The Equity Derivative Payoff Bias

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Abstract

Most U.S. equity index derivatives cease trading at 16:15 Eastern Time on the 3$^{\text{rd}}$ Thursday of each month and settle "a.m" on the 3$^{\text{rd}}$ Friday via the index special opening quotation (SOQ), which is a price calculated after all constituents stocks have traded. Unconditionally, the daily SOQ is close to its preceding closing price. However, when derivative payoffs are calculated, the SOQ exceeds Thursdays close by a significant margin. An abnormally large positive overnight return into the SOQ raises (lowers) S&P 500 call (put) option payoffs, inducing a wealth transfer of around $4 billion per year in SPX options alone. These findings are most consistent with inventory management by option market makers and/or market manipulation by sophisticated investors. Both explanations rely on the existence of an illiquid trading period that precedes option settlement; thus, we argue that current settlement design generates a market inefficiency.

Keywords: Stocks; Derivatives; Futures; Market Microstructure; Market Design.

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The majority of index derivative trading activity is concentrated in products for which the S&P 500 index (the SPX) is the underlying. Moreover, most SPX derivatives are "a.m.-settled", meaning they expiry on the 3$^{\text{rd}}$ Friday of each month with payoffs determined via the index Special Opening Quotation (SOQ).[1] The SOQ is calculated from the opening sales price of index component stocks on their primary listing exchange. Thus, the SOQ is available only once all component stocks have traded during the regular market session after 9:30:00 Eastern Time (ET).

This paper studies index derivative payoffs, documenting a economically large bias in settlement prices around a.m.-derivative expiration. Measured over all days in our sample (2003.2 - 2021.12), the daily difference between the SOQ and the preceding closing price is (almost) mean zero.[2] However, a persistent positive bias occurs on days when it MATTERS: the 3$^{\text{rd}}$ Friday of each month when index option payoffs are determined. On these days the SOQ exceeds the index closing price by an average of 18.5 basis points, which is different to the unconditional close-to-SOQ return with high level of statistical confidence (t-statistic exceeding 4). A simple calculation shows that this bias generates a wealth transfer in the SPX vanilla option market of ∼\$3.8 billion annually. Moreover, this calculation represents a lower bound since it ignores futures markets, options on futures, ETF options, and derivative products on alternative indices which also display a similar bias.

Studying continuous trading via equity futures, we uncover a tent-shaped reversal pattern from the close of regular trade on 3$^{\text{rd}}$ Thursdays which peaks exactly when the SOQ (i.e., around 9:30 ET) is calculated on 3$^{\text{rd}}$ Fridays. We dub this empirical irregularity the Third Friday Price Spike (3FPS). The 24-hour price path around the 3FPS displays a classic reversal pattern that arises in models of demand for immediacy and inventory risk management. However, reversals in these models are typically symmetric and average to zero.[3] Exploring the asymmetric nature of our finding we condition average 24-hour returns on whether its overnight return component was positive or negative. In total, out of 225 observations, 143 (64%) overnight returns are positive while 82 (36%) are negative. Averaging within these sets we find that positive overnight returns are followed by a reversal that begins at exactly 9:30 ET, while negative overnight returns display no reversal, which unconditionally leads an asymmetric 'tent' shaped reversal pattern. This provides

[1] Figure 1 provides empirical evidence on volumes and open interest for SPX index options versus single stock options, SPX futures options and settlement in the a.m. vs p.m. window.

[2] The index closing price is computed from the last trade amongst constituent stocks that precedes the closing bell (16:00:00 ET).

[3] For a textbook treatment of these models see Foucault, Pagano, and Röell (2013) and for a survey of the literature on price reversals and slow-moving capital we refer the reader to the Duffie (2010) Journal of Finance presidential address.

a clue of the underlying mechanism, which we elaborate on below.

To demonstrate a causal relationship between intraday and overnight returns, we estimate standard microstructure reversal regressions. The overnight return is measured from SPX trades on each month's 3$^{\text{rd}}$ Thursday at 16:00 to the reported SOQ on 3$^{\text{rd}}$ Fridays and the subsequent intraday return is measured from the SOQ to the SPX traded price at 12:00 by which point the return reversal completes.[4] We regress 3$^{\text{rd}}$ Friday intraday returns on preceding Thursday overnight returns (a predictive relationship). The slope estimate and its 95% confidence intervals are strongly negative implying that large overnight returns Thursday are indeed reversed intraday 3$^{\text{rd}}$ Friday, consistent with standard theories of price pressure. The R^2 is equal to 12% which is large given the high-frequency nature of the exercise.

We study the properties of a strategy that exploits this reversal. The trade buys the index at its closing price on 3$^{\text{rd}}$ Thursdays, rebalances and sells the index at the SOQ price, and closes this position at the market close on Friday. This strategy yields a positive return with a 69% probability, in 16 out of 19 years in our sample, and deliverers annualized Sharpe ratio of 1.3.[5] Accounting for potential small sample biases in our findings, we estimate the distribution of returns reversal strategy via block bootstrap and show the left tail (low returns) do not intersect zero; the 2.5% confidence interval is equal to 22 bps while 97.5% confidence interval is 47 basis points, demonstrating that positive 3$^{\text{rd}}$ Friday overnight returns followed by negative 3$^{\text{rd}}$ Friday intraday returns is strong in both economic and statistical terms. Moreover, we show the 3FPS is exploitable after transaction costs, with the reversal strategy in the E-mini futures yielding an average return of 24 bps over 20 hours net of transaction costs. Furthermore, the pattern is present not only in the SPX but in all main U.S. equity indices, and controlling for other known intraday effects. Summarising, we show that U.S. equity derivative payoffs are biased.

Historically, most expiry activity occurs on "triple witching days", the 3$^{\text{rd}}$ Friday of the quarterly cycle (March, June, September, December) when index options, futures contracts, and options on futures contracts expire simultaneously in the a.m. settlement window.[6] Splitting intraday and overnight returns around monthly settlements by quarterly and off-quarterly dates, we show that returns are stronger on quarterly settlements, with an average overnight return of 27 bps (t-statistic = 4.4), reverting -37 bps intraday (t-statistic = -3.5). However, considering the sample

[4]The quantitative implications of the particular reversal regression specification around 3$^{\text{rd}}$ settlement is robust to the points of trade.

[5]The SOQ can be traded via "market on open" orders for the index component stocks.

[6]Some traders call these days quadruple witchings as options on individual stocks also expire at market close.

of off-quarterly expiries we still observe a strong reversal pattern around the SOQ.

Next, we show that the bias in U.S. equity derivative payoffs is isolated to those contracts that expire into the SOQ, i.e. with a.m. settlement. Several S&P500 option derivatives due not settle in the SOQ, but instead are p.m.-settled: serial options on the SPX futures, options on ETFs and options on individual stocks expiry expire in the market close on 3$^{\text{rd}}$ Fridays. Around the p.m. settlement window we find no evidence of an upward drift and subsequent reversal. To confirm this finding we exploit the (re-)introduction of p.m. settled SPX option on 3$^{\text{rd}}$ Fridays: in 2010, settlement of SPX options at p.m. was (re-)introduced under the SEC "P.M Option Expiration Pilot Program". We find that since 2010 there is no return reversal around 3$^{\text{rd}}$ Friday p.m. settlement: negative 3$^{\text{rd}}$ Friday intraday returns continue as negative weekend returns until Monday open. Thus, the bias that we document is specific to a.m.-settled derivative contracts, but not a general feature of index option settlement procedures.

The 3FPS impacts options as follows: (*i*) a higher payoff for already in-the-money calls; (*ii*) some calls which would have expired out-the-money without the price spike now expire in-the-money; (*iii*) a lower payoff for in-the-money puts; and (*iv*) some puts which would have expired in-the-money now expire out-the-money. Since index options are cash settled and option payoffs are zero sum game, a natural question that arises is whether the temporary price pattern pattern documented above has a meaningful effect in economic terms, i.e., is there a welfare impact? We address this question two ways.

First, noting that a.m settled options cease trading at 16:15 p.m on 3$^{\text{rd}}$ Thursday but that the 3FPS in the underlying generates price pressure in derivatives overnight, we compute SPX index option returns into expiry. We compare actual overnight option settlement returns with counterfactual returns that replace the time-series of realised 3FPSs with the unconditional overnight return measured across all days. Relative to their counterfactuals we estimate overnight option returns (measured over 17 hours and 15 minutes) are: 34% for at-the-money calls and -20% for at-the-money puts.

Second, we replace the SOQ in the max operator which determines option payoffs with the SPX closing price on Thursday. These calculations show that SPX call options paid off \$10.5 billion on the average 3$^{\text{rd}}$ Friday morning. Had their settlement been determined at Thursday close, they would have paid off \$10.2 billion. The exact difference of \$230 million a month, or \$2.8 billion a year, represents the wealth transfer from call option writers to call option buyers. Similarly, SPX put options paid off \$3 billion on the average 3^{rd} Friday morning, versus a counter-factual \$3.1 billion, yielding a wealth transfer from put option buyers to put option writers of ∼\$90 million a month, or \$1 billion a year. We interpret the sum of the wealth transfers in call and put options as the total wealth transfer, implying a \$3.8 billion annual wealth transfer.[7]

What then explains the bias? We investigate first three obvious candidates: Fundamental Shocks (overnight news, earnings, and macro announcements), non-fundamental shocks (shocks the balance sheet capacity and funding constraints), and "pinning" which is the well studied phenomenon in which underlying prices tend to cluster around their nearest strikes on expiration days. Conducting a rigorous assessment we easily rule out these channels.

We then focus on the merits of two potential explanations that we cannot rule out: (1) inventory and hedging practices of option market makers; and (2) market price manipulation.

Consider a hedging based explanation we exploit option market maker positioning data from the CBOE. We uncover that option market makers' hold a positive net delta position across their their total option position implying they would hold a short index position. However, in the run up to 3^{rd} Thursdays their positions adjust so they are on average delta neutral; thus, implying they have already closed out their index position. However, consider the rate of change of their delta due to the passage of time (the exotic Greek dubbed "Charm") calculated between 16:15 on Thursday and a.m settlement on Friday, we can show that overnight price pressure due to hedging into expiration is a plausible explanation.

A second plausible alternative is that manipulators might seek to push the underlying index price up in the period immediately preceding settlement, such that settlement prices move in the direction that benefits their position. Equities trading pre-open is much less liquid than during regular trading hours, making the overnight window most suited for manipulation. Subsequently, prices revert as manipulators offload their positions.[8]

A manipulation hypothesis predicts temporary price pressure that reverts quickly (prices are pushed away from fundamentals); it predicts price patterns especially during a finite window just before expiry (as payoffs become fixed at expiry); it predicts no price pattern during periods when manipulation is unlikely to be successful, such as during the p.m. settlement window; and it

[7] We note that this calculation is a lower bound since it only considers listed SPX index options, ignore futures options, OTC options, ETF options, and options on other U.S. indices.

[8] For individual stocks (Ni, Pearson, and Poteshman, 2005) and the VIX index (Griffin and Shams, 2018) extant evidence suggests that manipulator are indeed active around option expiration dates and this evidence aligns with several of our key results.

predicts stronger effects when incentives are greater like during triple witching days. Moreover, the on average tent shaped 3FPS is also consistent with a manipulation story: since short selling is costly the most obvious manipulation strategy would be to take a positive net delta position in options and push up prices in the underlying through relatively cheap purchases on index constituents (in pre-market trading) or futures (during 24-hour trading)

Analysis again exploiting positions data from the CBOE reveals a likely group of manipulators (professional traders and hedge funds) do indeed hold positions that would benefit from the wealth transfer we document, and they actually increase these positions jnto expiry. That said, a direct identification of market manipulation is challenging since the practice is inherently latent and remains to be demonstrated (or not) by the regulator (the SEC).

I. Data

We collect our data from several sources. From Bloomberg, we obtain a daily continuous series on the S&P 500 index special opening quotation (SOQ) from February 2003 - December 2021. From Refinitiv we examine settlement day pricing effects by collecting tick-level data on the S&P 500 (SPX) and E-mini S&P 500 futures traded on the CME. We obtain tick-level best bid offers, trade prices, and volumes. Sampling of tick-level data follows standard practices, for example, we construct 1, 5 and 15 minute frequencies for quantities and prices following Boyarchenko, Larsen, and Whelan (2023). Within each sampling frequency for each interval of the day we obtain first and last quote updates, first, last and volume-weighted-average prices. We source intraday SPX index options data sampled at 15-minute intervals from the Chicago Board Options Exchange (CBOE). The CBOE data provides intraday quotes alongside a number of option characteristics at 15-minute intervals. OptionMetrics provides us with EOD option data.[9] We also exploit the CBOE Open-Close dataset that provides daily buy- and sell volumes of SPX options by "market makers", "broker-dealers", "customers" and "firms. We aggregate these daily volumes to cumulative positions for each group and document positions into option expiry. Finally, we obtain data on the CBOE S&P 500 BuyWrite Index (BXM index) and the CBOE S&P 500 PutWrite Index (PUT index) which are based on option trading strategies which by the put-call parity should deliver identical returns.

[9] In line with standard derivatives research practice we exclude the expiry days of September and October 2008 from the main analysis.

II. The Special Opening Quotation

In 1987 the Securities and Exchange Commission (SEC), the Commodity Futures Trading Commission(CFTC), the Chicago Mercantile Exchange (CME) and Chicago Board Options Exchange (CBOE) agreed to shift their reference point for S&P500 (SPX) settlement prices from p.m. to a.m. settlement. The primary motive for this change was concerns over the "Triple Witching" events where the simultaneous expiry of futures, futures options, index options and single stock options occurs. This happens only four times per year on the 3$^{\text{rd}}$ Friday of March, June, September, and December. Liquidity providers and designated market makers complained to regulators that they were often unable to manage imbalances on their books due to the extreme volatility and volumes on these days.

On June 19th 1987 an industry wide shift to a.m. settlement was actioned and the settlement price computed on 3$^{\text{rd}}$ Friday mornings via the special opening quotation (SOQ). The SOQ is computed as follows. Index weights are computed from the opening (first reported) trade price of constituent stocks on their primary listing exchange.[10] Hence, the SOQ can only be calculated once all constituent stocks have opened for trading and the SOQ is typically published 30-45 minutes after market open. Indeed, immediately after the opening bell, many stocks in the index will not yet have opened for trading, due to a lack of - or imbalance between - buy and sell orders. At the opening bell when Standard & Poor's publishes the "current" opening SPX value, it includes the previous day's closing prices for each stock that has not yet opened.[11]

Highly liquid, large cap stocks usually trade on their primary exchange very close to the market opening time. In the case of the SPX, the exchange reports this opening trade price to S&P and the price enters the SOQ calculation according to each stocks' weight in the SPX. Less liquid stocks might not have opened for trade on their primary listing exchange, in which case the exchange does not immediately report an opening price. The exchange will report the opening price only after the first stock trade post market open has occurred. This rarely takes more than a few

[10] Securities are often traded on several exchanges. The primary market is the exchange where a security is listed. Primary listing exchanges conduct opening auctions to compute the opening prices. Opening auctions details differ by venue but are designed to maximize volumes. Today the four primary listing exchanges are Nasdaq, NYSE, NYSE Arca, and BATS. The Nasdaq focuses on common stocks and ETFs, NYSE focuses on common stocks only, and the latter two focus on ETFs.

[11] The opening trade price and time of single stocks is determined by its DMM and the procedure differs by primary listing exchange. On the NYSE, for example, orders can be entered and canceled from 6:30 until 9:30. Between 8:00 and 9:30 imbalances are reported every second if there is a change in imbalance from the previous second. At 9:30 DMMs automatically open a security for trade if the securities auction price is within 10% of its closing price from the previous session. Securities outside this range have to be manually opened and so will trade after 9:30.

minutes but theoretically can take longer for very illiquid stocks. Therefore, the SOQ is comprised of single stock trade prices from different points in time.

Figure I illustrates the SOQ calculation for a hypothetical three stock equally weighted index. In panel (a), at open (9:30:00) only stock 1 trades on the exchange. Thus, the index value is based on stock 1's opening price and stock 2 and 3's previous close price. The SOQ only becomes available once all component stocks have traded (on their primary listing exchange) which is recorded at 9:33:29. Thus, the SOQ is based on each stock's opening sales price, which are observed at different points in time. In panel (a), the overnight index return is positive, all individual stock opening returns are positive, and the SOQ minus opening quote (or trade) wedge is positive. In panel (b), the index opens up with a negative overnight return, all stocks opening trades are negative, and the SOQ minus opening quote (trade) wedge is negative. These examples highlight the difference between the closing traded price of an index, the opening quoted price of an index, which includes closing prices for stocks that did not trade overnight, and the SOQ.

[INSERT TABLE I HERE]

We start by visually inspecting the SPX SOQ relative to its previous days closing trade price. Panel (a) of figure 2 plots the (log) difference in basis points (bps) between the SOQ and preceding closing trade of the SPX

$$\text{ReturnSOQ}_t = \log(\text{SOQ}_t) - \log(\text{SPXClose}_{t-1}) \tag{1}$$

for all days since February 2003. Visually inspecting panel we observe an approximately equal mass of red ($\text{ReturnSOQ}_t > 0$) and blue bars ($\text{ReturnSOQ}_t < 0$). This shows that closing trades and opening trades according to the SOQ are generally different, but that this difference follows appears unbiased. Panel (b) displays ReturnSOQ_t only on 3$^{\text{rd}}$ Friday settlement days.[12] This image is dramatically different: there is clearly a larger mass of red bars compared to blue bars. In other words, the SOQ - the value weighted average of the SPX constituent traded prices - appears structurally upward biased on 3$^{\text{rd}}$ Fridays - the days when they determine settlement payoffs - compared to close on 3$^{\text{rd}}$ Thursdays.[13]

[12] If the 3$^{\text{rd}}$ Friday is not trading due to a public holiday, we follow the option expiry rule-books and use the preceding Wednesday and Thursday. There are four such dates in our sample.

[13] We observe a similar pattern in the SOQ on option settlement days when studying the difference between SOX and open prices. As many open prices distributed by exchanges are a combination of first traded prices and previous day closing prices for stocks that did not trade at the open, we choose to focus on SOQ versus the preceding closing trade of the SPX.

[INSERT FIGURE 2 HERE]

Table II reports summary statistics for ReturnSOQ_t on all days (column 1), option expiry dates (column 2), and non-expiry dates (column 3). Confirming our eye-ball econometrics from above ReturnSOQ_t is positive but close to zero, equal to 2.3 bps (t-statistic = 2.2), aligning with the findings of Boyarchenko, Larsen, and Whelan (2023) who document a structural overnight drift in U.S. equity prices. Overnight returns are also positive but close to zero on non-expiry days, registering at 1.5 bps. However, on 3$^{\text{rd}}$ Fridays ReturnSOQ_t is an order of magnitude larger equal to 18.5 bps (t-statistic = 4.7). Furthermore, splitting expiration days into quarterly versus off-quarterly expiry days we find that the quarterly cycle dates display a 26.7 basis points bias while off-quarterly the bias is equal to 14.5 basis points with t-statistics of 4.2 and 2.8, respectively. Summarizing, this section provides strong evidence that underlying prices on 3$^{\text{rd}}$ Friday a.m. derivative settlements are upward biased and by a sizable margin.

[INSERT TABLE II HERE]

III. Pricing Bias

A. Overnight Returns

In the previous section we have shown that the SOQ is structurally upward biased on 3$^{\text{rd}}$ Fridays. Next we examine the pattern in overnight returns using the SPX futures contracts - contracts that trade almost around the clock. The defining features of futures markets is that profits and losses on positions is marked-to-market daily. The daily marked-to-market value of equity index futures contracts traded on the CME is determined by prices on the CME Globex platform up until the last trade before 15:45:00 Eastern Time (E.T). Futures prices trade at various maturities and for the major U.S. equity indices these run on the so-called quarterly cycle (March, June, September, December). The final marked-to-market settlement when a futures contract expires is not determined by a closing price but via the 3$^{\text{rd}}$ Friday SOQ on the quarterly cycle.

We compute traded returns around *monthly* 3$^{\text{rd}}$ Friday settlement dates from 5-minute volume weighted average prices.[14] To obtain a continuous return series on off-quarterly settlement dates we trade the front month contract, and on quarterly settlement dates, to avoid a roll-return, we

[14] If the 3$^{\text{rd}}$ Friday is not trading due to a public holiday, we follow the option expiry rule-books and use the preceding Wednesday and Thursday. There are four such dates in our sample.

trade the next to delivery contract.[15] Returns on all other days are computed using the front month contract.

The black line in panel (a) of figure 3 displays cumulative 5-minute returns between 16:00 on Thursdays (left hand side of the x-axis) and 16:00 on 3rd Fridays (right hand side of the x-axis). From around 2:00, which is the opening of the London market, equity prices drift steadily up and continue drifting in early morning trade until *exactly* the 9:30 interval, at which point returns sharply revert. The average overnight cumulative return in the active futures contract is equal to 14 bps which completely reverses by 12:00.[16]

To highlight the surprising nature of this pattern, consider the unconditional intraday return profile (red line) which displays no obvious reversal patterns and shows that overnight returns on 3rd Fridays are an order of magnitude larger than what should be expected unconditionally. [17]

$\Big[$ INSERT FIGURE 3 HERE $\Big]$

Panel (b) of figure 3 focuses on early morning trading by displaying average 15-minute returns (blue bars) between 7:00 and 12:00 alongside cumulative returns over this interval (black line). The figure shows that equity prices drift up continuously from 7:00 until exactly the 9:30 interval with a cumulative return of around 6 bps (hence 43% of the total effect), which reverts immediately afterward 9:30. Considering average 15-minute returns, we observe a positive spike equal to 2.5 bps between 9:15 and 9:30, and a reversal of 6 bps between 9:30 and 9:45.

The 24-hour price path around 3rd Fridays displays a classic reversal pattern that typically arises in models of demand for immediacy and inventory risk management. This point is discussed by numerous studies.[18] Indeed, the Duffie (2010) presidential address reviews price dynamics with 'slow-moving' capital and highlights that *'Even in markets that are extremely active, price dynamics reflect slow capital when viewed from a high-frequency perspective.'*. Next, we examine the asymmetric nature of the pattern we uncover. To this end, we condition the average 24-hour

[15] In the Online Appendix we repeat our analysis with an alternative return series. We compute returns from the front month contract on off-quarterly settlement dates and on quarterly settlement dates we track the front month (about to expire) contract then roll into the next-to-delivery contract at 9:30 a.m. Results are quantitively similar.

[16] Please note that this pattern focuses solely on traded futures prices and does not include the SOQ settlement price on futures expiry days, as we consider the next to delivery contract on expiration days.

[17] Unconditional returns are relatively linear, except for hours between 2:00 and 4:00 - the overnight drift puzzle studied by Boyarchenko, Larsen, and Whelan (2023) highlighted by the shaded area in the plot.

[18] Important early contributions include Stoll (1978), Ho and Stoll (1981), Ho and Stoll (1983), Grossman and Miller (1988), Biais (1993), and more recently Brunnermeier and Pedersen (2009). There also exists a related literature studying price formation with large risk averse investors; for example see Vayanos (1999, 2001) or more recently Rostek and Weretka (2015). For a textbook treatment of the predictions studied here we refer the reader to Foucault, Pagano, and Röell (2013).

return profile on whether its overnight return component was positive or negative and summarize the results in figure 4. In total, out of 225 observations, 143 (64%) overnight returns are positive while 82 (36%) are negative. Averaging within these sets figure 4 shows that positive overnight returns are followed by a reversal that begins in the 9:30 ET interval, while negative overnight returns display no reversal displaying momentum through 9:30 ET continuing to be negative during regular trading hours on Friday. Thus, statistically speaking, the asymmetric price path documented in figure 3 arises because there are far more positive overnight returns than negative and only these returns display a reversal around 9:30 ET. This result provides a first clue as the underlying economic channel driving our central empirical contribution; we explore a host of potential explanations in section V that follows.

[INSERT FIGURE 4 HERE]

Next, table III reports average returns in basis points per trading period (first row) and basis points per 24-hour period (second row) for all days (columns 1 - 3) in our sample for the close-to-open (CTO), open-to-close (OTC), and close-to- close (CTC) trading periods, and for trading periods around monthly 3rd Friday settlement dates (columns 4 - 7).[19] Panel (a) reports return statistics from trading the SPX closing price and the SOQ at open, while panels (b), and (c) are calculated from closing and opening prices for the SPX, and the E-mini, respectively.

[INSERT TABLE III HERE]

Considering all days, CTO, OTC and CTC returns are all slightly positive. On average, the market CTC return appreciates approximately 3.6 bps per day (9.1% p.a) in our sample. Now consider the sub-period returns in the run up to 3rd Friday settlement. Wednesday close to Thursday open, and Thursday open to Thursday close display returns not statistically different from zero.

The final two columns highlighted in grey display return statistics for Thursday close to Friday open and Friday open to Friday close. In panel (a) Thursday overnight returns are abnormally large and *positive* equal to 19 bps. Friday intraday returns are also abnormally large but *negative* equal to -17 bps. Considering panels (b) and (c) the magnitudes are lower, as expected, but remain statistically significant and between 4 and 10 times larger than their all day counterparts.

[19]The column "All days CTO" contains summary statistics for returns over both nights and weekends.

The statistical difference between all day CTO returns and 3$^{\text{rd}}$ Friday CTO returns is large with t-statistics equal to 4.9 (panel a), 3.3 (panel b) and 3.6 (panel c).

B. Triple Witchings

Interestingly, most expiry activity on derivative markets takes place on the "triple witching day", the 3$^{\text{rd}}$ Friday of each quarterly cycle. On these days, expiry volume is maximal as different types of contracts expire simultaneously: a.m. settled futures contracts, options on futures contracts, and index options, as well as p.m. settled single stock options.[20] The financial press often comment on the special nature of these days and for U.S. derivative traders they are the most important date in the calendar.[21]

In table IV we split the results of panel (a) of table III by the OTC and CTO windows around 3$^{\text{rd}}$ Friday quarterly (panel a) and off-quarterly expiries (panel b). Effects are stronger on the quarterly triple-witch days, with a 3$^{\text{rd}}$ Thursday overnight return of on average 27 bps, reverting -37 bps intraday on the third Friday. Off-quarterly expiries still display a strong reversal pattern around the publication of the SOQ, equal to 14 bps overnight and -6 bps intraday. Again, the economic and statistical difference between all day CTO returns and 3$^{\text{rd}}$ Friday CTO returns is large with t-statistics equal to 3.9 (panel a), and 3.3 (panel b). Summarizing, although displaying different magnitudes price moves and reversal effects have the same directional effects on the quarterly versus off-quarterly expiry days. This result demonstrates that the empirical irregularity documented in this paper is distinct from index futures pinning effects studied by Golez and Jackwerth (2012).[22] Section **??** in the Online Appendix (OA) provides a rigorous analysis of pinning in our sample period and shows the effect is unrelated to the 3FPS.

[INSERT TABLE IV HERE]

C. P.M Settled Options

Options on the SPX index began trading on the Chicago Board Options Exchange (CBOE) on July 1, 1983. The introduction of SPX options provided investors with a new way to gain exposure

[20] Some traders even refer to them as "quadruple witchings".

[21] https://www.nytimes.com/1986/03/22/business/triple-witching-hour-havoc.html

[22] Stock pinning is the well-documented phenomenon whereby stock prices that are close to at-the-money (ATM) option strike prices display price dynamics that are very different from a random walk. These stocks tend to move towards their closest strike and become "pinned".

to the stock market, and they quickly became a popular means of hedging and speculating on the direction of the broader equity market. Today, SPX options are among the most heavily traded index options in the world, with robust liquidity and trading volume across multiple expirations and strike prices.

The standard options are European style, have a monthly expiry calendar, trade at strike prices $5 apart, are cash-settled, and contracts trade with a multiplier of 100 of the underlying index value. Expiry is 3rd Friday of the month and settlement is determined by the difference between the option strike and the SOQ and delivered in cash.[23] Trading in expiring options ceases at the market close of the Thursday before expiry and all option contracts which have not been traded out by the end of the last trading day must be settled.[24]

Over time, the CBOE has introduced many variants of the basic option product, with different settlement details like weekly or even daily expiration, end-of-month expiry, or closing-price settlement. Interestingly, settlement of SPX options at p.m. was re-introduced in 2010 when the SEC introduced the p.m. option expiration pilot program. Initially, these were options expiring the last business day of a calendar month, followed by weekly options in 2010, options on other broad-based indices as of 2015, and the more recently options that expire daily. However, the standard 3rd Friday expiry contract have generally been the most liquid and largest in terms of open interest and activity, although more recently daily and weekly option that are p.m. settled at close prices have attracted substantial attention. The main contract specifications of S&P500 index options are summarized in table **??** in the OA.

Table V repeats the analysis of table III for the subsample in which p.m. settled options were traded and also including the weekend return (Friday close to Monday open). Considering overnight Thursday and intraday 3rd Friday the positive - negative return reversal pattern persists and is quantitatively and statistical very similar to the full sample analysis. Returns measured from Friday close to Monday open are, however, negative but statistically insignificant. Moreover, panel (a) of figure 3 displayed no significant pattern of upward or downward drift in SPX futures prices between noon (when the SOQ reversals is complete) and the 3rd Friday close. Overall, we observe no significant price patterns around 3rd Friday p.m. settlement time. We conclude that

[23]Initially SPX options were American and traded on a quarterly cycle. In April 1986, monthly options were introduced and SPX options became European style. In 1997 SPX options switched from p.m to a.m settlement.

[24]Since the options expire into the SOQ but trading ceases the night before, option holders run overnight risk relative to their last traded Thursday price. Option market makers typically hedge this risk with index products like futures, ETFs and the basket of individual stocks, which need to be unwind around the SOQ to minimize hedging risk.

the bias in option settlements is isolated in 3rd Friday a.m settled derivative contracts.

[INSERT TABLE V HERE]

D. Return Reversals

The analysis so far has provided convincing evidence that overnight returns in advance of 3rd Friday a.m settlements are systematically positive and subsequently revert intraday Friday. To demonstrate a formal link between the two sub-period returns we estimate a standard microstructure reversal regression. The overnight return is measured from SPX trades on each month's 3rd Thursday at 16:00 to the reported SOQ on Fridays and the subsequent intraday return is measured from the SOQ to the SPX traded price at 12:00. We then regress Friday intraday returns on Thursday overnight returns. Table VI, panel (a) displays the point estimates and 95% confidence intervals computed from a block bootstrap sampling 1,000 times with the optimal block length chosen following Patton, Politis, and White (2009). The intercept in the regression is negative implying that the Friday intraday return overshoots the preceding overnight returns, or other words, the reversal is more than 'undone'. More importantly, the predictive slope coefficient is strongly negative implying that large overnight returns are causally reversed intraday consistent with standard theories of price pressure. The R^2 is equal to 12%, which is large given the high-frequency nature of the regression.[25] Panel (b) of table VI repeats the above analysis for all days, showing also a significant reversal but with magnitudes three orders of magnitude smaller.

[INSERT TABLE VI HERE]

Next, we examine a trading strategy that exploits the reversal patterns, shedding light on its pervasive nature and magnitude. We consider a trade that buys the SPX at close, reverses into a short positions at open via mimicking the SOQ and closes this position at market close trading the SPX closing price. Table VII reports summary statistics of the trading strategy. The first column considers this strategy on all days, the second column considers only non expiry dates, the third column considers 3rd Fridays and the fourth and filth columns break column three down into quarterly and off-quarterly dates. Considering all dates in our sample this strategy returns 1.3 bps, which is not statistically significant. On non-expiry days mean returns are slightly negative

[25] For example, Boyarchenko, Larsen, and Whelan (2023) estimate a comparable range of high-frequency predictability regressions and obtain maximum R^2's less than 1%.

but again not statistically significant. Considering monthly 3^{rd} Fridays we obtain a mean return of 36 bps per expiry day. Out of 225 observations 69% are positive and we easily reject the null of a random walk. Triple witching days have a mean return of 48 bps with 77% being positive, while off-quarterly expirations have a mean return of 31 basis points with 65% being positive; again easily rejecting the null of a random walk.

[INSERT TABLE VII HERE]

Figure 5 translates these returns over time by computing their realized cumulative value. The long overnight, short intraday and reversal strategy are remarkably stable and similar over time. A \$1 investment in 2003 grows to $\sim$ \$1.5 in both the overnight and intraday trade, and the reversal strategy grows to \$2.3.

Figure 5 panel b displays the annualized Sharpe ratio of this trading strategy by year.[26] The strategy earns positive returns in all years except 2015, 2016 and 2018. Sharpe rations are generally large, with many exceeding 2 and some exceeding 3. Although the highest Sharpe ratios occur in the early part of our sample, the high Sharpe rations in 2019 to 2021 show that the 3^{rd} price spike is present until the end of our sample.

[INSERT FIGURE 5 HERE]

E. Robustness

E.1. Small Sample Bias

Accounting for potential small sample biases in our findings, we estimate the distribution of returns reversal strategy via block bootstrap, sampling 1,000 times with the optimal block length chosen following Patton, Politis, and White (2009). Figure 6 plots the empirical distribution, which is scaled to be interpreted as a density function, i.e., its integral sums to one. The first, second and third dotted lines represent 2.5%, 50% and 97.5% percentiles. Eyeballing the figure we observe a relatively symmetric distribution. The far left tail (low returns) does not intersect zero, the 2.5% confidence interval is equal to 22 bps and 97.5% confidence interval is 47 basis points demonstrating that overnight returns followed by negative intraday returns is a strong in both economic and statistical terms.

[INSERT FIGURE 6 HERE]

[26] We compute the annualized Sharpe ratio by scaling the daily excess return to volatility ratio by 12 (trading) periods.

E.2. Transaction Costs

Limits to arbitrage may prevent investors from taking advantage of the 3FPS. Next, we explore the 3FPS trading strategy including transaction costs. We take a conservative perspective by considering the entire bid-ask spread by buying at the ask and selling at the bid.[27] More specifically, returns on trading day j earned on a strategy that goes long the E-mini contract in the sub-period $[t_1, t_2]$ are computed as

$$R^L_{j,[t_1,t_2]} = \frac{P_{j,t_2} - P_{j,t_1}}{P_{j,t_1}}, \tag{2}$$

where P denotes the price of the ES contract. The analogous short position earns $R^S = -R^L$. Transaction costs are incorporated from bid-ask quotes and returns are computed from quotes as

$$R^L_{j,[t_1,t_2]} = \frac{P^{\text{bid}}_{j,t_2} - P^{\text{ask}}_{j,t_1}}{P^{\text{ask}}_{j,t_1}} \quad , \quad R^S_{j,[t_1,t_2]} = -1 \times \frac{P^{\text{ask}}_{j,t_2} - P^{\text{bid}}_{j,t_1}}{P^{\text{bid}}_{j,t_1}}. \tag{3}$$

Table VIII reports summary statistics for a trading strategy that buys the front month E-mini futures contract on off-quarterly 3$^{\text{rd}}$ Fridays and trades the next to deliver contract on quarterly expiry dates (as this becomes the on-the-run contract and liquidity is highest in the second contract close to expiry of the front contract). The trade reverses into a short positions at open and closes the position at noon (12:00 ET). All returns are in basis points.

[INSERT TABLE VIII HERE]

The mean reversal return for this trade across all expiry dates is 24 bps per day, or about 3.0% a year, and equal to 35 and 19 bps per day on quarterly and off quarterly expiry dates, respectively. The t-statistics against zero are large and always reject at the 1% level. Sharpe ratios on this strategy are economically large with values between 0.5 (off-quarterly) and 0.9 (on quarterly expiry dates), which is particularly impressive given that it incorporates a conservative estimate of transaction costs. Note that, as in Lucca and Moench (2015), annualised Sharpe ratios are computed based on holding periods, i.e., we are trading 12 times per year on third Fridays or 4 times a year on the quarterly expiration cycle. Finally, the last two rows VIII regress the net returns on market returns to current for any implicit market risk effects. Again, results are sizable

[27] The spread in the ES futures contract is almost always one tick, or \$12.5 per contract, with large depth at the best bid and ask. In practice, investors apply execution algorithms for optimal liquidity resulting in transaction costs that are typically well below half a tick (typically executions are only slightly worse than the midquote).

and highly significant, with alphas close to average net returns, highlighting the robustness of the strategy returns.

F. The 3FPS and Return Gap on Option Indices

We have shown a economically sizable and statistically significant 3FPS effect. Next, we link the 3FPS effect to explain substantial return differences between two popular S&P500 option indices, namely the S&P500 buywrite (ticker: BXM) and putwrite (ticker: PUT) indices. These indices, well utilized in the investment industry, basically consist of a long S&P500 index position with combined with a short position in the nearest to at-the-money index call option contract (buywrite), or a short position in the nearest to at-the-money index put option contract (putwrite). Options used have a maturity of one month and follow the monthly 3$^{\text{rd}}$ Friday expiry calendar. As S&P500 index options are European style both strategies should deliver (near) equal returns for reason of put-call parity. However, they differ on on remarkable future: the rolling of option positions on the expiry day (i.e. the 3$^{\text{rd}}$ Friday of each month). As the exact time of the SOQ is undetermined, these indices have to rely on other pre-determined procedure to enter new option positions. For these indices this is not directly at expiry but rather at noon of the expiry day. As a result the buywrite index has only a long S&P500 exposure between the SOQ and noon, while the putwrite index has no market exposure during these same window. Note that this occurs 12 times a year for about 2.5 hours. As document above, during this window index prices fall substantially on average, and as such studying returns on these indices and their listed ETFs allows for (another) a real-life impact study of the 3FPS.

[INSERT TABLE IX HERE]

Table IX display the returns and return gap on the S&P500 buywrite and putwrite indices over our sample that runs from January 2005 till December 2022. The putwrite (PUT) index returns on average 7.13% a year compared to 5.73% for the buywrite (BXM) index. The return gap, hence, equals an economically sizable 1.40% percent a year. Note that the average return during 3$^{\text{rd}}$ Friday open to noon is of similar magnitude. We next decompose this return gap in expiry versus non-expiry days. Return differences on non-expiry days equal an insignificant -0.38% a year, while return differences on expiry days equal a sizable 1.93% a year. As the effect on expiry days might simply be a reflection of a general 3FPS effect, we also consider average return gaps on non-expiry Fridays. The last column of table IX shows close to zero return differences on these days, averaging to 0.10% a year, hence dismissing a general Friday effect explanation. Overall, we can conclude that the return gap is a manifestation of the bias in the equity derivative payoff: SPX prices are upward biased in the SOQ and revert intraday 3$^{\text{rd}}$ Fridays.

IV. Wealth Implications

Persistent positive overnight returns preceding 3$^{\text{rd}}$ Fridays biases the payoffs of all U.S. equity derivatives that have monthly 3$^{\text{rd}}$ Friday a.m. expiry. Most importantly, this includes index options, futures and futures options written on various equity indices (e.g., S&P500, Russell2000, the Nasdaq100).

We compute the wealth transfer generated by the payoff bias in U.S. equity derivatives. In light of table V, we only consider a.m. settled SPX options and quantify the derivative settlement bias. Since we only consider listed SPX index options (and hence do not consider many other large and potentially affected derivatives markets) our estimates can be interpreted as a lower bound on the potential wealth transfer.[28]

We take two approaches. First, noting that a.m settled options cease trading at 16:15 p.m on 3$^{\text{rd}}$ Thursday but that the 3FPS in the underlying generates price pressure in derivatives overnight, we compute the SPX index option returns into expiry. We compare actual overnight option settlement returns - as measured between 3$^{\text{rd}}$ Thursday close and the SOQ - with counterfactual returns that replace realized returns with the unconditional *average* overnight return measured across all days.

Table X, panel (a) contains the resulting overnight option returns split per in-the-money (moneyness below 0.99), at-the-money (moneyness within the 0.99 and 1.01 interval), and out-the-money (moneyness above 1.01) call and put options. On average, in-the-money and especially at-the-money call (put) option returns are upward (downward) biased, while out-the-money options are less affected. Relative to their counterfactuals we estimate overnight option returns (measured over 17 hours and 15 minutes) are a striking 34.4% for at-the-money calls and -20.0% for at-the-money puts. In other words, the overnight pre-settlement drift in SPX prices has a tremendous influence on realized option returns.

[28] For example, we ignore futures options, OTC options, and options on other U.S. indices like the Nasdaq100 and Russell2000.

Next, we translate option payoffs to dollar-terms by multiplying the payoff by expiring open interest over all strikes. Panel (b) of table X contains the resulting numbers. At-the-money call options are upward biased by \$24.5 million per 3rd Friday expiry, and at-the-money put options are downward biased by \$13.8 million per expiry. To compute the total wealth transfer we sum all numbers across all call or put option contracts in the bottom row of panel (b). Call options payoffs are upward biased by \$176.5 minus \$9.1 million, or \$167.4 million per expiry. This translates to \$2.0 billion a year. Put options payoffs are downward biased by -\$126.9 minus \$64.9 million, or \$62.0 million per expiry and \$0.7 billion a year. The absolute sum, \$2.7 billion a year, we interpret as the estimated wealth transfer from option returns.

[INSERT TABLE X HERE]

As second approach to computing a wealth transfer we compare the realized payoff of all SPX options (calculated from 3rd Friday SOQ) with a hypothetical payoff calculated from Thursday SPX closing price.[29] The overnight return bias impacts options as follows: (*i*) a higher payoff for already in-the-money calls; (*ii*) some calls which would have expired out-of-the money without the price spike now expire in-the-money; (*iii*) a lower payoff for in-the-money puts; and (*iv*) some puts which would have expired in-of-the money now expire out-the-money. Since SPX options do not trade over night before expiry, there are no changes in option positions that we need to consider. Therefore, the hypothetical payoff from Thursday close represents a natural *counterfactual.*

The total call option settlement value is calculated as

$$SettlValue_{Calls} = \Sigma_i^I max(0, SOQ - K_i) * OpenInterest_i \tag{4}$$

where I is the number of different expiring call option contracts and K is their strike price. The total put option settlement value is calculated equivalently as[30]

$$SettlValue_{Puts} = \Sigma_i^I max(0, K_i - SOQ) * OpenInterest_i \tag{5}$$

The counterfactual we consider replaces SOQ in the max operator with the SPX closing price on

[29] The difference between closing prices computed from trades versus quotes is almost zero. We use the traded closing price.

[30] We obtain SPX Options data from OptionMetrics. OptionMetrics lags open interest by one day. Thus, the last observation of each options contract before expiry provides open interest from Wednesday close, not Thursday close. This limitation from a standard dataset should not have an outsized influence on our estimates on average.

Thursday, which is also the point in time when the options stop trading.

Table XI shows that SPX call options paid off $10.46 billion on the average 3$^{\text{rd}}$ Friday morning. Had their settlement been determined at Thursday close, they would have paid off $10.23 billion. The difference of $230 million a month represents the wealth transfer from call option writers to call option buyers. Similarly, the table shows that SPX put options paid off $3.04 billion on the average 3$^{\text{rd}}$ Friday morning, versus a counterfactual $2.12 billion, yielding a wealth transfer from put option buyers to put option writers of $90 million a month.[31] We interpret the sum of the wealth transfers in call and put options as the total wealth transfer and multiplication by 12 (expiries a year) yields our headline number of $3.8 billion annual wealth transfer.

Figure 7 displays this monthly difference in option payoffs from 3$^{\text{rd}}$ Friday a.m. settlement versus hypothetical Thursday close settlement. Of course, not every equity return between Thursday close and Friday open represents a market inefficiency and thus not every difference between actual and hypothetical option payoffs represents a bias. However, considering call options in panel (a), it is remarkable to see that this difference (actual minus hypothetical payoff) is positive for the vast majority of option expiry days. Considering put option in panel (b), the difference is negative for the vast majority of expiry dates. Thus, the estimates in table XI are not driven by unique expiries, but are a pervasive feature of US derivatives markets.

[INSERT TABLE XI AND FIGURE 7 HERE]

V. Potential Explanations

In the previous sections we documented a sizable and significant bias in the payoffs on U.S. equity derivatives. In this section we explore a set of plausible explanations for this empirical regularity.

A. Is the Equity Derivative Payoff Bias Driven by the SOQ Mechanism?

First, we answer an obvious question the reader might ask "Does the existence and design of the SOQ calculation somehow drive the 3FPS?" To answer this question we ideally examine an equity index with derivatives trading on it and a different settlement price calculation. Interestingly, since June 2005 derivatives on this index settle on the NASDAQ Official Opening Price (NOOP)

[31] Despite the demand for SPX put options, aggregate call option payoffs are more affected by a bias in the SOQ because put options are more likely to expire out-of-the-money and are thus less unaffected.

which is based on the first opening *cross* of every constituent of the NASDAQ 100 index.[32] This cross is based on the order imbalance among orders at the open book disseminated to investor between 9:25 and 9:30 a.m. and initiated at 9:30 a.m. In other words, the NOOP is based on the order book imbalance available at NASDAQ open, and unlike the SPX SOQ does not depend on the first traded price of stocks *after* open. Hence, examining the Thursday overnight and 3$^{\text{rd}}$ Friday reversal effects around expiry of index options in the NASDAQ 100 Index allows us to rule out any explanation that relies purely on the SOQ.

[INSERT FIGURE 8 HERE]

The black line in panel a of figure 8 shows the 3FPS in the NASDAQ 100 index. Similar to the SPX results we find a sizable and significant Thursday overnight return before the option expiry of 14bps, about the same size as for the SPX index, followed by a significant reversal between expiry and noon on the 3$^{\text{rd}}$ Fridays. Further, this pattern is remarkably different from the average pattern on all other days, as depicted by the red line. Tests confirm that the 3$^{\text{rd}}$ Friday intraday pattern is predicted by the Thursday overnight move and that the size of the reversal is not significantly different from the initial overnight move. These results suggest the 3FPS is unlikely to be solely due to the SOQ calculation, but combined with the finding of no 3FPS around p.m. settlement times suggest an explanation that relies on settlement values directly after an illiquid or eventful trading period.

B. Mechanisms We Can Rule Out

We briefly discuss three explanations that can be easily ruled out and relegate a rigorous analysis to the OA.

A first possible explanation for the 3FPS is the arrival of fundamental information that is incorporated into prices. However, such an explanation is difficult to reconcile with prices rising pre-macroeconomic or earnings announcements, which are typically at 8:30 a.m but revert at 9:30 a.m an hour after the announcement. Moreover, if news is incorporated correctly, we would not expect to see a complete reversal after the announcements, at odds with the empirical pattern of equity prices rising overnight till exactly the 9:30 interval on 3$^{\text{rd}}$ Fridays and reversing afterwards

[32] If a stock does not have an opening cross, the NASDAQ Official Opening Price is determined by the first last-sale eligible trade reported at or after 9:30 a.m., when regular trading hours begin. If a stock does not trade on a given day, the NOOP is zero and the security's adjusted closing price for the previous day is used. Before June 2005, settlement values were based on the volume weighted opening price.

intraday. In addition, an explanation based on fundamental shocks seems hard to reconcile with asymmetric response in the 3FPS we document of reversals after positive overnight returns. To further test an information-based explanation, we examine the release times of macroeconomic or earnings news, variation in reversal effects across 3$^{\text{rd}}$ Fridays with or without major macroeconomic or earnings announcements, or positive versus negative macroeconomic or earnings surprises and find no significant relationship with 3FPS patterns.

An second possible explanation is based on the rational pinning, or anti-pinning, of index prices around option strike prices on option expiry dates. Index prices might rationally cluster towards, or away from, option strike prices due to changes in the optimal delta hedges resulting from the passage of time when option market makers have net long (short) positions (Avellaneda and Lipkin, 2003). Ni, Pearson, and Poteshman (2005) present evidence that the prices of individual stocks pin at popular option strike prices on option expiry days. Golez and Jackwerth (2012) show that SPX futures prices are pulled toward the at-the-money (ATM) strike price of futures options on the non-quarterly expiration's times (i.e., pinning). Most importantly, in contrast to a pinning explanation, we fail to find evidence of pinning in the SOQ prices, and we find the same directional effects on the quarterly versus off-quarterly expiry dates. Furthermore, a pinning explanation would predict that determinants explaining pinning, most notably the open interest on the ATM strike price, determine to a certain extent the bias in equity derivative payoffs. We also fail to confirm such a relationship in our tests.

An third possible explanation is the existence of "non-fundamental" shocks that cause temporary price pressure at the index level and subsequent reversal. The market microstructure literature offers a possible explanation based on inventory management of financial intermediaries (for example, Grossman and Miller, 1988, Gromb and Vayanos, 2002, Nagel, 2012 or Brunnermeier and Pedersen, 2009). In supplying liquidity, risk-averse market makers face inventory risk in providing liquidity to investors who demand immediacy for which they earn a premium. A shock to market makers' inventory pushes prices in the direction of the order imbalance, and the reversal afterward compensates market makers for facilitating demand shocks. These theories can generate asymmetric reversal patterns if: (a) order imbalances are systematically in one direction, or (b) if funding constraints are state dependent.[33] Such an explanation is again hard to reconcile

[33] Boyarchenko, Larsen, and Whelan (2023) study overnight reversals empirically and the internet appendix to that paper derives a constrained intermediary extension to Grossman and Miller (1988) that shows how asymmetric reversal patterns arise naturally from existing theory. Krohn, Mueller, and Whelan (2022) show that the U.S. dollar appreciates in the run-up to foreign exchange fixes and depreciates thereafter. These authors argue a prolonged return reversal is consistent with

with asymmetric response in the reversal pattern: price movements before expiry only revert after positive overnight returns. We test for state-dependence by studying the relationship between the bias in equity derivative payoffs and past returns or volatility, as funding constraints tend to tighten in times of market stress or higher volatility, but fail to find a significant link.

C. Mechanisms We Cannot Rule Out

What then explains the payoff bias? Order imbalances that are systematically in one direction before the 3rd Friday open present a likely explanation. But, why would order imbalances be systematically in one direction on these days, and not on other days? We consider two potential drivers: hedging and market price manipulation.

C.1. Hedging

Option market makers (OMMs) face demand imbalances as they are typically short index put options and long index call options (Gârleanu, Pedersen, and Poteshman (2009) and Golez and Jackwerth (2012)). The resulting options positions can expose them to significant inventory risk. Therefore, OMMs typically hedge their directional risk from options with offsetting positions in the underlying asset (here the S&P 500 index).[34]

For example, a typical OMM that sells many puts and buys many calls would have a positive inventory "net delta" from those positions (long positive delta from the calls, short negative delta from the puts). Such a market maker would short the S&P 500 to get their total inventory net delta to zero. They would then be approximately hedged against directional moves in the S&P 500.[35]

When the options expire the market maker would also wish to close out the hedge position in the S&P 500. In our example this would entail buying back the index into option expiry. This could create positive price pressure and potentially explain the payoff bias that we document.

To examine this potential "unwinding delta-hedges" explanation we document the positions of option market makers in S&P 500 index options in table XII.[36] Data comes from the CBOE Open-

pre-fix hedging by foreign exchange dealers which is observationally equivalent to market manipulation.

[34]This hedging by OMMs can be done directly in the constituent stocks but also in other linear derivative products like SPX futures and ETFs.

[35]Such a hedge would only be an approximation since delta is only a linear approximation of the change in options price for a change in underlying price.

[36] The table only considers options that expire during the observation month. We do not consider positions in non-expiring options here as they are not relevant for the unwinding delta-hedges hypothesis.

Close dataset that provides daily buy- and sell volumes of SPX options since 2006 aggregated by (*i*) customer; (*ii*) professional customer (hedge funds); (*iii*) broker-dealer; and (*v*) market maker. We aggregate these daily volumes to cumulative positions for each group and document positions into option expiry.

The first row shows that on average the market maker sector is short 691 thousand expiring call options during the expiry month. On the Wednesday (Thursday) before option expiry (Opex) this short position grows to 1.008 mil. (1.34 mil.) call contracts. However, the aggregate *number* of call options in the market maker portfolio does not reveal their exposure to the price of the underlying. Market makers might be very short deep out-of-the money calls (with deltas close to 0) and long in-the-money calls (with deltas close to 1). The number of contracts would be very negative but their net-delta would still be positive. Therefore, we document market maker net-delta on the right hand side of table XII.

Row one shows that on average the market maker sector has a net delta of 588 thousand from expiring call options during the expiry month. Thus, when the price of the underlying rises by $1, the market maker call options portfolio value rises on average by 588 thousand dollars. Column 6 shows that at 3$^{\text{rd}}$ Thursday close OMMs have a small positive net-delta from their expiring call options positions.

Row 6 contains the equivalent information for put options. On average OMMs hold a short position of 7.2 mil expiring put options. On 3$^{\text{rd}}$ Thursday close they hold a short position in 6.5 mil. expiring put options. Column 6 shows that this results in a net delta from puts of -66 thousand.[37]

With respect to the potential "unwinding delta-hedges" explanation, market maker net delta from expiring calls at Thursday close is low and positive (0.56) and from expiring puts is low and negative (-0.66). The two almost perfectly offset each other, leading to a total market maker net delta from expiring options positions close to 0 (-10 thousand). Thus, OMMs would need only a very small positive position in the underlying as a hedge. Unwinding this small hedging position into expiry would create a small negative price pressure. Consequently, "unwinding delta-hedges" seems hard to reconcile with our findings of strong positive returns into the option expiry. In addition, we like to note that such a hedging explanation is seemingly at odds with the asymmetric response in the reversal pattern: price movements before expiry only revert after

[37] Most of the short positions are deep out-the-money, with 0 deltas and thus do not result in a very low market maker net delta.

positive overnight returns while the unwinding of hedges requires trading after both upward and downward overnight market movements.

An alternative explanation from OMMs hedging flows relates to "Charm", i.e. the change in option delta as the option time to expiry goes to zero. Charm movements imply OMMs need to adjust delta hedges with the passage of time. Figure 9 illustrates how the delta of call or put options varies with time to expiry. Upon expiry the delta of a call option is either 1 or 0, and just before expiry Charm movements are most substantial. This phenomenon is particularly strong for near at-the-money options, options that have a delta close to 0.5 just before expiry, but for which their delta will be in-the-money (delta 1) or out-of-the-money (delta 0) at expiry.

If market makers have a short (long) position in just-in-the-money (just out-the-money) calls, their net delta would fall quickly as these options approach expiry. To keep their portfolio delta neutral OMMs would need to buy the underlying overnight before expiry, possibly creating positive price pressure and explain the derivatives payoff Bias. The same argument applies for a potential short (long) position in just-out-the-money (just-in-the-money) puts.

Column 6, rows 3 and 8 of table XII show that market makers have relatively large at-the-money put positions in expiring options.[38] Thus, such a "Charm" explanation might seem plausible. However, when we split at-the-money positions into just-in-the-money and just-out-of-the-money we do not observe the positions outlined above that would result in positive price pressure from Charm. OMMs have large positive net delta from jitm calls and jitm puts, and positions in these instruments exceeds the position in jotm calls and jotm puts by an order of magnitude. These positions should create *negative* price pressure into expiry as the delta of the jitm positions moves to 1 (assuming prices do not move or move up) due to Charm, at odds with the empirical pattern.

In conclusion, we consider two hedging explanations for the high S&P500 returns into option expiry. An examination of total market maker call and put positions reveals that an unwinding of delta hedges around expiry is unlikely to explain our findings. An examination of at-the-money positions indicates that a Charm-based explanations is possible.

[INSERT TABLE XII and FIGURE 9 HERE]

[38] We count all options within 4 strikes (that is $20) of the underlying price as at-the-money. We count all calls (puts) within 4 strikes below (above) the underlying price to be just-in-the-money (jitm). The opposite applies for just-out-the-money (jotm).

C.2. Price manipulation

Another potential explanation is market price manipulation. Sophisticated market participants with short positions in puts or long positions in calls might gain from manipulating the index price immediately preceding settlement such that settlement prices move in the direction that benefits their position. For example, a manipulator which a large long call or short put position might seek to push the underlying index up such that the option is (deeper) in-the-money or out-the-money. Such attempts may occur directly in the way an arbitrage position is unwound, or indirectly through arbitrage unwoundings that benefit other positions, and are more likely if prices can be more easily manipulated. Indeed, equities trading pre-open is much less liquid than during regular trading hours, making the overnight window most suited for manipulation.

For individual stocks (Ni, Pearson, and Poteshman, 2005) and the VIX index (Griffin and Shams, 2018) extant evidence suggests that manipulator are active around option expiration dates, and there have been several high profile cases of manipulation (Aggarwal and Wu, 2006). The empirical evidence we observe aligns with a manipulation hypothesis; it predicts temporary price pressure that reverts quickly (prices are pushed away from fundamentals); it predicts price patterns especially during a finite window just before expiry (as payoffs become fixed at expiry); it predicts no price pattern during periods when manipulation is unlikely to be successful, such as during the p.m. settlement window; it predicts an asymmetric response if prices are more easily pushed up than down - for example due to short-sales constraints, and it predicts stronger effects when incentives are greater like during triple witching days.

This raises the question: who would be the potential manipulator? In the previous section we saw OMMs positioning would not benefit much from price manipulation, as they are on average short delta into expiry. As alternative, we explore the positioning of professional customers - typically hedge funds - using the above outlined CBOE dataset. Table XIII contains the summary statistics. On average, the pro-customers are net long delta on the 3$^{\text{rd}}$ Thursday before expiry in both calls and puts. In other words, they would benefit from a price rise overnight just before expiry. Interestingly, when comparing the 3$^{\text{rd}}$ Wednesday to 3$^{\text{rd}}$ Thursday, we can observe that these pro-customers increased their option delta Thursday intraday, increasing the payoff of a overnight price spike. The above results and discussion suggest that market manipulation by professional customers is also a plausible explanation.

[INSERT TABLE XIII HERE]

VI. Conclusions

We document and sizeable bias in the payoff of U.S. equity index derivatives. On the 3$^{\text{rd}}$ Friday of each month - the day when equity index options and other derivatives expire in the special opening quotation (SOQ) - the SOQ on the S&P500 index exceeds the previous day closing price by over 18 bps on average.

This bias is due to high equity returns overnight, which revert intraday after the settlement time. Reversal profits exploiting this Third Friday Price Spike (3FPS) are sizeable with a gross Sharpe ratio exceeding 1.3, remain high after accounting for transaction costs, and are present across U.S. stocks. There is no corresponding pattern in 3$^{\text{rd}}$ Friday p.m. settled options. A positive overnight return bias raises (lowers) S&P 500 call (put) option payoffs inducing an annual wealth transfer in the region of $4 billion per year.

We rule out a set of plausible explanations based on informational shocks, pinning, or limited risk-bearing capacity of market makers. As an alternative, we conjecture and study two plausible alternatives: (1) hedging motivates by option market makers; and (2) an explanation based on market manipulation. Both explanations rely on the existence of an illiquid trading period directly preceding payoff settlement. However, regardless of the cause, we argue that our findings suggest that current settlement procedures lead to a market inefficiency and that regulators should critically evaluate current settlement practices.

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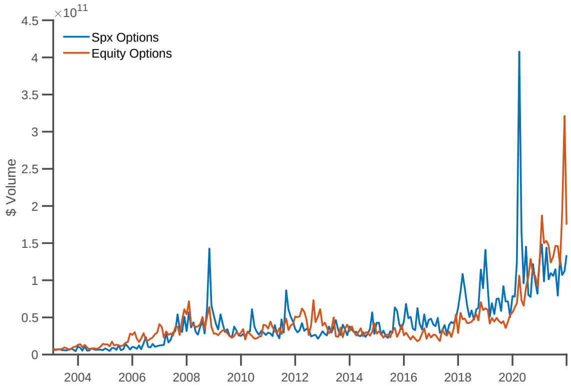
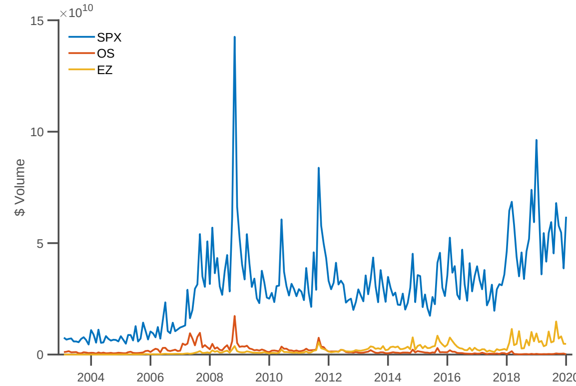
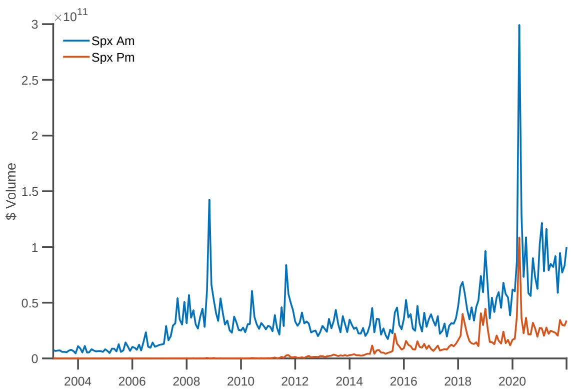
VII. Appendix: Figures



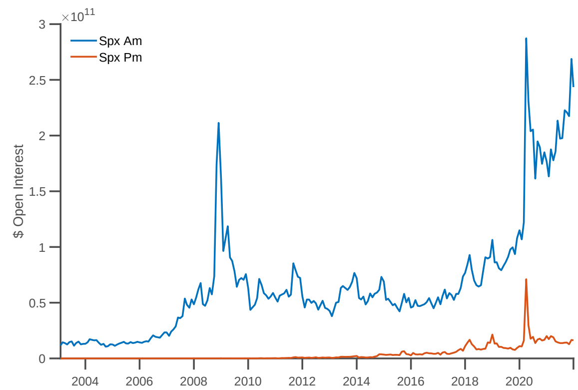
(a) Volume: Index Options vs. Stock Options



(b) Volume: Index Options vs. Futures Options



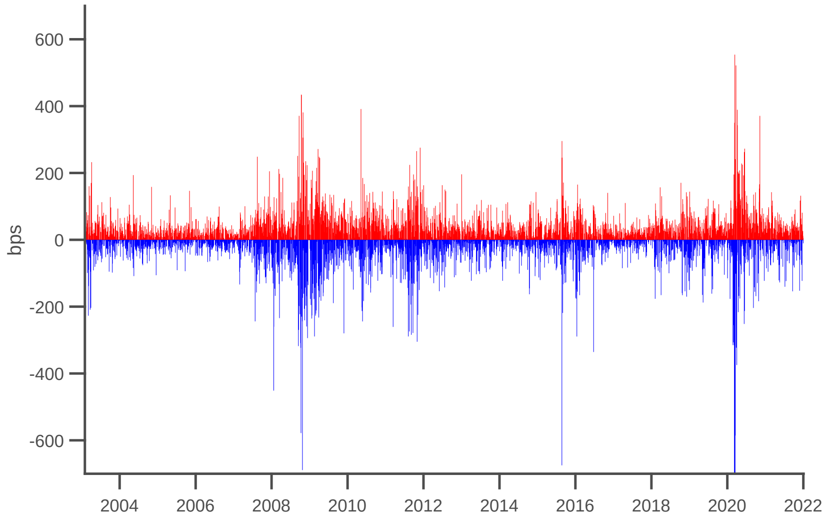
(c) Volume: Am vs. Pm Settlement



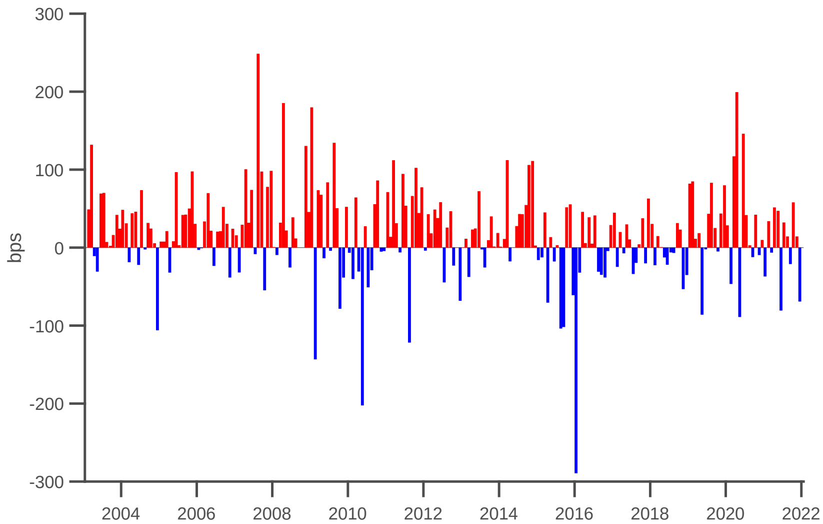
(d) Open Interest: Am vs. Pm Settlement

Figure 1. Spx Option Market Size

This figure illustrates the size of the S&P500 index (SPX) options market. Panel a displays monthly dollar trading volume of spx index options and options on the S&P 500 constituent stocks. Panel b displays monthly dollar trading volume of spx index options and sp index futures options. Panel c displays monthly dollar trading volume of Spx options with Am and Pm settlement. Panel d displays monthly average dollar open interest of Spx options with Am and Pm settlement. The sample period is 2003.1 - 2021.12. Panel b ends in 2019.12.



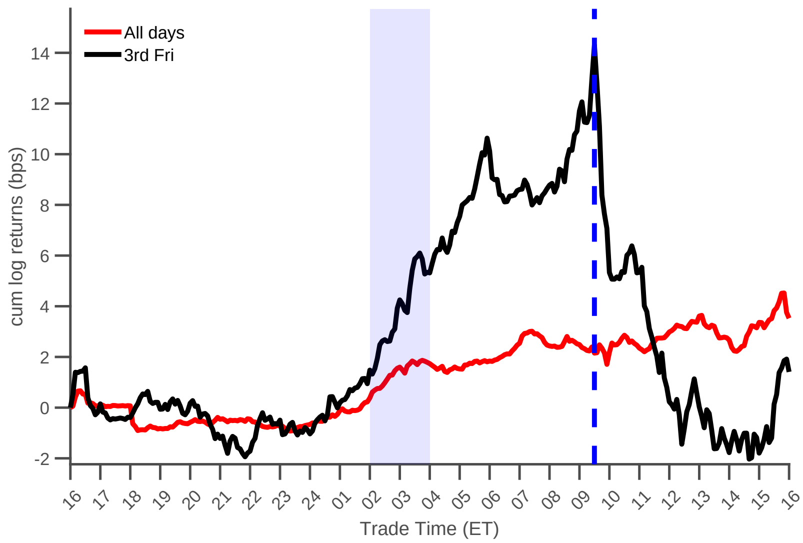
(a)



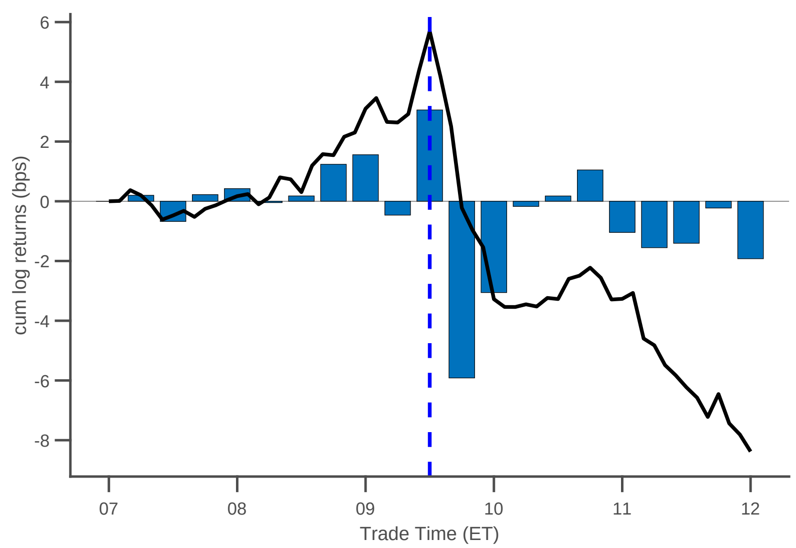
(b)

Figure 2. SOQ vs Opening Prices vs Closing Prices

These figures plot the times-series $ReturnSOQ_t = log(SOQ_t) - log(SpxClose_{t-1})$. The SOQ is calculated from the opening sales price index component stocks on their primary listing exchange and the SOQ is available only once all component stocks have traded during the regular market session after 9:30 Eastern Time (ET). The index closing price is computed from the last traded price of the index at 16:00 while the opening price is computed from the first traded price after 9:30. Panel (a) contains all days in our sample while panel is sampled on 3^{rd} Fridays. The sample period is 2003.2 - 2021.12.



(a)



(b)

Figure 3. 3rd Friday Price Spike in E-mini futures: S&P 500
In panel a, the black line plots average cumulative 5 minute log returns around 3rd Friday market open (0930 E.T., blue dotted line). The red line plots cumulative returns on all other days. The y-axis is in basis points and the x-axis is time of day in Eastern time (E.T). The purple shaded region highlights the opening of European markets. Panel b zooms in on the 2.5 hour window around market open. The blue bars show average 15 minute log returns. The sample period is 2003.2 - 2021.12.

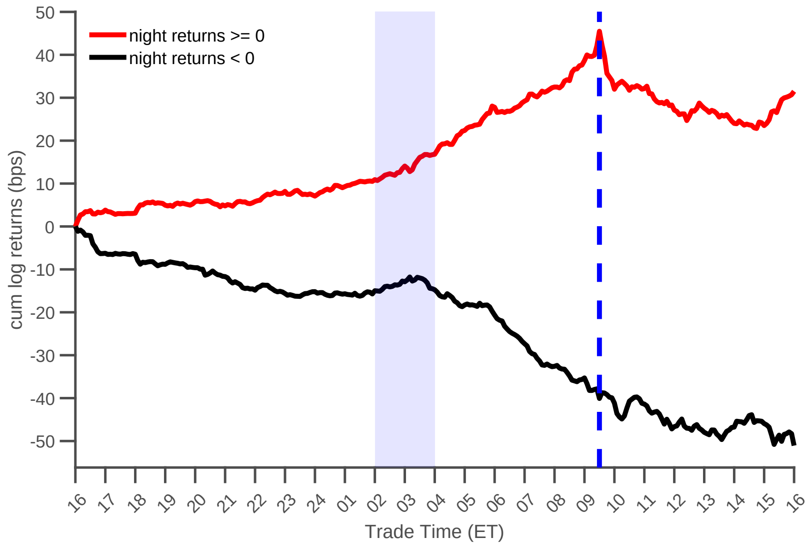
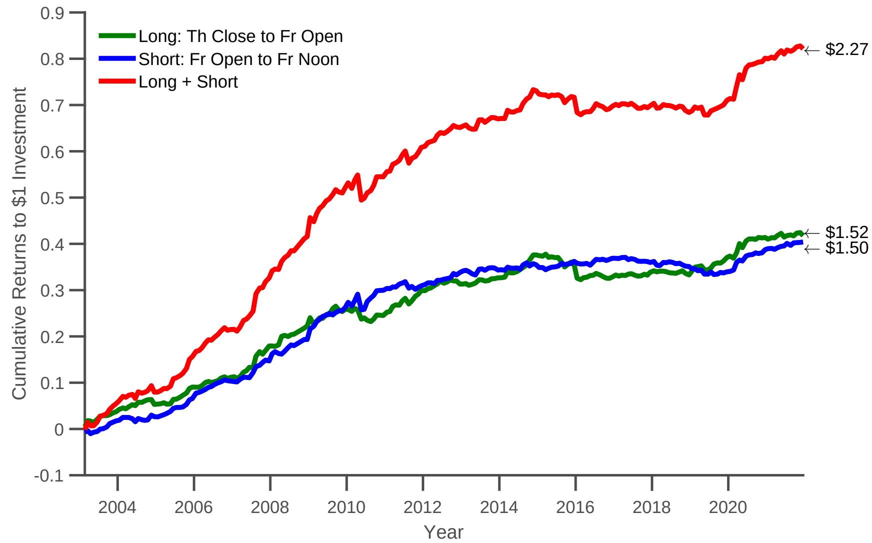
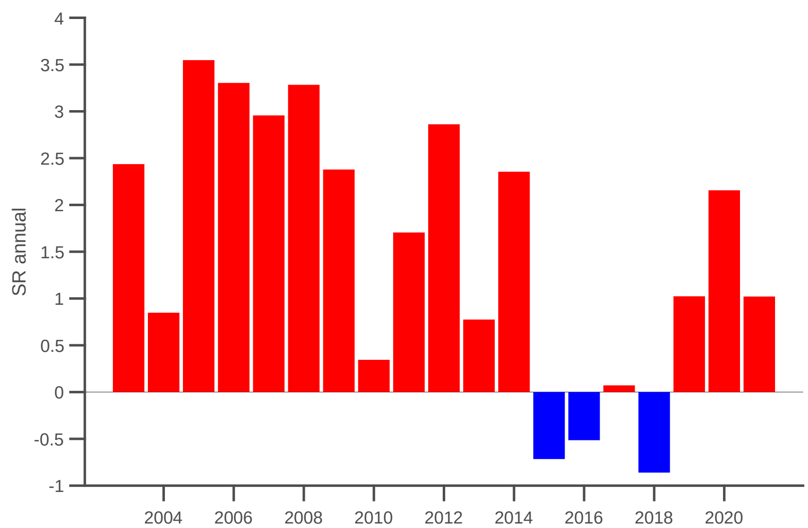


Figure 4. 3rd Friday Price Spike: Positive vs Negative night returns

This figure shows average cumulative 5 minute log returns around 3rd Friday market open (0930 E.T., blue dotted line). The red (black) line cumulates only returns that were positive (negative) between 16h and 0930h. The y-axis is in basis points and the x-axis is time of day in Eastern time (E.T). The purple shaded region highlights the opening of European markets. The sample period is 2003.2 - 2021.12. In total, there are 225 observations of which 143 are positive overnight returns (the red line) and 82 are negative (the black line).



(a) Cumulative TFPS



(b) Annual Sharpe Ratio

Figure 5. Trading the Third Friday Price Spike
In panel a, the blue line plots the cumulative returns of the reversal strategy: Once every month, go long the S&P500 index via inx trades at 3rd Thursday close, switch to a short position at 3rd Friday open via the Special Opening Quotation and close the position at 3rd Friday noon via inx trades. Opening times are 0930 , noon is 1200 and closing times are 1600. Panel b displays the Sharpe ratio of that trading strategy by year. The sample period is 2003.2 - 2021.12.

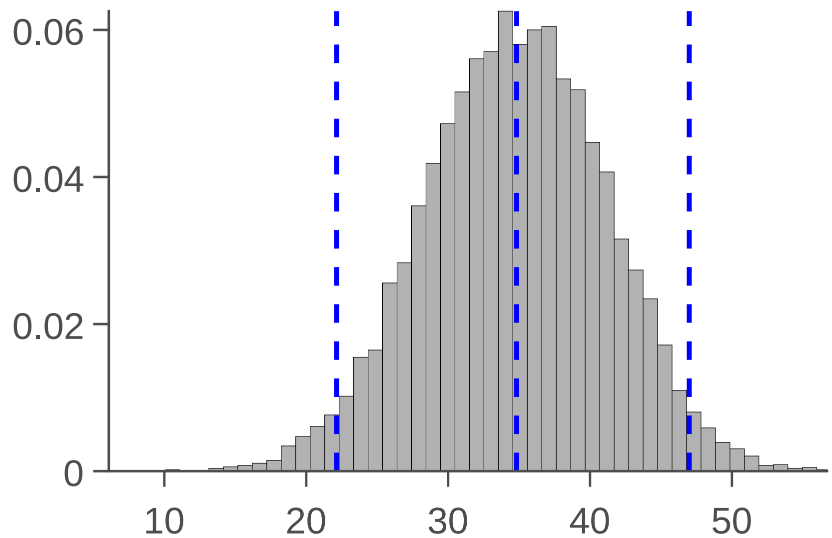
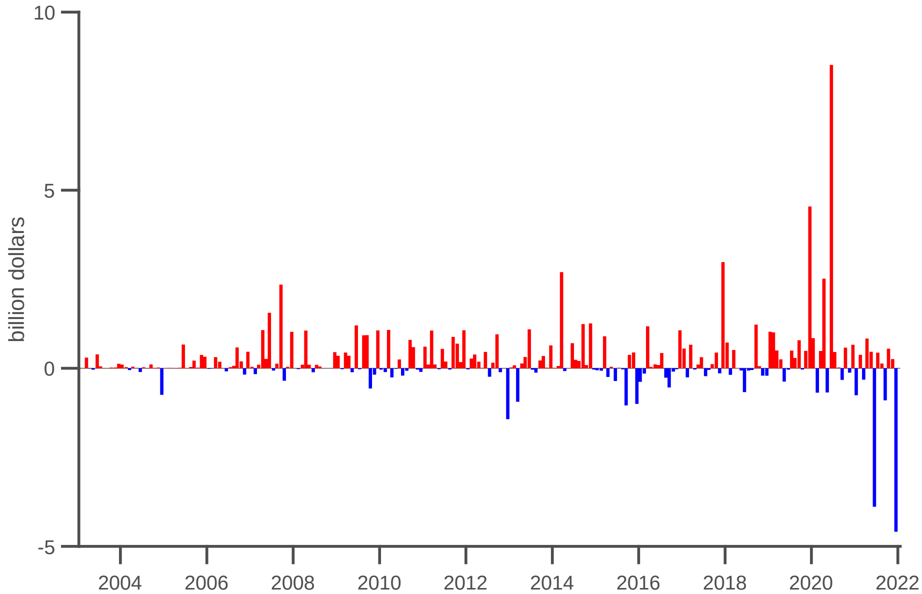
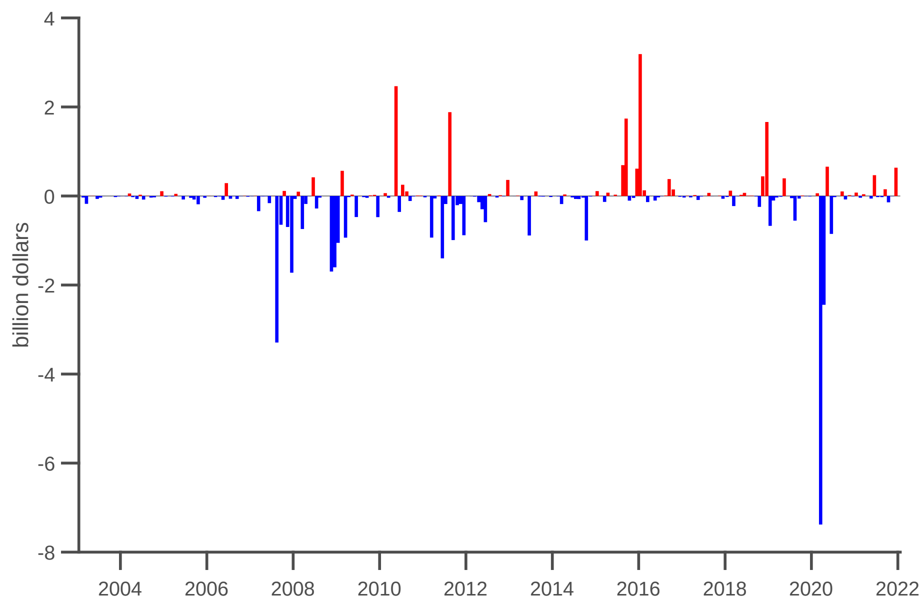


Figure 6. Bootstrapped return differences

Via block bootstrap resampling we estimate the return distribution of the reversal strategy: Once every month, go long the S&P500 index via inx trades at 3rd Thursday close, switch to a short position at 3rd Friday open via the Special-Opening-Quotation and close the position at 3rd Friday close via inx trades. Opening times are 9:30 ET and closing times are 16:00 E.T. The Histogram is scaled to be interpreted as a density function, i.e., its integral sums to one. The first, second and third dotted lines represent 2.5%, 50% and 97.5% percentiles. The sample period is 2003.2 - 2021.12.



(a) Call Options



(b) Put Options

Figure 7. Wealth Transfer in SPX Options

This table displays actual monthly SPX options payoffs at 3rd Friday SOQ minus hypothetical payoffs if settlement occurred at Thursday close instead. That is, if settlement occurred before the significant night price pressure. Positive values are in red, negative values are in blue. Panel a displays call options, panel b displays puts. The sample period is 2003.2 - 2021.12.

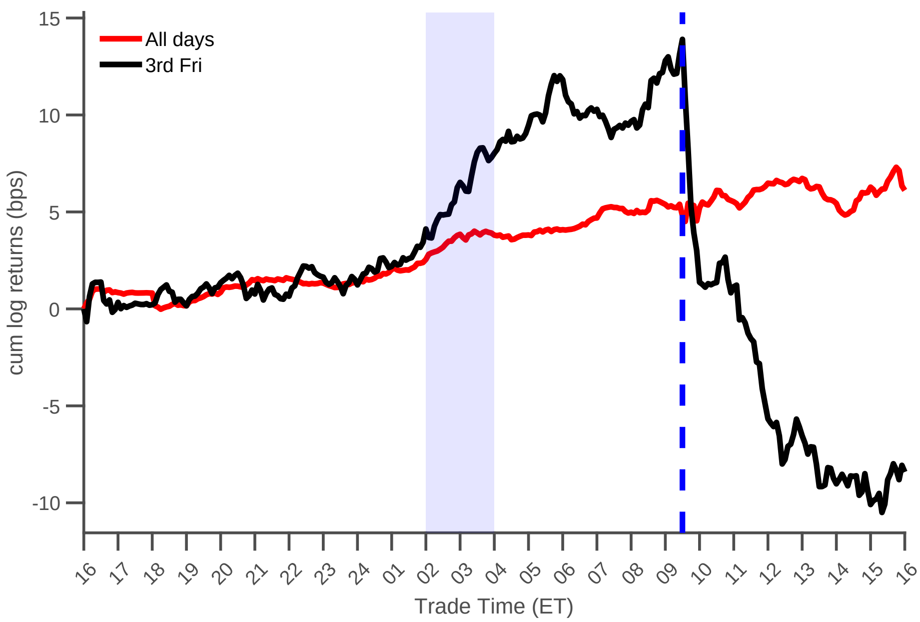
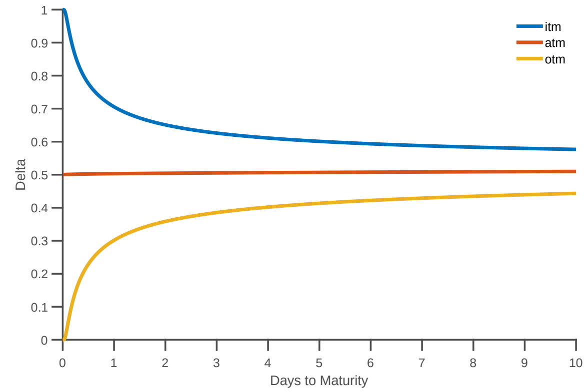
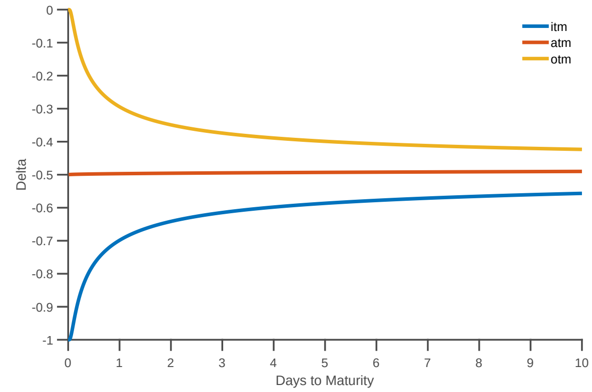


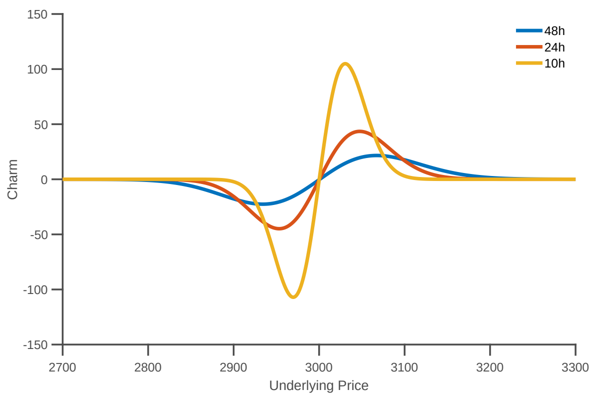
Figure 8. 3rd Friday Price Spike in E-mini futures: Nasdaq
The black line plots average cumulative 5 minute log returns of Nasdaq 100 (NQ) E-mini futures around 3rd Friday market open (0930 E.T., blue dotted line). The red line plots cumulative returns on all other days. The y-axis is in basis points and the x-axis is time of day in Eastern time (E.T). The purple shaded region highlights the opening of European markets. The sample period is 2003.2 - 2021.12.



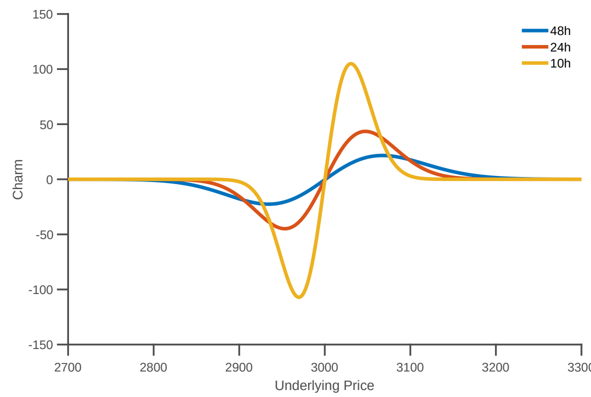
(a) Call Delta



(b) Put Delta



(c) Call Charm



(d) Put Charm

Figure 9. Illustration: Option Charm

This figure illustrates the change in options delta with changes in time to expiry, i.e. "Charm". Panels a and b show Black-Scholes Delta for a European Option with UnderlyingPrice=3000, rate=0, yield=0, volatility=30%. For calls (puts), itm denotes a strike of 2975 (3025), atm denotes 3000 (3000) and otm denotes 3025 (2975). Panels c and d show Black-Scholes Charm for a European Option with strike=3000, rate=0, yield=0, volatility=30% and three different times to expiry.

VIII. Appendix: Tables

	Previous Close	9:30:00	9:30:31	9:33:29
		Panel A: SOQ > Index Open		
Stock 1	50	55	55	56
Stock 2	20	No Trade	22	23
Stock 3	10	No Trade	No Trade	11
Index	26.7	28.3	29	30
SOQ		Not Available	Not Available	29.3
		Panel B: SOQ < Index Open		
Stock 1	50	45	45	44
Stock 2	20	No Trade	18	17
Stock 3	10	No Trade	No Trade	9
Index	26.7	25	24.3	23.3
SOQ		Not Available	Not Available	24

Table I. Illustration: The Special Opening Quotation

Panel A illustrates an example where SOQ (29.3) is higher than the index opening quote (28.3) in a hypothetical market with three equally weighted stocks. At open (9:30 am E.T.) only stock 1 trades on exchange. Thus, the index value is based on stock 1's opening price and stock 2 and 3's previous close price. The SOQ only becomes available once all component stocks have traded (on their primary listing exchange). It is then based on each stock's opening sales price, which is observed at a different time for all three stocks. Panel B illustrates an example where the SOQ (24) is lower than the index opening quote (25)

days:	all	expiry	non expiry	qtr	non-qtr
mean	2.30	18.54	1.48	26.71	14.45
median	4.62	18.77	4.20	27.63	12.61
t-stat	2.22	4.65	1.38	4.42	2.81
std	71.08	59.82	71.50	52.39	62.98

Table II. Over-Night S&P500 Returns

The table reports summary statistics for

$$ReturnSOQ_t = log(SOQ_t) - log(SpxClose_{t-1})$$

The columns display results for all days (column 1), option expiry dates (column 2), non-expiry dates (column 3), quarterly option expiry dates (column 4) and non-quarterly option expiry dates (column 5). Option expiry dates are the third Friday of every month. Estimates are in basis points. The SOQ is calculated from the opening sales price of the index component stocks on their primary listing exchange. Thus, the SOQ is available only once all component stocks have traded during the regular market session after 9:30 Eastern Time (ET). The index closing prices on 3^{rd} Thursdays at 16:00 ET. The sample period is 2003.02 to 2021.12.

	All days			Around 3rd Fridays			
	CTO	OTC	CTC	We_c to Th_o	Th_o to Th_c	Th_c to Fr_o	Fr_o to Fr_c
				Panel a : SOQ / SPX			
mean	2.30	1.06	3.59	-3.17	-0.55	18.54	-16.91
mean(24H)	3.15	3.90	3.59	-4.34	-2.04	25.43	-62.42
t-stat	2.22	0.79	2.08	-0.91	-0.09	4.65	-2.99
Std	71.08	92.11	117.88	51.92	88.21	59.82	84.95
				Panel b : SPX			
mean	1.32	2.44	3.76	-1.60	-1.98	5.11	-2.60
mean(24H)	1.81	9.02	3.76	-2.19	-7.32	7.00	-9.61
t-stat	2.58	1.66	2.28	-0.93	-0.30	3.33	-0.43
Std	34.91	100.45	112.61	25.62	98.26	23.00	89.80
				Panel c : E-mini			
mean	2.69	0.91	3.60	-2.09	-1.71	14.30	-12.89
mean(24H)	3.69	3.38	3.60	-2.86	-6.31	19.61	-47.61
t-stat	2.75	0.68	2.12	-0.60	-0.28	3.54	-2.40
Std	67.47	92.25	117.16	51.96	90.33	60.53	80.45

Table III. Equity Returns

The table reports average returns in basis points per trading period (first row) and basis points per 24-hour period (second row). t-statistics and return standard deviations (per period) are report in the third and fourth rows, respectively. The first 3 columns show returns for all days. The subsequent columns show returns around options expiry at 3rd Friday open (Fr_o). Abbreviations: close-to-open (CTO), open-to-close (OTC), close-to-close (CTC), special opening quotation (SOQ), All returns are log returns computed from trades. Panel (a) reports statistics for a hypothetical strategy that trades the S&P500 via SOQ at open and via SPX at close. Panel (b) reports statistics for a strategy that trades the SPX at open and close. Panel (c) reports statistics for a strategy that trades the E-mini at open and close. The sample period is 2003.2 to 2021.12.

	Around 3rd Fridays				
	We_c to Th_o	Th_o to Th_c	Th_c to Fr_o	Fr_o to Fr_c	Fr_c to Mo_o
			PANEL A : quarterly expiries		
mean	4.79	0.52	26.71	-37.23	-10.84
mean(24H)	6.57	1.93	36.64	-137.48	-3.97
t-stat	0.83	0.05	4.42	-3.54	-1.31
Std	50.14	82.48	52.39	91.03	71.76
			PANEL B : off-quarterly expiries		
mean	-7.94	-0.90	14.26	-6.25	-5.05
mean(24H)	-10.89	-3.33	19.56	-23.09	-1.85
t-stat	-1.86	-0.12	2.74	-0.95	-0.66
Std	52.39	92.31	63.75	80.36	94.21

Table IV. Triple Witchings

The table reports average returns in basis points per trading period (first row) and basis points per 24-hour period (second row). t-statistics and return standard deviations (per period) are report in the third and fourth rows, respectively. The first 3 columns show returns for all days. The subsequent columns show returns around options expiry at 3rd Friday open (Fr_o). Abbreviations: close-to-open (CTO), open-to-close (OTC), close-to-close (CTC). The strategy trades the S&P 500 via SOQ at open and SPX at close. The sample period is 2003.2 to 2021.12.

	Around 3rd Fridays		
	Th_c to Fr_o	Fr_o to Fr_c	Fr_c to Mo_o
mean	11.02	-17.62	-9.25
mean(24H)	15.11	-65.05	-3.39
t-stat	2.25	-2.58	-1.23
Std	58.72	82.08	89.93

Table V. P.M Settlement Returns Post 2010

The table reports average returns in basis points per trading period (first row) and basis points per 24-hour period (second row). t-statistics and return standard deviations (per period) are report in the third and fourth rows, respectively. The columns show returns around options expiry at 3rd Friday open (Fr_o). Abbreviations: close-to-open (CTO), open-to-close (OTC), close-to-close (CTC). The strategy trades the S&P 500 via SOQ at open and SPX at close. The sample period is 2010.1 to 2021.12.

	intercept	slope	$R^2(\%)$
PANEL A, days: expiry			
Point Estimate	-12.07	-0.32	12.10
Lower Bound	-18.67	-0.48	
Upper Bound	-6.19	-0.16	
PANEL B, days: all			
Point Estimate	1.66	-0.10	1.47
Lower Bound	0.33	-0.15	
Upper Bound	2.96	-0.04	

Table VI. Regression: Day Returns on Preceding Night Returns

The first row reports OLS coefficients from regressing third Friday intra-day returns on an intercept and the preceding over-night return. Rows two and three report 95% bootstrapped confidence intervals. The over-night return is measured from SPX trades on each month's third Thursday at 16h Easter Time (ET) to the Special-Opening-Quotation at the subsequent market open. The intra-day return is measured from the SOQ on each month third Friday open to SPX trades on third Fridays at 12am ET. Returns are in basis points. The sample period is 2003.02 to 2021.12.

days:	all	non expiry	expiry	qtr	non qtr
mean	1.73	-0.03	36.49	48.45	30.51
median	3.76	2.23	35.85	43.49	30.44
t-stat	1.21	-0.02	5.83	5.36	3.72
std	97.40	97.26	93.90	78.33	100.50
SR	0.21	-0.08	1.32	1.22	0.84
N obs pos	2,461.	2,305.	156.	52.	104.
N obs	4,690.	4,465.	225.	75.	150.
p binom	7.	311.	0.	10.	0.

Table VII. SPX/SOQ Reversal Returns around SPX Options Expiry

The table reports summary statistics for a trading strategy that buys the sp500 at close via SPX trades, reverses into a short positions at open via the SOQ and closes the position at noon (1200) via SPX trades. The first column considers this strategy around every daily open, the second column considers only non expiry dates, the third column considers only the third Friday of every month (when SPX options expire), the fourth (fifth) column considers only quarterly (non-quarterly) third Fridays. The last row contains p-values for a binomial test that positive reversal returns occur with probability 50%. Everything except "t-stat" and "N" is in basis points. The sample period is 2003.02 to 2021.12.

	Reversal		
days:	expiry	qtr	non qtr
mean	24.43	34.51	19.39
t-stat	3.93	3.99	2.35
std	93.25	74.98	101.01
SR	0.90	0.91	0.54
alpha	24.40	32.93	19.52
beta	0.17	0.44	0.08

Table VIII. Trading the Third-Friday Price Spike: Transaction Costs
Columns 1 to 3 report summary statistics for a trading strategy that buys the sp500 at close via S&P 500 e-mini futures, reverses into a short positions at open and closes the position at noon (1200). The first column considers only the third Friday of every month (when SPX options expire), the second (third) column considers only quarterly (non-quarterly) third Fridays. The last two rows display the alpha and beta from regressing reversal returns on the return of a pure long position in the S&P 500 e-mini futures. Buys occur at the ask and sells at the bid. All returns are in basis points. The sample period is 2003.02 to 2021.12.

	Put	Bxm	Put Minus Bxm			
			all days	non exp days	exp days	non exp fridays
mean	8.70	7.34	1.35	-0.63	2.00	0.01
std	13.24	13.85	2.80	2.05	1.83	0.59
SR	0.57	0.45	0.48	-0.31	1.10	0.02

Table IX. Index Returns: PUT and BXM

This table reports average annualized returns in percent for the CBOE PutWrite (PUT) and CBOE BuyWrite (BXM) indices. Columns 1 and 2 report mean, standard deviation and sharpe ratio for put and bxm returns. The subsequent columns report the difference between put and bxm returns for all days, non-expiry days, expiry days and non-expiry fridays, respectively. Returns are measured close-to-close. Thus, an expiry-day return is measured from Thursday close to 3rd Friday close. The sample period is 2003.02 to 2021.12.

	actual		counter-factual	
	Calls	Puts	Calls	Puts
	Panel a : Returns (%)			
itm	2.08	-3.88	0.23	-0.37
atm	6.02	-52.79	-28.35	-32.81
otm	-99.43	-99.40	-99.69	-99.18
	Panel b : Returns ($ mil.)			
itm	173.70	-89.87	30.94	-41.93
atm	7.67	-20.25	-16.79	-6.59
otm	-4.86	-16.79	-5.06	-16.44
sum	176.51	-126.91	9.09	-64.95

Table X. SPX Index Option Returns into Expiry

Columns 1 and 2 anel A reports average returns of expiring S&P500 index options from 3rd Thursday close to their final settlement value on 3rd Friday open in percent. Columns 3 and 4 report counter-factual returns, calculated under the assumption that each 3rd Friday SOQ was 16 basis points lower. Panel B reports average returns in millions of dollars, calculated as $Dollar\ Return = Net\ Return * Open\ Interest * Price$. We measure moneyness as strike / underlying price. Calls are itm if 0.5 < mnes <= 0.99, atm if 0.99 < mnes <= 1.01 and otm if 1.01 < mnes <= 1.5. Puts are otm if 0.5 < mnes <= 0.99, atm if 0.99 < mnes <= 1.01 and itm if 1.01 < mnes <= 1.5. The total monthly wealth effect is calculated as the difference between actual and counter-factual dollar returns, summed over puts and calls. The sample period is 2003.02 to 2021.12.

	Calls			Puts			
	Fr Op	Th Cl	Diff	Fr Op	Th Cl	Diff	Σ Abs Diff
mean	10.46	10.23	0.23	3.04	3.12	-0.09	0.31
std	15.71	15.57	0.13	12.29	12.73	-0.44	0.57

Table XI. The Payoff Bias in S&P 500 Options

The table reports summary statistics for actual and hypothetical spx option settlement values. Column 1 contains the settlement value of call options that is determined on third friday via the SOQ. The call option settlement value is calculated as

$$SettlValue_{Calls} = \Sigma_i^I max(0, SOQ - K_i) * OpenInterest_i$$

where I is the number of different call options, is the option price. Column 2 contains the settlement value of call options if settlement occured on thusday at the SPX closing quote. Column 3 displays the difference. Columns 4 to 6 display put option settlement values. The put option settlement value is calculated as

$$SettlValue_{Puts} = \Sigma_i^I max(0, K_i - SOQ) * OpenInterest_i$$

Column 7 contains the sum of absolute differences over calls and puts. All numbers are in billions of dollars. The sample period is 2003.2 - 2021.12.

	Nr. Contracts			Sum Delta			Idx PP from	
	exp mon	3 We	3 Th	exp mon	3 We	3 Th	Opex	Charm
Calls	-6.91	-10.08	-13.40	5.88	2.51	0.56	↑	
Calls itm	9.24	4.15	1.13	6.32	2.88	0.53		
Calls atm	4.76	3.13	2.70	3.35	2.56	2.63		
Calls jitm	5.09	3.84	2.85	3.37	2.76	2.41		↓
Calls jotm	-0.34	-0.79	-0.14	-0.03	-0.23	0.22		↑
Puts	-72.24	-71.00	-65.20	1.43	0.88	-0.66	↓	
Puts itm	2.73	0.55	1.14	-3.15	-1.39	-2.04		
Puts atm	-6.39	-6.98	-7.22	2.45	2.95	2.50		
Puts jitm	-1.19	-2.32	-2.66	0.64	1.58	1.70		↓
Puts jotm	-5.21	-4.67	-4.56	1.82	1.37	0.81		↑

Table XII. Market Maker Positions into Opex

The table reports Option Market Maker positions in am settled 3rd Friday options during their expiry month. Row 1 considers all expiring call options, row 2 only in-the-money calls, row 3 only at-the-money calls (within 4 strikes of the underlying price). Rows 4 and 5 separate atm calls into just-in-the-money and just-out-of-the-moeny. The subsequent rows contain the equivalent information for put options. Column 1 contains the average number of contracts held by market makers at close before expiry during the expiry month. Columns 2 (3) display information for the Wednesday (Thursday) before expiry. Columns 4 to 6 contain Net Delta positions, calculated as the sumproduct of nr. of contracts held by market makers and the respective contracts delta at close. All numbers are in 100 thousands. The sample period is 2006.1 to 2020.12.

	Nr. Contracts			Sum Delta		
	exp mon	3 We	3 Th	exp mon	3 We	3 Th
Calls	-0.77	-2.68	-3.03	0.41	0.47	0.87
Calls itm	0.06	0.52	0.90	-0.11	0.12	0.67
Calls atm	1.28	2.22	2.02	0.51	1.00	1.09
Calls jitm	0.32	0.00	1.07	0.21	0.66	0.88
Calls jotm	0.00	1.22	0.95	0.31	0.34	0.21
Puts	7.48	3.77	1.48	-0.08	0.35	0.38
Puts itm	-0.09	-0.31	-0.34	0.03	0.16	0.29
Puts atm	-0.35	-1.05	-0.40	0.18	0.43	0.14
Puts jitm	-0.23	-0.24	-0.08	0.14	0.14	0.05
Puts jotm	-0.16	-0.81	-0.32	0.06	0.29	0.09

Table XIII. Pro-Customer Positions into Opex

The table reports Pro-Customer positions in am settled 3rd Friday options during their expiry month. Row 1 considers all expiring call options, row 2 only in-the-money calls, row 3 only at-the-money calls (within 4 strikes of the underlying price). Rows 4 and 5 separate atm calls into just-in-the-money and just-out-of-the-moeny. The subsequent rows contain the equivalent information for put options. Column 1 contains the average number of contracts held by pro-customers at close before expiry during the expiry month. Columns 2 (3) display information for the Wednesday (Thursday) before expiry. Columns 4 to 6 contain Net Delta positions, calculated as the sumproduct of nr. of contracts held by pro-customers and the respective contracts delta at close. All numbers are in 100 thousands. The sample period is 2011.1 to 2020.12.