The Equity Derivative Payoff Bias

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Abstract

The payoff of most U.S. equity index derivatives is determined on the 3rd Friday of each month via the special opening quotation price (SOQ). Unconditionally, the daily SOQ is equal to the index opening quote. However, when payoffs are calculated, the SOQ exceeds the index open quote by 15 bps on average. This bias is due to high equity returns over night, which immediately revert after the settlement time. We study and rule out a set of plausible explanations. Independent of the cause, this positive bias raises (lowers) S&P 500 call (put) option payoffs, inducing a wealth transfer of around $4 billion per year. These findings suggest that current settlement procedures generate a market inefficiency. We discuss implications for market design.

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

JEL Classifications: G10, G12, G13, G14.

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The market for U.S. equity index derivatives is sizeable and the majority of index derivative trading activity is concentrated in products for which the S&P 500 index (the SPX) is the underlying. Furthermore, most SPX derivatives are “a.m.-settled”, meaning they expire on the 3rd Friday of each month with payoffs determined via the index Special Opening Quotation (SOQ) price. 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). As a result the SOQ can differ from the index open price.

In this paper, we study 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 SPX SOQ differs from the SPX open price but the difference is mean zero (unbiased). However, a persistent positive bias exists on days when it matters: the 3rd Friday of each month when index option payoffs are determined. On these days the SOQ exceeds the index opening price by an average of 15 basis points, and the statistical significance of this bias is large with a t-statistic exceeding 4. A simple calculation shows that this bias generates a wealth transfer in the SPX vanilla option market of $4 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.

Infrequent trading (Lo and MacKinlay, 1990), sluggish response to economy-wide information (Brennan and Subrahmanyam, 1995) or intraday momentum (Baltussen, Da, Lammers, and Martens, 2021) could induce a positive or negative correlation between overnight returns and the SOQ minus index opening price return gap. We document that this correlation is, in fact, strongly positive. This implies that an unconditionally positive index option payoff bias aligns with unconditionally positive overnight returns in the run up to 3rd Friday a.m.-option expiration. Studying overnight equity returns, we uncover a strong tent-shaped reversal pattern from the close of regular trade on “3rd” Thursdays which peaks at exactly 9:30 ET on 3rd Fridays. Across alternative return calculations, based on index open, the SOQ, and E-mini futures prices, we document a

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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 opening price is computed from first traded prices after 9:30 on 3rd Fridays or otherwise from closing prices on the preceding business day at 16:00 ET.

3 Surprisingly, few papers have studied index option settlement prices via the SOQ. An exception to this statement is an early contribution by Stoll and Whaley (1991) who are concerned with questions about price volatility, as opposed to potential settlement biases.
consistent and persistent positive overnight return between 12 and 19 basis points from Thursday close to 3rd Friday open, which is “undone” (reverses) intraday Friday. We dub this irregularity the Third Friday Price Spike (3FPS). Regardless of how we measure returns around a.m.-option expiration, we obtain point estimates for the 3FPS that are significant at the 1% significance threshold, while for p.m.-option expiration there no detectable bias.

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 3rd Thursday at 16:00 to the reported SOQ on 3rd 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 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 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 3rd 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 3rd Friday overnight returns followed by negative 3rd 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 3rd Friday of the quarterly cycle (March, June, September, December) when index options, futures contracts, and op-

\(^4\)The quantitative implications of the particular reversal regression specification around 3rd settlement is robust to the points of trade.

\(^5\)The SOQ can be traded via "market on open" orders for the index component stocks.
tions on futures contracts expire simultaneously in the a.m. settlement window. 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 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. Indeed, while several option derivatives are p.m. settled (serial options on the SPX futures, options on ETFs and options on individual stocks expiry) we find no evidence of an upward drift and subsequent reversal around the p.m. settlement window. In 2010, settlement of SPX options at p.m. was (re-)introduced under the SEC “P.M Option Expiration Pilot Program”. We show that negative friday returns continue as negative weekend until monday open. Thus, there is no return reversal around 3rd Friday p.m. settlement. The bias that we document is specific to a.m. settled derivative contracts.

A natural question that arises is whether the temporary price pattern documented above has a meaningful effect in economic terms, i.e., is there a welfare impact? We answer this question by computing a counter-factual wealth transfer in the options market. To compute the wealth transfer, we compare the realized payoff of all SPX options (calculated from 3rd Friday SOQ) with a hypothetical payoff calculated from Thursday’s SPX closing prices. 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-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 SPX options do not trade overnight before expiry, there are no changes in option positions that we need to consider. Therefore, the hypothetical payoff from the Thursday close represents a natural counter-factual.

The total dollar values of realized option payoffs values is calculated as the actual payoffs multiplied by their open interest summed over all strike prices. The counter-factual we consider replaces SOQ in the max operator with the SPX closing price on Thursday, or the point in time when the options stop trading. These calculations show that SPX call options paid off $10.5 billion on the average 3rd 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

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6Some traders call these days quadruple witchings as options on individual stocks also expire at market close.
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 3rd 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. 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.

Finally, we show the 3FPS has a strong spillover effect examining the performance gap between the SPX buywrite and putwrite indices, an apparent arbitrage that has puzzled many investors. These indices are well-known and tracked in the industry and should deliver equal returns for reasons of put-call parity. However, their returns differ by a remarkable 140 basis points a year over our sample. We trace this return gap to the 3FPS by showing that the rolling of expiring options on the expiry day (i.e., the 3rd Friday of each month) causes a difference in the SPX exposure of both indices between the SOQ and noon. We show that the return gap fully originates from this difference, a is only present 12 times a year for about 2.5 hours, and that the return gap is a manifestation of the bias in the equity derivative payoff that reverts intraday.

What causes the bias in equity derivative payoffs? One explanation could be 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. Testing an information-based explanation, we examine the variation in reversal effects across 3rd Fridays with or without major macroeconomic or earnings announcements, or positive versus negative macroeconomic or earnings surprises and find no significant differences.

An alternative 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). In contrast to a pinning explanation, we
fail to find evidence of pinning at the SOQ, and find the same directional effects on the quarterly versus off-quarterly expiries. 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 additional 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.\(^7\) 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, and find no significant link.

What then explains the bias? Order imbalances that are systematically in one direction before the 3\(^{rd}\) Friday open might present an explanation. But, why would order imbalances be systematically in one direction on these days, and not on other days? A potential explanation is option market manipulation. Manipulators might seek to manipulate the underlying index 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.

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 expiries and this evidence aligns with several of our key results. Indeed, a manipulation hypothesis predicts

\(^7\)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 pre-fix hedging by foreign exchange dealers which is observationally equivalent to market manipulation.
temporary price pressure that reverts quickly; it predicts no price pattern during periods when manipulation is unlikely to be successful, such as during the p.m. settlement window; it predicts stronger effects when incentives are greater like during triple witching days. 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). We source SPX high-frequency index options data 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. 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.

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 3rd Friday of March, June, Septem-

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8 In principle the SOQ is available from 1987 but neither the Chicago Mercantile Exchange (CME) nor Chicago Board Options Exchange (CBOE) keep a historical record. Bloomberg has a continuous record from February 2003 and an incomplete record pre-2003 which we analysis separately in an internet appendix.

9 In line with standard derivatives research practice we exclude the expiry days of September and October 2008 from the main analysis.
ber, and December. Liquidity providers and designated market makers (DMMs) 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 3rd 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.\textsuperscript{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.\textsuperscript{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 the 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 minutes but theoretically can take hours for very illiquid stocks. Therefore, the SOQ is comprised of single stock trade prices from different points in time.

The SOQ calculation drives a wedge between its value and the opening quote of the SPX published by S&P, which includes the previous day’s closing prices for each stock that did not trade on open. Figure I illustrates how such a difference could arise 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

\textsuperscript{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 maximise 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.

\textsuperscript{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.
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 wedge is positive $(29.3 - 28.3 > 0)$. In panel (b), the index opens up with a negative overnight return, all stocks opening trades are negative, and the SOQ minus opening quote wedge is negative $(24 - 25 < 0)$.

These examples highlight how the SOQ differs from the opening index quote and also that the SOQ minus opening quote wedge is likely to be positively correlated with the overnight index return computed from quotes.\footnote{The positive correlation is not mechanical. For example, in panel (a) had the third stock opened up at 5 the SOQ minus opening quote wedge would flip sign.} An implication of the SOQ minus opening quote wedge is that the SPX can appear to have “opened” with only a modest increase (decline) but due to stocks that did not trade on open the final settlement price (the SOQ) can be substantially higher (lower).

Panel (a) of figure 2 plots the difference in \textit{basis points} between the SOQ and the opening quote for the SPX, normalised by the opening price

\[
OpenGap_t = \frac{SOQ_t - SpxOpen_t}{SpxOpen_t}
\]

for all days since February 2003. Visually inspecting panel (a) we observe an approximately equal mass of red ($OpenGap_t > 0$) and blue bars ($OpenGap_t < 0$). This shows that opening quote and SOQ are generally different, but this difference follows close to a random walk. Panel (b) displays $OpenGap_t$ only on third Friday settlement days. The imagine in panel (b) is dramatically different: there is clearly a larger mass of red bars compared to blue bars.

Table II reports summary statistics $OpenGap_t$ for all days (column 1), option expiry dates (column 2) and non-expiry dates (column 3). Confirming our eye-ball econometrics from figure 2 the all day $OpenGap_t$ is unbiased; it equals 1.2 bps ($t$-statistic $= 1.6$). On expiry days, however, when the SOQ determines derivative settlements, $OpenGap_t$ is abnormally large and positive equal to 15 bps with a $t$-statistic equal to 4.4. With the S&P 500 at its average level of 2000 in our sample period this implies the SOQ was 3 index points above the opening value.
Due to sluggish opening of some stocks, the sign of $\text{OpenGap}_t$ is likely to be the same as the sign of the overnight returns. The last row of table II shows the correlation between $\text{OpenGap}_t$ and SPX index return from previous close to open tend to be positive. Table III reports regression estimates of $\text{OpenGap}_t$ on overnight returns measured from SPX close to opening quotations. Panel (a) shows on all days there is a very strong positive relationship with an $R^2 = 19\%$. Panels (b) to (d) show that on expiry days (on the quarterly and off-quarterly cycle) the relationship is stronger as evidenced by larger slope estimates, and on these days the relationship remains highly significant.

Considering the findings of table II and table III we infer that overnight returns preceding 3rd Friday a.m. settlements are more likely to be positive than negative. We study this conjecture in the following section.

### III. Derivative Pricing and Wealth Implications

We now study how a positive bias in the 3rd Friday SOQ is related to intraday (overnight) equity price dynamics. Subsequently, we discuss implications for market (in)-efficiency by calculating an option market wealth transfer via a counterfactual payoff.

#### A. Overnight Returns

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, in fact, not determined by a closing price but via the 3rd Friday SOQ on the quarterly cycle.

We compute traded returns around monthly 3rd Friday settlement dates from 5-minute volume
weighted average prices. 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 trade the next to delivery contract. 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 9:30, at which point returns sharply revert. The average overnight cumulative return is equal to 14 bps which completely reverses by 14:00.

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.

Panel (b) of figure 3 focuses on early morning trading by displaying average cumulate returns (black line) between 7:00 and 12:00 alongside average 15-minute returns (blue bars). The figure shows that equity prices drift up continuously from 7:00 until exactly 9:30 with a cumulative return of around 6 bps, 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.

Table IV 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). Panel (a) reports return statistics

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13. If the third 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.

14. 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.

15. Unconditional returns are relatively linear, except for hours between 2:00 and 4:00 - the overnight drift puzzle studied by Boyarchenko, Larsen, and Whelan (2020).

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

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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.

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 similar magnitudes to the ‘all day’ returns, although with a negative sign for overnight Wednesday and no return is statistically different than 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 remains between 4 and 10 times larger than their all day counterparts. The statistical difference between all day CTO returns and 3rd Friday CTO returns is large with t-statistics equal to 4.9 (panel a), 3.3 (panel b) and 3.6 (panel c).

Figure 3, and table IV provided 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 third Thursday at 16:00 to the reported SOQ on Fridays and the subsequent intra-day 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 V displays the point estimates and in parenthesis we report 95% confidence intervals computed from a block bootstrap sampling 1000 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’. The magnitude of the intercept is however very close to zero. 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.$^{17}$

$^{17}$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%.
B. Robustness

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 VI 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 fifth 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 but again not statistically significant. Considering monthly 3rd 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.

Figure 4 translates these returns over time by computing their realised cumulative value. The long overnight, short intraday and reversal strategy are remarkably stable over time. A $1 investment in 2003 grows to $1.5 in both the overnight and intraday trade, and the reversal strategy grows to $2.3.

Figure 4 panel b displays the annualized Sharpe ratio of this trading strategy by year.\textsuperscript{18} The strategy earns positive returns in all years except 2015, 2016 and 2018. Sharpe ratios 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 ratios in 2019 to 2021 show that the 3rd price spike is present until the end of our sample.

\textsuperscript{18}We compute the annualized Sharpe ratio by scaling the daily excess return to volatility ratio by 12 (trading) periods.
C. Small Sample Bias

Accounting for potential small sample biases in our findings, we estimate the distribution of returns reversal strategy via block bootstrap, sampling 1000 times with the optimal block length chosen following Patton, Politis, and White (2009). Figure 5 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.

D. 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. 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

$$R_{j,[t_1,t_2]}^L = \frac{P_{j,t_2} - P_{j,t_1}}{P_{j,t_1}},$$

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

$$R_{j,[t_1,t_2]}^L = \frac{P_{\text{bid},j,t_2} - P_{\text{ask},j,t_1}}{P_{\text{ask},j,t_1}}, \quad R_{j,[t_1,t_2]}^S = -1 \times \frac{P_{\text{ask},j,t_2} - P_{\text{bid},j,t_1}}{P_{\text{bid},j,t_1}}.$$  \hspace{1cm} (3)

Table VII reports summary statistics for a trading strategy that buys the front month E-mini futures contract on off-quarterly 3rd 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.

19 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).
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 expiries, respectively. T-statistics against zero are large and always reject at the 1% level. The 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 VII regress the net returns on market returns to current for any implicit market risk effects. Again, results are sizable and highly significant, with alphas close to average net returns, highlighting the robustness of the strategy returns.

E. Option Markets

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 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. 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.

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

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20 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.

21 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.
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 IX.

[INSERT TABLE IX AND VIII HERE]

Table VIII repeats the analysis of table IV 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 and statistically insignificant. Thus, a bias in option settlements is isolated in 3rd Friday a.m settled derivative contracts.

F. Wealth Transfer

Persistent positive overnight returns preceding 3rd Fridays biases the payoffs of all US equity derivatives that have monthly 3rd Friday am expiry. This includes index options, futures and futures options written on various equity indices (S&P500, Russel2000, the Nasdaq100) as well as options written on exchange traded funds such as the S&P500 SPDR.

In light of table VIII, we only consider a.m. settled SPX options and quantify the derivative settlement bias. Since we 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.

To compute a wealth transfer we compare the realised payoff of all SPX options (calculated from 3rd Friday SOQ) with a hypothetical payoff calculated from Thursday SPX closing price. 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

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22The difference between closing prices computed from trades versus quotes is almost zero. We use the traded closing price.
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

\[
SettValue_{\text{Calls}} = \sum_{i} I_i \max(0, SOQ - K_i) \times OpenInterest_i
\]

(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

\[
SettValue_{\text{Puts}} = \sum_{i} I_i \max(0, K_i - SOQ) \times OpenInterest_i
\]

(5)

The counterfactual we consider replaces \(SOQ\) in the max operator with the SPX closing price on Thursday, which is also the point in time when the options stop trading.

Table X shows that SPX call options paid off $10.46 billion on the average 3rd 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 3rd 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. 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. We believe this number to be a lower bound, as we only consider listed SPX index options and ignore futures options, OTC options, and options on other U.S. indices.

Figure 6 displays this monthly difference in option payoffs from 3rd 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

\[23\]

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.

\[24\]

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.
negative for the vast majority of expiry dates. Thus, the estimates in table X are not driven by unique expiries, but are a pervasive feature of US derivatives markets.

G. 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 3rd 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 3rd 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.

Table XI 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 3rd 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 XI 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 3rd Fridays.

IV. 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) which is based on the first opening cross of every constituent of the NASDAQ 100 index.\textsuperscript{25} 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 3rd 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.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure7}
\caption{Insert Figure 7 Here}
\end{figure}

The black line in panel a of figure 7 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 3rd Fridays. Further, this pattern is remarkably different from the average pattern

\textsuperscript{25}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.
on all other days, as depicted by the red line. Tests confirm that the 3rd 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. The Arrival of Fundamental Information

A second potential explanation is that news arrives overnight Thursday driving up prices through
an information channel. For a persistent positive overnight return to arise from this channel news
revelation to investors would need to arrive systematically between the U.S. market close on 3rd
Thursday and open on 3rd Friday. We consider two primary sources of news that arrives over this
period: firm specific news releases and macroeconomic releases.

Hypothesis $H_{01}$: Overnight Firm Specific News. A large fraction of U.S. corporate
earnings announcements are released outside of regular trading hours with the common release
day being Friday ((Boyarchenko, Larsen, and Whelan, 2023). Previous literature (see, e.g.,
Bernard and Thomas, 1989; Sadka, 2006, and the subsequent literature) has documented a pos-
tive (negative) drift in stock prices of individual firms following a positive (negative) earnings
announcement surprise. Consequently, a significant positive arrival of earnings news 3rd Thurs-
day overnight might be driving the upward return drift observed over the same interval.

To examine whether firm-specific announcements drives the 3FPS predict we collect earnings
data of all S&P 500 index constituents from I/B/E/S and Compustat. Following Hirshleifer, Lim,
and Teoh (2009), for each firm $i$ and on day $t$ we define the earnings surprise as

$$ES_{i,t} = \frac{A_{i,t} - F_{i,t} - P_{i,t}^{-}}{P_{i,t}^{-}},$$

where $A$ is the actual earnings per share (EPS) as reported by the firm, $F$ is the most recent
median forecast of the EPS and $P$ is the stock price of the firm at the end of the quarter. Since
I/B/E/S updates the professional forecasters’ expectations on a monthly basis, the shock is the

\[26\] Approximately 95 percent of firms announce earnings outside regular trading hours, roughly equally split between firms
announcing in the pre-open (between midnight and the opening bell) and post-close (between the closing bell and midnight).
Pre-open most earnings announcements are concentrated in the four hours before open. Post-close the vast majority of
earnings announcements are concentrated in the first hour after market close.
difference between the actual earnings and forecasters expected earnings approximately 1-month
prior to the announcement date. We define the daily earnings surprise of the S&P 500 index, $ES_t$, as
the daily sum of all $ES_i$ multiplied by their daily stock index weights and scaled by the index
price.

Figure 8 plots the time series of $ES_t$. Earnings shocks are periodic on a quarterly basis and
generally positive ($\sim 75\%$ of all shocks are positive). Notably, we see large negative earnings shocks
during especially the financial crisis and mostly positive shocks following the financial crisis.

To examine an 3FPS explanation based on firm specific news, we sort announcements based
on being published before (“day”) or after (“evening”) the U.S. market closes (16:00 ET) and
examine the aggregate earnings surprise over both intervals. Announcements published early in
the day should be incorporated into the price on that day, while announcements that occur after
market close could affect returns overnight. To reiterate, the 3FPS shows that, on average, prices
rise between close and 3rd Friday open but revert at 9:30 a.m till about noon. The first two
columns of Table XIII report the average $ES_t$ split over all evening or day periods. On average
earnings surprises tend to be positive for both sub-periods. The last two columns report the
$ES_t$ around 3rd Fridays. We observe a positive but insignificant positive earnings surprise during
the evening periods, and a more positive but again insignificant earnings surprise during the day
period. Overall, the pattern in earnings news around 3rd Fridays differs from the patterns in
equity returns.

If an information-based channel drives the 3FPS we expect higher returns when more news is
observed. To further examine an information-based channel we regress the 3FPS reversal return
on the $ES_t$ observed during the preceding evening period on 3rd Fridays. Table XIV reports
the results. On average 3FPS reversal returns are highly positive but unrelated to $ES_t$ with an
insignificant coefficient of -6.5 ($t$-statistics $= -1.22$).

Hypothesis $H_{02}$: Overnight Macroeconomic News. We next examine whether overnight
news released overnight before 3rd Friday open might be responsible for the 3FPS. Equity risk
 premia are consistently larger on days when important macroeconomic news is released (e.g., Savor
and Wilson, 2014, Wachter and Zhu, 2022) or just preceding FOMC announcements (Lucca and Moench (2015)). The 3FPS might be a reflection of such significant news arriving in the overnight window that causes a strong upward drift pre-open on 3rd Fridays.

To examine an 3FPS explanation based on macroeconomic news, we collect dates and times from Bloomberg’s Economic Calendar on the major U.S. macroeconomic announcements based on investor attention according to Bloomberg users. From these series we filter the series that are released in the overnight window preceding 3rd Fridays and have a Bloomberg attention score above 60. Subsequently, we classify these series into growth or inflation series, as market responses to growth or inflation news tend to differ.27 These series are released on 37 (inflation) or 90 (growth) of the 3rd Fridays, mostly at 8:30 a.m., or an hour before market open. This timing seems hard to reconcile with the 3FPS pattern: a macroeconomic news-based explanation needs to explain rising equity prices from 3rd Thursday close till an hour after after the announcement, followed by a subsequent reversal.

We test the effect of macroeconomic announcements on the 3FPS by regressing the 3FPS reversal return on a dummy variable that equals 1 on days when either an inflation or growth series is released during the preceding evening period on 3rd Fridays. Table XV reports the results. On average 3FPS reversal returns are highly positive but not significantly different on inflation or growth macroeconomic announcement days, witnessing insignificant coefficients on the inflation or growth dummy variables. In sum, the pattern in 3FPS differs from the pattern in earnings or macroeconomic news and the size of the 3FPS does not vary with measures of news content, leaving us to conclude that an information channel is hard to reconcile with the empirical patterns in the 3FPS.

\[ \text{INSERT TABLE XV HERE} \]

C. Pinning

An alternative explanation is based on the pinning, or anti-pinning, of index prices around option strike prices on option expiry dates. 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 strike and become

\[ \text{Common series include GDP QoQ, CPI Ex Food and Energy (CPI), Industrial Production, Housing Starts, Retail Sales, Empire Manufacturing, and University of Michigan Sentiment Index.} \]
“pinned”, i.e., closing prices at expiration will be fractions away from the strike price. Stock 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 or short positions (Avellaneda and Lipkin, 2003). (Krishnan and Nelken, 2001) show that Microsoft closes near integer multiples of $5 on a much larger percentage of expiration Fridays compared to other days. (Ni, Pearson, and Poteshman, 2005) show that on 3rd Friday expiry days optionable stocks are more likely to experience returns that are small in absolute value and argue that expiration date clustering is due to stock prices that are close to at-the-money option strike prices remain in the neighbourhood of these strikes.

At the index level, Golez and Jackwerth (2012) show that S&P 500 futures prices are pulled towards the at-the-money strike price of futures options (pinning) around their 3rd Friday p.m. settlement on non-quarterly expirations days, but are pushed away (anti-pinning) from the cost-of-carry adjusted at-the-money strike price of index options on mostly Thursday close price before the expiration of index options. The magnitude of this effect in the futures market is estimated at around $115 million per expiration estimated using open interest in futures. Moreover, Golez and Jackwerth (2012) show that S&P 500 futures are more likely to be pinned from below, meaning close prices of SPX futures on the non-quarterly 3rd Friday expiration days tend to be higher. Although, Golez and Jackwerth (2012) fail to find significant evidence of pinning in the SPX SOQ on 3rd Friday expiration days, pinning might cause the 3rd Friday a.m. settlement prices to be biased upward and thereby explain the 3FPS effect documented above. We consider three tests to examine the role of pinning in the 3FPS: the distribution of equity prices around expiry, the difference in 3FPS on quarterly versus non-quarterly expiration’s, and the impact of outstanding at-the-money open interest on the 3FPS.

**Hypothesis H\textsubscript{03}: Expiry Price Distribution.** To examine an 3FPS explanation based on pinning we first compute the distance between equity index or futures prices in 3rd Friday open relative to the nearest at-the-money strike price from below. Figure 9 shows the resulting distribution over our sample period when dividing the distance in bins of $0.50 increments. We separately show the distribution for (i) the ES futures prices on quarterly expiration dates when both the index and futures options expire in the a.m. window (panel a), (ii) the ES futures price on non-quarterly expiration dates when only index options expiry on the a.m. window (panel b),

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28These authors argue the these effects are driven by rebalancing of delta hedges due to the time decay in addition to reselling and early exercise effects.
(iii) the SPX SOQ on quarterly expiration dates (panel c), and (iv) the SPX SOQ on non-quarterly expiration dates (panel d). Note that options come in strike price increments of $5 and hence this distance can be mostly $5. If equity prices follow a random walk we would expect to see a uniform distribution with about equally sized bars for each bin, each with a mass of on average 10 percent.

We fail to find evidence of pinning behaviour in both the ES futures open price and the SPX SOQ on 3rd Fridays. The empirical percentages generally differ little from 10 percent, with no bars systematically clustering at the ends (pinning) or middle (anti-pinning) of the distribution. Kolmogorov-Smirnov or chi-square tests confirm that none of the four distributions differs significantly from a uniform distribution.

**Hypothesis H04: Quarterly versus Off-Quarterlies.** The analyses of Golez and Jackwerth (2012) reveals pinning in the SPX futures to differ remarkably across quarterly versus non-quarterly expiration dates: on quarterly expirations they observe cross anti-pinning from SPX index option expiry on the SPX futures in the Thursday close prices. Interestingly, most expiry activity on options and futures takes place on the “triple witching day”, the 3rd 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.29 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.30

In table XII we split the results of panel (a) of table IV by the OTC and CTO windows around 3rd Friday quarterly (panel a) and off-quarterly expiries (panel b). Effects are stronger on the quarterly triple-witch days, with a 3rd 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 3rd Friday CTO returns is large with t-statistics equal to 3.9 (panel a), and 3.3 (panel b). Hence, price moves and reversal effects have the same directional effects on the quarterly versus off-quarterly expiries, unlike the SPX futures price pinning effects document by Golez and Jackwerth (2012). Further, price effects

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29Some traders even refer to them as “quadruple witchings”.
are stronger around quarterly expiration’s, a pattern that differs from the SOQ and ES opening price distances displayed in figure 9.

Hypothesis $H_{05}$: The role of ATM Open Interest. A pinning explanation predicts that determinants explaining pinning determine to a certain extent the bias in equity derivative payoffs. Avellaneda and Lipkin (2003) show that as time-to-maturity goes to zero aggregate delta-hedging can drive stock prices towards its at-the-money strike price. Their theory predicts that pinning effects vary with the outstanding option open interest as market makers are required to hedge more when open interest is higher. Hence, we would expect that if pinning is responsible for our findings we should see larger reversals when open interest on the at-the-money option strikes is larger.

We test the impact of open interest in the at-the-money option strike by regressing it on the 3FPS reversal return. At-the-money open interest is defined as the number of SPX index option contracts that are within two strikes of the underlying price on the Thursday before expiry. As such, we capture the open interest on the option contracts that are would be most affected by pinning. Our sample runs from 2006 to 2019 as we utilize the CBOE high frequency option dataset that allows us the measure SPX option open interest at Thursday close. To remove time trends, open interest is normalized within every year of the sample. Table XVI contains the results. On average 3FPS reversal returns are highly positive, but unrelated to open interest in at-the-money option contracts. This holds for both call and put open interest, as well as levels and changes in open interest. Overall, we fail to find confirming evidence of pinning effects causing the 3FPS.

D. Price Pressure from Non-Fundamental Shocks

Another 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

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31Open interest on SPX option contracts is published with one-day lag in OptionMetrics and not available for third Thursdays.
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 the 3FPS patterns if: (a) order imbalances are systematically in one direction, or (b) if funding constraints are state dependent. These theories align with the 3FPS when market makers absorb demand shocks overnight and offload inventories during 3rd Friday trading.

**Hypothesis $H_{06}$: Funding Constraints.** Models in which intermediaries are financially constrained predict that a tightening of funding constraints of market makers reduces their liquidity-provision capacity and thereby should increase price pressure effects. Funding constraints tend to tighten in times of market stress or higher market volatility (e.g., Nagel, 2012). Consequently, we would expect the 3FPS to be stronger in times of heightened market volatility or poor past market returns.

We test the impact of past returns by regressing it on the 3FPS reversal return. Table XVII contains the results, revealing no significant effect of past 1-week to past 4-weeks returns on 3FPS reversal returns. Unreported analysis reveal the 3FPS reversal return is also unrelated to VIX levels or changes. Overall, we fail to find evidence supporting a link between non-fundamental shocks and 3FPS reversals.

**E. Price manipulation**

What then explains the bias? Order imbalances that are systematically in one direction before the 3rd Friday open might present an explanation. But, why would order imbalances be systematically in one direction on these days, and not on other days? A potential explanation is option market 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 indeed active around option expiries and this evidence aligns with several of our key results. Indeed, a manipulation hypothesis predicts temporary price pressure that reverts quickly; it predicts no price pattern during periods when manipulation is unlikely to be successful, such as during the p.m. settlement window; it predicts stronger effects when incentives are greater like during triple witching days. 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), a challenge beyond the scope of the current version of this paper.

V. Conclusions

We document and sizeable bias in the payoff of U.S. equity index derivatives. On the 3rd 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 index open quote by 15 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 3rd 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 an explanation based on market manipulation during an illiquid trading period directly preceding payoff settlement. However, regardless of the cause, we argue findings suggest that current settlement procedures lead to a market inefficiency and that regulators should critically evaluate current settlement practices.
References


VI. 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 displays the time series:

$$OpenGap_t = (SOQ_t - SpxOpen_t)/SpxOpen_t$$

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 opening price is computed from closing prices on 3rd Thursdays at 16:00 ET and the first traded price after 9:30 on 3rd Fridays. The sample period is 2003.2 - 2021.12.
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. 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 5. 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.
Figure 6. 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 7. 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.
This figure displays the daily dollar-weighted earning announcement surprise of US public companies in IBES. We consider only announcements between 1200 and 2400 ET. The sample period is 2003.2 - 2021.12.

**Figure 8. Earnings Surprises from 12h to 24h**
Figure 9. Distance of Equity Index Prices to options strike on 3Fr morning

These figures show that neither S&P 500 stocks nor associated futures contracts shows signs of "pinning" behaviour at 3rd Friday market open. Pinning is the tendency of asset prices to be abnormally close to strike prices of options contracts. S&P 500 stock index options have strike prices every 5$. This figure shows the percentage of 3rd Friday open prices by distance to the closest lower strike. If asset prices are unrelated to option strikes all bars should by at 10%. Panel a displays second-to-maturity S&P 500 e-mini futures on quarterly 3rd Fridays. Panel b displays first-to-maturity S&P 500 e-mini futures on non-quarterly 3rd Fridays. Panels c and d displays the S&P 500 SOQ on quarterly and off-quarterly 3rd Fridays, respectively. The sample period is 2003.2 - 2021.12.
Table I. Illustration of 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).
Table II. Deviation of Soq from Spx by date

The table reports summary statistics for

$$OpenGap_t = (SOQ_t - SpxOpen_t)/SpxOpen_t$$

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 last row reports the correlation with the SPX index return over the previous night computed from quotes. Correlations are in percent. 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 opening price is computed from closing prices on 3rd Thursdays at 16:00 ET and the first traded price after 9:30 on 3rd Fridays. The sample period is 2003.02 to 2021.12.
<table>
<thead>
<tr>
<th></th>
<th>intercept</th>
<th>slope</th>
<th>$R^2$(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PANEL A: all days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>coeff</td>
<td>0.46</td>
<td>0.66</td>
<td>19.03</td>
</tr>
<tr>
<td>t-stat</td>
<td>0.74</td>
<td>13.65</td>
<td></td>
</tr>
<tr>
<td>PANEL B: expiry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>coeff</td>
<td>12.02</td>
<td>0.81</td>
<td>11.10</td>
</tr>
<tr>
<td>t-stat</td>
<td>3.47</td>
<td>3.37</td>
<td></td>
</tr>
<tr>
<td>PANEL C: qtr expiry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>coeff</td>
<td>16.90</td>
<td>0.72</td>
<td>9.07</td>
</tr>
<tr>
<td>t-stat</td>
<td>2.93</td>
<td>2.46</td>
<td></td>
</tr>
<tr>
<td>PANEL D: non-qtr expiry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>coeff</td>
<td>9.79</td>
<td>0.83</td>
<td>11.49</td>
</tr>
<tr>
<td>t-stat</td>
<td>2.48</td>
<td>2.85</td>
<td></td>
</tr>
</tbody>
</table>

**Table III. Regression: Opening gap on previous night return**

In each panel, the first row reports OLS coefficients from regressing

$$OpenGap_t = \frac{(SOQ_t - SpxOpen_t)}{SpxOpen_t}$$

on an intercept and the preceding equity night return, measured from Spx quotes. The second row reportes bootstrapped t-statistics. Panels a, b, c and d display results for all days, 3rd Fridays, quarterly 3rd Fridays and non-quarterly 3rd Fridays, respectively. Returns are in basis points. The sample period is 2003.02 to 2021.12.
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.

### Table IV. Equity Returns

<table>
<thead>
<tr>
<th></th>
<th>All days</th>
<th>Around 3rd Fridays</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CTO</td>
<td>OTC</td>
</tr>
<tr>
<td>Mean</td>
<td>2.30</td>
<td>1.06</td>
</tr>
<tr>
<td>Mean(24H)</td>
<td>3.15</td>
<td>3.90</td>
</tr>
<tr>
<td>T-Stat</td>
<td>2.22</td>
<td>0.79</td>
</tr>
<tr>
<td>Std</td>
<td>71.08</td>
<td>92.11</td>
</tr>
</tbody>
</table>

### Panel A: SOQ / SPX

<table>
<thead>
<tr>
<th></th>
<th>Panel B: SPX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.18 0.60 3.78</td>
</tr>
<tr>
<td>Mean(24H)</td>
<td>4.36 2.21 3.78</td>
</tr>
<tr>
<td>T-Stat</td>
<td>3.23 0.45 2.19</td>
</tr>
<tr>
<td>Std</td>
<td>67.07 89.86 117.54</td>
</tr>
</tbody>
</table>

### Panel C: E-mini

<table>
<thead>
<tr>
<th></th>
<th>Panel C: E-mini</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.69 0.91 3.60</td>
</tr>
<tr>
<td>Mean(24H)</td>
<td>3.69 3.38 3.60</td>
</tr>
<tr>
<td>T-Stat</td>
<td>2.75 0.68 2.12</td>
</tr>
<tr>
<td>Std</td>
<td>67.47 92.25 117.16</td>
</tr>
</tbody>
</table>
### Table V. 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.

<table>
<thead>
<tr>
<th>days: expiry</th>
<th>intercept</th>
<th>slope</th>
<th>R²(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A, days: expiry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point Estimate</td>
<td>-12.07</td>
<td>-0.32</td>
<td>12.10</td>
</tr>
<tr>
<td>Lower Bound</td>
<td>-18.67</td>
<td>-0.48</td>
<td></td>
</tr>
<tr>
<td>Upper Bound</td>
<td>-6.19</td>
<td>-0.16</td>
<td></td>
</tr>
<tr>
<td>Panel B, days: all</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point Estimate</td>
<td>1.66</td>
<td>-0.10</td>
<td>1.47</td>
</tr>
<tr>
<td>Lower Bound</td>
<td>0.33</td>
<td>-0.15</td>
<td></td>
</tr>
<tr>
<td>Upper Bound</td>
<td>2.96</td>
<td>-0.04</td>
<td></td>
</tr>
</tbody>
</table>

### Table VI. 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.

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

<table>
<thead>
<tr>
<th>Days:</th>
<th>Reversal</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>expiry</td>
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<tr>
<td>Mean</td>
<td>24.43</td>
</tr>
<tr>
<td>T-stat</td>
<td>3.93</td>
</tr>
<tr>
<td>Std</td>
<td>93.25</td>
</tr>
<tr>
<td>SR</td>
<td>0.90</td>
</tr>
<tr>
<td>Alpha</td>
<td>24.40</td>
</tr>
<tr>
<td>Beta</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Table VIII. Equity Returns: SOQ open & SPX close, 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.

<table>
<thead>
<tr>
<th>Around 3rd Fridays</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Mean(24H)</td>
</tr>
<tr>
<td>T-stat</td>
</tr>
<tr>
<td>Std</td>
</tr>
</tbody>
</table>
Table IX. Contract Specifications

<table>
<thead>
<tr>
<th>Security</th>
<th>S&amp;P500 Index Options</th>
<th>S&amp;P500 Futures Options</th>
<th>S&amp;P500 Futures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underlying</td>
<td>100 x S&amp;P500 Index (SPX)</td>
<td>E-mini S&amp;P500 Futures (ES)</td>
<td>50 x S&amp;P500 Index</td>
</tr>
<tr>
<td>End of Trading</td>
<td>Th pre 3rd Fr p.m.</td>
<td>3rd Friday a.m.</td>
<td>3rd Friday a.m.</td>
</tr>
<tr>
<td>Settlement</td>
<td>3rd Friday a.m.</td>
<td>3rd Friday a.m.</td>
<td>3rd Friday a.m.</td>
</tr>
<tr>
<td>Settlement Method</td>
<td>Cash (via SOQ)</td>
<td>Futures</td>
<td>Cash (via SOQ)</td>
</tr>
<tr>
<td>Expiration months</td>
<td>12 months + leaps</td>
<td>9 quarters + 3 Dec</td>
<td>9 quarters + 3 Dec</td>
</tr>
<tr>
<td>Exercise Style</td>
<td>European</td>
<td>American</td>
<td>/</td>
</tr>
<tr>
<td>Strikes</td>
<td>5 idx points</td>
<td>5 idx points</td>
<td>/</td>
</tr>
<tr>
<td>Exchange</td>
<td>CBOE</td>
<td>CME</td>
<td>CME</td>
</tr>
</tbody>
</table>
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

\[
SettlValue_{\text{Calls}} = \sum_{i} \max(0, SOQ - K_{i}) * OpenInterest_{i}
\]

where I is the number of different call options, is the option price. Column 2 contains the settlement value of call options if settlement occurred on thursday 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

\[
SettlValue_{\text{Puts}} = \sum_{i} \max(0, K_{i} - SOQ) * OpenInterest_{i}
\]

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.

<table>
<thead>
<tr>
<th></th>
<th>Calls</th>
<th></th>
<th></th>
<th>Puts</th>
<th></th>
<th></th>
<th>Σ Abs Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>10.46</td>
<td>10.23</td>
<td>0.23</td>
<td>3.04</td>
<td>3.12</td>
<td>-0.09</td>
<td>0.31</td>
</tr>
<tr>
<td>std</td>
<td>15.71</td>
<td>15.57</td>
<td>0.13</td>
<td>12.29</td>
<td>12.73</td>
<td>-0.44</td>
<td>0.57</td>
</tr>
</tbody>
</table>
Table XI. 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.

<table>
<thead>
<tr>
<th></th>
<th>Put</th>
<th>Bxm</th>
<th>Put Minus Bxm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>all days</td>
</tr>
<tr>
<td>mean</td>
<td>8.70</td>
<td>7.34</td>
<td>1.35</td>
</tr>
<tr>
<td>std</td>
<td>13.24</td>
<td>13.85</td>
<td>2.80</td>
</tr>
<tr>
<td>SR</td>
<td>0.57</td>
<td>0.45</td>
<td>0.48</td>
</tr>
</tbody>
</table>
## Around 3rd Fridays

<table>
<thead>
<tr>
<th></th>
<th>$W_{c}$ to $T_{h}$</th>
<th>$T_{h}$ to $T_{c}$</th>
<th>$T_{c}$ to $F_{r}$</th>
<th>$F_{r}$ to $M_{o}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>We</strong> to <strong>Th</strong> to <strong>Th</strong> to <strong>Fr</strong> to <strong>Fr</strong> to <strong>Mo</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Panel A</strong>: quarterly expiries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>4.79</td>
<td>0.52</td>
<td>26.71</td>
<td>-37.23</td>
</tr>
<tr>
<td>mean(24H)</td>
<td>6.57</td>
<td>1.93</td>
<td>36.64</td>
<td>-137.48</td>
</tr>
<tr>
<td>t-stat</td>
<td>0.83</td>
<td>0.05</td>
<td>4.42</td>
<td>-3.54</td>
</tr>
<tr>
<td>Std</td>
<td>50.14</td>
<td>82.48</td>
<td>52.39</td>
<td>91.03</td>
</tr>
<tr>
<td><strong>Panel B</strong>: off-quarterly expiries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
<td>-7.94</td>
<td>-0.90</td>
<td>14.26</td>
<td>-6.25</td>
</tr>
<tr>
<td>mean(24H)</td>
<td>-10.89</td>
<td>-3.33</td>
<td>19.56</td>
<td>-23.09</td>
</tr>
<tr>
<td>t-stat</td>
<td>-1.86</td>
<td>-0.12</td>
<td>2.74</td>
<td>-0.95</td>
</tr>
<tr>
<td>Std</td>
<td>52.39</td>
<td>92.31</td>
<td>63.75</td>
<td>80.36</td>
</tr>
</tbody>
</table>

### Table XII. Equity Returns: SOQ open & SPX close

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 reported 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 ($F_{r_{o}}$). 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.
<table>
<thead>
<tr>
<th></th>
<th>All days</th>
<th></th>
<th>Around 3rd Fridays</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>evening</td>
<td>day</td>
<td>evening</td>
</tr>
<tr>
<td>mean</td>
<td>5.38</td>
<td>5.89</td>
<td>2.80</td>
</tr>
<tr>
<td>median</td>
<td>1.74</td>
<td>1.95</td>
<td>2.01</td>
</tr>
<tr>
<td>t-stat</td>
<td>9.19</td>
<td>6.76</td>
<td>1.31</td>
</tr>
<tr>
<td>Std</td>
<td>28.38</td>
<td>48.02</td>
<td>29.74</td>
</tr>
</tbody>
</table>

**Table XIII. Earnings Surprises**
The table reports average dollar weighted earnings announcement surprises during “evening” (1200 to 2400 E.T.) and during the rest of the “day” (0930 to 1200 E.T.). Columns 1 and 2 consider all days. Columns 3 and 4 consider only the evening and day surrounding the market open of the monthly third Friday. All numbers are in hundredth of bps. The sample period is 2003.2 to 2021.12.

<table>
<thead>
<tr>
<th></th>
<th>intercept</th>
<th>slope</th>
<th>$R^2$ (%)</th>
</tr>
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<tbody>
<tr>
<td>coeff</td>
<td>33.54</td>
<td>-6.50</td>
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<tr>
<td>t-stat</td>
<td>4.84</td>
<td>-1.22</td>
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</tr>
</tbody>
</table>

**Table XIV. Regression: reversal return on previous earnings news**
In panel a, the first row reports OLS coefficients from regressing the 3rd Friday reversal return on an intercept and the dollar weighted earnings announcement surprises during preceding post-trading hours. The second row reports bootstrapped t-statistics. Returns are in basis points. Earnings news are normalized. The sample period is 2003.02 to 2021.12.

<table>
<thead>
<tr>
<th>rev ret</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>36.49</td>
<td>36.82</td>
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<tr>
<td>Dummy</td>
<td>5.88</td>
<td>5.70</td>
</tr>
<tr>
<td>Dummy</td>
<td>-1.99</td>
<td>-0.10</td>
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</table>

**Table XV. Regression: reversal return on macro announcement dummies**
The table reports point estimates and t-statistics from regressions of third friday reversal returns on macro announcement dummies. We consider all macro announcements listed on Bloomberg that occurred on a third friday before (and including) market open. We only consider announcements with an Bloomberg attention score above 60 and group them into inflation or growth categories. Column 2 contains "cpi", "ppi" and "gdp price index". Column 3 contains the other releases (growth). Returns are in basis points. Underlying returns are normalized. Every second row displays robust t-statistics. The sample period is 2003.2 - 2021.12.
Table XVI. Regression: reversal return on expiring atm oi
The table reports point estimates and t-statistics from regressing the third friday reversal return on S&P 500 index option open interest. We consider only open interest in at-the-money options, that is options within two strikes of the underlying price. Column 2 contains open interest in both puts and calls. Column 3 (4) contains only call (put) open interest. Column 5 contains the change in atm open interest since the last third Friday. The reversal return is in basis points. Open Interest and change in open interest are normalized within every year. Every second row displays robust t-statistics. The sample period is 2006.1 - 2019.12.

<table>
<thead>
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</thead>
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<tr>
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<td>33.38</td>
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<tr>
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<td>4.35</td>
<td>4.38</td>
<td>4.28</td>
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<tr>
<td>atm oi</td>
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<tr>
<td>atm oi calls</td>
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<td></td>
<td></td>
<td>0.72</td>
</tr>
<tr>
<td>atm oi puts</td>
<td></td>
<td></td>
<td>-1.82</td>
<td></td>
<td>-0.29</td>
</tr>
<tr>
<td>∆ atm oi</td>
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<td></td>
<td>1.32</td>
<td>0.22</td>
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</tbody>
</table>

Table XVII. Regression: reversal return on lagged underlying return
The table reports point estimates and t-statistics from regressions of third Friday reversal returns on past S&P 500 index returns. Columns 1,2,3,4 contain the regression on the past 1,2,3,4 week underlying return, respectively. Returns are in basis points. Underlying returns are normalized. Every second row displays robust t-statistics. The sample period is 2003.2 - 2021.12.

<table>
<thead>
<tr>
<th></th>
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<th>rev ret</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
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<td>36.49</td>
<td>36.49</td>
<td>36.49</td>
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<td></td>
<td>5.89</td>
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<td>5.87</td>
<td>5.89</td>
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<tr>
<td>Ret Undl 1w</td>
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<td>Ret Undl 2w</td>
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<tr>
<td>Ret Undl 3w</td>
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<tr>
<td>Ret Undl 4w</td>
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