviation Ratio." It is calculated only for the close.

As a third measure, a metric designed to measure the extent to which there is a price reversal immediately surrounding the close is employed. The measure of reversals is a modified version of the metric employed by SEC staff economists in their study of the Reg SHO pilot.[30]

At a high level, this metric is constructed by (1) partitioning the last 15 minutes of the day into one-minute intervals, (2) identifying the minimum and maximum price within each minute, (3) using these minimum and maximum levels to compute the largest price reversal observed during a group of three adjacent minutes, and (4) counting the number of times within the last 15 minutes that the largest reversal exceeded a certain threshold level.

More specifically, $Pmax_t$ is defined to indicate the highest price observed during minute *t* and $Pmin_t$ to indicate the lowest price observed during minute *t*. Using $Pmax_t$ and $Pmin_t$, the maximum and minimum returns across three adjacent minutes are calculated as follows:

Highest return from minute *t-1* to *t.*:

$$MaxRet_t = \frac{Pmax_t - Pmin_{t-1}}{Pmin_{t-1}} \qquad (1)$$

Lowest return from *t-1* to *t*:

$$MinRet_t = \frac{Pmin_t - Pmax_{t-1}}{Pmax_{t-1}} \qquad (2)$$

Lowest return from *t* to *t+1,* as a percentage of lagged minimum price:

[30] "Economic Analysis of the Short Sale Price Restrictions Under the Regulation SHO Pilot," *Office of Economic Analysis U.S. Securities and Exchange Commission*, February 6, 2007.

$$MinRetL_{t+1} = \frac{Pmin_{t+1} - Pmax_t}{Pmin_{t-1}} \quad (3)$$

Highest return from *t* to *t+1*, as a percentage of the lagged maximum price:

$$MaxRetL_{t+1} = \frac{Pmax_{t+1} - Pmin_t}{Pmax_{t-1}} \quad (4)$$

The largest reversal during a group of three adjacent minutes is then given by the formula:

$$MaxReversal = \max(PosRev, NegRev)/STD \quad (5)$$

where PosRev represents the largest positive reversal, calculated by the formula:

$$PosRev = \begin{cases} \min(MaxRet_t, -MinRetL_{t+1}) & \text{if } \mathrm{MaxRet_t} > 0 \text{ and } \mathrm{MinRetL_{t+1}} < 0 \\ 0 & \text{otherwise,} \end{cases} \quad (6)$$

and NegRev represents the largest negative reversal, calculated by the formula:

$$NegRev = \begin{cases} \min(-MinRet_t, MaxRetL_{t+1}) & \text{if } \mathrm{MinRet_t} < 0 \text{ and } \mathrm{MaxRetL_{t+1}} > 0 \\ 0 & \text{otherwise.} \end{cases} \quad (7)$$

The metrics PosRev and NegRev are similar to the positive and negative reversal measures defined in the Reg SHO pilot study conducted by SEC staff. The denominator in equation (5) is a measure of recent market volatility used to normalize the return. Specifically, STD is defined as the standard deviation of intraday returns, computed using one-minute intervals over a rolling window of five trailing trading days, including regular trading hours excluding the first and last 15 minutes of each day.

The values computed for the largest reversal from the minute before to the minute after the close, MaxReversal in equation (5), form the basis of the reversal metrics used in the regression analysis.

B. Cash Index Metrics

Index values are computed and disseminated periodically to market participants during regular trading hours for the stock market, based on the most recent transaction prices of the component stocks. It is assumed and understood that cash index values are not updated outside of regular trading hours, even if the component stocks may be trading off exchange during pre-market and after-hours sessions. Cash index values are used only to compute various metrics of abnormal transitory volatility in the time period leading up to the close of regular trading. The metrics described below are implemented using the cash index data for the Nasdaq 100 and S&P 500 indices. The metrics are implemented using ETF data for the Russell 2000 index.

The first metric of interest is the absolute magnitude of the index return over the last minute prior to market close. This is calculated as the absolute value of the percentage change in the cash index between 3:59 and 4:00 p.m. ET (or over the final minute of regular trading hours on holidays when the market closes early).[31]

Cash index data are used to calculate the Standard Deviation Ratio, which is implemented using the same methodology as outlined above in Section V.A in order to measure the abnormal volatility of short-horizon returns in the last 15 minutes of a trading day relative to the volatility of the rest of the trading day.

The third measure of transitory volatility is based on the reversal measure outlined in Section V.A above, but modified in a way so as to measure transitory volatility in the 15 minutes leading up to the close rather than the narrow window surrounding the close. Specifically, the number of minutes during the last 15 minutes of the day for which the largest reversal is greater

[31] Returns are calculated using the closest available index values observed immediately prior to 3:59 and 4:00 p.m. ET.

than two standard deviations is calculated. In terms of the formulas described in Section V.A above, the number of times during the last 15 minutes of regular trading hours that the variable MaxReversal takes on a value greater than two is counted.[32]

C. Summary Statistics

Table 4 provides summary statistics for all volatility metrics. Over the full time period analyzed, the median absolute return over the last minute of the day for the S&P 500 cash index is 0.03%, with a standard deviation of 0.05%. The median Standard Deviation Ratio is 113%, with a standard deviation of 41%. This implies that on a standard day, volatility is 13% higher during the last 15 minutes of a trading day compared to the middle of the trading day (excluding the first and last 15 minutes).

For the S&P 500-mini futures contract, the median absolute return over the last minute of the day over the full time period analyzed is 0.03%, with a standard deviation of 0.05%. The median Standard Deviation Ratio is 111%, with a standard deviation of 37%. The median magnitude of reversals leading up to the close is 1.96 standard deviations, with a standard deviation of 1.12. The median absolute return over the first minute of the day is 0.04%, with a standard deviation of 0.06%. The median magnitude of reversals in the period leading up to the open is 2.09 standard deviations, with a standard deviation of 0.96.

Over the full time period analyzed, the median absolute return over the last minute of the day for the Nasdaq 100 cash index is 0.04%, with a standard deviation of 0.08%. The median Standard Deviation Ratio is 111%, with a standard deviation of 42%. This implies that on a

[32] For the cash index reversal metric, STD is defined as the standard deviation of intraday returns, computed using one-minute intervals over a rolling window of 21 trailing trading days, including regular trading hours excluding the first and last 15 minutes of each day.

standard day, volatility is 11% higher during the last 15 minutes of a trading day compared to the middle of the trading day (excluding the first and last 15 minutes).

For the Nasdaq 100-mini futures contract, the median absolute return over the last minute of the day over the full time period analyzed is 0.03%, with a standard deviation of 0.06%. The median Standard Deviation Ratio is 104%, with a standard deviation of 40%. The median magnitude of reversals in the period leading up to the close is 1.58 standard deviations, with a standard deviation of 0.97. The median absolute return over the first minute of the day is 0.04%, with a standard deviation of 0.07%. The median magnitude of reversals in the period leading up to the open is 2.46 standard deviations, with a standard deviation of 1.29.

Over the full time period analyzed, the median absolute return over the last minute of the day for the Russell 2000 ETF is 0.01%, with a standard deviation of 0.02%. The median Standard Deviation Ratio is 92%, with a standard deviation of 31%. This implies that on a standard day, there is about 8% less volatility during the last 15 minutes of a trading day compared to the rest of the trading day.

VI. Methodology

A. Regression Specification I

To assess the impact of option expiration on volatility around the market close, a regression model is employed, whereby each of the futures and cash index volatility metrics described in Section V above is regressed on (1) the settlement quantity of p.m.-settled options,

(2) expiring open interest on futures,[33] and (3) control variables for other market conditions that could explain abnormal market activity.[34] Observations of settlement quantity and index futures expiring open interest correspond to a particular underlying index, such as the S&P 500, on a given expiration date.

This specification can be summarized by the regression equation:

$$PM\ Volatility\ Metric_t = \beta_0 + \boldsymbol{\beta_1 PM\ Settlement\ Quantity_t} + \beta_2 Controls_t + \epsilon_t \qquad (8)$$

where PM Volatility Metric_t represents one of the metrics described in Section V above, the subscript *t* denotes the date, and *Controls* is a vector of control variables including the expiring open interest of index futures, lagged aggregate trading volume in index options, the level of the VIX volatility index, and the open interest of non-expiring option series. This regression is estimated separately for the S&P 500, Russell 2000, and Nasdaq 100 indices.

The coefficient $\boldsymbol{\beta_1}$ measures the degree to which the volatility metric is related to the amount of options settling at the close. To test whether the expiration of p.m.-settled options has an effect on price volatility around the market close, the standard t-test is used to test whether the coefficient $\boldsymbol{\beta_1}$ is significantly different from zero.

The same specification is estimated for the cash index and index futures volatility metrics at market open to test whether there is any effect at the open, by replacing the closing settlement quantity with the opening settlement quantity.

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[33] Open interest of expiring futures contracts, observed on the day prior to expiration. Due to data limitations, this control is only calculated for the S&P 500.
[34] Control variables include lagged trading volume of options, the VIX closing price, and total open interest of non-expiring option series.

B. Regression Specification II

The specification described in the previous section tests whether abnormal volatility metrics are related to the level of settling open interest in a sample of expiration dates. As an alternative, a specification that uses non-expiration days as a control sample is developed. Each futures market and cash index volatility metric at the market close is regressed on the level of open interest of "very short term" p.m.-settled options (i.e., options with less than two days to expiration), as well as an indicator variable for expiration days, and an interaction term for the expiration indicator variable and the open interest variable:

$$PM\ Volatility\ Metric_t = \beta_0 + \beta_1 OpenInt_t + \beta_2 Expire_t + \beta_3 Expire_t * OpenInt_t + \beta_4 Controls_t + \epsilon_t \quad (9)$$

where $OpenInt_t$ respresents the open interest of options with less than two days to expiration, $Expire_t$ is an indicator variable taking on a value of one on expiration days and zero otherwise, and *Controls* is a vector of control variables including the expiring open interest of index futures, lagged aggregate trading volume in index options, the level of the VIX volatility index, and the open interest of non-expiring option series. This regression is estimated separately for the S&P 500, Russell 2000, and Nasdaq 100 indices.

This specification tests whether the relationship between abnormal market activity near the close and the level of open interest is significant on the days the options are expiring compared to a benchmark of other days when the options are not expiring. The coefficient on the interaction term ($\boldsymbol{\beta_3}$) is the coefficient of interest to test whether the expiration of p.m.-settled options has an effect on price volatility around the market close.

C. Regression Specification III

To assess whether the impact of option expiration on volatility around the market close is different during days of high volatility ("high stress days") relative to days of low volatility, a modified version of Regression Specification I, which controls for days with particularly high volatility, is employed. Specifically, a regression model is used whereby each of the futures and cash index volatility metrics described in Section V above is regressed on (1) the settlement quantity of p.m.-settled options, (2) expiring open interest on futures, (3) an interaction variable consisting of a high stress day indicator and the settlement quality of p.m.-settled options, and (4) control variables for other market conditions that could explain abnormal market activity.

The level of the VIX closing index value for the day is used as a proxy for high stress days. The high stress day indicator takes on a value of 1 for the days where the VIX index was in the highest 10% of values in the sample and takes on a value of 0 otherwise. The cutoff for the highest 10% of VIX values is 29.02.

This specification can be summarized by the regression equation:

$$PM\ Volatility\ Metric_t = \beta_0 + \boldsymbol{\beta_1 PM\ Settlement\ Quantity_t} + \boldsymbol{\beta_2 PM\ Settlement\ Quantity_t * VIX\ High\ Value\ Indicator_t} + \beta_3 Controls_t + \epsilon_t \qquad (10)$$

where PM Volatility $Metric_t$ represents one of the metrics described in Section V above, the subscript *t* denotes the date, and *Controls* is a vector of control variables including the expiring open interest of index futures, lagged aggregate trading volume in index options, the level of the VIX volatility index, and the open interest of non-expiring option series. This regression is estimated for the S&P 500 index.

The coefficient $\boldsymbol{\beta_2}$ measures the differential effect for high stress days that the amount of options settling at the close has on the volatility metric relative to other days. The standard t-test is used to test whether the coefficient $\boldsymbol{\beta_2}$ is significantly different from zero.

The same specification is estimated for the index futures volatility metrics at market open to test whether there is any effect at the open, by replacing the closing settlement quantity with the opening settlement quantity.

D. Constituent Analysis

To study the impact of index option expiration at the close on the volatility of the components of the indices, a modified version of Specification II is employed by estimating the regression equation outlined in the previous subsection on a large panel data set that includes one observation for each constituent each day. The end-of-day volatility metrics described in Section V above are computed for each index constituent each day. All trading days in 2018 are included.

As described in the previous section, this specification tests whether the relationship between abnormal market activity near the close and the level of open interest is significant on the days the options are expiring compared to a benchmark of other days when the options are not expiring. This analysis is estimated for the S&P 500 index, the Nasdaq 100 index, and the Russell 2000 index.

To confirm that the impact of index option expiration on the volatility of index components is not driven by firm-specific factors, *less liquid* index components are studied. The end-of-day volatility metrics described in Section V above are computed for each *relatively illiquid* constituent each day. All trading days in 2018 are included.

Relatively illiquid ("*less liquid*") constituents are defined using three different measures calculated for January 2, 2018: (i) the 100 smallest as per the constituents' market capitalization; (ii) the 100 most illiquid per the constituents' time-weighted relative bid-ask spread; and (iii) the 100 most illiquid per the constituents' notional trading volume. This sensitivity test is focused on constituents of the S&P 500 index for 2018. The intent of selecting three different definitions of *liquidity* is to verify that the results are not being driven by the definition of *liquidity*.

As described in the previous subsection, this specification tests whether the relationship between abnormal market activity near the close and the level of open interest is significant on the days the options are expiring compared to a benchmark of other days when the options are not expiring.

VII. Results: S&P 500 Index Options

This section presents results from an application of the methodologies described in Section VI above, testing whether a higher quantity of expiring p.m.-settled options is associated with greater volatility leading up to and surrounding the close on expiration dates for S&P 500 options.

Results for the S&P 500 index, discussed in detail in the subsections below, do indicate statistical evidence of a positive association between settlement quantity and volatility around the close in both the cash index and in the index futures market. For purposes of comparison, the same methodology is applied to evaluate whether a similar association exists between the expiring a.m.-settled options and volatility around the open, and no statistically significant association is observed at the open. As discussed below, evidence of a statistical association does not necessarily imply that the magnitude of the impact is large enough to be economically important. Illustrative computations are provided below to aid in assessing economic significance. Summary statistics of regression variables can be found in Tables 25 to 27.

A. Results Based on Futures Market Metrics

1. Specification I

Table 5 contains results for the regression specification that assesses volatility effects around the market close or open for the index futures volatility metrics for the S&P 500 index.

For the S&P 500 index futures, larger option settlement quantities are associated with higher price volatility near the close. However, the economic magnitude is not necessarily large. This is illustrated in Table 5, which shows regression results for the index futures volatility metrics using total settlement quantity as the key independent variable for p.m.-settled S&P 500 index options. Total settlement quantity is measured in units of $10 billion in notional value. There is a positive and statistically significant relationship between total settlement quantity and two of the three volatility metrics, which suggests that higher option settlement quantities are associated with higher price volatility of S&P 500 futures near the close. While the effect of total settlement quantity on the absolute return in the last minute of trading is not statistically significant at the 5% level, it is very nearly so (the p-value is 0.052).

The coefficient on total settlement quantity for the standard deviation ratio (see second column of numbers in Table 5) is 0.07918. The estimated coefficient of 0.07918 means that if there is an additional $10 billion in expiring notional of p.m.-settled options, the standard deviation ratio would be 0.07918 higher. An increase of 7.92 percentage points in the standard deviation ratio corresponds to a price movement of about $0.06 for a hypothetical index level of 2,500. Over the period analyzed, the median unconditional standard deviation of one-minute returns during the middle of the trading day (excluding the first and last 15 minutes of the day) is 0.032%, and the median unconditional standard deviation of one-minute returns during the last 15 minutes of the day is 0.035%. This indicates that the volatility during the last 15 minutes before the market close is generally higher than during the rest of the trading day. For a hypothetical index level of 2,500, this translates to a nominal standard deviation of one-minute returns of about $0.80 during the day and $0.88 in the last 15 minutes. Based on the regression results presented in Table 5, an additional $10 billion in expiring notional of p.m.-settled options therefore is associated with a marginal increase in the price movement during the last 15 minutes of about $0.06.

The coefficient on total settlement quantity for the reversal measure regression (see last column of Table 5) is 0.31705. To help understand the economic magnitude of this finding, this implies that a $20 billion (about 1.6 standard deviations) increase in settlement quantity is associated with an increase in the magnitude of reversals of 0.6341 standard deviations. The median magnitude of reversals near the close is 1.96.

Index futures data are also used for the analysis of a.m.-settled S&P 500 options. Volatility metrics at the open using cash index data are not calculated because cash index data both before and for a brief period after the beginning of regular trading hours (until the last component stock has officially opened) are calculated based on stale information.

Across the volatility measures, none of the coefficients on the variable of interest are statistically significant. Thus, there is no evidence of a relationship between the quantity of options that settle at the market open and volatility around the market open. These results are presented in Table 6, which reports results for index futures volatility and total settlement quantity as the key independent variable for a.m.-settled S&P 500 index options. Total settlement quantity is measured in units of $10 billion in notional value.

2. Specification II

For the S&P 500 index futures, the results indicate that higher open interest levels are associated with higher volatility near the close on expiration days relative to non-expiration days. Similar to the Specification I results, the economic magnitude is not necessarily large. This is illustrated in Table 7, which shows regression results for the index futures volatility metrics and includes days without an option expiration for p.m.-settled S&P 500 options.[35] The key independent variable is the interaction term between expiration day indicator and the near-expiration open interest (settlement quantity). Open interest is measured in units of $10 billion. The coefficient on the interaction term is positive and significant for two out of three regressions, which is largely consistent with all the previously discussed regression results for the S&P 500 index.

The coefficient on the interaction term for the standard deviation ratio (see second column of numbers in Table 7) is 0.07619. The estimated coefficient of 0.07619 means that if there is an additional $10 billion in expiring notional of p.m.-settled options, the standard deviation ratio would be 0.07619 higher. An increase of 7.62 percentage points in the standard deviation ratio corresponds to a price movement of about $0.05 for a hypothetical index level of 2,500.

[35] Days without an option expiration are used as a control sample. For S&P 500 options, Tuesdays and Thursdays do not have an option expiration (unless a Friday is a holiday and options with a Friday expiration are settled on the previous Thursday). All other days of the week have an option expiration. The different metrics of volatility are therefore calculated on all days of the week, and compared for days with options settlement (i.e., Mondays, Wednesdays, and Fridays) to days without options settlement (i.e., Tuesdays and Thursdays).

The coefficient on total settlement quantity for the reversal measure (see last column of Table 7) is 0.28289. This implies that a $20 billion marginal increase in notional value of open interest of near-expiration options is associated with an increase in the magnitude of reversals of 0.5658 standard deviations. The median magnitude of reversals at the close is 2.08.

3. Specification III

Table 8 (9) contains results for the regression specification that assesses whether volatility effects around the market close (open) for the index futures volatility metrics for the S&P 500 index are different during high stress days than on other days. The coefficient on interaction term VIX High-Value Indicator x Settlement Quantity – P.M. Options (VIX High-Value Indicator x Settlement Quantity – A.M. Options) measures the difference.

For the p.m.-settled options, the coefficient on the interaction term is negative and statistically significant for one out of three volatility measures: the absolute last return of day. The value of the coefficient is -0.0001 which implies that for every $10 billion in settlement quantity during high stress days, the return near the close is lower by 0.01% (see first column of numbers in Table 8). This corresponds to a fluctuation of approximately $0.30 on an index level of 2,500. The coefficients on the interaction terms for the other two volatility measures are statistically insignificant. Since none of the volatility measures shows a greater effect due to settlement quantity on high stress days, the overall results do not support the notion that there are higher effects due to p.m. settlements on high stress days.

For the a.m.-settled options, the coefficient on the interaction term is statistically insignificant for two volatility measures (see Table 9, 4th line of coefficients). Since none of the volatility measures shows a greater effect due to settlement quantity on high stress days, the overall results do not support the notion that there are higher effects due to a.m. settlements on high stress days.

B. Results Based on Cash Index Metrics

1. Specification I

Similar to the findings for the S&P 500 index futures, there is statistical evidence for the S&P 500 index that higher settling open interest is associated with higher volatility in the period leading up to the close. Again, the economic magnitude of the effect is not necessarily large. This is illustrated in Table 10, which shows regression results for the cash index volatility metrics using total settlement quantity as the key independent variable for p.m.-settled S&P 500 index options. Total settlement quantity is measured in units of $10 billion in notional value. There is a positive and statistically significant relationship between total settlement quantity and all three metrics of volatility. This suggests that higher settlement quantities of options settling at the close are associated with higher price volatility of the underlying index leading up to the close.

The coefficient on the absolute value of the last return of the day is approximately 0.00006 (see the first column in Table 10). This implies that a $20 billion (about 1.6 standard deviations) marginal increase in settlement quantity is associated with an increase in absolute return of 0.0001 or 0.01% near the close. This corresponds to a fluctuation of approximately $0.30 on an index level of 2,500.

The coefficient on total settlement quantity for the standard deviation ratio (see second column of numbers in Table 10) is 0.11518. The estimated coefficient of 0.11518 means that if there is an additional $10 billion in expiring notional of p.m.-settled options, the standard deviation ratio would be 0.11518 higher. An increase of 11.52 percentage points in the standard deviation ratio corresponds to a price movement of about $0.08 for a hypothetical index level of 2,500.[36]

The coefficient on total settlement quantity for the reversal measure suggests that it would require an increase of $34 billion in notional value of total settlement quantity for one additional reversal of greater than two standard deviations to occur (see third column of numbers in Table 10).

2. Specification II

Table 11 contains results for the regression specification that assesses volatility effects around the market close for the cash index volatility metrics for the S&P 500 index on days with and without an option expiration at the close.

The results show that higher open interest levels are associated with higher volatility near the close on expiration days relative to non-expiration days. The economic magnitude does not seem large. The key independent variable of the regression that is illustrated in Table 11 is the interaction term between the expiration day indicator and the near-expiration open interest. Open interest is measured in units of $10 billion. There is a positive and statistically significant relationship between the interaction term and all three metrics of volatility, which suggests that higher levels of open interest of options that are close to expiration are associated with higher price volatility near the close.

[36] Over the period analyzed, the median unconditional standard deviation of one-minute returns during the middle of the trading day (excluding the first and last 15 minutes of the day) is 0.027%, and the median unconditional standard deviation of one-minute returns during the last 15 minutes of the day is 0.030%. For a hypothetical index level of 2,500, this translates to a nominal standard deviation of one-minute returns of about $0.68 during the day and $0.75 in the last 15 minutes.

The coefficient on the interaction term for the absolute value of the last return of the day (see first column of numbers in Table 11) is 0.00006. This implies that a $20 billion (about 1.6 standard deviations) marginal increase in notional value of total settlement quantity is associated with an increase in absolute return of 0.0001 or 0.01% ($0.30 at the 2,500 level of the index).

The coefficient on the interaction term for the standard deviation ratio (see second column of numbers in Table 11) is 0.10950. The estimated coefficient of 0.10950 means that if there is an additional $10 billion in expiring notional of p.m.-settled options, the standard deviation ratio would be 0.10950 higher. An increase of 10.95 percentage points in the standard deviation ratio corresponds to a price movement of about $0.06 for a hypothetical index level of 2,500.

The coefficient on the interaction term for the reversal measure suggests that it would require a $34 billion increase in settlement quantity for one additional reversal of greater than two standard deviations to occur (see third column of numbers in Table 11).

3. Specification III

Table 12 contains results for the regression specification that assesses whether volatility effects around the market close for the cash index volatility metrics for the S&P 500 index are different during high stress days than on other days. The coefficient on the interaction term (VIX High-Value Indicator x Settlement Quantity – P.M. Options) measures the difference.

The coefficient on the interaction term is positive and statistically significant for one out of three volatility measures: reversals above 2 standard deviations. The coefficient is approximately 0.97. This implies that a $10 million marginal increase in notional value of total settlement quantity during high stress days is associated with approximately one additional reversal with a size of more than 2 standard deviations (see third column of numbers, 4th row of coefficients in Table 12). Since only one out of three volatility measures shows a greater effect due to settlement quantity on high stress days, the overall results are inconsistent and inconclusive regarding a differential effect on high stress days.

C. Results Based on Constituent Stock Prices

For the constituents of the S&P 500 index, higher levels of open interest of p.m.-settled S&P 500 options that are close to expiration are associated with higher price volatility near the close on the days of expiration relative to options with lower levels of open interest or days without an option expiration at the close. However, the economic magnitude does not necessarily seem large. This is illustrated in Table 13, which shows regression results for the index constituents. The regression estimation includes days without an option expiration for p.m.-settled S&P 500 index options. As for the index-level regressions, these additional days are included to act as a control sample. The key independent variable is the interaction term between expiration day indicator and the near-expiration open interest (settlement quantity). Open interest is measured in units of $10 billion. There is a positive and statistically significant relationship between the interaction term and all three metrics of volatility, which suggests that larger settlement quantities are associated with higher price volatility near the close for constituents of the index. The constituent results are consistent with earlier results pertaining to the S&P 500 cash index volatility where larger settlement quantities were associated with higher volatility of the index at the close.

The coefficient on the interaction term for the absolute value of the last return of the day (see first column of numbers in Table 13) is 0.00006. This implies that a $20 billion (about 1.6

standard deviations) marginal increase in notional value of total settlement quantity is associated with an increase in absolute return of 0.0001 or 0.01% ($0.03 for a $200 stock).

The coefficient on the interaction term for the standard deviation ratio (see second column of numbers in Table 13) is 0.04013. The estimated coefficient of 0.04013 means that if there is an additional $10 billion in expiring notional of p.m.-settled options, the standard deviation ratio would be 0.04013 higher.

The coefficient on the interaction term for the reversal measure suggests that it would require a $7 billion increase in settlement quantity for one additional reversal of greater than two standard deviations to occur (see third column of numbers in Table 13).

To confirm that the results described above are not driven by firm-specific factors, the results' sensitivity is tested by analyzing a subsample of the most illiquid and smallest S&P 500 constituents as of January 2, 2018. Overall, there is no evidence to support the notion that less liquid securities experience a different effect from settlement at the close relative to more liquid or larger securities.

Table 14 provides results for the 100 smallest constituents of the S&P 500 index, where size is measured by a constituent's market capitalization. The key independent variable is the interaction term between expiration day indicator and the near-expiration open interest (settlement quantity). The coefficients on the interaction terms are positive and significant, and are the same or lower than those of the entire sample (see Table 13).

Table 15 provides results for the 100 most illiquid constituents as measured by time-weighted relative bid-ask spreads. The coefficients on the interaction term are positive and significant, and are the same or lower than those of the entire sample (see Table 13).

Table 16 provides results for a variation of the analysis presented in Table 15. The 100 most illiquid stocks are analyzed, where liquidity is measured by notional trading volume. The coefficients on the interaction terms are positive and significant, and are the same or lower than those of the entire sample (see Table 13).

VIII. Results: Other Indices

This section presents results from an application of the methodologies described in Section VI above, testing whether a higher quantity of expiring options is associated with greater volatility leading up to and surrounding the close (or open) on expiration dates.

In contrast to the results for the S&P 500 index described in the previous section, results for the Russell 2000 and Nasdaq 100 indices are less clear. For the Russell 2000 index, settling open interest was found to be related only to the standard deviation ratio, but not to the other metrics. The coefficients of interest for the standard deviation ratio are higher than what was found for the corresponding specifications for the S&P 500 index, but the overall economic magnitude is of similar size. The results are illustrated in Tables 17 and 18.

For the Nasdaq 100 index, the results are more difficult to interpret. Settling open interest was found to be statistically associated with the number of reversals in the last 15 minutes of the day in both the cash index and the futures market, but no significant relationship was found for the other metrics. The coefficients of interest for the reversal metrics are notably higher than what was found for the corresponding specifications for the S&P 500 index. Results are presented in Tables 19 through 24.

For the constituents of the Nasdaq 100 index, the results are mixed. The results show a positive relationship of settling quantity and the reversal metric. However, for the standard deviation ratio and the absolute last return, there is either no association or a negative association with the quantity of settling options. The results, which are illustrated in Table 24, are therefore difficult to interpret.

For the analysis of a.m.-settled Nasdaq 100 options, higher option settling quantities are associated with higher volatility around the open. This is in contrast to the findings for the a.m.-settled options of the S&P 500 index, for which higher option settling quantities were not found to be associated with higher volatility around the open. Results for the a.m.-settled Nasdaq 100 options are illustrated in Table 20.

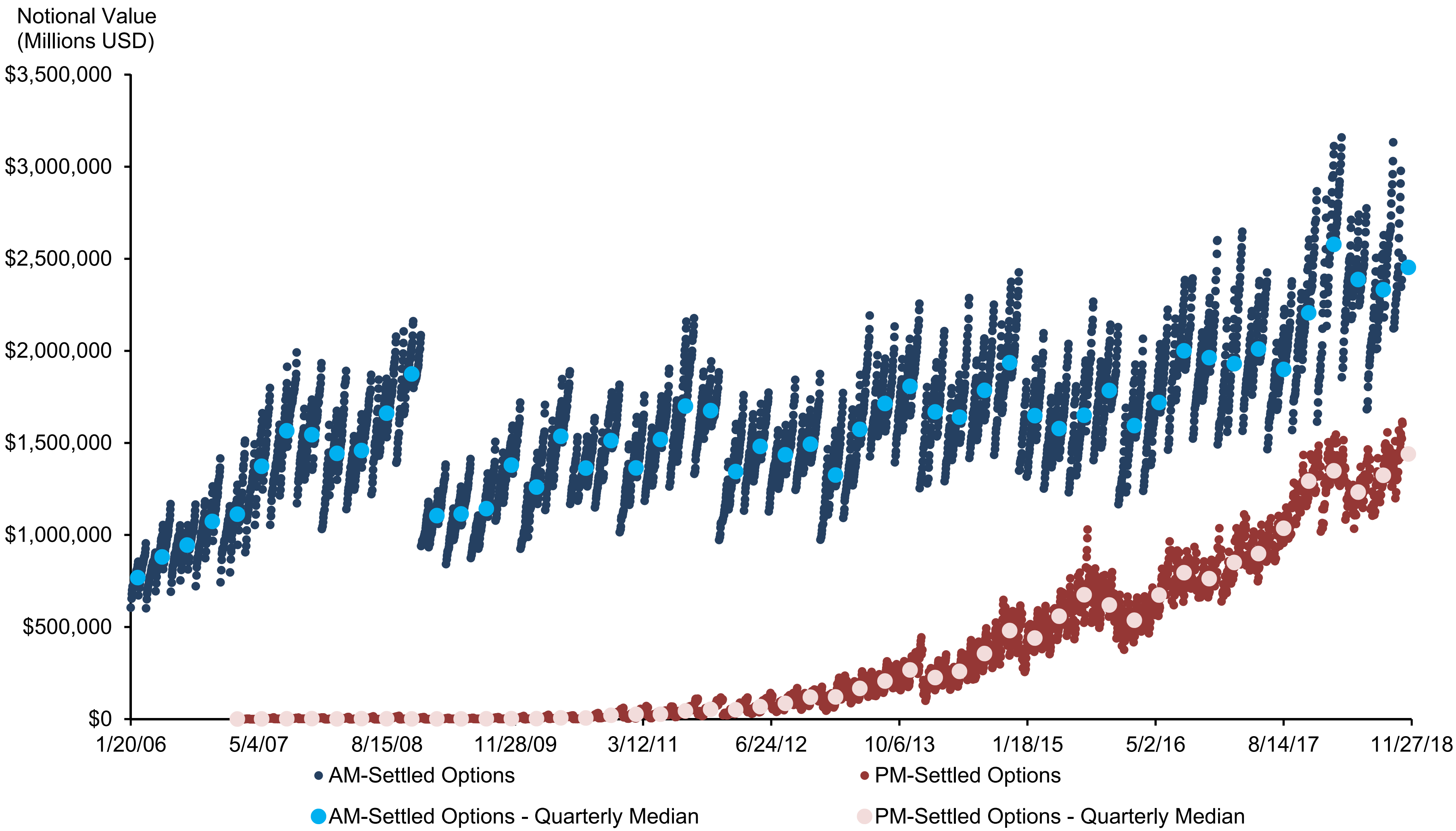
IX. Findings – Control Variables

The findings for the control variables generally show mixed results across all regression analyses. None of the control variables, which include the VIX index, the lagged total option trading volume, a proxy for expiring open interest of futures contracts, and the notional open interest across non-expiring option contracts, shows a consistently statistically significant relationship with the index futures and cash index volatility metrics. Yet, none of the control variables shows a consistently insignificant relationship with the volatility metrics either.

For example, when analyzing results for the regression specification that assesses volatility effects around the market close or open for the index futures volatility metrics for the S&P 500 index, the coefficients on the control variables are generally not significant except for the following two instances. The coefficient for the VIX index level is positively and statistically significantly correlated with the absolute last return. The coefficient on the lagged total trading volume of options is negatively and statistically significantly correlated with the reversal metric. This looks slightly different when analyzing results for the regression specification that assesses volatility effects around the market close for the index futures volatility metrics for the S&P 500 index on days with and without an option expiration at the close. For example, the coefficient on the lagged total trading volume of options is now insignificant for the reversal metric, whereas the VIX index level continues to be positively and statistically significantly correlated with the absolute last return.

Figure 1

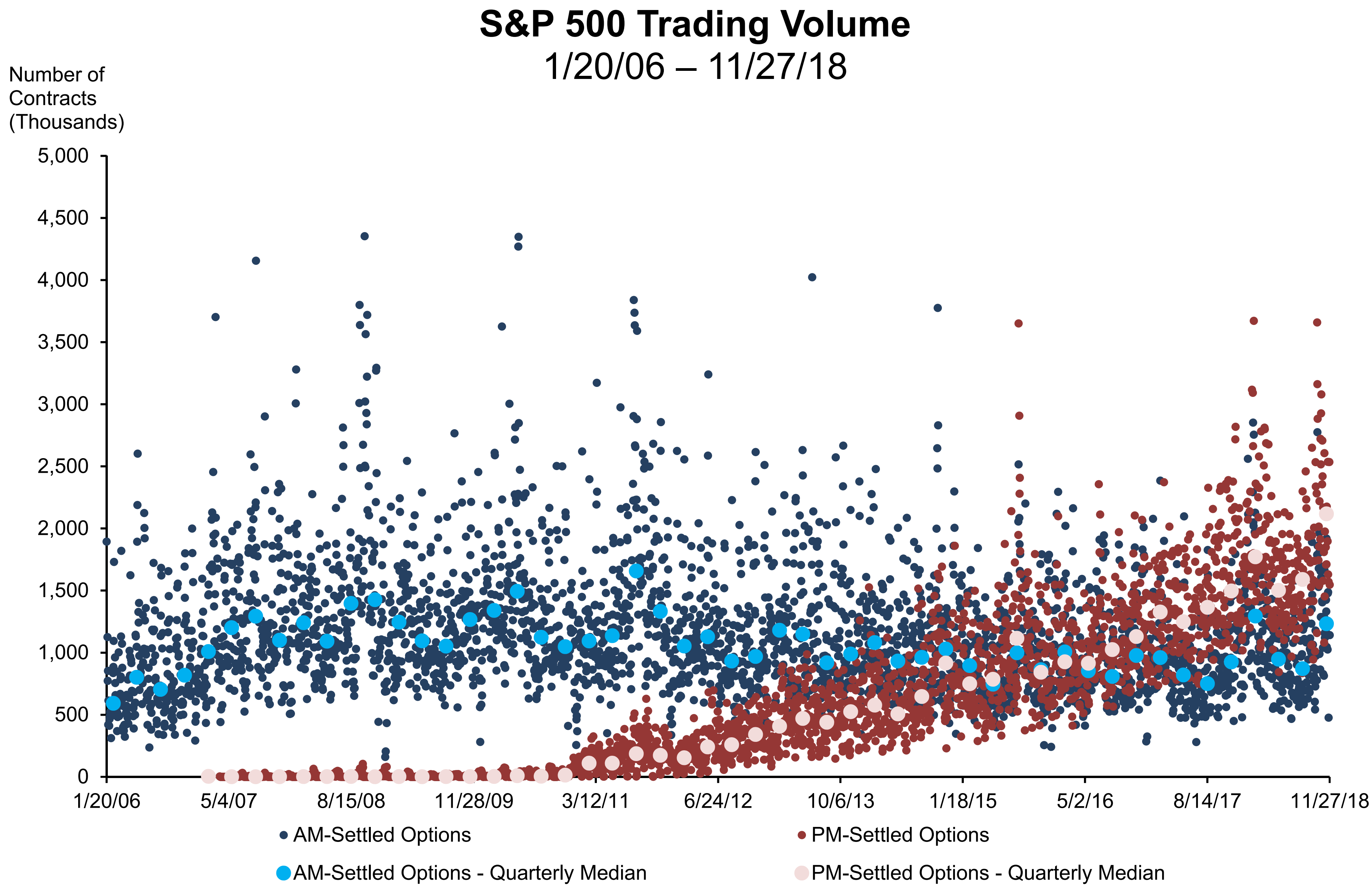
S&P 500 USD Notional Open Interest
1/20/06 – 11/27/18



Source: Cboe

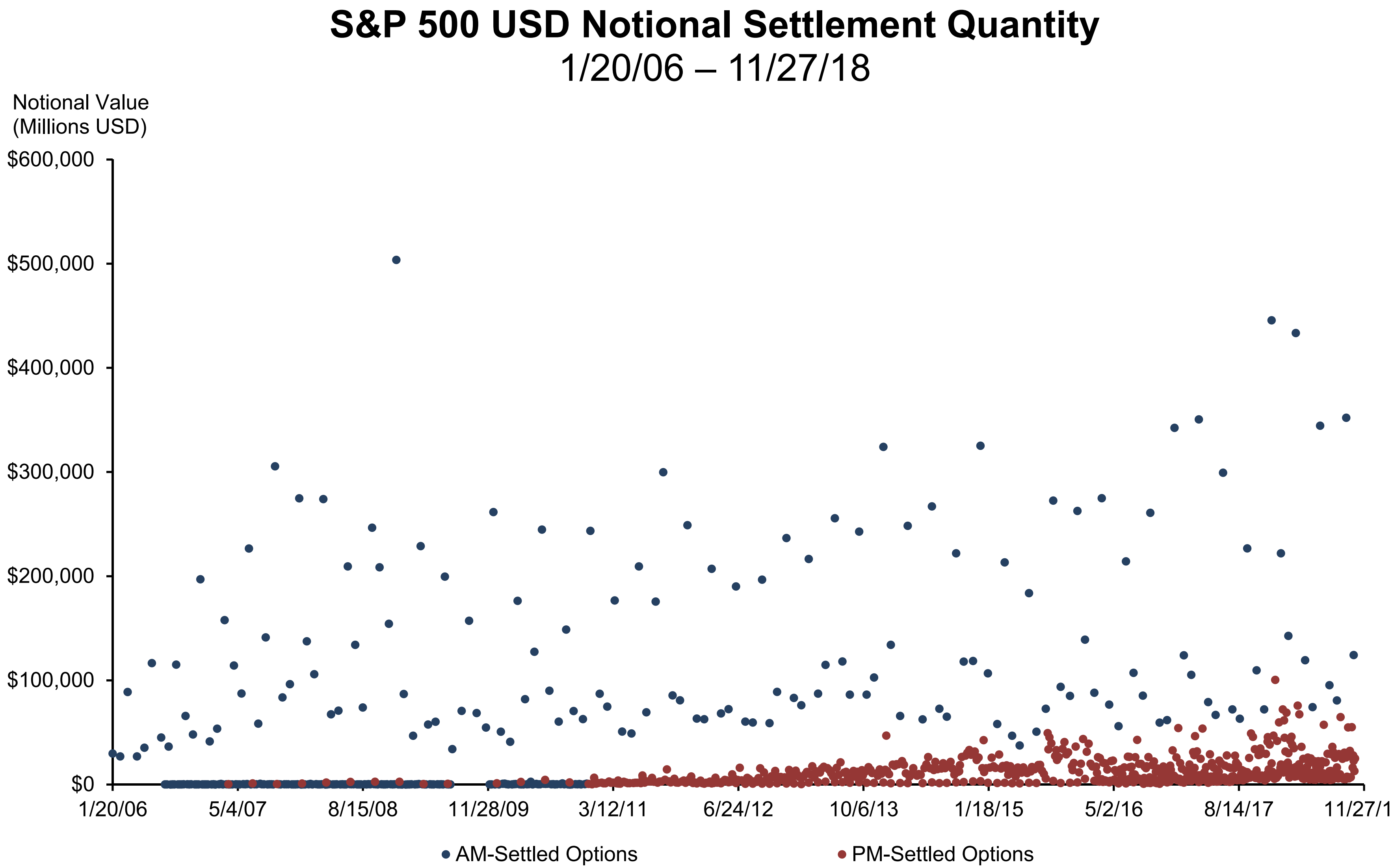
Note: The date range is the time period over which the S&P 500 regression specifications were estimated. For the PM specification, the regression is estimated from 3/30/07 to 11/27/18. The notional value is calculated by multiplying the number of contracts by the strike price for each option series and then summing across option series.

Figure 2



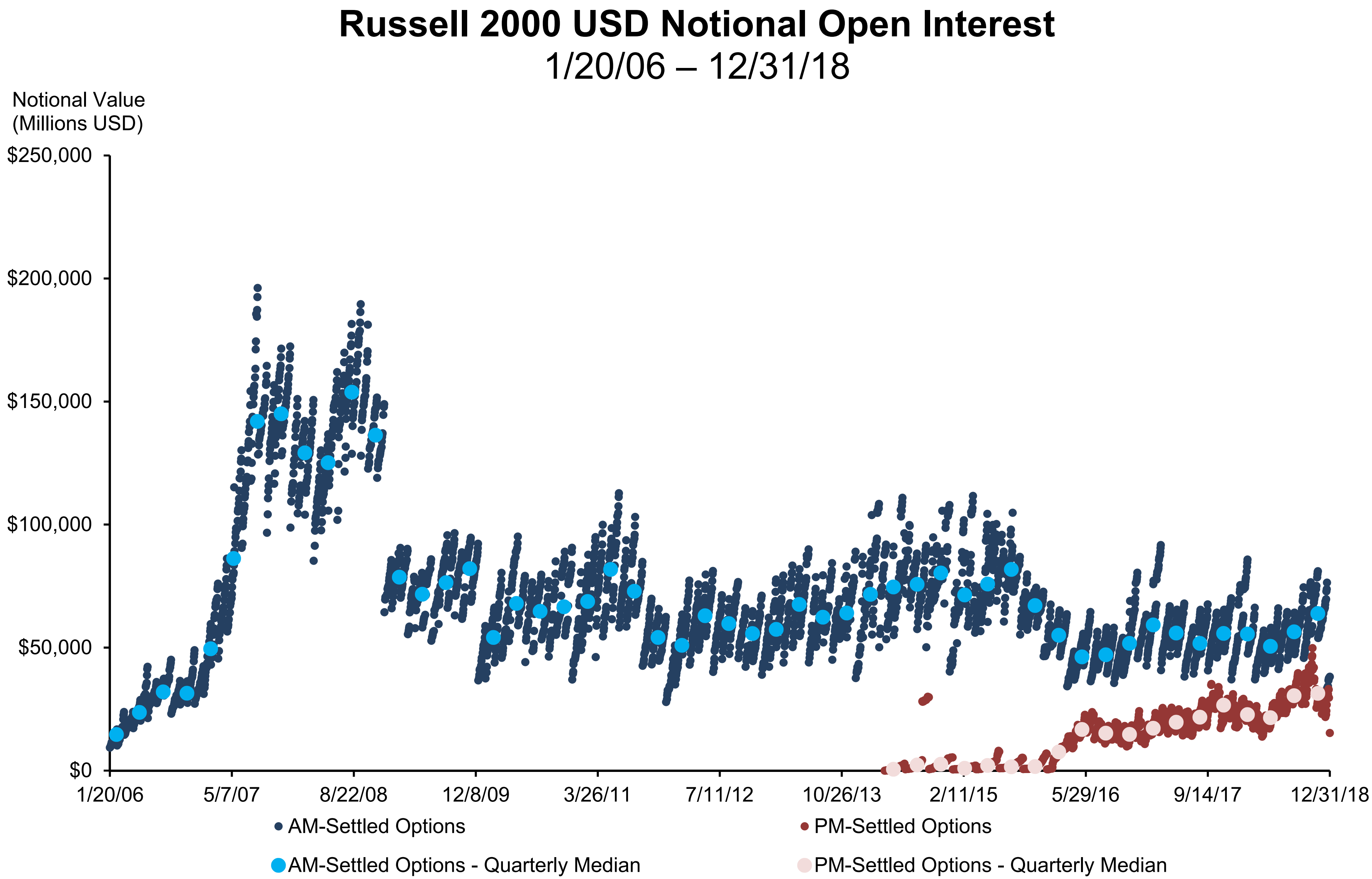
Source: Cboe

Note: The date range is the time period over which the S&P 500 regression specifications were estimated. For the PM specification, the regression is estimated from 3/30/07 to 11/27/18.



Source: Cboe

Note: The date range is the time period over which the S&P 500 regression specifications were estimated. For the PM specification, the regression is estimated from 3/30/07 to 11/27/18. The notional value is calculated by multiplying the number of contracts by the strike price and then summing across option series. Only settlement days where the standard size options contract settled are included.

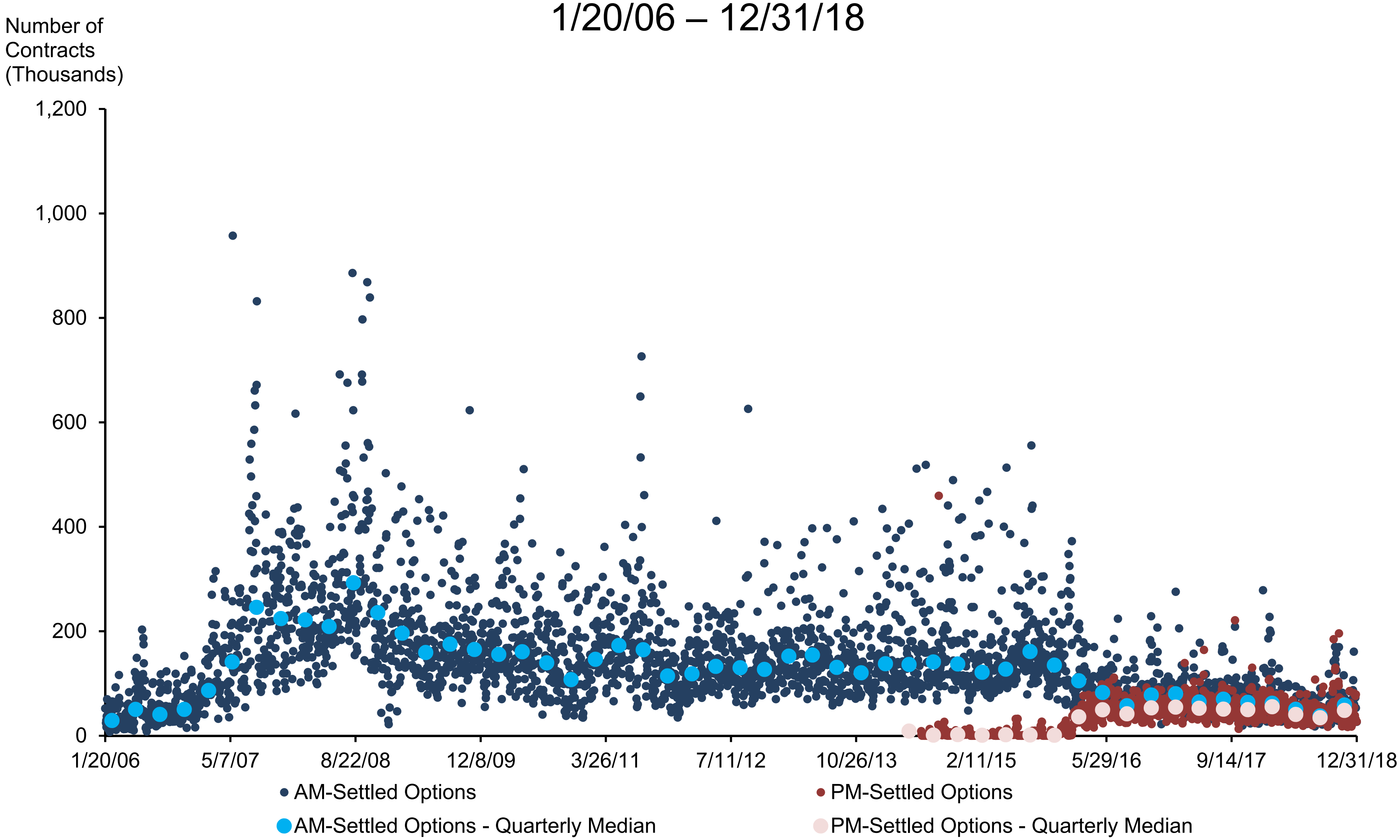


Source: Cboe

Note: The date range is the time period over which the Russell 2000 regression specifications were estimated. For the PM specification, the regression is estimated from 6/30/14 to 12/31/18. The notional value is calculated by multiplying the number of contracts by the strike price and then summing across option series.

Figure 5

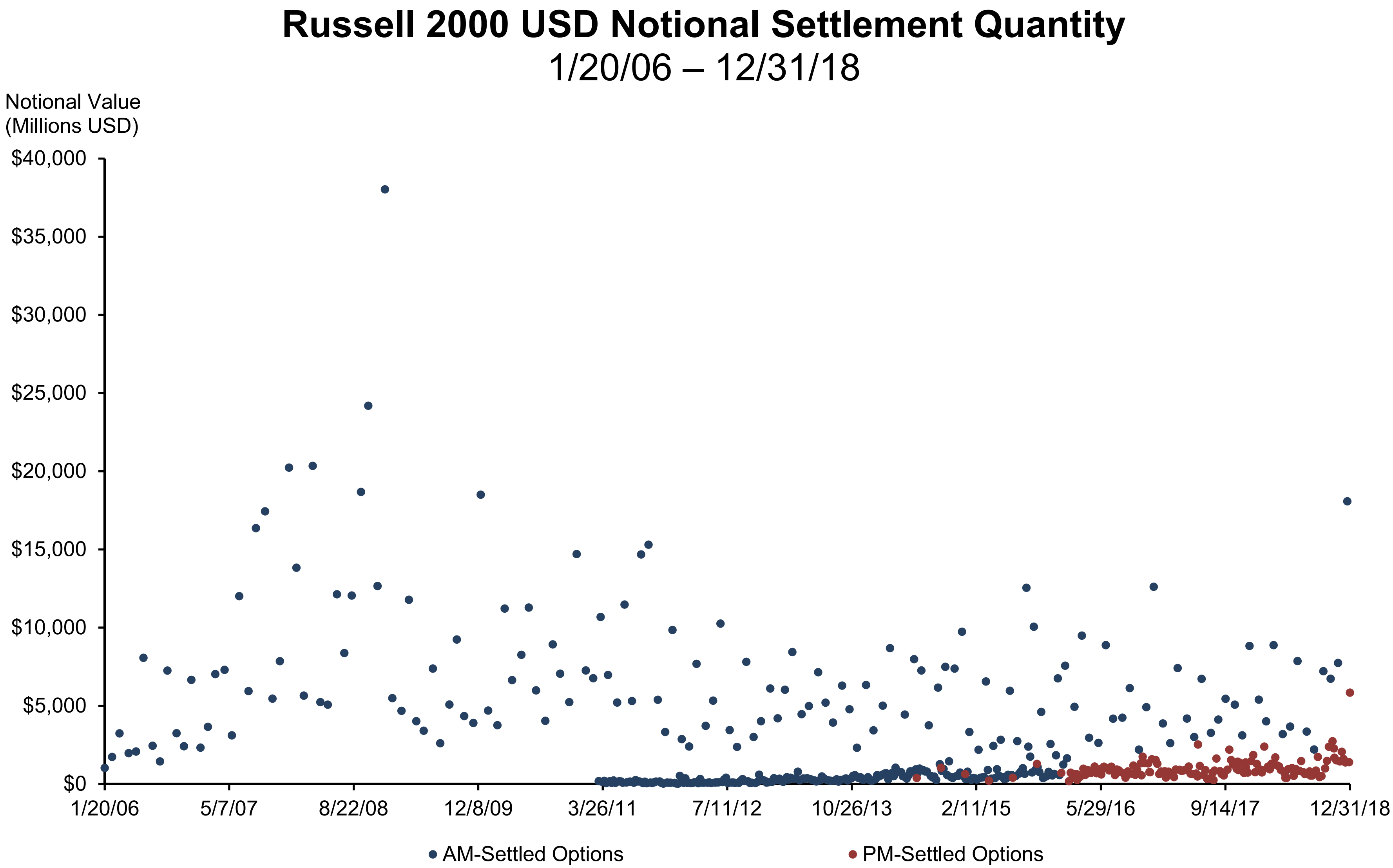
Russell 2000 Trading Volume
1/20/06 – 12/31/18



Source: Cboe

Note: The date range is the time period over which the Russell 2000 regression specifications were estimated. For the PM specification, the regression is estimated from 6/30/14 to 12/31/18.

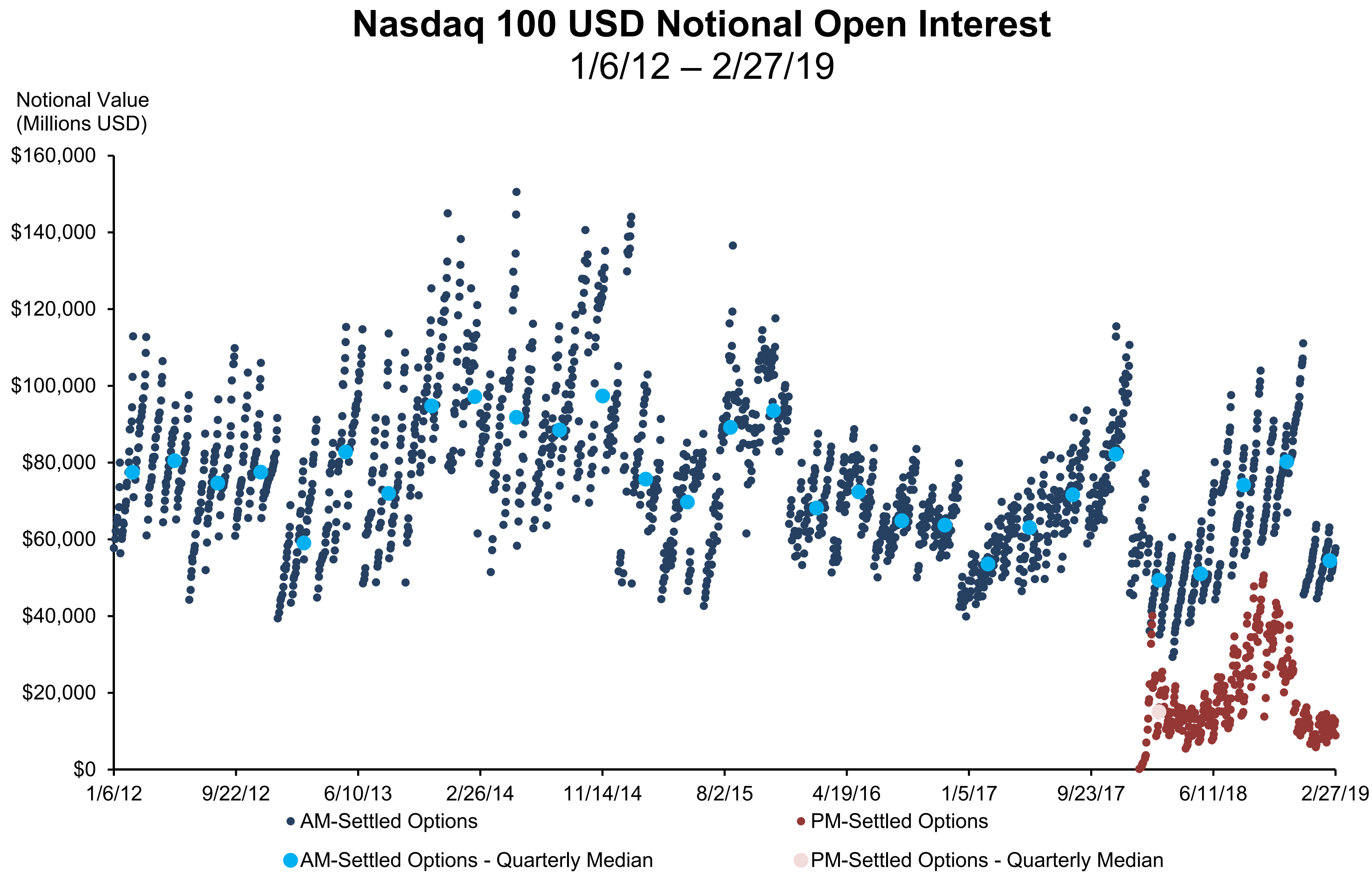
Figure 6



Source: Cboe

Note: The date range is the time period over which the Russell 2000 regression specifications were estimated. For the PM specification, the regression is estimated from 6/30/14 to 12/31/18. The notional value is calculated by multiplying the number of contracts by the strike price and then summing across option series.

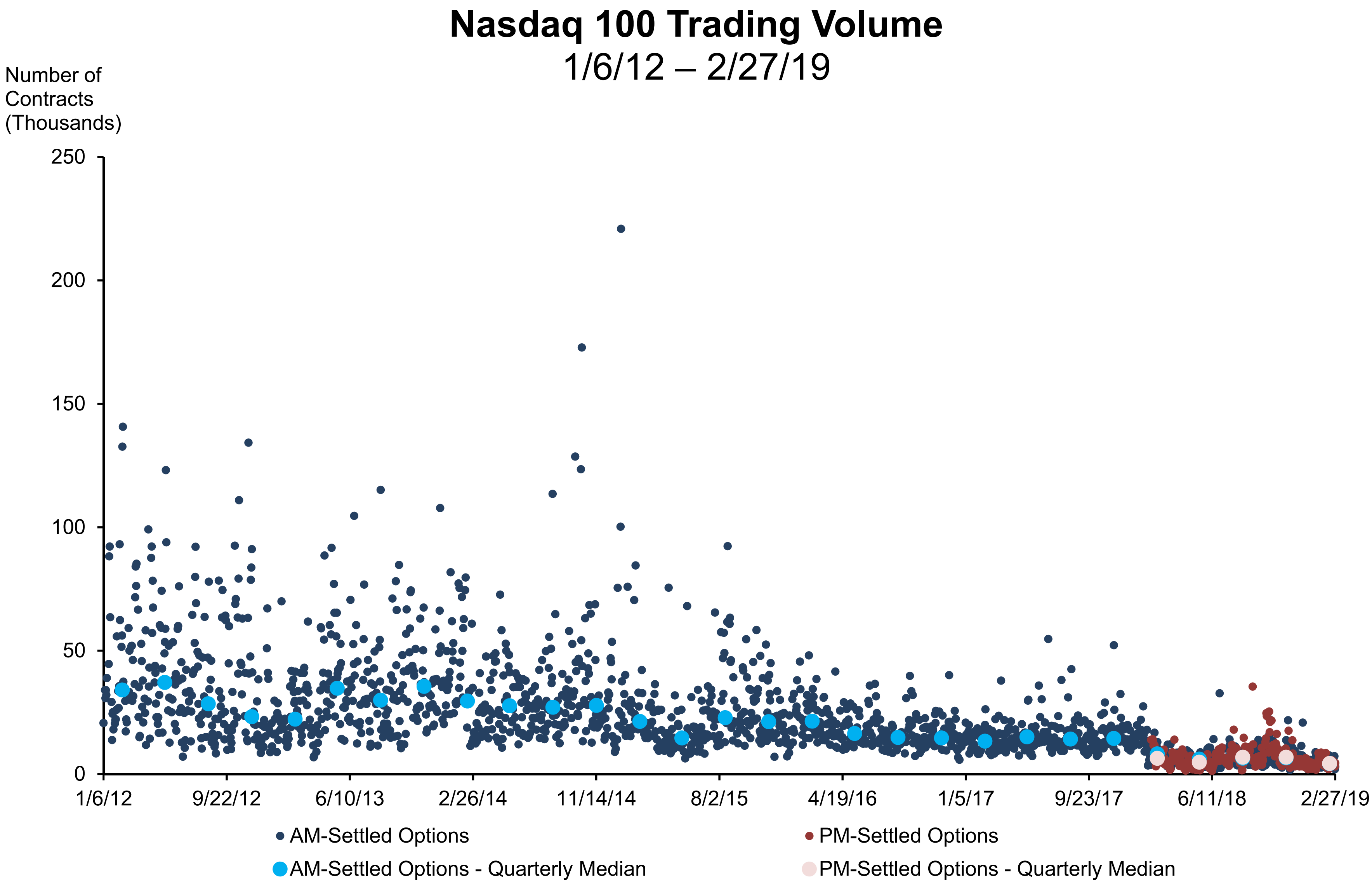
Figure 7



Source: ISE/PHLX

Note: The date range is the time period over which the Nasdaq 100 regression specifications were estimated. For the PM specification, the regression is estimated from 2/2/18 to 2/27/19. The notional value is calculated by multiplying the number of contracts by the strike price and then summing across option series.

Figure 8

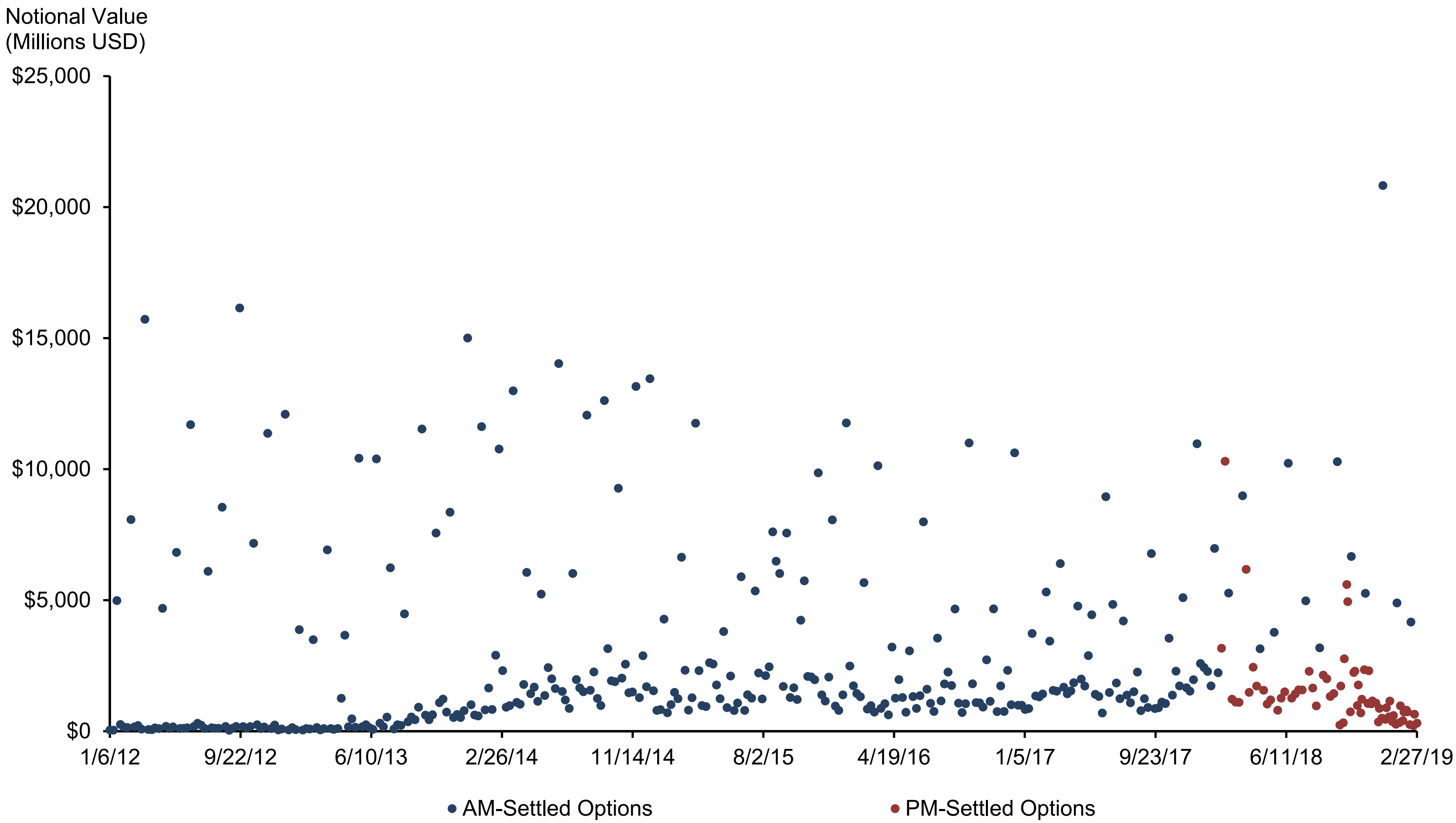


Source: ISE/PHLX

Note: The date range is the time period over which the Nasdaq 100 regression specifications were estimated. For the PM specification, the regression is estimated from 2/2/18 to 2/27/19.

Nasdaq 100 USD Notional Settlement Quantity

1/6/12 – 2/27/19



Source: ISE/PHLX

Note: The date range is the time period over which the Nasdaq 100 regression specifications were estimated. For the PM specification, the regression is estimated from 2/2/18 to 2/27/19. The notional value is calculated by multiplying the number of contracts by the strike price and then summing across option series. Only settlement days where the standard size options contract settled are included.

Table 1

Total USD Notional Settlement Quantity By Year[1]

S&P 500

1/20/06 – 11/27/18

Year	P.M.-Settled Options (Millions USD)[2]	Number of P.M. Settlement Days[2]	A.M.-Settled Options (Millions USD)[3]	Number of A.M. Settlement Days[3]
2006	–	0	$833,639	29
2007	$2,736	4	$1,647,988	50
2008	$9,695	4	$2,193,228	52
2009	$2,199	3	$1,330,121	37
2010	$16,335	6	$1,412,448	49
2011	$126,393	42	$1,608,029	12
2012	$232,901	53	$1,364,660	12
2013	$539,936	54	$1,793,645	12
2014	$830,894	55	$1,699,337	11
2015	$1,000,527	59	$1,483,405	12
2016	$1,288,317	119	$1,765,927	12
2017	$2,000,458	161	$2,014,382	12
2018	$2,798,301	130	$2,113,967	10

Source: Cboe

Note:
[1] Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for XSP/XSPAM options but no settlement quantity for SPX/SPXPM options are not included. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when the Cboe provided data for those days. The notional value is calculated by multiplying the number of contracts by the strike price and then summing across option series.
[2] Data is included from 3/30/07 through 11/27/18, the date range over which the S&P 500 P.M. regression specifications were estimated.
[3] Data is included from 1/20/06 through 11/27/18, the date range over which the S&P 500 A.M. regression specifications were estimated.

Total USD Notional Settlement Quantity By Year[1]

Russell 2000

1/20/06 – 12/31/18

Year	P.M.-Settled Options (Millions USD)[2]	Number of P.M. Settlement Days[2]	A.M.-Settled Options (Millions USD)[3]	Number of A.M. Settlement Days[3]
2006	–	0	$41,550	12
2007	–	0	$108,707	12
2008	–	0	$176,250	12
2009	–	0	$80,425	12
2010	–	0	$91,794	12
2011	–	0	$105,978	45
2012	–	0	$65,148	52
2013	–	0	$76,874	52
2014	$2,049	3	$96,833	51
2015	$2,590	4	$89,243	52
2016	$38,216	45	$73,586	14
2017	$43,174	47	$57,644	12
2018	$58,182	47	$78,329	12

Source: Cboe

Note:
[1] Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain Russell 2000 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Non-trading days were removed from the dataset, even when the Cboe provided data for those days. The notional value is calculated by multiplying the number of contracts by the strike price and then summing across option series.
[2] Data is included from 6/30/14 through 12/31/18, the date range over which the Russell 2000 P.M. regression specifications were estimated.
[3] Data is included from 1/20/06 through 12/31/18.

Table 3

Total USD Notional Settlement Quantity By Year[1]

Nasdaq 100

1/6/12 – 2/27/19

Year	P.M.-Settled Options (Millions USD)[2]	Number of P.M. Settlement Days[2]	A.M.-Settled Options (Millions USD)[3]	Number of A.M. Settlement Days[3]
2012	–	0	$118,931	52
2013	–	0	$107,661	52
2014	–	0	$191,186	52
2015	–	0	$150,934	53
2016	–	0	$129,160	52
2017	–	0	$131,103	52
2018	$91,352	50	$95,834	15
2019	$8,348	15	$9,061	2

Source: Cboe

Note:
[1] To the extent that Nasdaq options settled on a Saturday, the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for NQX options but no settlement quantity for NDXP options are not included in the regression. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when data was provided for those days. The notional value is calculated by multiplying the number of contracts by the strike price and then summing across option series.
[2] Data is included from 2/2/18 through 2/27/19, the date range over which the Nasdaq 100 P.M. regression specifications were estimated.
[3] Data is included from 1/6/12 through 2/27/19, the date range over which the Nasdaq 100 A.M. regression specifications were estimated.

Table 4

Cash Index and Futures Volatility Metrics
Summary Statistics

	Absolute Last Return of Day		Standard Deviation Ratio		Magnitude of Maximum Reversal Overlapping Close		Absolute First Return of Day		Magnitude of Maximum Reversal Overlapping Open	
Index/Contract Name	Median	Standard Deviation	Median	Standard Deviation	Median	Standard Deviation	Median	Standard Deviation	Median	Standard Deviation
S&P 500 Cash Index	0.03%	0.05%	113%	41%	–	–	–	–	–	–
S&P 500-mini Futures	0.03%	0.05%	111%	37%	1.96	1.12	0.04%	0.06%	2.09	0.96
Russell 2000 ETF	0.01%	0.02%	92%	31%	–	–	–	–	–	–
Nasdaq 100 Cash Index	0.04%	0.08%	111%	42%	–	–	–	–	–	–
Nasdaq 100-mini Futures	0.03%	0.06%	104%	40%	1.58	0.97	0.04%	0.07%	2.46	1.29

Source: Cboe Settlement Quantity Data; ISE/PHLX Settlement Quantity Data; Tick Data

Note: Refer to report Section V.A and Section V.B for detailed explanations of volatility metric methodology and calculations. Reversal magnitude metrics and metrics related to the open of trading are not calculated for cash indices. Summary statistics are calcluated on days that were included in the settlement quantity regression analyses. For the S&P 500, this included data from 1/20/06 through 11/27/18 for metrics related to the open of trading and from 3/30/07 through 11/27/18 for metrics related to the close of trading. For the Nasdaq 100, this included data from 1/6/12 through 2/27/19 for metrics related to the open of trading and from 2/2/18 through 2/27/19 for metrics related to the close of trading. For the Russell 2000, this included data from 6/30/14 thorugh 12/31/18 for metrics related to the close of trading.

Table 5

P.M.-Settlement Quantity Regression Results[1]

Impact on Index Futures Volatility at the Close

S&P 500

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Magnitude of Maximum Reversal Overlapping Close[2]
Settlement Quantity – P.M. Options[3]	0.00002	**0.07918*** **	**0.31705*** **
	1.944	5.555	3.373
Settlement Quantity – Futures[4]	0.00000	**0.02516***	**0.07927***
	0.313	2.550	2.445
VIX Closing Value[5]	**0.00450*** **	0.62841	-1.58324
	9.418	1.452	-1.529
Lagged Option Volume[6]	0.00000	-0.00000	**-0.00036*** **
	0.811	-0.148	-3.664
Non-Expiring Open Interest[7]	-0.00000	-0.00034	0.00076
	-0.865	-1.328	0.840
Constant	-0.00029	1.14138	2.96609
Observations	704	704	652
R-squared	0.293	0.060	0.095

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Refinitv; Tick Data

Note:

[1] Only options under the tickers SPX (including SPXPM and SPXW) and XSP are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all futures metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for XSP options but no settlement quantity for SPX/SPXPM/SPXW options are not included in the regression. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from March 2007 – November 2018.

[2] Refer to report Section V.A for detailed explanations of volatility metric methodology and calculations.

[3] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion.

[4] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.

[5] The VIX closing value divided by 100.

[6] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.

[7] The sum of notional open interest across non-expiring contracts and across all option series (AM-settled options and PM-settled options), calculated at the end of the day divided by $10 billion.

A.M.-Settlement Quantity Regression Results[1]

Impact on Index Futures Volatility at the Open
S&P 500

Metric	Absolute First Return of Day[2]	Magnitude of Maximum Reversal Overlapping Open[2]
Settlement Quantity – A.M. Options[3]	0.00001	-0.00665
	1.208	-0.656
Settlement Quantity – Futures[4]	0.00001	-0.00390
	0.187	-0.065
VIX Closing Value[5]	**0.00383*** **	-0.06275
	4.052	-0.067
Lagged Option Volume[6]	0.00000	**0.00033** **
	0.769	2.668
Non-Expiring Open Interest[7]	-0.00000	-0.00055
	-0.081	-0.384
Constant	-0.00037	1.86310
Observations	311	295
R-squared	0.331	0.047

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Refinitv; Tick Data

Note:
[1] Only options under the tickers SPX and XSP (including XSPAM) are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all futures metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for XSP/XSPAM options but no settlement quantity for SPX options are not included in the regression. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from January 2006 – November 2018.
[2] Refer to report Section V.A for detailed explanations of volatility metric methodology and calculations.
[3] The total notional settlement quantity listed for expiring options with an AM settlement specification divided by $10 billion.
[4] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[5] The VIX closing value divided by 100.
[6] The total volume, in number of contracts, across all option series, including non-expiring options and PM-settled options, on the previous trading day reported in thousands.
[7] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 7

P.M.-Expiration Day Regression Results[1]

Impact on Index Futures Volatility at the Close
S&P 500

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Magnitude of Maximum Reversal Overlapping Close[2]
Open Interest – P.M. Options[3]	0.00000	0.00132	**0.01638***
	0.940	0.637	2.395
Expiration Day[4]	0.00004	-0.00103	0.03764
	1.268	-0.032	0.278
Expiration Day x Open Interest – P.M. Options	0.00002	**0.07619*****	**0.28289****
	1.516	5.566	3.092
VIX Closing Value[5]	**0.00367*****	0.22321	**-2.81796*****
	7.723	0.862	-3.301
Settlement Quantity - Futures[6]	-0.00000	**0.02580****	0.06051
	-0.403	2.735	1.900
Lagged Option Volume[7]	**0.00000***	0.00001	-0.00012
	1.989	0.524	-1.642
Non-Expiring Open Interest[8]	-0.00000	-0.00006	0.00065
	-0.320	-0.310	0.978
Constant	-0.00030	1.09289	2.62869
Observations	1,209	1,209	1,119
R-squared	0.207	0.054	0.081

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Refinitv; Tick Data

Note:
[1] Only options under the tickers SPX (including SPXPM and SPXW) and XSP are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all futures metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. All days that are either a trading day on which PM SPX/SPXPM/SPXW options expire or the trading day prior to a day on which PM SPX/SPXPM/SPXW options expire are included. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from December 2010 – November 2018.
[2] Refer to report Section V.A for detailed explanations of volatility metric methodology and calculations.
[3] On the day of an option's expiration, this metric is defined as the option settlement quantity, divided by $10 billion. On non-expiration days, this metric is defined as the notional open interest for options one trading day from expiration, divided by $10 billion.
[4] A day is classified as an expiration day if at least one included option expires on that day.
[5] The VIX closing value divided by 100.
[6] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[7] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[8] The sum of notional open interest across non-expiring contracts across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 8

P.M.-Settlement Quantity Regression Results[1]

Impact on Index Futures Volatility at the Close for High-Stress Days

S&P 500

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Magnitude of Maximum Reversal Overlapping Close[2]
Settlement Quantity – P.M. Options[3]	**0.00003***	**0.08024*****	**0.31229****
	2.188	5.559	3.267
Settlement Quantity – Futures[4]	0.00000	**0.02530***	**0.07864***
	0.368	2.562	2.410
VIX Closing Value[5]	**0.00466*****	0.69162	-1.86620
	9.426	1.531	-1.738
VIX High-Value Indicator x Settlement Quantity – P.M. Options[6]	**-0.00010*****	-0.03750	0.16011
	-4.560	-1.297	1.839
Lagged Option Volume[7]	0.00000	-0.00000	**-0.00036*****
	0.818	-0.147	-3.655
Non-Expiring Open Interest[8]	-0.00000	-0.00032	0.00071
	-0.728	-1.274	0.780
Constant	-0.00033	1.12807	3.02496
Observations	704	704	652
R-squared	0.297	0.061	0.096

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Refinitv; Tick Data

Note:
[1] Only options under the tickers SPX (including SPXPM and SPXW) and XSP are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all futures metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for XSP options but no settlement quantity for SPX/SPXPM/SPXW options are not included in the regression. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from March 2007 – November 2018.
[2] Refer to report Section V.A for detailed explanations of volatility metric methodology and calculations.
[3] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion.
[4] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[5] The VIX closing value divided by 100.
[6] The VIX High-Value Indicator takes a value of 1 on the ten percent of all trading days from January 20, 2006 through December 31, 2018 with the highest VIX Closing Value; the VIX Indicator takes the value of 0 for all other days. This is then multiplied by the total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion.
[7] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[8] The sum of notional open interest across non-expiring contracts and across all option series (AM-settled options and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 9

A.M.-Settlement Quantity Regression Results[1]

Impact on Index Futures Volatility at the Open for High-Stress Days
S&P 500

Metric	Absolute First Return of Day[2]	Magnitude of Maximum Reversal Overlapping Open[2]
Settlement Quantity – A.M. Options[3]	0.00000	-0.00994
	0.565	-0.846
Settlement Quantity – Futures[4]	0.00003	0.01251
	0.781	0.230
VIX Closing Value[5]	**0.00356*** **	-0.25939
	3.381	-0.232
VIX High-Value Indicator x Settlement Quantity – A.M. Options[6]	0.00002	0.01422
	1.107	0.342
Lagged Option Volume[7]	0.00000	**0.00032***
	0.821	2.514
Non-Expiring Open Interest[8]	0.00000	-0.00037
	0.216	-0.281
Constant	-0.00032	1.91265
Observations	311	295
R-squared	0.339	0.047

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Refinitv; Tick Data

Note:
[1] Only options under the tickers SPX and XSP (including XSPAM) are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all futures metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for XSP/XSPAM options but no settlement quantity for SPX options are not included in the regression. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from January 2006 – November 2018.
[2] Refer to report Section V.A for detailed explanations of volatility metric methodology and calculations.
[3] The total notional settlement quantity listed for expiring options with an AM settlement specification divided by $10 billion.
[4] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[5] The VIX closing value divided by 100.
[6] The VIX High-Value Indicator takes a value of 1 on the ten percent of all trading days from January 20, 2006 through December 31, 2018 with the highest VIX Closing Value; the VIX Indicator takes the value of 0 for all other days. This is then multiplied by the total notional settlement quantity listed for expiring options with a AM settlement specification divided by $10 billion.
[7] The total volume, in number of contracts, across all option series, including non-expiring options and PM-settled options, on the previous trading day reported in thousands.
[8] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 10

P.M.-Settlement Quantity Regression Results[1]

Impact on Cash Index Volatility at the Close

S&P 500

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Reversals Above 2 Standard Deviations in Last 15 Min[2]
Settlement Quantity – P.M. Options[3]	**0.00006*** **	**0.11518*** **	**0.34731*** **
	5.561	5.267	4.270
Settlement Quantity – Futures[4]	0.00000	**0.02645***	-0.04704
	0.585	2.444	-1.160
VIX Closing Value[5]	**0.00374*** **	0.46784	**12.86990*** **
	5.268	0.987	5.232
Lagged Option Volume[6]	0.00000	-0.00004	**0.00043***
	1.611	-1.108	2.491
Non-Expiring Open Interest[7]	0.00000	-0.00046	**0.00467** **
	0.143	-1.446	2.893
Constant	-0.00034	1.28610	-3.15299
Observations	688	689	689
R-squared	0.272	0.076	0.181

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Refinitv; Tick Data

Note:

[1] Only options under the tickers SPX (including SPXPM and SPXW) and XSP are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all cash index metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for XSP options but no settlement quantity for SPX/SPXPM/SPXW options are not included in the regression. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from March 2007 – October 2018.

[2] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.

[3] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion.

[4] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.

[5] The VIX closing value divided by 100.

[6] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.

[7] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 11

P.M.-Expiration Day Regression Results[1]

Impact on Cash Index Volatility at the Close
S&P 500

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Reversals Above 2 Standard Deviation in Last 15 Min[2]
Open Interest – P.M. Options[3]	**0.00001****	0.00099	0.01427
	2.694	0.405	1.179
Expiration Day[4]	0.00003	-0.01008	-0.25128
	1.014	-0.254	-1.349
Expiration Day x Open Interest – P.M. Options	**0.00006*****	**0.10950*****	**0.33620*****
	4.955	5.170	4.173
VIX Closing Value[5]	**0.00328*****	0.30959	**14.68114*****
	7.510	1.018	6.897
Settlement Quantity – Futures[6]	0.00000	**0.02557***	-0.05995
	0.370	2.450	-1.585
Lagged Option Volume[7]	**0.00000****	-0.00002	**0.00061*****
	3.249	-0.767	4.400
Non-Expiring Open Interest[8]	0.00000	-0.00008	**0.00280***
	0.118	-0.352	2.296
Constant	-0.0003	1.1811	-3.0821
Observations	1,182	1,185	1,185
R-squared	0.247	0.068	0.189

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Refinitv; Tick Data

Note:
[1] Only options under the tickers SPX (including SPXPM and SPXW) and XSP are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all cash index metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. All days that are either a trading day on which PM SPX/SPXPM/SPXW options expire or the trading day prior to a day on which PM SPX/SPXPM/SPXW options expire are included. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from December 2010 – October 2018.
[2] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[3] On the day of an option's expiration, this metric is defined as the option settlement quantity, divided by $10 billion. On non-expiration days, this metric is defined as the notional open-interest for options one trading day from expiration, divided by $10 billion.
[4] A day is classified as an expiration day if at least one included option expires on that day.
[5] The VIX closing value divided by 100.
[6] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[7] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[8] The sum of notional open interest across non-expiring contracts across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 12

P.M.-Settlement Quantity Regression Results[1]

Impact on Cash Index Volatility at the Close for High-Stress Days
S&P 500

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Reversals Above 2 Standard Deviations in Last 15 Min[2]
Settlement Quantity – P.M. Options[3]	**0.00006***	**0.11689***	**0.31734***
	5.212	5.300	3.975
Settlement Quantity – Futures[4]	0.00000	**0.02664***	-0.05035
	0.530	2.459	-1.215
VIX Closing Value[5]	**0.00355***	0.57005	**11.08166***
	5.729	1.152	4.865
VIX High-Value Indicator x Settlement Quantity – P.M. Options[6]	0.00010	-0.05526	**0.96688***
	0.577	-1.382	2.484
Lagged Option Volume[7]	0.00000	-0.00004	**0.00043***
	1.602	-1.104	2.440
Non-Expiring Open Interest[8]	-0.00000	-0.00043	**0.00425**
	-0.037	-1.363	2.663
Constant	-0.00030	1.26321	-2.75267
Observations	688	689	689
R-squared	0.278	0.077	0.193

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Refinitv; Tick Data

Note:
[1] Only options under the tickers SPX (including SPXPM and SPXW) and XSP are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all cash index metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for XSP options but no settlement quantity for SPX/SPXPM/SPXW options are not included in the regression. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from March 2007 – October 2018.
[2] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[3] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion.
[4] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[5] The VIX closing value divided by 100.
[6] The VIX High-Value Indicator takes a value of 1 on the ten percent of all trading days from January 20, 2006 through December 31, 2018 with the highest VIX Closing Value; the VIX Indicator takes the value of 0 for all other days. This is then multiplied by the total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion.
[7] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[8] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

P.M.-Expiration Day Regression Results[1]

Impact on Index Constituent Volatility at the Close
S&P 500

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Reversals Above 2 Standard Deviations in Last 15 Min[2]
Open Interest – P.M. Options[3]	**0.00000*** **	**0.00119*** **	**0.01959*** **
	6.934	7.018	23.649
Expiration Day[4]	**-0.00007*** **	**-0.03605*** **	0.01769
	-11.160	-10.996	1.323
Expiration Day x Open Interest – P.M. Options	**0.00006*** **	**0.04013*** **	**0.06509*** **
	37.009	39.611	20.051
VIX Closing Value[5]	**0.00528*** **	**1.81352*** **	**26.84360*** **
	58.906	57.846	82.566
Settlement Quantity - Futures[6]	**0.00001*** **	**0.00297*** **	**-0.04366*** **
	6.911	4.542	-16.150
Lagged Option Volume[7]	**0.00000*** **	**0.00002*** **	**0.00027*** **
	17.842	11.618	34.445
Non-Expiring Open Interest[8]	**-0.00000*** **	**-0.00113*** **	**-0.01008*** **
	-13.629	-40.110	-55.049
Constant	0.00002	0.99147	-0.31742
Observations	124,478	124,478	124,978
R-squared	0.154	0.107	0.323
Stock Fixed Effects	Yes	Yes	Yes

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Compustat; Cboe; Refinitv; TAQ Data; Tick Data

Note:
[1] This table reports results from panel regressions estimating the effects of the level of settlement quantity of index options on volatility at the close of the index's constituents. The sample includes data for all S&P 500 constituents as well as for options under the tickers SPX (including SPXPM and SPXW) and XSP. All days in 2018 that are either a trading day on which PM SPX/SPXPM/SPXW options expire or the trading day prior to a day on which PM SPX/SPXPM/SPXW options expire are included. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. Stock fixed effects are used. 60-second returns are used to calculate all volatility metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Non-trading days were removed from the dataset, even when the Cboe provided data for those days.
[2] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[3] On the day of an option's expiration, this metric is defined as the option settlement quantity, divided by $10 billion. On non-expiration days, this metric is defined as the notional open interest for options one trading day from expiration, divided by $10 billion.
[4] A day is classified as an expiration day if at least one included option expires on that day.
[5] The VIX closing value divided by 100.
[6] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[7] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[8] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 14

P.M.-Expiration Day Regression Results[1]

Impact on Index Constituent Volatility at the Close

S&P 500 – 100 Constituents With Lowest Market Capitalization[2]

Metric	Absolute Last Return of Day[3]	Standard Deviation Ratio[3]	Reversals Above 2 Standard Deviations in Last 15 Min[3]
Open Interest – P.M. Options[4]	**0.00000*** **	**0.00167*** **	**0.01220*** **
	4.507	4.696	8.256
Expiration Day[5]	**-0.00005*** **	**-0.02758*** **	**-0.05111* **
	-3.711	-3.863	-1.995
Expiration Day x Open Interest – P.M. Options	**0.00006*** **	**0.03449*** **	**0.04926*** **
	16.086	14.387	8.221
VIX Closing Value[6]	**0.00456*** **	**1.62448*** **	**21.18333*** **
	26.934	19.208	41.782
Settlement Quantity - Futures[7]	**0.00001** **	**0.00047**	**-0.03938*** **
	2.678	0.306	-7.613
Lagged Option Volume[8]	**0.00000*** **	**0.00002*** **	**0.00025*** **
	6.524	5.411	15.504
Non-Expiring Open Interest[9]	**-0.00000*** **	**-0.00122*** **	**-0.00817*** **
	-6.678	-22.834	-25.266
Constant	0.00006	0.99216	-0.18612
Observations	24,900	24,900	25,000
R-squared	0.147	0.093	0.280
Stock Fixed Effects	Yes	Yes	Yes

Source: Cboe Open Interest Data; Cboe Settlement Quantity Data; Cboe Volume Data; Cboe; Compustat; CRSP; Refinitv; TAQ Data; Tick Data

Note:
[1] This table reports results from panel regressions estimating the effects of the level of settlement quantity of index options on volatility at the close of the index's constituents. The sample includes data for all S&P 500 constituents as well as for options under the tickers SPX (including SPXPM and SPXW) and XSP. All days in 2018 that are either a trading day on which PM SPX/SPXPM/SPXW options expire or the trading day prior to a day on which PM SPX/SPXPM/SPXW options expire are included. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. Stock fixed effects are used. 60-second returns are used to calculate all volatility metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Non-trading days were removed from the dataset, even when the Cboe provided data for those days.
[2] The regressions were estimated over the 100 S&P 500 constituents that remained in the S&P 500 through the full year of 2018 and had the lowest market capitalization as of January 2, 2018.
[3] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[4] On the day of an option's expiration, this metric is defined as the option settlement quantity, divided by $10 billion. On non-expiration days, this metric is defined as the notional open interest for options one trading day from expiration, divided by $10 billion.
[5] A day is classified as an expiration day if at least one included option expires on that day.
[6] The VIX closing value divided by 100.
[7] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[8] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[9] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 15

P.M.-Expiration Day Regression Results[1]

Impact on Index Constituent Volatility at the Close

S&P 500 – 100 Constituents With Largest Relative Bid-Ask Spread[2]

Metric	Absolute Last Return of Day[3]	Standard Deviation Ratio[3]	Reversals Above 2 Standard Deviations in Last 15 Min[3]
Open Interest – P.M. Options[4]	**0.00000*** **	**0.00086** **	**0.01220*** **
	4.566	2.974	6.858
Expiration Day[5]	**-0.00005*** **	**-0.02638*** **	**-0.03741**
	-4.073	-3.926	-1.358
Expiration Day x Open Interest – P.M. Options	**0.00006*** **	**0.03076*** **	**0.05345*** **
	19.914	17.578	9.426
VIX Closing Value[6]	**0.00514*** **	**1.81529*** **	**21.73441*** **
	26.562	27.966	38.750
Settlement Quantity - Futures[7]	**0.00001** **	**0.00058**	**-0.04237*** **
	2.760	0.491	-8.761
Lagged Option Volume[8]	**0.00000*** **	**0.00001*** **	**0.00024*** **
	6.725	4.698	13.802
Non-Expiring Open Interest[9]	**-0.00000*** **	**-0.00110*** **	**-0.00836*** **
	-8.831	-23.760	-25.288
Constant	0.00012	0.89573	-0.20632
Observations	24,900	24,900	25,000
R-squared	0.160	0.120	0.280
Stock Fixed Effects	Yes	Yes	Yes

Source: Cboe Open Interest Data; Cboe Settlement Quantity Data; Cboe Volume Data; Cboe; Compustat; Refinitv; TAQ Data; Tick Data

Note:
[1] This table reports results from panel regressions estimating the effects of the level of settlement quantity of index options on volatility at the close of the index's constituents. The sample includes data for all S&P 500 constituents as well as for options under the tickers SPX (including SPXPM and SPXW) and XSP. All days in 2018 that are either a trading day on which PM SPX/SPXPM/SPXW options expire or the trading day prior to a day on which PM SPX/SPXPM/SPXW options expire are included. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. Stock fixed effects are used. 60-second returns are used to calculate all volatility metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Non-trading days were removed from the dataset, even when the Cboe provided data for those days.
[2] For all S&P 500 constituents on January 2, 2018, the time-weighted NBBO bid-ask relative spread was calculated across the trading day, excluding the first and last 15 minutes of the trading day. Crossed or locked spreads were removed from the calculation. The relative spread was calculated as the time-weighted average bid-ask spread, divided by the closing share price on the previous trading day, December 29, 2017. The regressions were then estimated over the 100 S&P 500 constituents that remained in the S&P 500 through the full year of 2018 and had the highest relative bid-ask spread.
[3] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[4] On the day of an option's expiration, this metric is defined as the option settlement quantity, divided by $10 billion. On non-expiration days, this metric is defined as the notional open interest for options one trading day from expiration, divided by $10 billion.
[5] A day is classified as an expiration day if at least one included option expires on that day.
[6] The VIX closing value divided by 100.
[7] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[8] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[9] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

P.M.-Expiration Day Regression Results[1]

Impact on Index Constituent Volatility at the Close

S&P 500 – 100 Constituents With Lowest Trading Volume[2]

Metric	Absolute Last Return of Day[3]	Standard Deviation Ratio[3]	Reversals Above 2 Standard Deviations in Last 15 Min[3]
Open Interest – P.M. Options[4]	**0.00000***	**0.00147***	**0.01770***
	3.751	4.851	10.632
Expiration Day[5]	**-0.00006***	**-0.03522***	**-0.00335**
	-4.879	-5.545	-0.123
Expiration Day x Open Interest – P.M. Options	**0.00006***	**0.03702***	**0.06491***
	15.437	20.074	11.918
VIX Closing Value[6]	**0.00469***	**1.87294***	**24.63603***
	33.004	28.235	47.674
Settlement Quantity - Futures[7]	**0.00001**	**0.00345***	**-0.04526***
	2.820	2.263	-8.498
Lagged Option Volume[8]	**0.00000***	**0.00001***	**0.00029***
	7.527	4.024	17.302
Non-Expiring Open Interest[9]	**-0.00000***	**-0.00111***	**-0.00918***
	-5.655	-20.492	-31.093
Constant	0.00000	0.95674	-0.43699
Observations	24,900	24,900	25,000
R-squared	0.157	0.115	0.319
Stock Fixed Effects	Yes	Yes	Yes

Source: Cboe Open Interest Data; Cboe Settlement Quantity Data; Cboe Volume Data; Cboe; Compustat; CRSP; Refinitv; TAQ Data; Tick Data

Note:
[1] This table reports results from panel regressions estimating the effects of the level of settlement quantity of index options on volatility at the close of the index's constituents. The sample includes data for all S&P 500 constituents as well as for options under the tickers SPX (including SPXPM and SPXW) and XSP. All days in 2018 that are either a trading day on which PM SPX/SPXPM/SPXW options expire or the trading day prior to a day on which PM SPX/SPXPM/SPXW options expire are included. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. Stock fixed effects are used. 60-second returns are used to calculate all volatility metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain S&P 500 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Non-trading days were removed from the dataset, even when the Cboe provided data for those days.
[2] The regressions were estimated over the 100 S&P 500 constituents that remained in the S&P 500 through the full year of 2018 and had the lowest notional trading volume as of January 2, 2018.
[3] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[4] On the day of an option's expiration, this metric is defined as the option settlement quantity, divided by $10 billion. On non-expiration days, this metric is defined as the notional open interest for options one trading day from expiration, divided by $10 billion.
[5] A day is classified as an expiration day if at least one included option expires on that day.
[6] The VIX closing value divided by 100.
[7] As a proxy for the settlement quantity of S&P 500 futures, the open interest balance on the day prior to expiration for a contract was used. If no futures contracts expired on the date of an observation, the futures settlement quantity is defined as zero. This is divided by $10 billion.
[8] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[9] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

P.M.-Settlement Quantity Regression Results[1]

Impact on Volatility at the Close
Russell 2000

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Reversals Above 2 Standard Deviations in Last 15 Min[2]
Settlement Quantity – P.M. Options[3]	0.00023	**1.15440****	3.22594
	0.814	2.804	0.764
VIX Closing Value[4]	**0.00096****	-0.31294	**15.59185***
	2.632	-0.459	1.990
Lagged Option Volume[5]	0.00000	-0.00055	0.00451
	0.346	-1.123	1.346
Non-Expiring Open Interest[6]	-0.00001	**-0.06132****	0.07069
	-0.585	-3.157	0.360
Constant	0.00007	1.53545	-1.77355
Observations	145	145	146
R-squared	0.099	0.068	0.099

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Tick Data

Note:
[1] Only options under the ticker RUT are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all cash index metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain Russell 2000 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. Non-trading days were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from June 2014 – December 2018.
[2] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[3] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion.
[4] The VIX closing value divided by 100.
[5] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[6] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 18

P.M.-Expiration Day Regression Results[1]

Impact on Volatility at the Close

Russell 2000

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Reversals Above 2 Standard Deviations in Last 15 Min[2]
Open Interest – P.M. Options[3]	0.00001	0.02809	0.00752
	0.299	0.454	0.015
Expiration Day[4]	0.00000	0.04722	0.01243
	0.104	0.716	0.024
Expiration Day x Open Interest – P.M. Options	0.00025	**0.83444***	2.20153
	0.967	2.409	0.616
VIX Closing Value[5]	**0.00078*****	-0.03983	**14.57614****
	3.426	-0.082	3.190
Lagged Option Volume[6]	0.00000	-0.00010	**0.00907****
	0.834	-0.281	3.001
Non-Expiring Open Interest[7]	-0.00001	-0.02677	0.16828
	-0.703	-1.858	1.246
Constant	0.00007	1.16881	-2.83022
Observations	280	280	281
R-squared	0.084	0.056	0.138

Source: Cboe Open Interest Data; Cboe Volume Data; Cboe Settlement Quantity Data; Cboe; Tick Data

Note:
[1] Only options under the ticker RUT are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all cash index metrics. Prior to the transition of Saturday expiration options to Friday expiration (as outlined in Cboe Regulatory Circular RG12-135), certain Russell 2000 options expired on Saturday; the settlement quantity for these options was moved to the previous trading day. All days that are either a trading day on which PM RUT options expire or the trading day prior to a day on which PM RUT options expire are included. Non-trading days were removed from the dataset, even when the Cboe provided data for those days. These models are estimated from June 2014 – December 2018.
[2] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[3] On the day of an option's expiration, this metric is defined as the option settlement quantity. On non-expiration days, this metric is defined as the notional open interest for options one trading day from expiration, divided by $10 billion.
[4] A day is classified as an expiration day if at least one included option expires on that day.
[5] The VIX closing value divided by 100.
[6] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[7] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 19

P.M.-Settlement Quantity Regression Results[1]

Impact on Index Futures Volatility at the Close

Nasdaq 100

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Magnitude of Maximum Reversal Overlapping Close[2]
Settlement Quantity – P.M. Options[3]	-0.00062	0.21195	**2.38542***
	-1.582	0.665	2.655
VIX Closing Value[4]	**0.00653****	0.65841	0.41993
	3.202	0.708	0.113
Lagged Option Volume[5]	0.00001	-0.00457	-0.01131
	0.510	-0.556	-0.331
Non-Expiring Open Interest[6]	0.00003	0.00680	0.00700
	0.803	0.254	0.092
Constant	-0.00074	0.97289	1.60887
Observations	65	65	60
R-squared	0.229	0.018	0.107

Source: Cboe; ISE/PHLX Open Interest Data; ISE/PHLX Volume Data; ISE/PHLX Settlement Quantity Data; Tick Data

Note:
[1] Only options under the tickers NDXP and NQX are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all futures metrics. To the extent that Nasdaq 100 options settled on a Saturday, the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for NQX options but no settlement quantity for NDXP options are not included in the regression. Non-trading days were removed from the dataset, even when data was provided for those days. These models are estimated from February 2018 – February 2019.
[2] Refer to report Section V.A for detailed explanations of volatility metric methodology and calculations.
[3] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion.
[4] The VIX closing value divided by 100.
[5] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[6] The sum of notional open interest across non-expiring contracts and across all option series (AM-settled options and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 20

A.M.-Settlement Quantity Regression Results[1]

Impact on Index Futures Volatility at the Open
Nasdaq 100

Metric	Absolute First Return of Day[2]	Magnitude of Maximum Reversal Overlapping Open[2]
Settlement Quantity – A.M. Options[3]	**0.00025***	0.02823
	2.266	0.109
VIX Closing Value[4]	**0.00286*****	0.25058
	3.347	0.071
Lagged Option Volume[5]	-0.00000	-0.00006
	-0.224	-0.015
Non-Expiring Open Interest[6]	0.00001	**-0.14645****
	0.769	-2.807
Constant	0.00002	4.09522
Observations	330	306
R-squared	0.074	0.028

Source: Cboe; ISE/PHLX Open Interest Data; ISE/PHLX Volume Data; ISE/PHLX Settlement Quantity Data; Tick Data

Note:
[1] Only options under the ticker NDX are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all futures metrics. To the extent that Nasdaq 100 options settled on a Saturday, the settlement quantity for these options was moved to the previous trading day. Non-trading days, including October 29, 2012 and October 30, 2012, were removed from the dataset, even when data was provided for those days. These models estimated from January 2012 – February 2019.
[2] Refer to report Section V.A for detailed explanations of volatility metric methodology and calculations.
[3] The total notional settlement quantity listed for expiring options with an AM settlement specification divided by $10 billion.
[4] The VIX closing value divided by 100.
[5] The total volume, in number of contracts, across all option series, including non-expiring options and PM-settled options, on the previous trading day reported in thousands.
[6] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 21

P.M.-Expiration Day Regression Results[1]

Impact on Index Futures Volatility at the Close
Nasdaq 100

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Magnitude of Maximum Reversal Overlapping Close[2]
Open Interest – P.M. Options[3]	0.00013	**0.19883***	0.57926
	0.673	2.592	1.867
Expiration Day[4]	0.00030	0.18393	0.39854
	1.575	1.647	1.331
Expiration Day x Open Interest – P.M. Options	-0.00088	-0.09951	1.30924
	-1.588	-0.305	1.342
VIX Closing Value[5]	**0.00812*****	**1.68645***	4.09165
	3.454	2.359	1.396
Lagged Option Volume[6]	0.00000	-0.00359	-0.00297
	0.388	-0.775	-0.200
Non-Expiring Open Interest[7]	0.00002	-0.02202	-0.03679
	0.728	-1.141	-0.701
Constant	-0.00122	0.84837	0.88099
Observations	129	129	123
R-squared	0.292	0.084	0.140

Source: Cboe; ISE/PHLX Open Interest Data; ISE/PHLX Volume Data; ISE/PHLX Settlement Quantity Data; Tick Data

Note:
[1] Only options under the tickers NDXP and NQX are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all futures metrics. To the extent that Nasdaq 100 options settled on a Saturday, the settlement quantity for these options was moved to the previous trading day. All days that are either a trading day on which NDXP options expire or the trading day prior to a day on which NDXP options expire are included. Non-trading days were removed from the dataset, even when data was provided for those days. These models are estimated from February 2018 – February 2019.
[2] Refer to report Section V.A for detailed explanations of volatility metric methodology and calculations.
[3] On the day of an option's expiration, this metric is defined as the option settlement quantity, divided by $10 billion. On non-expiration days, this metric is defined as the notional open interest for options one trading day from expiration, divided by $10 billion.
[4] A day is classified as an expiration day if at least one included option expires on that day.
[5] The VIX closing value divided by 100.
[6] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[7] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 22

P.M.-Settlement Quantity Regression Results[1]

Impact on Cash Index Volatility at the Close
Nasdaq 100

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Reversals Above 2 Standard Deviations in Last 15 Min[2]
Settlement Quantity – P.M. Options[3]	-0.00060	0.21174	**10.76307*** **
	-1.744	0.706	4.025
VIX Closing Value[4]	**0.00694*** **	0.40788	**22.31768** **
	3.492	0.419	3.420
Lagged Option Volume[5]	0.00003	-0.00599	-0.01452
	1.866	-0.662	-0.263
Non-Expiring Open Interest[6]	0.00001	0.01098	0.23724
	0.208	0.365	1.348
Constant	-0.00086	1.06810	-5.47067
Observations	64	64	65
R-squared	0.264	0.012	0.538

Source: Cboe; ISE/PHLX Open Interest Data; ISE/PHLX Volume Data; ISE/PHLX Settlement Quantity Data; Tick Data

Note:
[1] Only options under the tickers NDXP and NQX are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all cash index metrics. To the extent that Nasdaq 100 options settled on a Saturday, the settlement quantity for these options was moved to the previous trading day. Days when there is settlement quantity for NQX options but no settlement quantity for NDXP options are not included in the regression. Non-trading days were removed from the dataset, even when data was provided for those days. These models are estimated from February 2018 – February 2019.
[2] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[3] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion.
[4] The VIX closing value divided by 100.
[5] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[6] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

P.M.-Expiration Day Regression Results[1]

Impact on Cash Index Volatility at the Close
Nasdaq 100

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Reversals Above 2 Standard Deviation in Last 15 Min[2]
Open Interest – P.M. Options[3]	0.00017	**0.23533***	**1.93850****
	0.995	2.416	2.930
Expiration Day[4]	0.00015	0.23321	0.85525
	0.691	1.930	1.337
Expiration Day x Open Interest – P.M. Options	-0.00081	-0.14242	**7.44169****
	-1.671	-0.456	2.709
VIX Closing Value[5]	**0.01048*****	1.49821	**26.27203*****
	6.023	1.950	4.908
Lagged Option Volume[6]	0.00001	-0.00511	0.05048
	0.918	-1.027	1.010
Non-Expiring Open Interest[7]	-0.00004	-0.02105	0.04708
	-1.205	-1.019	0.406
Constant	-0.00102	0.91116	-6.07407
Observations	128	128	129
R-squared	0.331	0.084	0.485

Source: Cboe; ISE/PHLX Open Interest Data; ISE/PHLX Volume Data; ISE/PHLX Settlement Quantity Data; Tick Data

Note:
[1] Only options under the tickers NDXP and NQX are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. 60-second returns are used to calculate all cash index metrics. To the extent that Nasdaq 100 options settled on a Saturday, the settlement quantity for these options was moved to the previous trading day. All days that are either a trading day on which NDXP options expire or the trading day prior to a day on which NDXP options expire are included. Non-trading days were removed from the dataset, even when data was provided for those days. These models are estimated from February 2018 – February 2019.
[2] Refer to report Section V.B for detailed explanations of volatility metric methodology and calculations.
[3] On the day of an option's expiration, this metric is defined as the option settlement quantity, divided by $10 billion. On non-expiration days, this metric is defined as the notional open interest for options one trading day from expiration, divided by $10 billion.
[4] A day is classified as an expiration day if at least one included option expires on that day.
[5] The VIX closing value divided by 100.
[6] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[7] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 24

P.M.-Expiration Day Regression Results[1]

Impact on Index Constituent Volatility at the Close
Nasdaq 100

Metric	Absolute Last Return of Day[2]	Standard Deviation Ratio[2]	Reversals Above 2 Standard Deviations in Last 15 Min[2]
Open Interest – P.M. Options[3]	**0.00005***	**0.09226*****	**1.18542*****
	2.187	13.292	26.210
Expiration Day[4]	**0.00009****	**0.13015*****	**0.47409*****
	3.284	11.188	7.316
Expiration Day x Open Interest – P.M. Options	**-0.00065*****	-0.01917	**4.51062*****
	-7.031	-0.674	24.241
VIX Closing Value[5]	**0.00869*****	**1.68603*****	**21.72974*****
	26.660	23.939	29.294
Lagged Option Volume[6]	0.00000	**-0.00177*****	**0.03917*****
	0.933	-4.234	12.858
Non-Expiring Open Interest[7]	**-0.00005*****	**-0.01907*****	0.00351
	-10.144	-11.332	0.323
Constant	-0.00025	0.76795	-3.97174
Observations	9,906	9,906	10,006
R-squared	0.190	0.068	0.318
Stock Fixed Effects	Yes	Yes	Yes

Source: Cboe; Compustat; ISE/PHLX Open Interest Data; ISE/PHLX Volume Data; ISE/PHLX Settlement Quantity Data; TAQ Data; Tick Data

Note:
[1] This table reports results from panel regressions estimating the effects of the level of settlement quantity of index options on volatility at the close of the index's constituents. The sample includes data for all Nasdaq 100 constituents as well as for options under the tickers NDXP and NQX. All days in 2018 that are either a trading day on which NDXP options expire or the trading day prior to a day on which NDXP options expire are included. T-statistics are based on standard errors adjusted for heteroscedasticity and are reported below the coefficient estimates. * indicates a significant coefficient at a 5% significance level, ** indicates a significant coefficient at a 1% significance level, and *** indicates a significant coefficient at a 0.1% significance level. Stock fixed effects are used. 60-second returns are used to calculate all cash index metrics. To the extent that Nasdaq 100 options settled on a Saturday, the settlement quantity for these options was moved to the previous trading day. Non-trading days were removed from the dataset, even when data was provided for those days.
[2] Refer to report Section V.B for detailed explanations of volatilty metric methodology and calculations.
[3] On the day of an option's expiration, this metric is defined as the option settlement quantity, divided by $10 billion. On non-expiration days, this metric is defined as the notional open interest for options one trading day from expiration, divided by $10 billion.
[4] A day is classified as an expiration day if at least one included option expires on that day.
[5] The VIX closing value divided by 100.
[6] The total volume, in number of contracts, across all option series, including non-expiring options and AM-settled options, on the previous trading day reported in thousands.
[7] The sum of notional open interest across non-expiring contracts and across all option series (including AM-settled and PM-settled options), calculated at the end of the day divided by $10 billion.

Table 25

Summary Statistics for P.M.-Settlement Quantity Regression Variables[1]

	Mean	Standard Deviation	25th Percentile	Median	75th Percentile
S&P 500[2]					
Settlement Quantity – P.M. Options[3]	1.26	1.28	0.40	0.82	1.66
Settlement Quantity – Futures[4]	5.90	2.11	4.11	5.82	7.16
VIX Closing Value[5]	0.20	0.09	0.13	0.17	0.23
Lagged Option Volume[6]	1,747.27	748.68	1,208.31	1,585.33	2,141.01
Non-Expiring Open Interest[7]	202.90	77.63	145.81	180.45	243.43
Russell 2000[8]					
Settlement Quantity – P.M. Options[9]	0.10	0.06	0.06	0.09	0.12
VIX Closing Value[5]	0.15	0.04	0.12	0.14	0.17
Lagged Option Volume[6]	141.25	69.71	98.85	124.06	160.56
Non-Expiring Open Interest[7]	7.67	1.40	6.63	7.48	8.59
Nasdaq 100[10]					
Settlement Quantity – P.M. Options[11]	0.15	0.16	0.07	0.12	0.17
VIX Closing Value[5]	0.17	0.05	0.13	0.16	0.20
Lagged Option Volume[6]	13.52	6.25	9.56	11.91	15.80
Non-Expiring Open Interest[7]	8.30	2.29	6.35	7.41	10.35

[1] For additional details on the included tickers, data sources, and on the way metrics are calculated see Tables 5, 10, 17, 19, and 22.
[2] Statistics for the S&P 500 model are caculated based on data from March 2007 – November 2018.
[3] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion. Days without SPX/SPXPM/SPXW options settlement are excluded from the calculations.
[4] The futures settlement quantity divided by $10 billion. If no futures contracts were scheduled to expire on the date of an observation, the date is excluded from the calculations.
[5] The VIX closing value divided by 100.
[6] The total volume, in number of contracts, across all option series on the previous trading day reported in thousands.
[7] The sum of notional open interest across non-expiring contracts and across all option series, calculated at the end of the day divided by $10 billion.
[8] Statistics for the Russell 2000 model are caculated based on data from June 2014 – December 2018.
[9] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion. Days without PM RUT options settlement are excluded from the calculations.
[10] Statistics for the Nasdaq 100 model are caculated based on data from February 2018 – February 2019.
[11] The total notional settlement quantity listed for expiring options with a PM settlement specification divided by $10 billion. Days without NDXP options settlement are excluded from the calculations.

Table 26

Summary Statistics for A.M.-Settlement Quantity Regression Variables[1]

	Mean	Standard Deviation	25th Percentile	Median	75th Percentile
S&P 500[2]					
Settlement Quantity – A.M. Options[3]	6.84	9.63	0.01	0.10	9.53
Settlement Quantity – Futures[4]	5.83	2.03	4.13	5.73	7.12
VIX Closing Value[5]	0.19	0.09	0.13	0.16	0.22
Lagged Option Volume[6]	1,671.14	765.34	1,127.39	1,525.62	2,076.52
Non-Expiring Open Interest[7]	193.12	80.23	136.57	172.63	234.61
Nasdaq 100[8]					
Settlement Quantity – A.M. Options[9]	0.28	0.35	0.08	0.14	0.35
VIX Closing Value[5]	0.15	0.04	0.13	0.14	0.17
Lagged Option Volume[6]	25.30	18.75	13.62	19.10	30.35
Non-Expiring Open Interest[7]	7.87	1.99	6.37	7.54	9.12

[1] For additional details on the included tickers, data sources, and on the way metrics are calculated see Tables 6 and 20.
[2] Statistics for the S&P 500 model are caculated based on data from January 2006 – November 2018.
[3] The total notional settlement quantity listed for expiring options with a AM settlement specification divided by $10 billion. Days without SPX options settlement are excluded from the calculations.
[4] The futures settlement quantity divided by $10 billion. If no futures contracts were scheduled to expire on the date of an observation, the date is excluded from the calculations.
[5] The VIX closing value divided by 100.
[6] The total volume, in number of contracts, across all option series on the previous trading day reported in thousands.
[7] The sum of notional open interest across non-expiring contracts and across all option series, calculated at the end of the day divided by $10 billion.
[8] Statistics for the Nasdaq 100 model are caculated based on data from January 2012 – February 2019.
[9] Days without NDX options settlement are excluded from the calculations.

Table 27

Summary Statistics for P.M.-Expiration Day Regression Variables[1]

	Mean	Standard Deviation	25th Percentile	Median	75th Percentile
S&P 500[2]					
Open Interest – P.M. Options[3]	5.08	6.85	0.70	1.81	6.34
Settlement Quantity – Futures[4]	5.92	2.36	3.95	5.65	7.22
VIX Closing Value[5]	0.16	0.05	0.13	0.15	0.18
Lagged Option Volume[6]	1,935.03	755.24	1,386.24	1,795.79	2,357.21
Non-Expiring Open Interest[7]	231.08	77.52	170.66	213.56	276.93
Russell 2000[8]					
Open Interest – P.M. Options[9]	0.32	0.31	0.09	0.21	0.50
VIX Closing Value[5]	0.15	0.04	0.12	0.14	0.17
Lagged Option Volume[6]	141.40	69.87	98.87	124.16	160.70
Non-Expiring Open Interest[7]	7.67	1.40	6.63	7.49	8.59
Nasdaq 100[10]					
Open Interest – P.M. Options[11]	0.49	0.56	0.11	0.23	0.75
VIX Closing Value[5]	0.17	0.05	0.13	0.16	0.20
Lagged Option Volume[6]	13.51	6.24	9.66	11.90	15.66
Non-Expiring Open Interest[7]	8.30	2.29	6.36	7.42	10.35

[1] For additional details on the included tickers, data sources, and on the way metrics are calculated see Tables 7, 11, 18, 21, and 23.
[2] Statistics for the S&P 500 model are caculated based on data from December 2010 – November 2018.
[3] Option settlement quantity or notional open interest for options one trading day from expiration, divided by $10 billion. Days more than one day away from SPX/SPXPM/SPXW options settlement are excluded from the calculations.
[4] The futures settlement quantity divided by $10 billion. If no futures contracts were scheduled to expire on the date of an observation, the date is excluded from the calculations.
[5] The VIX closing value divided by 100.
[6] The total volume, in number of contracts, across all option series on the previous trading day reported in thousands.
[7] The sum of notional open interest across non-expiring contracts and across all option series, calculated at the end of the day divided by $10 billion.
[8] Statistics for the Russell 2000 model are caculated based on data from June 2014 – December 2018.
[9] Option settlement quantity or notional open interest for options one trading day from expiration, divided by $10 billion. Days more than one day away from PM RUT options settlement are excluded from the calculations.
[10] Statistics for the Nasdaq 100 model are caculated based on data from February 2018 – February 2019.
[11] Option settlement quantity or notional open interest for options one trading day from expiration, divided by $10 billion. Days more than one day away from NDXP options settlement are excluded from the calculations.