

The Derivative Payoff Bias

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Abstract

Most U.S. equity index derivatives settle “a.m” on the 3rd Friday of each month via the constituent stocks’ opening trade price. We show that these prices are biased upward since the advent of overnight equity trading in the early 2000s. U.S. equity prices drift significantly upwards from Thursday close to 3rd Friday open and revert immediately after derivative payoffs are calculated. Consequently, equity futures and call option payoffs are biased upwards, while put option payoffs are biased downwards. We estimate a wealth transfer of around \$4 billion per year in SPX options alone. These findings are consistent with channels relating to inventory management by option market makers or market manipulation by sophisticated investors during an illiquid trading period that precedes option settlement. We find support for these explanations in the positioning of market makers and likely manipulators the days before expiry. Both explanations rely on the existence of an illiquid trading period that precedes option settlement; thus, we argue that the current a.m settlement design is inefficient and propose alternative times of expiry that are not immediately after the illiquid overnight period.

Keywords: Equity; Derivatives; Futures; Market Microstructure; Market Design; Hedging; Manipulation.

JEL Classifications: G10, G12, G13, G14.

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This paper studies U.S. equity index derivative payoffs. The majority of global index derivative trading activity is concentrated in products for which the S&P 500 index (the SPX) is the underlying. Moreover, most SPX derivatives are “a.m.-settled”, meaning they expiry on the 3rd Friday of each month with payoffs determined via the index Special Opening Quotation (SOQ). The SOQ is calculated from the opening sales price of index component stocks on their primary listing exchange. Hence, the SOQ is available only once all component stocks have traded during the regular market session after 9:30:00 Eastern Time. Despite its importance, the SOQ and associated derivative payoffs have received little attention in the academic literature.¹

We document an economically large bias in settlement prices around a.m.-derivative expirations. Measured on all days between 2003 and 2021, the daily difference between the SOQ and the preceding closing price is (almost) mean zero. However, a persistent positive bias occurs 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 closing price by an average of 18.5 basis points (bps), which is different to the unconditional close-to-SOQ return with a high level of statistical confidence (*t*-statistic exceeding 4.5). Interestingly, the pre-2003 sample period displays no such effect, which we argue is due to the emergence of a (more) active yet relatively illiquid overnight market in equity futures and single stocks around that time. This gives rise to overnight price pressures which can affect a.m.-derivative payoffs. We discuss potential sources of price pressure below and expand on these explanations in the paper.

The positive bias in the SOQ is not only reflected in stock prices but also in equity futures returns. To illustrate this result, consider Figure 1 which displays the price path of S&P 500 E-mini futures contracts overnight preceding 3rd Fridays. Studying 24-hour continuous trading via equity futures, we detect clear tent-shaped reversal pattern from the close of regular trading on 3rd Thursdays, which peaks exactly when the SOQ is calculated on 3rd Fridays and fully reverts afterward by about noon 3rd Friday.² We dub this empirical irregularity the Third Friday Price Spike (3FPS).

The 3FPS is stronger on days with more expiry activity (i.e., “triple witching days”), and also present in other major U.S. equity indices with sizable option markets with a.m. settlements

¹Stoll and Whaley (1991) and Hancock (1993) study expiration effects around a.m settlement days, finding little price impact around expiries with less than a handful years of data.

²Throughout the paper we will refer to the option expiry date as the 3rd Friday, even though on four occasions in our sample the option expiry occurred on the preceding Thursday due to market holidays. Similarly we regularly refer to the Thursday immediately preceding option expiry as the 3rd Thursday, even though this does not have to be true.

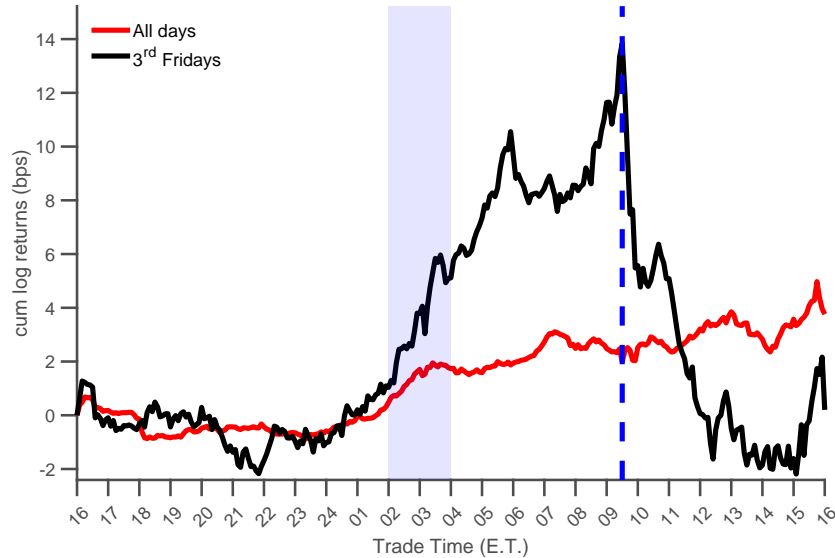


Figure 1. The 3rd Friday price spike in S&P 500 E-mini futures

The black line plots average cumulative 5 minute log returns of S&P 500 E-mini futures around 3rd Friday market open (09:30, 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.

like the Dow Jones Industrial Average and Nasdaq 100 indices. Further, it is present in almost every year since 2003, and is exploitable after transaction costs. A strategy that exploits the 3FPS-reversal pattern yields a positive return in 16 out of 19 years in our sample, and delivers a gross (net) Sharpe ratio of 1.3 (0.8). Further, the reversal of the overnight price spike has another important investment application. The reversal explains the sizable performance gap between 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 due to put-call parity. However, their returns differ by a remarkable 135 basis points a year over our sample, which we fully trace to the reversal of the bias in the equity derivative payoff between market open and noon on 3rd Fridays.

Importantly, the 3FPS is confined to the a.m. settlement window. Several S&P500 option derivatives do not settle into the SOQ, but instead are p.m.-settled at market close on 3rd Fridays. However, around the p.m. settlement window there is no corresponding pattern, highlighting the specialness of the a.m. settlement window. Thus, the bias that we document is isolated in contracts that expire into the SOQ, i.e. with a.m. settlement and not a general

feature of index option settlement procedures.

The price path around the 3FPS displays a classic reversal pattern which arises in models of demand for immediacy and inventory risk management. We indeed confirm that the 3FPS is not only present in returns but also in order imbalances. However, reversals in such models are typically symmetric and average to zero.³ Exploring the asymmetric nature of our finding we condition average 24-hour returns on whether its overnight return component was positive or negative. In total, out of 225 observations, 143 (64%) overnight returns are positive while 82 (36%) are negative. Averaging within these sets we find that positive overnight returns are followed by a reversal that begins at exactly 9:30 a.m., while negative overnight returns display no reversal, which unconditionally leads an asymmetric ‘tent’ shaped reversal pattern. This provides a first clue of the underlying mechanism driving the 3FPS, which we elaborate on below.

The 3FPS impacts derivative payoffs at settlement. Specifically, we observe: (i) a higher payoff for in-the-money calls; (ii) some calls which would have expired out-the-money without the price spike now expire in-the-money; (iii) a lower payoff for in-the-money puts; and (iv) some puts which would have expired in-the-money now expire out-the-money. Since index options are cash settled and option payoffs are zero sum game, a natural question that arises is “does the 3FPS have a welfare impact?” We address this question two ways.

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

Second, we compute SPX index option payoffs at expiry. For counter-factual evidence, we replace the SOQ in the max operator which determines option payoffs with the SPX closing price on 3rd Thursday. These calculations show that SPX call options paid off \$10.46 billion on the average 3rd Friday morning. Had their settlement been determined at Thursday close, they

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

would have paid off \$10.23 billion. The difference of \$230 million a month, or \$2.8 billion a year, represents the wealth transfer from call option writers to call option buyers. Similarly, SPX put options paid off \$3.04 billion on the average 3rd Friday morning, versus a counter-factual \$3.12 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.⁴

What explains the bias in U.S. equity derivatives payoffs? We first investigate three obvious candidates: Fundamental Shocks (overnight news, earnings, and macro announcements), non-fundamental shocks (shocks to balance sheet capacity and funding constraints), and “pinning” - the phenomenon whereby underlying prices tend to cluster around their nearest strikes on expiration days. We fail to find evidence in support of these explanations across a battery of tests. Instead, our tests point to two potential alternative channels: (1) hedging practices of option market makers; and (2) market manipulation.

We exploit option market maker positioning data from the CBOE to examine these channels. First, we show that market makers positions in expiring options are on average delta-neutral. Thus, there should be no need for them to trade in- or out of the underlying as options expire. However, we also show that option market maker positions have large negative “Charm”, especially immediately before option expiry. Charm is the rate of change change of market makers delta due to the passage of time and is particular important close to expiration and over weekends.⁵ That is, as time to expiry falls, ceteris paribus, the delta of options that market makers hold falls. Thus, they have to continuously buy the underlying index to maintain a delta-neutral portfolio. Specifically, we find that market maker inventory delta from SPX options falls substantially over the approximately 17 hours from the end of SPX options trading to their final settlement. Thus, option market makers exposure to market risk mechanically falls into 3rd Friday a.m. option expiry. To offset this change in market risk exposure market makers have to buy the underlying equities, or related products like equity futures. Such buying could account for the temporary positive price pressure that we document.

A second possible explanation is that manipulators push the underlying index price up in

⁴Note that our wealth calculations represent a lower bound since these estimates ignore other SPX derivatives contracts as well as other U.S. equity indices with sizable option markets which are a.m. settled and also display a significant 3FPS.

⁵Black-Scholes Charm is decreasing in time-to-maturity, is rapidly decreasing close to expiration, and is closely monitored by market markers in the run up to expiration and over extended non-trading periods.

the period immediately preceding settlement, such that settlement prices move in the direction that benefits their position. Theoretical models of manipulation identify three key factors that facilitate market manipulation: differing price-order elasticities across markets, cash settlement, and a finite period to manipulate (Kumar and Seppi (1992) and Spatt (2014)), three conditions present before the a.m.-settlement point. Equities trading pre-open is much less liquid than during regular trading hours with larger price impacts (Barclay and Hendershott (2003)), making the overnight window most suited for manipulation. Subsequently, prices revert as manipulators offload their positions, given rise to the 3FPS.

The manipulation explanation aligns with all our key empirical findings; it predicts temporary price pressure that reverts quickly (prices are pushed away from fundamentals); it predicts price patterns especially during a finite window just before expiry (as payoffs become fixed at expiry); it predicts no price pattern during periods when manipulation is unlikely to be successful, such as during the p.m. settlement window; and it predicts stronger effects when incentives are greater like during triple witching days. We find supporting evidence for all these. Moreover, the on average tent shaped 3FPS is also consistent with a manipulation story: since short selling is costly the most obvious manipulation strategy would be to take a positive net delta position in options and push up prices in the underlying through relatively cheap purchases on index constituents (in pre-market trading) or futures (during 24-hour trading). CBOE positions data reveals that a likely group (professional traders or hedge funds) hold positions that would benefit from the wealth transfer we document, and these positions increase into expiry. That said, a direct identification of market manipulation is challenging since the practice is inherently latent. The question of market manipulation around a.m. derivatives settlement remains to be demonstrated (or not) by the SEC.

We conclude by discussing policy implications. Options are a zero sum game. The payoffs to market makers, professional traders and retail traders sum up to zero. We show likely beneficiaries of the bias are professional traders - actors that are net delta positive on 3rd Thursdays. By contrast, we show that market makers are net delta zero in a.m. settled options just before expiry. Thus, retail investors are net delta negative and hence loose at least \$3.8 billion per year due to the derivative payoff bias. Our results suggest that retail investors could be protected from these losses if settlement was moved to a time that follows liquid trading in the underlying and is less susceptible to price pressures.

I. Related Literature

Our paper contributes to several strands of literature. Firstly, our paper contributes to an empirical literature on the effects of demand pressures and intermediary inventory risks. Golez and Jackwerth (2012) studies the pinning of S&P 500 prices around option strike prices. Ni, Pearson, Poteshman, and White (2021) show option market maker rebalancing affects a sizable part of the return volatility and jump probability of individual stocks. Baltussen, Da, Lambers, and Martens (2021) show that gamma hedging practices of option market makers drives intraday momentum around market close times, while Krohn, Mueller, and Whelan (2022) document prolonged intraday reversals in spot currency markets driven by inventory management practices of dealers. Different than these papers, we focuses on a specific intraday interval in the world’s most liquid option and futures markets: the close of regular trading hours on the 3rd Thursday of the month to close of regular trading hours on the 3rd Friday of the month.

Secondly, our paper relates to the literature on market manipulation and market design. For individual stocks and the VIX index (Ni, Pearson, and Poteshman, 2005 and Griffin and Shams, 2018) extant evidence suggests that manipulator are active around option expiration dates. Filippou and Zapatero (2022) show individual stock returns are predictable by option strike prices around option expiries, which they argue is driven by stock manipulation. Aggarwal and Wu (2006) summarizes evidence of several high profile cases of stock price manipulation by analyzing SEC litigation cases. Further evidence on stock manipulation is provided in the influential study of Carhart, Kaniel, Musto, and Reed (2002) who show that fund managers inflated year-end portfolio prices through trading in order to optimize performance numbers, which generated a one time year-end reversal in single stocks resembling the 3rd Friday pattern documented in this paper. In addition, theoretical research has examined the characteristics of markets that might be vulnerable to manipulation (e.g., Kumar and Seppi, 1992 and Spatt, 2014). The empirical evidence and theoretical results presented in these studies aligns with several of our key results.

II. Data

We collect our data from several sources. From Bloomberg, we obtain a daily series on the S&P 500 index special opening quotation (SOQ) from January 1992 to December 2021.⁶ From Refinitiv we examine settlement day pricing effects by collecting tick-level data on the S&P 500 (SPX) and E-mini S&P 500 futures traded on the CME. We obtain tick-level best bid offers, trade prices, and volumes. Sampling of tick-level data follows standard practices, for example, we construct 1, 5 and 15 minute frequencies for quantities and prices following Boyarchenko, Larsen, and Whelan (2023). Within each sampling frequency for each interval of the day we obtain first and last quote updates, first, last and volume-weighted-average prices. We source intraday SPX index options data sampled at 15-minute intervals from the Chicago Board Options Exchange (CBOE). The CBOE data provides intraday quotes alongside a number of option characteristics at 15-minute intervals. OptionMetrics provides us with EOD option data.⁷ We also exploit the CBOE Open-Close dataset that provides daily buy- and sell volumes of SPX option market participants. From 2006.01 to 2010.12 trade volumes are separated by “firms” and “customers”, leaving “market makers” as the residual. From 2011.01 to 2020.12 the residual to “firms” and “customers” is further separated into “professional customers”, “broker dealers” and “market makers”. For consistency, we calculate “market maker” trades as the residual to “firms” and “customers” (post 2011 that includes “pro customers”) over the whole sample. We aggregate these daily volumes to cumulative positions for each group. Finally, we obtain data on the CBOE S&P 500 BuyWrite Index (BXM index) and the CBOE S&P 500 PutWrite Index (PUT index) from Bloomberg.

III. Derivatives Settlement and Overnight Trading

A. *Derivatives Settlement and the bias in SOQ Prices*

Options on the S&P 500 index (SPX) started trading on the Chicago Board Options Exchange (CBOE) on July 1, 1983 and quickly became a popular product. Today, SPX options are the

⁶BB ticker SPXM until 2006 and ticker SPXSET afterwards.

⁷In line with standard derivatives research practice we exclude the expiry days of September and October 2008 from the main analysis. Also, we exclude the expiry day of September 2001. Our main findings are robust to the inclusion of these dates.

world's most heavily traded index options, with robust liquidity and trading volume across various expirations and strike prices. Below we highlight key settlement practices of the SPX derivatives market, while the Online Appendix (OA) offers a more extensive description of SPX option markets, as well as SPX futures and SPX Exchange Traded Funds (ETFs).

Standard SPX options expire on the 3rd Friday of each month, with settlement prices originally based on the official closing price on the expiry day. Driven by concerns about dealer inventory management, on June 18th 1987, the Securities and Exchange Commission (SEC), the Commodity Futures Trading Commission (CFTC), the Chicago Mercantile Exchange (CME) and Chicago Board Options Exchange (CBOE) shifted their reference point for SPX settlement prices from p.m. (i.e., market close) to a.m. settlement (i.e., market open).⁸ Since June 19th, 1987 (November 20th, 1992), the settlement price of quarterly (monthly) SPX index options has been computed on 3rd Friday mornings via the Special Opening Quotation (SOQ), and settlement is delivered in cash instead of stocks. Furthermore, trading in expiring options ceases at the market close of the Thursday before expiry (that is 17 hours and 15 minutes before settlement values are determined). All option contracts which have not been closed out by the end of the last trading day must be settled. Related, since June 1987, SPX futures also expire in the SOQ.

The SOQ is computed as the sum product of stocks' weight in the SPX and their first reported trade price on their primary listing exchange. Thus, the SOQ can only be calculated once all constituent stocks have opened for trading, and is typically published 30-45 minutes after market open. After the opening bell, many stocks in the index may not yet have opened due to a lack of - or imbalance between - buy and sell orders. Highly liquid, large-cap stocks usually trade close to the market opening time on their primary exchange. Less liquid stocks may take several minutes to open. Therefore, the SOQ is comprised of single stock trade prices from different points in time.⁹

Besides the monthly a.m. settled SPX options, the CBOE has introduced SPX options with other settlement practices over time. Notably, p.m.-settled options were reintroduced in 2007 with the SEC's PM Option Expiration Pilot program. Initially, these were options expiring on

⁸There were particular concerns over "Triple Witching" events, occurring only four times per year on the 3rd Friday of March, June, September, and December, where simultaneous expiry of futures, futures options, index options, and single stock options takes place.

⁹At the opening bell when Standard & Poor's publishes the "current" opening SPX value (which differs from the SOQ), it includes the previous day's closing prices for each stock that has not yet opened.

the last business day of a calendar month, followed by weekly options in 2010, monthly options expiring on the 3rd Friday in 2011, and more recently, zero-day (ODTE) options expiring daily.¹⁰

B. Overnight Trading

As options expire into the SOQ but trading ceases the night before, option holders face overnight risk relative to their last traded Thursday price. To manage this risk, overnight trading could be a very important tool.

The first major instrument for overnight trading are equity futures. In 1995, SPX futures contracts began trading electronically via the CME GLOBEX electronic platform, with trading hours that coincided with the cash market. In September 1997, the e-mini futures (ES) futures contract was introduced, trading electronically on the CME GLOBEX platform almost 24-hours a day. Panel (a) of figure 2 shows the fraction of trading volume in the SP and ES contracts traded overnight relative to intraday since 1998 (when overnight volumes become available). We define the intraday window as the regular trading hours of the stock exchange (i.e., 09:30 a.m. to 16:00 p.m.) and measure volume as the total number of contracts traded in the most liquid contract.¹¹ The figure shows that, while the annual volume traded overnight as a percentage of overall volume was small and constant at around 3% until the years 2002, it increased sharply from 2003 to around 15% in 2010 and about 25% towards the end of our sample.

[INSERT FIGURE 2 HERE]

The second major instrument for overnight trading are individual stocks, including ETFs. Index stocks originally traded almost exclusively during regular market hours (9:30 a.m. - 16:00 p.m. for SPX stocks). More recently, market participants have developed electronic trading platforms that allow investors to trade stocks relatively easily before or after the regular market session.¹² In 1991 the Instinet system was introduced, allowing large investors to trade stocks

¹⁰Related, options on front-contract SPX futures trade on the quarterly expiry calendar, expiring in the SOQ. Options on SPX futures also trade outside the quarterly expiry calendar, most notably options that expiry on the off-quarterly dates in the p.m. window. Further, in 2005, the CBOE introduced option contracts on the SPDR ETF. As ETFs are generally traded like common stock, SPDR options have the same features as individual U.S. stock options (e.g., they settle on the 3rd Friday of the month at the close price of that day.). The OA describes these options in more detail.

¹¹We multiply the volume for the SP contract by 5 to make its volume comparable to the ES.

¹²Before, it was also possible to trade overnight by negotiating with a market maker over the telephone or trading dual-listing on other exchanges. However, these practices were uncommon.

outside of regular market hours. The pre-market session began at 6:30 a.m. and ended at 9:20 a.m.. In 1998, the Securities and Exchange Commission (SEC) approved the introduction of the pre-market trading session on the NASDAQ stock exchange. In the early 2000s, other major stock exchanges, such as the NYSE and the CME, also began offering pre-market trading sessions to their customers. Nowadays, pre-market typically begins at 4:00 a.m. and ends at the start of regular trading hours at 9:30 a.m..

To gauge the size of pre-market trading in stocks, in figure 2 we plot the fraction of total SPDR ETF (SPY) volume which is traded overnight. The SPY is the most actively traded ETF, essentially trading the basket of SPX stocks, and follows the regular trading hours of individual stocks. Pre-market volume is mostly absent before 2003, increased to about 1% of intraday volume in 2005, and jumped to about 4% after 2005. That said, equities trading overnight is much less liquid than during regular trading hours with higher transaction costs (Barclay and Hendershott (2004)), larger price impacts (Barclay and Hendershott (2003)), and is especially concentrated in the minutes before open (Barclay, Hendershott, and Jones (2008)). In summary, overnight trading - important for option holders to manage risks around option expiries - emerged in futures around 2003 and in index stocks around 2005.

C. Special Opening Quotation Dynamics

Having summarized key details on settlement practices and trading, we next examine the dynamics in the SOQ. Panel (a) of figure 3 plots the (log) difference in basis points (bps) between the SOQ and preceding closing trade of the SPX

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

[INSERT FIGURE 3 HERE]

for all days since November 1992 (when all SPX options became a.m. settled). Visually inspecting panel a, we observe an approximately equal mass of red ($\text{ReturnSOQ}_t > 0$) and blue bars ($\text{ReturnSOQ}_t < 0$). This shows that while closing and opening trade prices are generally different, this difference appears unbiased.

Panel (b) displays ReturnSOQ_t only on 3rd Friday settlement days. In addition, motivated by the evidence in figure 2 we draw a black vertical line which marks the approximate date

after which we observe the emergence of overnight equity trading. To the left of this line there are persistent periods of positive (red) and negative (blue) overnight returns in the run up to a.m settlement. This image to the right of this line is dramatically different: there is clearly a much larger mass of red bars compared to blue bars. In other words, compared to close prices on 3rd Thursdays, the SOQ - the value weighted average of the SPX constituent traded prices - appears structurally upward biased on 3rd Fridays - when the SOQ determines derivative payoffs.

[INSERT FIGURE 3 HERE]

Estimating a set of supF structural break tests yields a consistent significant break point on January 17th, 2003. Based on this result, table I examines the SOQ dynamics formally in three sample splits: Panel A contains 1992.11 to 2021.12 (full sample), Panel B contains 1992.11 to 2003.01 (early sample) and Panel (C) contains 2003.02 to 2021.12 (late sample). We report summary statistics for ReturnSOQ_t on all non-expiry days (column 1), option expiry dates (column 2), their difference (column 3), and all non-expiry dates Fridays (column 4).

We first consider the February 1992 - December 2021 period. Confirming our eye-ball econometrics from above ReturnSOQ_t is positive but close to zero on non-expiry days, equal to 1.4 bps (t -statistic = 1.7). However, on 3rd Fridays ReturnSOQ_t is an order of magnitude larger equal to 10.4 bps (t -statistic = 3.1). The difference between is a significant 9.0 bps (t -statistics = 2.5), and hence the SOQ exceeds the close price both compared to zero and its all day counterpart. By contrast, the last column of table I shows the SOQ-gap is close to zero on non-expiry Fridays, and, hence, the positive SOQ-gap on expiry Fridays is not a reflection of a weekly (seasonal) Friday effect.

[INSERT TABLE I HERE]

An interesting pattern emerges over the two subperiods. Panel (b) shows that pre-2003 the SOQ-gap (equation 1) was close to zero and insignificant on both expiry and non-expiry days (gap = -3.3 bps, t -statistic = -0.6). Panel (c) shows that post-2003 we observe a large positive SOQ-gap on expiry Fridays, equal to 18.2 bps, a number that is 16.9 bps larger than on non-expiry days with a t -statistic of the difference equal to 3.5. To analyze robustness to the choice of sample split in February 2003 (motivated by the structural break test), we vary

the sample split by up to six months up or down, as shown in table A.3 in the OA. The results show the message of table I is robust to the exact choice of sample split around February 2003.

Summarizing, an economically large and statistical significant SOQ-gap emerged around 2003, coinciding with the substantial advent of overnight trading in single stock equities and futures on index contracts. The remainder of the paper studies further pricing and wealth implications in the post-2003 sample.

IV. Pricing Bias

In the previous section we have shown that the SOQ is structurally upward biased on 3rd Fridays. Next we examine the pattern in overnight returns using trading strategies in the SPX index or the SPX futures contracts, which trades (almost) around the clock and expire on the 3rd Friday SOQ price. To this end, we compute traded returns around *monthly* 3rd Friday settlement dates from 5-minute volume weighted average (VWAP) prices. To obtain a continuous return series on off-quarterly settlement dates we trade the front month contract, 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.¹³ Returns on all other days are computed using the front month contract.

The black line in panel (a) of figure 1 displays cumulative 5-minute returns between 16:00 on Thursdays (left hand side of the x-axis) and 16:00 on 3rd Fridays (right hand side of the x-axis). From around 2:00, which is the opening of the London market, equity prices drift steadily up and continue drifting in early morning trade until *exactly* the 9:30 interval, at which point returns sharply revert. The average overnight cumulative return in the active futures contract is equal to 14 bps which completely reverses by 12:00.¹⁴ Hence, SPX futures prices display a tent-shaped reversal pattern from the close of regular trading on 3rd Thursdays, which peaks exactly when the SOQ is calculated on 3rd Fridays and fully reverts afterward by about noon 3rd Friday. We dub this empirical irregularity the Third Friday Price Spike (3FPS).

To highlight the surprising nature of this pattern, consider the unconditional intraday return

¹³Computing returns on quarterly settlement dates using the next-to-delivery and avoiding the roll-return we obtain very similar results.

¹⁴Please note that this pattern focuses solely on traded futures prices and does not include the SOQ settlement price on futures expiry days, as we consider the next to delivery contract as of 9:30 a.m. on expiration days.

profile across all days (red line) which displays no reversal patterns and shows that overnight returns on 3rd Fridays are an order of magnitude larger than what should be expected unconditionally.¹⁵

[INSERT FIGURE 1 HERE]

The 24-hour price path around 3rd Fridays displays a classic (asymmetric) reversal pattern that typically arises in models of demand for immediacy and inventory risk management. This point is discussed by numerous studies (e.g., Brunnermeier and Pedersen (2009)). To demonstrate a causal relationship between intraday and overnight returns, we estimate standard microstructure reversal regressions and present the results in the OA. The results show that large overnight returns are indeed causally reversed intraday consistent with standard theories of price pressure. Moreover, the significance of the 3FPS reversal pattern is robust to a potential small sample biases as evident from a bootstrap exercise, and the 3FPS is not only present in returns but also shows up in order imbalances.

Next, table II 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).¹⁶ Panel (a) reports return statistics from trading the SPX closing price and the SOQ at open, while panels (b), and (c) are calculated from closing and opening prices for the SPX, and the e-mini, respectively.

[INSERT TABLE II HERE]

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

The final two columns highlighted in grey display return statistics for Thursday close to Friday open and Friday open to Friday close. In panel (a) Thursday overnight returns are

¹⁵Unconditional returns are relatively linear, except for hours between 2:00 and 4:00 - the “Overnight Drift” studied by Boyarchenko, Larsen, and Whelan (2023) highlighted by the shaded area in the plot.

¹⁶The column “All days CTO” contains summary statistics for returns that includes the weekend return from Friday to Monday morning.

abnormally large and *positive* equal to 19 bps. Friday intraday returns are also abnormally large but *negative* equal to -17 bps. Considering panels (b) and (c) the magnitudes are lower, as expected, but remain statistically significant and between 4 and 10 times larger than their all day counterparts. 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).

A. *Asymmetry*

Next, we examine the asymmetric nature of the pattern we uncover. To this end, we condition the average 24-hour return profile on whether its overnight return component was positive or negative and summarize the results in figure 5. In total, out of 225 observations, 143 (64%) overnight returns are positive while 82 (36%) are negative. Averaging within these sets figure 5 shows that positive overnight returns are followed by a reversal that begins in the 9:30 ET interval, while negative overnight returns display no reversal displaying momentum through 9:30 ET continuing to be negative during regular trading hours on Friday. Thus, statistically speaking, the asymmetric price path documented in figure 1 arises because there are far more positive overnight returns than negative and only these returns display a reversal around 9:30 ET. This result provides a first clue as the underlying economic channel driving our central empirical contribution.

[INSERT FIGURE 5 HERE]

B. *Triple Witchings*

Most expiry activity on derivative markets takes place on the “triple witching day”, the 3rd Friday of each quarterly cycle. On these days, expiry volume is unusually large 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. Barclay, Hendershott, and Jones (2008) show that witching days are accompanied by large liquidity shocks at the open due to the unwinding of index arbitrage positions, with more than 50 times increases in index arbitrage activity compared to its usual levels and more than five times higher pre-market volumes.

In table III we split the results of panel (a) of table II 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). Summarising, 3FPS effects are stronger on triple witching days but are also significantly present on the off-quarterly expiry days.

[INSERT TABLE III HERE]

C. P.M. Settled Options

Besides the monthly a.m. settled SPX options, the CBOE has introduced SPX options with other settlement practices over time. Notably, p.m.-settled options were reintroduced in 2007 with the SEC’s PM Option Expiration Pilot program. Initially, these were options expiring on the last business day of a calendar month, followed by weekly options in 2010, monthly options expiring on the 3rd Friday in 2011, and more recently, zero-day (ODTE) options expiring daily.¹⁷ For most of our sample period the standard 3rd Friday expiry contracts have generally been the most liquid and largest in terms of open interest and activity, although more recently especially zero-day (ODTE) option contracts that are p.m. settled at close prices have attracted most attention.

Table IV repeats the analysis above for the subsample in which 3rd Friday p.m. settled options were traded and also includes 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 similar to the discussion above. However, no such weekend reversal effect is detected. The return from Friday close to Monday open is not significantly different from zero. This is important, since it demonstrates that an asymmetric reversal pattern exists only around a.m. settlement.

[INSERT TABLE IV HERE]

¹⁷Related, options on front-contract SPX futures trade on the quarterly expiry calendar, expiring in the SOQ. Options on SPX futures also trade outside the quarterly expiry calendar, most notably options that expiry on the off-quarterly dates in the p.m. window. Further, in 2005, the CBOE introduced option contracts on the SPDR ETF. As ETFs are generally traded like common stock, SPDR options have the same features as individual U.S. stock options (e.g., they settle on the 3rd Friday of the month at the close price of that day.)

D. Trading Strategy and Transaction Costs

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 ES futures at close, reverses into a short positions at open and closes this position at 3rd Friday market close. Table V reports summary statistics of the trading strategy. The first column considers only 3rd Fridays, the second column considers all other days. Panel A trades from mid-quotes. Panel B buys at the ask and sells at the bid. Column 1 shows that the strategy generates large returns with a high statistical significance. Trade costs have only a small impact, reducing mean returns from 27 to 24 bps and t-statistics from 3.9 to 3.5. Column 2 shows that such a reversal strategy does not yield significant profits on other days. 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 3rd Fridays or 4 times a year on the quarterly expiration cycle. The last two rows V 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. Summarising, the 3FPS easily survives transaction costs and thus represents a form of market efficiency.

[INSERT TABLE V HERE]

Figure 4 illustrates these returns over time by computing their realised cumulative value. The long overnight, short intraday and reversal strategy are remarkably stable and similar over time. A \$1 investment in 2003 grows to \sim \$1.5 in both the overnight and intraday trade, and the reversal strategy grows to \$2.2.

Figure 4 panel b displays the annualized Sharpe ratio of this trading strategy by year.¹⁸ The strategy earns positive returns in all years except 2008, 2013 and 2016. 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.

[INSERT FIGURE 4 HERE]

¹⁸We compute the annualized Sharpe ratio by scaling the daily excess return to volatility ratio by 12 (trading) periods.

E. Other Markets

The U.S. equity index derivatives markets is one of biggest markets on the world, with sizable derivatives activity not only on the SPX but also other U.S. indices. We examine the presence of a similar 3FPS in the other U.S. indices with most index option and futures activity: the Dow Jones Industrial Average (DJIA) and the NASDAQ 100 (NDX) index. Akin to the SPX, index options and futures on this index settle in the a.m. window, with a settlement price computation comparable to the SOQ. Figure 6 contains the results, revealing a similar 3FPS pattern of about the same size. The NDX (DJIA) displays a overnight return before the option expiry of 14 bps (12 bps), followed by a significant reversal of about the same size between expiry and noon on the 3rd Fridays, a pattern markedly different from the average pattern on all other days.

Interestingly, settlement prices on the NDX are computed differently from the SPX-SOQ computation. Since November 2004 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 (see Barclay, Hendershott, and Jones (2008) for more details on the NASDAQ opening procedure). 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.¹⁹ In other words, the NOOP is based on the order book imbalance available at open, and unlike the SPX SOQ does not depend on the first traded price of stocks *after* open. Hence, the finding of a significant 3FPS in the NDX rules out any explanation that relies purely on the specifics of the SOQ calculation.

[INSERT FIGURE 6 HERE]

V. Wealth Implications

Persistent positive overnight returns preceding 3rd Fridays biases the payoffs of all U.S. equity derivatives that have monthly 3rd Friday a.m. expiry. This includes index options, futures and futures options written on various equity indices (e.g., S&P500, the Russell 2000, the Nasdaq

¹⁹If 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.

100). However, to quantify the wealth transfer induced by the 3FPS and thus highlight its economic significance, it suffices to consider a.m. settled SPX options. This is what we do here. As a result, our estimates should be interpreted as a lower bound on the wealth transfer.

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

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

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

[INSERT TABLE VI HERE]

As second approach to computing a wealth transfer we compare the realized payoff of all SPX options (calculated from 3rd Friday SOQ) with a hypothetical payoff calculated from Thursday

SPX closing price.²⁰ The overnight return bias impacts options as follows: (i) a higher payoff for already in-the-money calls; (ii) some calls which would have expired out-of-the money without the price spike now expire in-the-money; (iii) a lower payoff for in-the-money puts; and (iv) some puts which would have expired in-of-the money now expire out-the-money. Since SPX options do not trade over night before expiry, there are no changes in option positions that we need to consider. Therefore, the hypothetical payoff from Thursday close represents a natural counterfactual.

The total call option settlement value is calculated as

$$SettlValue_{Calls} = \sum_i^I \max(0, SOQ - K_i) * OpenInterest_i \quad (2)$$

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 as²¹

$$SettlValue_{Puts} = \sum_i^I \max(0, K_i - SOQ) * OpenInterest_i \quad (3)$$

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 VII 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.²² 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.

²⁰The difference between closing prices computed from trades versus quotes is almost zero. We use the traded closing price.

²¹We 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.

²²Despite 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.

Figure 7 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 negative for the vast majority of expiry dates. Thus, the estimates in table VII are not driven by unique expiries, but are a pervasive feature of US derivatives markets.

[INSERT TABLE VII AND FIGURE 7 HERE]

VI. Potential Explanations

So far we have documented a strong and persistent bias in U.S. equity derivatives payoffs that gives rise to a sizable wealth transfer. Since 2003 - when overnight trading in single stock equities and futures on index contracts gained substantially in prominence - prices rise overnight before option expiry and revert directly afterwards. The resulting 3FPS is stronger on triple witching days, absent around the p.m. settlement window, and a reflection of classic reversal pattern that typically arises in models of demand for immediacy and inventory risk management. Next, we explore economic explanations. We first investigate three obvious candidates: Fundamental Shocks (overnight news, earnings, and macro announcements), non-fundamental shocks (shocks to balance sheet capacity and funding constraints), and “pinning” - the phenomenon whereby underlying prices tend to cluster around their nearest strikes on expiration days. We fail to find evidence in support of these explanations across a battery of tests that we summarize in the OA. In this section we focus on testing two plausible explanations: (i) inventory management by option market makers; and (ii) market manipulation by sophisticated investors.

A. Hedging

Option market makers (OMMs) face demand imbalances as they are typically short index puts and long index calls (Garleanu, Pedersen, and Poteshman (2009) and Golez and Jackwerth

(2012)). The resulting options positions expose OMMs to significant inventory risk, which “conventional academic wisdom” suggests would be delta (Δ) hedged with offsetting positions in the underlying asset (here the S&P 500 index).²³

A typical OMM that sells many puts and buys many calls would have a positive net Δ inventory (long positive Δ from the calls, short negative Δ from the puts). Such an OMM would short the S&P 500 to obtain an approximate Δ hedge against directional moves in the S&P 500. At option expiry (OPEX) the OMM needs to close out their hedges, which, in our current example, means buying back the index into expiry. This could create positive price pressure and potentially explain the payoff bias that we document.

To examine a potential “unwinding Δ -hedges” explanation, we document the positions of option market makers in S&P 500 index options. As discussed in section II, positions data comes from the CBOE Open-Close dataset that provides daily buy- and sell volumes of SPX options since 2006 aggregated by (i) customer; (ii) professional customer (hedge funds); (iii) broker-dealer; and (v) market maker. We aggregate these daily volumes to cumulative positions for each group and document positions into option expiry.

Consider first table VIII which documents market positions in a.m settled options on *all days* and for *all maturities*. We condense the information provided and report the total numbers of long and short contracts in puts and calls since only net exposures matter for candidate explanations. On the call side, OMMs are roughly balanced in contract quantities but are exposed to positive net Δ . On the put side, they sell more contracts than they purchase and are again positive net Δ .

[INSERT TABLES VIII and IX HERE]

In contrast table IX considers *only* option positions which are due to expire in the current month and therefore relevant for an unwinding Δ -hedges hypothesis. The first row shows that on average on the Wednesday (Thursday) before Opex market makers are short 1.008 mil. (1.34 mil.) call contracts. However, the aggregate *number* of call options in the market maker portfolio does not reveal their exposure to the price of the underlying. OMMs might be very short deep out-of-the money calls with deltas close to 0 and long in-the-money calls (with deltas

²³In practice hedging is implemented by OMMs in approximate replicating baskets of constituent stocks but also in other linear derivative products like SPX futures, ETFs. Hedging trades are executed by “delta one” trading desks within equity finance or equity derivatives divisions of investment banks.

close to 1) which is, indeed, what we observe. Thus, the number of contracts would be very negative but their net- Δ would still be positive. Therefore, we directly document market maker net- Δ in columns two and three. On 3rd Thursday close, market makers have an average net delta from expiring calls (puts) of 60 thousand (-70 thousand).²⁴ The two almost perfectly offset each other, leading to a total market maker net delta from expiring options positions close to 0 (-10 thousand).

Figure 9 examines the market maker net delta in the 10 trading days in the run up to 3rd Friday expiration, split in options that are about to expire (panel a) and that expire during a later month (panel b). Panel (a) of the figure shows that market makers hold a significant position Δ inventory until around 3 days before expiration, which is usually Monday of the expiration week. During the expiration week across puts and calls and across strikes that trade their positions to reduce their directional exposure ending up net- Δ zero in expiring options on Thursday close. This patterns stands in sharp contrast to the pattern in option positions of non-expiring options as presented in panel b; OMMs do not materially change their open option positions in these contracts. Active management of option positions alone (absent observations in their positions in the underlying) pushes their Δ position to zero in anticipation of expiring options; As a result, we conclude that a simple “unwinding of Δ -hedges” story cannot account for the 3FPS.

[INSERT FIGURE 9 HERE]

However, an alternative hedging story might still be at play. “Charm” (\mathcal{C}) is a options Greek defined as the rate of change of Δ with respect to the passage off time. Ignoring the index dividend yield, for a European option the Black-Scholes \mathcal{C} is given by

$$\mathcal{C} = \frac{\partial \Delta}{\partial t} = -\frac{\partial \Delta}{\partial \tau} = -\frac{\partial^2 V}{\partial S \partial \tau} = -\frac{\partial \Theta}{\partial S \partial \tau} \quad (4)$$

where we have used the usual notation. \mathcal{C} is commonly used to monitor and adjust delta hedges over (a) weekends or holidays due to the extended non-trading; or (b) when option near expiration since \mathcal{C} changes quickly as time-to-maturity (τ) goes to zero. \mathcal{C} movements imply that to maintain a perfect hedge OMMs need to adjust deltas with the passage of time *even*

²⁴Most of the short positions that contribute towards positive delta are deep out-the-money, with 0 deltas; thus, do not generate a low market maker net delta.

if there is no movement in the underlying. Panels (a) and (b) of figure 8 illustrates how the well known properties of delta for itm compared with otm options varies as time $\tau \rightarrow 0$. Upon Opex the delta of a call option will be either 1 or 0, and just before expiry as $\tau \rightarrow 0$ Charm is large. Panels (c) displays the less well known properties of \mathcal{C} for a $\tau = 48$ and $\tau = 17.15$ hours until maturity option The x-axis is plotted in terms of moneyness $MN = \log \frac{S_t}{K}$.

Considering its effects around different levels of MN , The effect of \mathcal{C} for deep ITM and ITM options is zero since their deltas are already either 0 or 1; thus, their deltas have nowhere to be dragged to at Opex. For options with $MN = 0$, however, the effect of charm can be quite a large. For example, for just OTM calls with small negative MN but positive sizeable delta, overnight on 3rd Fridays their deltas are dragged rapidly towards 0 (negative \mathcal{C}), while for just ITM calls with small positive MN and delta greater than 0.50 but much lower than 1 their deltas are dragged rapidly towards 1 (positive \mathcal{C}). The intuition for put is symmetric: OTM puts experience a delta drag from negative to 0 while ITM puts experience a delta drag from negative to -1.

Thus, even if OMMs have a net- Δ zero position on 3rd Thursdays, if for some latent reason they are long (short) OTM (ITM) calls and long (short) ITM (OTM) puts their net \mathcal{C} positive would drive their delta *down* overnight; thus, to maintain a delta neutral portfolio OMMs would buy index replicating trades overnight as Opex approaches. The final column of table IX shows this is indeed the case as OMMs hold negative \mathcal{C} on both call and put sides of their trades. Specifically, we find that at the average 3rd Thursday close market makers have a net charm position of -26 billion. Thus, their inventory net-delta from SPX positions mechanically falls by approximately 50 million over the next 1715 hours and 15 minutes. Market makers would have to buy the underlying to prevent this change in directional market exposure. Therefore, a \mathcal{C} explanation is possible.

B. Price manipulation

Aggarwal and Wu (2006) summarize evidence of stock price manipulation by analyzing SEC litigation releases. The vast majority of these manipulation cases involve attempts to increase the stock price rather than to decrease the stock price, consistent with the idea that short-selling restrictions make it difficult to manipulate the price downward. Furthermore, theoretical

research has examined the characteristics of markets that might be vulnerable to manipulation. Kumar and Seppi (1992) and Spatt (2014) identify three key factors that facilitate market manipulation: differing price-order elasticities across markets, cash settlement, and a finite period to manipulate.²⁵

These three facilitators are present in the SOQ settlement mechanism on 3rd Fridays; (i) overnight markets are less liquid and exhibit higher price elasticities than intraday markets (see for example Barclay and Hendershott (2003)), (ii) derivatives settle in cash, and (iii) the bias emerges hours before the SOQ is determined. Conversely, we do not observe a bias further away from the SOQ time, nor around afternoon settlement times when markets are more liquid, or when several derivatives settle physically.

How would manipulation work in our setting? Sophisticated market participants with short positions in puts or long positions in calls would 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 with 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.

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

This raises the question: who would be the potential manipulator? In the previous section we saw OMMs positioning would not benefit much from price manipulation, as they are on average short delta into expiry. As alternative, we explore the positioning of professional customers - typically hedge funds - using the CBOE positioning dataset outlined above.

²⁵Manipulation is more difficult for an asset with physical settlement. Suppose a manipulator pushes the price of an asset up. When physical delivery of the asset takes place, the manipulator will take possession of an asset at an inflated price and that asset may quickly fall to the original value when the manipulator tries to exit the position. With cash settlement, the manipulator receives the settlement value in cash and does not necessarily need to unwind positions.

[INSERT TABLE X HERE]

Table X contains the summary statistics. On average, the pro-customers are net long delta on the 3rd Thursday before expiry in both calls and puts. In other words, they would benefit from a price rise overnight just before expiry. Interestingly, when comparing the 3rd Wednesday to 3rd Thursday, we can observe that these pro-customers increased their option delta Thursday intraday, increasing the payoff of a overnight price spike.

[INSERT FIGURE 10 HERE]

Figure 10 further examines pro-customer net delta in the 10 trading days in the run up to 3rd Friday expiration, as before split in options that are about to expire (panel a) and that expire during a later month (panel b). Panel a of the figure shows that the group classified as pro-customers hold no material net- Δ position in expiring options till about 5 days to expiry, but then build up a significant positive net- Δ position spiking at the Thursday before expiry. Panel b shows the pattern is different in non-expiring options; pro-customers hold positive net- Δ positions in these throughout the 10 days. These positions drop about 5 days before expiry - about the same time that their positions in expiring options increases. However, the net- Δ position in non-expiring options drops less than the net- Δ position in expiring options increases, especially the last day before expiry. This suggests pro-customers would benefit especially from temporary price spikes that impact the settlement price of expiring options. Overall, the above results suggest that market manipulation by professional customers is second plausible explanation.

VII. Policy Implications

The central finding of this paper suggests that settling derivative payoffs immediately after an illiquid trading period - such as the overnight window - creates space for price pressures to systematically affect investors' wealth. Regardless of the origins of 3rd Friday price pressure, its existence generates a sizeable wealth transfer; our estimates imply a lower bound of \$3.8 billion per annum on average.

Since option markets are a zero sum game the relevant question is "who is winning and who is losing?". Table X in the previous section showed that on 3rd Thursdays option market

markers have close to net delta zero positions, while professional traders (hedge funds) have net positive delta positions heading into expiry. This suggests professional traders gain from the upward bias in settlement prices, while complimentary trader types (retail investors) are hurt. The middle rows in table X show the position of these investors (“Cust”), confirming they have the opposite positions of professional traders and hence are hurt by the payoff bias. In sum, at option expiry wealth is transferred from retail investors to professional traders.

This finding carries important implications for exchanges and regulatory authorities. Since the current settlement practice appears to be susceptible to the adverse effects of hedging practices and/or price manipulation, alternative settlement designs should be explored. Our findings suggest that retail traders could be protected by an alternative settlement mechanism that minimises the impact of price pressure. One approach would be to avoid settling immediately after an illiquid trading period. This is because price that follow a liquid trading period are less likely to be influenced by expiry-related hedging or manipulation trades, as more market participants are available to counteract price pressure. While the market open is relatively liquid, the preceding overnight window is notably less liquid. Based on our current findings, we recommend considering another liquid point during the trading day.

One potential candidate is the market close of 3rd Fridays, the point when individual stock options, non-monthly options, and SPDR options already settle. As highlighted in Section III, settlement of SPX options used to be in the close of 3rd Fridays till June 1987. On June 19th 1987, the settlement of SPX futures and SPX option contracts changed from the close of trading to the SOQ in order to mitigate concerns about potential abnormal stock price movements at market close during Triple Witching days. These concerns, raised in 1987, are likely still prevail today, making p.m. settlement 3rd Friday a suboptimal alternative. Alternatively, settlement could be aligned to the close on 3rd Thursdays, the point in time when the current a.m settled SPX options cease trading. Another potential candidate settlement point is during regular trading hours on 3rd Friday. Indeed, some exchanges adopt such a settlement time. For example, the EURO STOXX 50 index options (ticker: OESX) - the most liquid equity index option market outside the U.S. - settles around noon. Specifically, “the final settlement price [...] is based on the average of the respective STOXX Index values calculated between 11:50 and 12:00 CET”.²⁶ Settling during regular trading hours would avoid the issue of running

²⁶www.eurex.com/ex-en/markets/idx/stx/blc/EURO-STOXX-50-Index-Options-46548.

up against an illiquid trading window and in addition would give market makers ample time to manage their inventories before close of trade on Fridays. The mechanism for calculating a settlement price intraday, however, represents an additional complication akin to the calculation of a fixing price in foreign exchange markets.²⁷ We leave this an open question for the exchanges (the CBOE) and the regulator (the SEC) to answer.

VIII. Conclusions

We document a sizeable bias in the payoff of U.S. equity index derivatives. On the 3rd Friday of each month - when equity index options and other derivatives expire via the special opening quotation (SOQ) - the S&P500 SOQ exceeds the previous day closing price by over 18 bps on average. This pattern emerged contemporaneously with an active yet illiquid overnight trading market.

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 and study two plausible alternatives: (1) hedging motivates by option market makers; and (2) an explanation based on market manipulation. Both explanations rely on the existence of an illiquid trading period directly preceding payoff settlement. Regardless of the cause, our findings suggest that current settlement procedures lead to a market inefficiency and that regulators should critically evaluate current settlement practices.

²⁷For a detailed discussion of the foreign exchange “fix” see Krohn, Mueller, and Whelan (2022).

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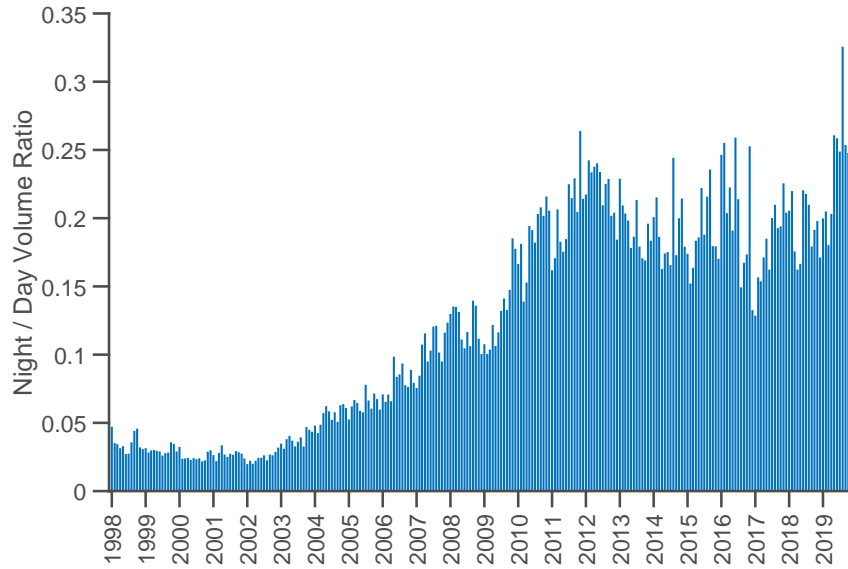
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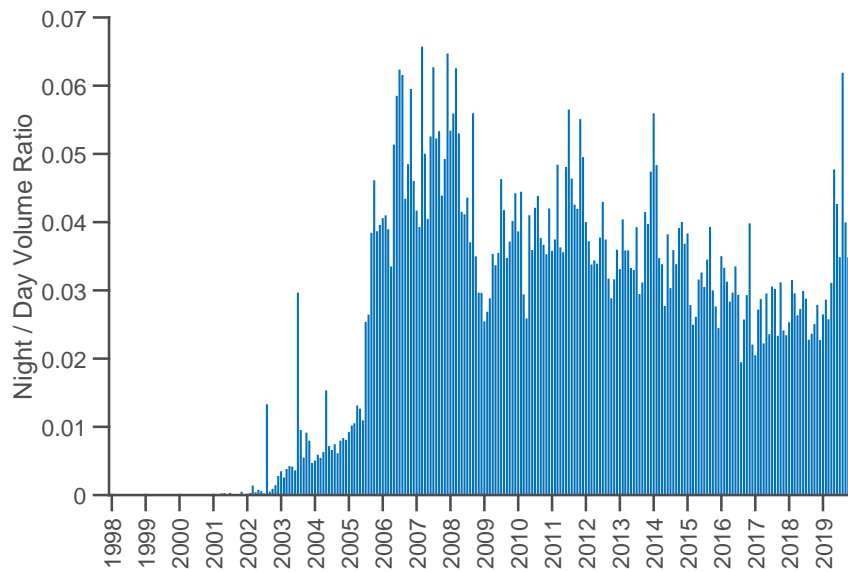
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IX. Appendix: Figures



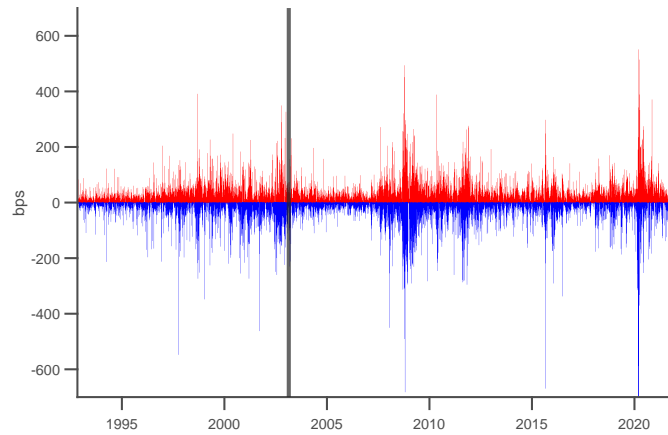
(a) Futures: ES and SP



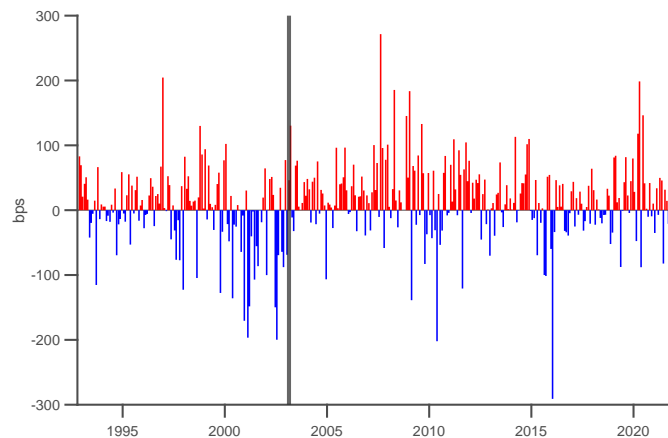
(b) ETF: SPY

Figure 2. Volume ratios: night vs. day

These figures plot the ratio of trading volumes over night (18:00 to 09:30) to trading volumes during regular market hours (09:30 to 16:00). Panel a contains the sum of regular "SP" S&P 500 futures and e-mini "ES" S&P 500 futures. Panel b contains the SPDR ETF (SPY). Trading Volume is measured in number of contracts. SP volumes are multiplied by 5 to account for the larger (5x) contract size. The sample period is 1998.01 - 2019.12.



(a) All Days



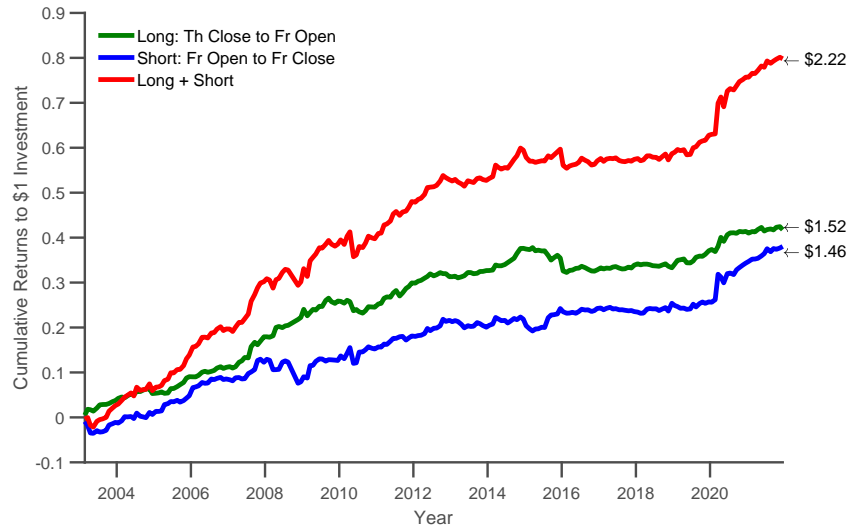
(b) OPEX Days

Figure 3. SOQ vs. SPX close prices

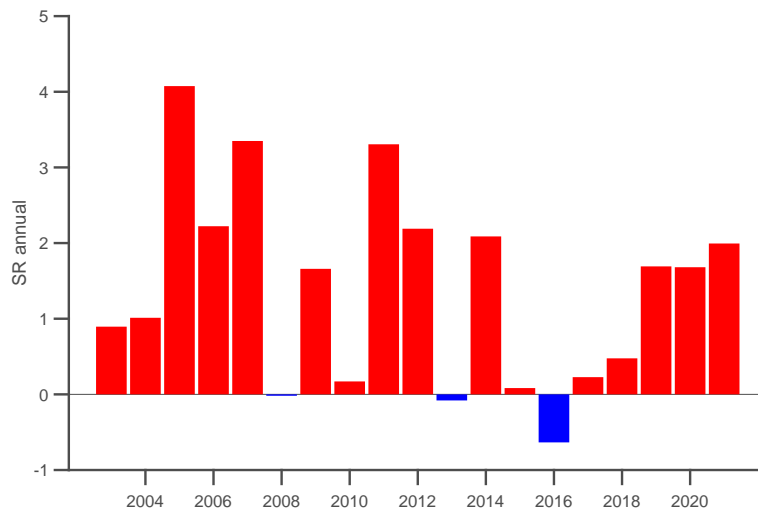
These figures plot the times-series

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

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 09:30. Close prices are computed from trades at 16:00. Panel a contains all days in our sample while panel b is sampled on OPEX days, which are almost exclusively 3rd Fridays. The vertical line shows 2003.02, the start of our main sample. SOQ and SPX close prices are from Bloomberg. The sample period is 1992.11 - 2021.12.



(a) Cumulative Returns



(b) Annual Sharpe Ratio

Figure 4. Trading the 3rd Friday price spike

In panel a, the blue line plots the cumulative returns of the reversal strategy: Once every month, go long the S&P 500 index at 3rd Thursday close (16:00), switch to a short position at 3rd Friday open via the Special Opening Quotation (at or shortly after 09:30) and close the position at 3rd Friday close. We use trade prices for both buys and sells. Panel b displays the Sharpe ratio of the reversal strategy by year. The sample period is 2003.2 - 2021.12.

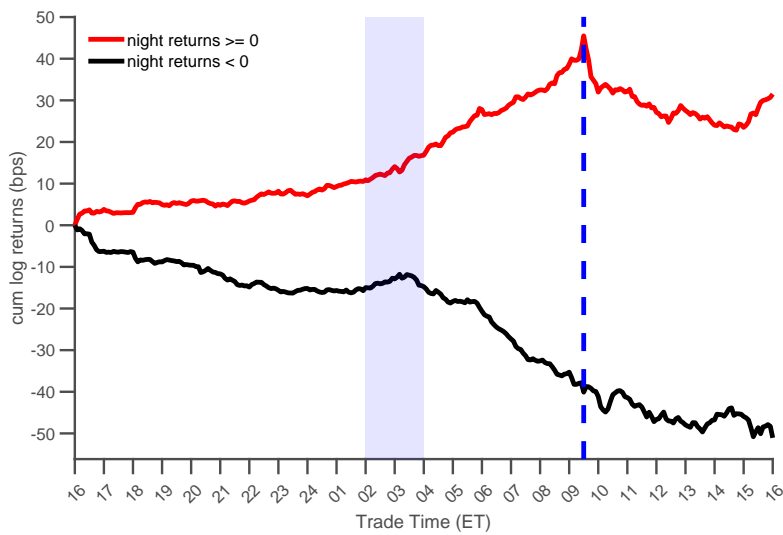
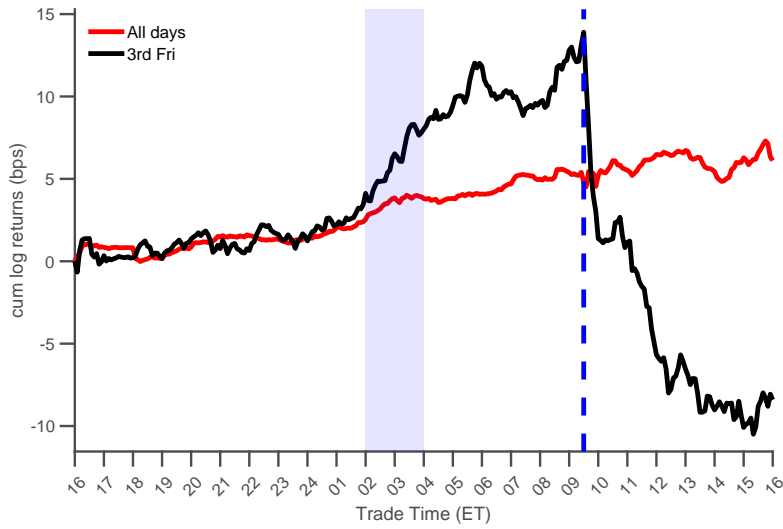
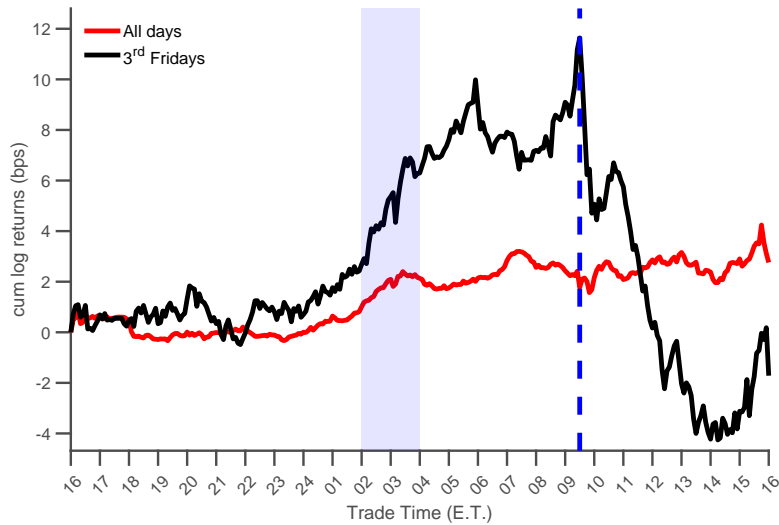


Figure 5. 3rd Friday price spike: Positive vs. negative

This figure shows average cumulative 5 minute log returns of S&P 500 E-mini futures around 3rd Friday market open (09:30, blue dotted line). The red (black) line cumulates only returns that were non-negative (negative) between 16:00 and 09:30. The y-axis is in basis points and the x-axis is time of day in Eastern Time (E.T). The purple shaded region highlights the opening of European markets. The sample period is 2003.2 - 2021.12. In total, there are 225 night returns of which 143 are positive and 82 negative.



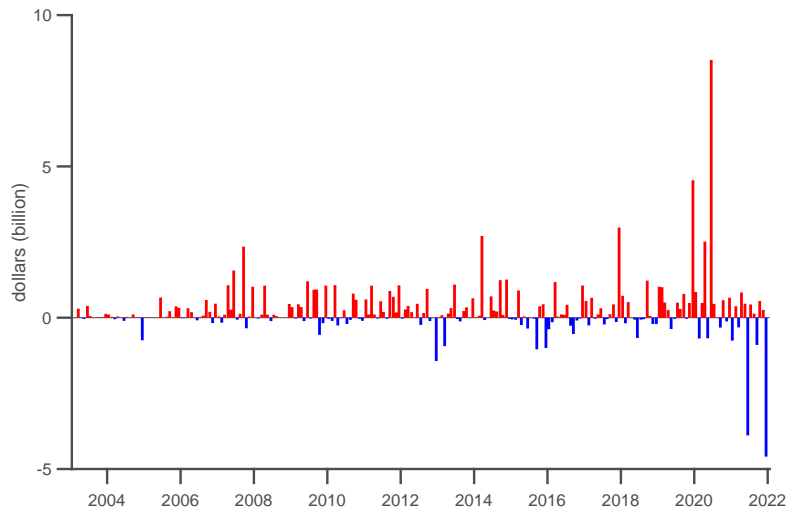
(a) Nasdaq



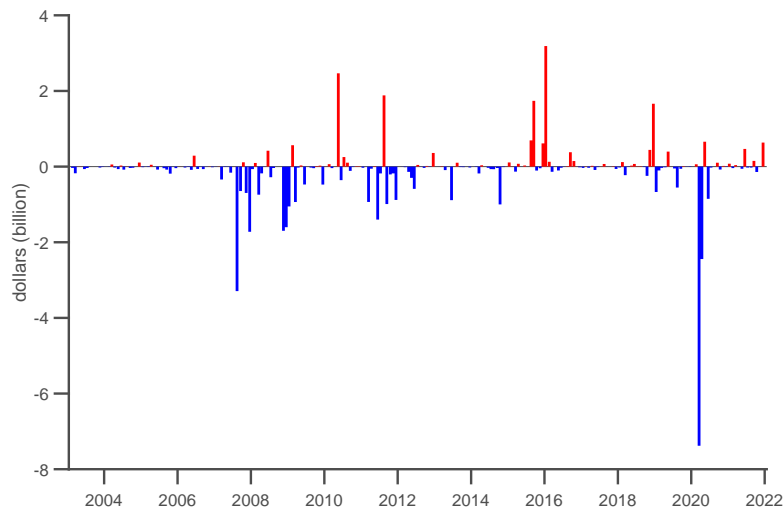
(b) Dow-Jones

Figure 6. 3rd Friday Price Spike in Nasdaq and Dow-Jones futures

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



(a) Call options



(b) Put options

Figure 7. Wealth transfer in SPX options

This table displays actual monthly SPX options payoffs at 3rd Friday open minus hypothetical payoffs if settlement occurred at the previous Thursday close instead. That is, the table shows the change in option payoffs due to the large positive price pressure in the S&P 500 that immediately precedes 3rd Friday OPEX. Positive values are in red, negative values are in blue. Panel a displays call options, panel b displays puts. The sample period is 2003.2 - 2021.12.

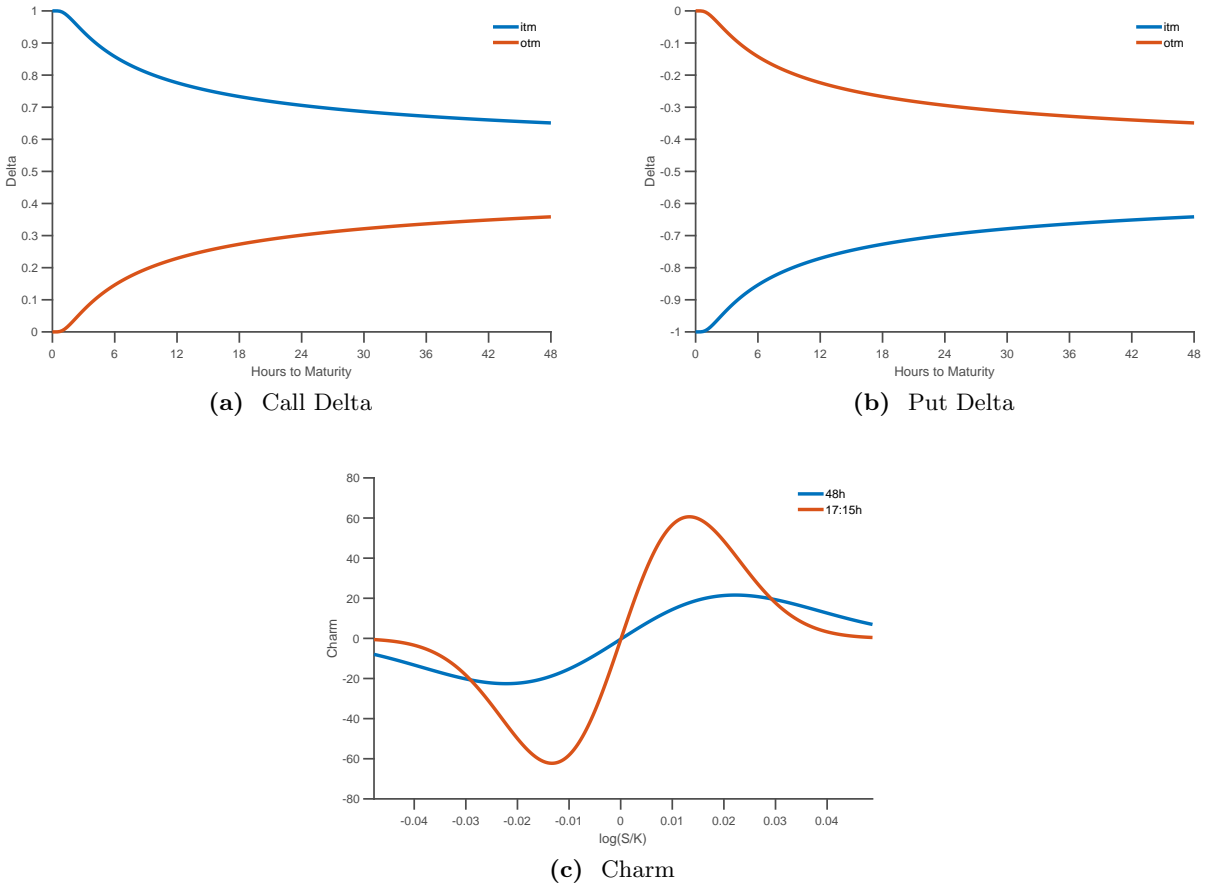
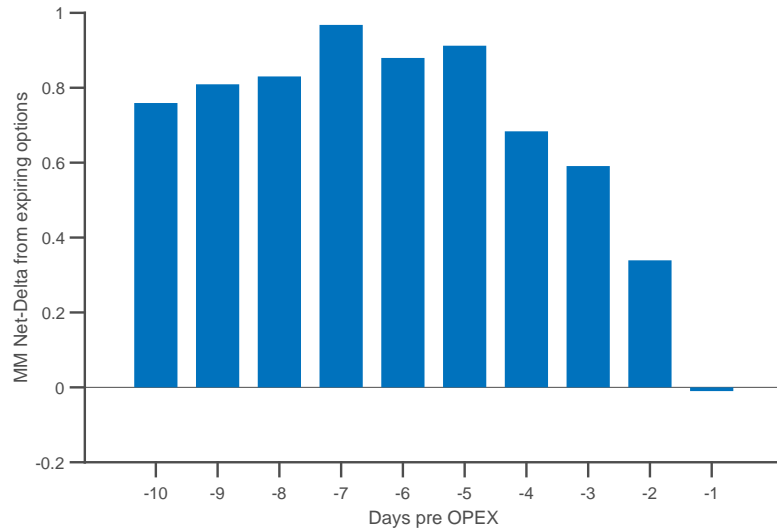
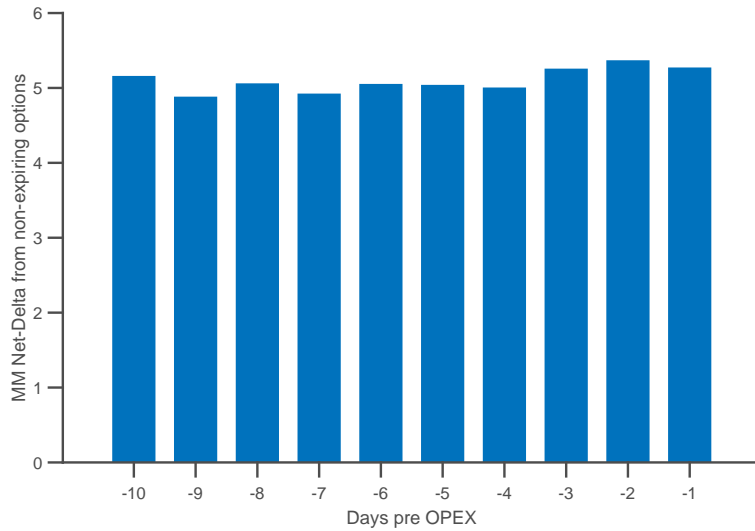


Figure 8. Illustration: Option Charm

This figure illustrates option “Charm”, i.e. the change in delta from changes in time to expiry. Panels a and b show the Black-Scholes Delta for European options with an underlying price of 3000, a rate of 0, a yield of 0 and underlying volatility of 30%. For calls (puts), “itm” denotes a strike of 2975 (3025), “atm” denotes 3000 (3000) and “otm” denotes 3025 (2975). Panel c shows Black-Scholes Charm for options with 48 and 17:15 hours until expiry. Charm is identical for put and call options.



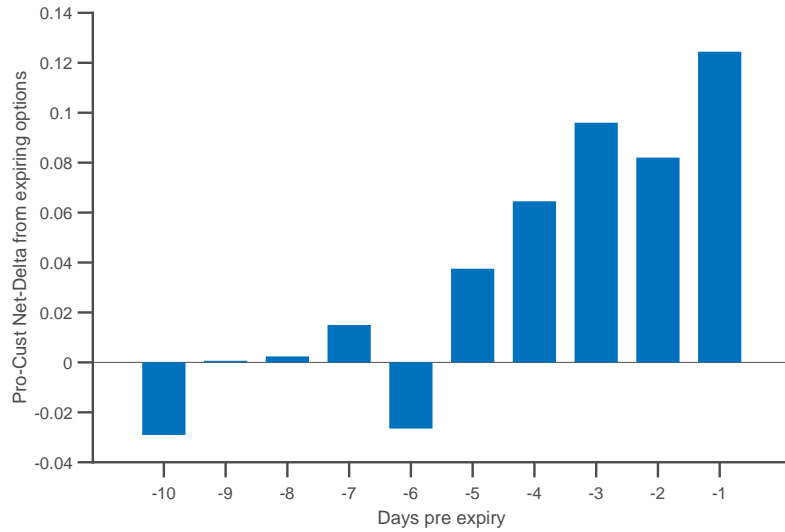
(a) Expiring options



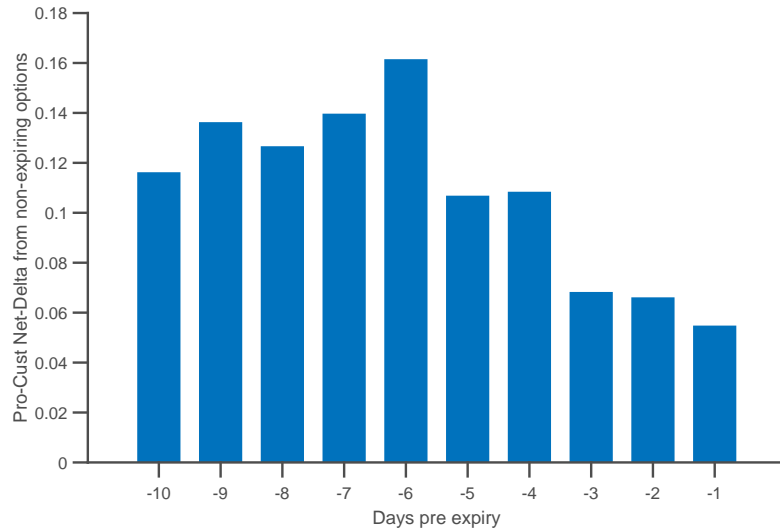
(b) Non-Expiring options

Figure 9. Positions into OPEX: Market Makers

The figure reports market maker positions in a.m. settled SPX options over the 10 days before 3rd Friday OPEX. Panel a reports positions in expiring options. Panel b reports positions in options that expire in any of the subsequent months. Positions are the sum-product of market maker positions across outstanding SPX options and the respective options' Delta at market close (16:15). Positions are in millions. The sample period 2006.01 to 2020.12.



(a) Expiring options



(b) Non-Expiring options

Figure 10. Positions into OPEX: Pro-Customers

The figure reports professional-customer positions in a.m. settled SPX options over the 10 days before 3rd Friday OPEX. Panel a reports positions in expiring options. Panel b reports positions in options that expire in any of the subsequent months. Positions are the sum-product of pro-customer positions across outstanding SPX options and the respective options' Delta at market close (16:15). Positions are in millions. The sample period 2011.01 to 2020.12.

X. Appendix: Tables

Days:	I. Non-OPEX	II. OPEX	II. - I.	Non-OPEX Fridays
<i>PANEL A: Full Sample (1992.11 to 2021.12)</i>				
mean	1.39	10.37	8.98	0.65
median	3.87	11.07		5.76
t-stat	1.73	3.08	2.45	0.32
std	66.91	62.64		69.19
<i>PANEL C: Early Sample (1992.11 to 2003.01)</i>				
mean	1.37	-3.25	-4.62	4.21
median	3.40	5.50		7.51
t-stat	1.24	-0.59	-0.91	1.44
std	56.17	62.49		59.89
<i>PANEL B: Late Sample (2003.01 to 2021.12)</i>				
mean	1.31	18.24	16.92	-0.97
median	4.10	17.88		5.20
t-stat	1.24	4.53	3.50	-0.36
std	71.26	60.40		72.95

Table I. S&P 500 returns over night

The table reports summary statistics for

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

The columns display results for non expiry days (column 1), expiry days (column 2), and non-expiry Fridays (column 4). Column 3 contains a test for difference of means between columns 1 and 2. Option expiry dates are mostly the 3rd Friday of every month. Estimates are in basis points. The SOQ calculation is discussed in section III. SPX close prices are calculated on 3rd Thursdays at 16:00. SOQ and SPX close prices are from Bloomberg. The sample period for panel A is 1992.11 to 2021.12. Panel B contains 1992.11 to 2003.01. Panel C contains 2003.02 to 2021.12.

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

Table II. Equity returns

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

	Around 3 rd Fridays				
	We _c to Th _o	Th _o to Th _c	Th _c to Fr _o	Fr _o to Fr _c	Fr _c to Mo _o
PANEL A : Quarterly OPEX					
mean	5.45	1.07	26.44	-37.23	-10.84
mean(24H)	7.47	3.95	36.26	-137.48	-3.97
t-stat	0.93	0.11	4.36	-3.54	-1.31
Std	50.16	82.90	52.47	91.03	71.76
PANEL B : Off-Quarterly OPEX					
mean	-7.17	-1.09	14.45	-6.74	-4.56
mean(24H)	-9.83	-4.03	19.82	-24.90	-1.67
t-stat	-1.67	-0.15	2.81	-1.03	-0.59
Std	52.50	91.20	62.98	80.13	94.48

Table III. Triple-Witching days

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 component trade prices at close. The sample period is 2003.2 to 2021.12.

	Around 3 rd Fridays		
	Th _c to Fr _o	Fr _o to Fr _c	Fr _c to Mo _o
mean	11.02	-17.62	-9.25
mean(24H)	15.11	-65.05	-3.39
t-stat	2.25	-2.58	-1.23
Std	58.72	82.08	89.93

Table IV. P.M. settlement returns, post 2010

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

Days:	OPEX	Other
PANEL A : Excl. Trade Costs		
mean	27.48	0.07
t-stat	3.94	0.04
std	104.61	112.39
SR	0.90	0.01
alpha	27.55	1.07
beta	-0.32	-0.27
PANEL B : Incl. Trade Costs		
mean	24.19	-3.21
t-stat	3.47	-1.92
std	104.60	112.42
SR	0.80	-0.44
alpha	24.26	-2.21
beta	-0.32	-0.27

Table V. Trading the 3rd Friday price spike: Transaction costs

The first column reports summary statistics for a trading strategy that buys S&P 500 e-mini futures at 3rd Thursday close, reverses into a short positions at 3rd Friday open and closes the position at 3rd Friday close. The second column reports summary statistics for the equivalent strategy around all non-OPEX market open. 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. Panel A assumes trades at mid-quotes. In panel B 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.

	Actual		Counter-Factual	
	Calls	Puts	Calls	Puts
PANEL A : Returns (%)				
itm	2.08	-3.88	0.23	-0.37
atm	6.02	-52.79	-28.35	-32.81
otm	-99.43	-99.40	-99.69	-99.18
PANEL B : Returns (\$ mil.)				
itm	173.70	-89.87	30.94	-41.93
atm	7.67	-20.25	-16.79	-6.59
otm	-4.86	-16.79	-5.06	-16.44
sum	176.51	-126.91	9.09	-64.95

Table VI. SPX option returns into OPEX

Columns 1 and 2 of panel A report average returns of expiring S&P 500 index options from 3rd Thursday close to their final settlement value on 3rd Friday open. Columns 3 and 4 report counter-factual returns, calculated via a hypothetical 3rd Friday SOQ that is 16 basis points below its actual value. Panel B reports average returns in millions of dollars, calculated as $Dollar\ Return = Net\ Return \cdot Open\ Interest \cdot Price$. We measure moneyness as the ratio of option strike to underlying price. Calls are itm if $0.5 < mnes \leq 0.99$, atm if $0.99 < mnes \leq 1.01$ and otm if $1.01 < mnes \leq 1.5$. Puts are otm if $0.5 < mnes \leq 0.99$, atm if $0.99 < mnes \leq 1.01$ and itm if $1.01 < mnes \leq 1.5$. The total monthly wealth effect is calculated as the difference between actual and counter-factual dollar returns, summed over puts and calls. Returns are in percent. The sample period is 2003.02 to 2021.12.

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

Table VII. The payoff bias in SPX options

The table reports summary statistics for actual and hypothetical SPX option settlement values. Column 1 contains the settlement value of call options that is determined on 3rd friday via the SOQ. The call option settlement value is calculated as

$$\text{SettlValue}_{Calls} = \sum_i^I \max(0, \text{SOQ} - K_i) \cdot \text{OpenInterest}_i$$

where I is the number of different call options and K is the strike price. Column 2 contains the settlement value of call options if settlement occurred on Thursday at the SPX close price. Column 3 displays the difference. Columns 4 to 6 display put option settlement values. The put option settlement value is calculated as

$$\text{SettlValue}_{Puts} = \sum_i^I \max(0, K_i - \text{SOQ}) \cdot \text{OpenInterest}_i$$

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

	Nr. Short	Nr. Long	Sum Delta	Sum Charm
Calls mean	-39.91	39.44	3.00	-0.43
std	12.71	14.11	4.47	4.95
Puts mean	-76.70	57.54	2.60	-1.89
std	16.95	18.65	4.59	9.24

Table VIII. Market Maker positions in SPX options

The table reports Market Maker positions in a.m. settled 3rd Friday options. Row 1 (3) contains the average over all call (put) options. Rows 2 and 4 contain standard deviations. Column 1 (2) contains the average long (short) position in number of contracts held by market makers at close. Column 3 contains Net Delta positions, calculated as the sum-product of the nr. of contracts held by market makers and the respective contracts' delta at close. Column 4 contains the equivalent number for option Charm. Columns 1 to 3 are in millions, column 4 (charm) is in billions. The sample period is 2006.1 to 2020.12.

	Nr. Contracts		Sum Delta		Sum Charm	
	3 rd We	3 rd Th	3 rd We	3 rd Th	3 rd We	3 rd Th
Calls mean	-1.01	-1.34	0.25	0.06	-1.12	-5.90
std	4.02	4.09	2.78	2.90	5.12	21.20
Puts mean	-7.10	-6.52	0.09	-0.07	-6.37	-19.67
std	7.14	6.52	2.46	2.67	9.78	35.73

Table IX. Market Maker positions in SPX options - into OPEX

The table reports Market Maker positions in a.m. settled 3rd Friday options over the days pre OPEX. Row 1 (3) contains the average over all call (put) options. Rows 2 and 4 contain standard deviations. Columns 1 and 2 contains the average number of contracts held by market makers at close. Columns 3 and 4 contain Net-Delta positions, calculated as the sum-product of the nr. of contracts held by market makers and the respective contracts' delta at close. Column 5 and 6 contains the equivalent number for option Charm. Columns 1 to 4 are in millions, columns 5 and 6 (charm) are in billions. Columns 1 to 4 contain only options that are about to expire. Columns 5 to 6 contain all 3rd Friday options. The sample period is 2006.1 to 2020.12.

	Nr. Contracts		Sum Delta	
	3 rd We	3 rd Th	3 rd We	3 rd Th
Mm Calls	-1.01	-1.34	0.25	0.06
Mm Puts	-7.10	-6.52	0.09	-0.07
Cust Calls	-1.66	-0.80	-1.53	-0.90
Cust Puts	5.63	4.65	-0.11	0.21
Firm Calls	2.66	2.14	1.28	0.84
Firm Puts	1.47	1.87	0.02	-0.15
Pro Cust Calls	-0.27	-0.30	0.05	0.09
Pro Cust Puts	0.38	0.15	0.03	0.04

Table X. All SPX option positions - into OPEX

The table reports option market participants' positions in expiring a.m. settled 3rd Friday options over the days pre expiry. Columns 1 and 2 show the average number of contracts held at close. Negative numbers indicate short positions. Columns 3 and 4 show Net Delta positions, calculated as the sumproduct of the nr. of contracts held and the respective contracts' Delta at close. All numbers are in millions. Abbreviations: Market maker (mm), customer (cust) and professional customer (pro cust). The sample period for Mm, Cust and Firm is 2006.1 - 2020.12. The sample period for pro-customers is 2011.1 - 2020.12.

The Derivative Payoff Bias

ONLINE APPENDIX

This online appendix is not intended for publication. Section A.1 contains a more extensive discussion of relevant U.S. equity index market details and shows an example of the Special Opening Quotation (SOQ) calculation. Section A.2 provides additional evidence and extensive robustness checks on the Third Friday Price Spike (3FPS). Section A.3 contains detailed results and a more extensive discussion of potential explanations that we rejected in the main paper. Section A.4 and A.5 contain all the supplementary tables and figures.

A.1. Market details

A. *Futures and Indices*

The S&P500 index (SPX) is the most widely tracked index in the world. Futures on the SPX (hereafter, SP futures) were introduced on the Chicago Mercantile Exchange (CME) on April 21st, 1982, with one futures contract initially having a size of \$500 per index point (hence offering exposure of 50 times the index). As the index level rose over time, the contract became expensive to trade at this multiplier and the contract multiplier was cut to \$250 times the index on November 3th, 1997. Contract since follow a quarterly expiry schedule, expiring the third Friday of the March-June-September-December cycle.²⁸ By far most activity (volume and open interest) is in the front contract (the contract closest to expiry) up to about one week before expiry, after which most market participants roll their positions forward to the next closest contract. Settlement is in cash, meaning that at expiration the futures holder receives or pays a cash payment equal to the difference between the index price and the settlement price of the futures contract. Between inception and June 1984 settlement prices were determined based on the close price of the third Thursday, which till June 18th, 1987 moves to the close price of the third Friday. Driven by worries about settlement effects, it was decided to change settlement to a special opening quotation (SOQ, explaining later in this section) as of June 19th, 1987, computed at the open of the third Friday.²⁹ Trading took place both by open outcry and electronically during U.S. regular trading hours concurrently with the cash market plus a 15 minutes settlement window after the close of the cash market (i.e., 9:30am ET - 4:15pm ET). In September 1993, the S&P500 futures contract began trading electronically outside regular hours via the CME GLOBEX electronic trading platform. Trading in the contract ceases the third Thursday of the expiry month and all futures contracts which have not been traded out by the end of the last trading day must be settled. As the futures expire on the SOQ, this means futures holders run overnight settlement risk relative to their last traded Thursday price.

Further, as of September 9th, 1997, e-mini futures on the SPX commenced trading, offering the same characteristics as the regular contract with two main exceptions. First, the contract

²⁸When the third Friday is a holiday, expiry is the latest business day before the third Friday, commonly the preceding Thursday.

²⁹Stoll and Whaley (1991) show that this change in settlement procedure resulted in more trading volume in the open, as well a slight increase in price reversals around the open. Their sample is, however, limited to a limited number of years before and after the change; January 1985 through June 1989. Further, futures and options on the Major Market Index, the S&P 100 and the Value Line index continued to settle at the closing price of the underlying index.

multiplier was \$50 per index point (hence offering exposure of 5 times the index).³⁰ Second, trading taking place only on the CME GLOBEX platform which facilitates global trade for most hours of the day, 5-days a week. Exact trading times on CME GLOBEX platforms have changed over time. Importantly, until July 2003 trading started at 1:00am. Afterwards, the trading day was extended to almost 24-hours a day to allow for greater access and flexibility for market participants around the world, a feature change we will exploit in this study. Hence, the mini contracts facilitated easier trading and offered more possibilities to trade at some liquidity around the clock. Since the introduction, the standard contracts were quickly outgrown in terms of traded volume by their mini versions, and as of September 17th, 2021, SPX contract have delisted.³¹ Hasbrouck (2003) shows that for the S&P500 and Nasdaq 100 indices most of the price discovery happens in the e-mini market.

Other U.S. equity futures share similar characteristics, with futures on the NYSE, DJIA, Nasdaq, Russell2000, S&P400 introduced in 1982, 1997, 1996, 1993, or 1992, respectively.³² These contracts also had e-mini contract introduced and shared similar trading hours and settlement procedures (i.e., third Friday expiries based on a special opening quotation and settlement in cash).³³ Further, Exchange Traded Funds (ETFs) commenced trading as of January 29th, 1993, on the S&P500 index, with the Standard & Poor's Depositary Receipts (ticker: SPY) ETF being nowadays one of the largest ETFs in the world. Soon ETFs on many other indices followed suit. ETFs trade on stock exchanges and hence typically follow stock exchange trading hours. Equity index futures and ETFs allow investors to accomplish two basic objectives: they can buy or sell the market, and they can more effectively and efficiently hedge against market risk, making them important instruments for option market makers.

B. Option Markets

Besides SPX index options, options on SPX futures trade actively since January 28, 1983 on the CME. These options are American style (i.e, they can be exercised early), refer to one underlying futures contract, also trade with strike prices \$5 apart, and are effectively cash-settled.³⁴ As of June 1987, futures options have the same quarterly third Friday settlement calendar as the futures themselves and expire at the SOQ. Further, starting in June 1987 SP options also are available for monthly expiries of the quarterly futures expiry calendar. Importantly, whereas the quarterly SP options are a.m.-settled, the serial monthly options are pm-settled based on

³⁰The minimum tick size was also cut to 0.25. See Karagozoglu, Martell, and Wang (2003) for a discussion on how this change affected market liquidity and volatility.

³¹See <https://www.cmegroup.com/education/articles-and-reports/faq-conclusion-of-standard-sp-500-futures-and-options-trading.html>.

³²Since the S&P 500 Index is the most widely accepted stock index benchmark of institutional investors, and because the CME's market had the most volume and liquidity, the S&P 500 stock index futures immediately became the dominant stock index futures contract. A multitude of futures were launched on other U.S. equity indices, but these were typically substantially smaller in volume and size. For example, in February, 1982, the Kansas City Board of Trade launched the first futures contract on a stock index, the Value Line Composite Index.

³³The exception was the S&P100 futures contract, which continued to settle at the close of the third Friday. However, this contract comes with relatively little trading activity.

³⁴At settlement, in the money futures options lead to delivery of the underlying futures contract. However, SP options and their underlying SP futures expire simultaneously and futures settlement values are determined via SOQ and paid in cash.

the close value of the underlying futures contract. As of 1997 S&P500 futures options are also offered on the e-mini contract sharing the same characteristics as options on the regular SP contract. Only trading mechanisms differ, following the regular versus e-mini futures trading mechanisms.

Further, in 2005 the CBOE introduced option contracts on the SPDR ETF. As ETFs are generally traded like common stock, SPDR options have the same features as individual U.S. stock options; they are American style, refer to 100 units of the underlying ETF (which is denominated at 10% of the value of the S&P500 index itself), and are not cash-settled but instead settle via physical delivery of ETFs. ETF options expire on the third Friday of the month at the close price of that day. ETF options trade about the same hours as the underlying ETF, in case of the SPDR this is 9:30am to 4:15pm ET. Johnson, Liang, and Liu (2016) show that SPX options have most option activity, followed by SP options and SPDR ETF options, with OTM put options being the prominent position type.³⁵

Trades in index options are more often motivated by the hedging demand of sophisticated investors, while options on stocks are actively traded by individual investors (Lemmon and Ni (2014)) Further, institutional investors are typically long index put options as they typically buy index puts as portfolio insurance (Bollen and Whaley (2004)). Garleanu, Pedersen, and Poteshman (2009) find that end users have a net long position in S&P500 index options with large net positions in out-of-the-money puts. Since there are no natural counter-parties to these trades, market makers must step in to absorb the imbalance. By contrast, index call options are typically shorted by market participants, for example via call overwriting strategies. Goyenko and Zhang (2019) provide evidence supporting positive net demand pressures by end users for S&P500 index puts, and negative net demand pressures for S&P500 index calls. Cici and Palacios (2015) study mutual fund holdings in options, finding that, for mutual funds using options written calls represent the majority of option positions, making up roughly 60 percent. Long (mostly index) put options represent the second largest category. Golez and Jackwerth (2012) show that market makers key position is short index put options. Overall, investors are typically long index put options and short index call options. As a result, option market makers are net short (index) put options, net long call options, and net short Gamma on average.

C. Option Trading Activity

The CBOE has introduced a diverse array of SPX option products over time. Notably, p.m.-settled options were reintroduced in 2007 with the SEC's PM Option Expiration Pilot program. Initially, these were options expiring on the last business day of a calendar month, followed by weekly options in 2010, monthly options expiring on the 3rd Friday in 2011, and more recently, options expiring daily.

Futures represent another major derivative on the SPX, introduced on the CME on April 21st, 1982. These contracts also settle into the SOQ, the same settlement price as for SPX options, and follow a quarterly expiry schedule, expiring on the 3rd Friday of the March-June-September-December cycle. Starting in June 1987, options on front-contract SPX futures trade on the quarterly expiry calendar.³⁶

³⁵Options on the SPX and other U.S. indices also trade over-the-counter (OTC). Johnson, Liang, and Liu (2016) show their size to be about half that of the listed market, while sharing a similar trend in option activity.

³⁶Options on SPX futures also trade outside the quarterly expiry calendar. The OA describes these options in detail.

Figure A.1 provides empirical evidence on volumes and open interest for SPX index options plotted against single stock options, SPX futures options and SPX options that settle in the a.m. versus p.m. window. Panel (a) plots the monthly trading volume of SPX options and all options on individual constituent stocks between January 1996 (the start date of OptionMetrics data) and December 2021. We observe substantial trading activity rising from about \$5 bln in 1996 to over \$100 bln a month towards the end of our sample. Next, we plot the monthly trading volume for SPX options versus options on the futures contracts in panel (b), showing that most volume resides in SPX options. Related, Johnson, Liang, and Liu (2016) show that SPX options have most option activity, followed by SP options and SPDR ETF options, with OTM put options being the prominent position type.³⁷ Panels (c) and (d) illustrate that the standard 3rd Friday a.m.-settled SPX option contracts have consistently been the most liquid and largest in terms of both volume and open interest, although recently the p.m.-settled contracts have also garnered increased attention.

[INSERT FIGURE A.1 HERE]

D. The SOQ calculation

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, September, and December. Liquidity providers and designated market makers complained to regulators that they were often unable to manage imbalances on their books due to the extreme volatility and volumes on these days.

On June 19th, 1987 an industry wide shift to a.m. settlement was actioned and the settlement price computed on 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.

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

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

Further, in 2005, the CBOE introduced option contracts on the SPDR ETF. As ETFs are traded like common stock, SPDR options have the same features as individual U.S. stock options (e.g., they settle via physical delivery and expire on the 3rd Friday of the month at the close price of that day.)

³⁷Options on the SPX and other U.S. indices also trade over-the-counter (OTC). Johnson, Liang, and Liu (2016) show their size to be about half that of the listed market, while sharing a similar trend in option activity.

publishes the “current” opening SPX value, it includes the previous day’s closing prices for each stock that has not yet opened.

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.

Highly liquid, large cap stocks usually trade on their primary exchange very close to the market opening time. In the case of the SPX, the exchange reports this opening trade price to S&P and the price enters the SOQ calculation according to each stocks’ weight in the SPX. Less liquid stocks might not have opened for trade on their primary listing exchange, in which case the exchange does not immediately report an opening price. The exchange will report the opening price only after the first stock trade post market open has occurred. This rarely takes more than a few minutes but theoretically can take longer for very illiquid stocks. Therefore, the SOQ is comprised of single stock trade prices from different points in time.

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

[INSERT TABLE A.2 HERE]

A.2. Supplementary Results to Special Opening Quotation Dynamics and Pricing Bias sections)

A. *Special Opening Quotation Dynamics: Robustness to Sample Split Date*

To analyze robustness to the choice of sample split (we use February 2003 in the main tables), we vary the sample split by up to six months up or down, as shown in table A.3. The results show the message of table I is robust to the exact choice of sample split around February 2003.

[INSERT TABLE I HERE]

B. Return Reversal Regressions

To demonstrate a formal link between the two sub-period returns we estimate a standard microstructure reversal regression. The overnight return is measured from SPX trades on each month’s 3rd Thursday at 16:00 to the reported SOQ on Fridays and the subsequent intraday return is measured from the SOQ to the SPX traded price at 12:00. We then regress Friday intraday returns on Thursday overnight returns. Table A.4, panel (a) displays the point estimates and 95% confidence intervals computed from a block bootstrap sampling 1,000 times with the optimal block length chosen following Patton, Politis, and White (2009). The intercept in the regression is negative implying that the Friday intraday return overshoots the preceding overnight returns, or other words, the reversal is more than ‘undone’. More importantly, the predictive slope coefficient is strongly negative implying that large overnight returns are causally reversed intraday consistent with standard theories of price pressure. The R^2 is equal to 12%, which is large given the high-frequency nature of the regression.³⁸ Panel (b) of table A.4 repeats the above analysis for all days, showing also a significant reversal but with magnitudes three orders of magnitude smaller. Moreover, Figure A.2 in the OA shows the significance of the 3FPS reversal pattern is robust to a potential small sample biases.

[INSERT TABLE A.4 HERE]

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 1,000 times with the optimal block length chosen following Patton, Politis, and White (2009). Figure A.2 plots the empirical distribution, which is scaled to be interpreted as a density function, i.e., its integral sums to one. The first, second and third dotted lines represent 2.5%, 50% and 97.5% percentiles. Eyeballing the figure we observe a relatively symmetric distribution. The far left tail (low returns) does not intersect zero, the 2.5% confidence interval is equal to 22 bps and 97.5% confidence interval is 47 basis points demonstrating that overnight returns followed by negative intraday returns is a strong in both economic and statistical terms.

[INSERT FIGURE A.2 HERE]

D. Pricing Pressures

The above results suggest price pressures exist that push prices up overnight and psuh prices down intraday 3rd Fridays. Next, we more formally examine the presence of price pressures by computing order imbalances. From the perspective of inventory risk models, the empirical measure of order imbalance would be net inventory held by market makers. As these are not directly observable, we follow Boyarchenko, Larsen, and Whelan (2023) (who in turn follow a large microstructure literature) and measure order imbalance by the signed volume - the number of contracts bought minus number of contracts sold expressed in thousands. We compute signed

³⁸For example, Boyarchenko, Larsen, and Whelan (2023) estimate a comparable range of high-frequency predictability regressions and obtain maximum R^2 ’s less than 1%.

volumes during the 3rd Thursday overnight trading window or during the 3rd Friday intraday window using all E-mini SPX futures trades over our sample period.

Table A.5 contains the results. On average, signed volumes are positive but insignificant during the overnight window, but significantly negative intraday consistent with the idea that futures are primarily a hedging instrument. More interesting in the context of the 3FPS, around expiries we observe a significantly positive signed volume overnight (t-statistic of 3.0), and a significantly negative signed volume intraday 3rd Fridays (t-statistic of -5.30).

[INSERT TABLE A.5 HERE]

E. The 3FPS and Return Gap on Option Indices

We have shown a economically sizable and statistically significant 3FPS effect. In this OA section, we link the 3FPS effect to explain substantial return differences between two popular SPX 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 SPX 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 in the main text, during this window index prices fall substantially on average, and as such studying returns on these indices and their listed ETFs allows for (another) a real-life impact study of the 3FPS.

[INSERT TABLE A.6 HERE]

Table A.6 display the returns and return gap on the S&P500 buywrite and putwrite indices over our sample that runs from February 2003 till December 2021. The putwrite (PUT) index returns on average 8.7% a year compared to 7.3% for the buywrite (BXM) index. The return gap, hence, equals an economically sizable 1.4% 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 -0.6% a year, while return differences on expiry days equal a sizable 2.0% 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 A.6 an average return difference of zero on these days, thus 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.

Finally, as the option indices do not reflect directly tradable return for reasons of transaction costs and implementation noise, we also confirm the above results for the major ETFs tracking the buywrite and putwrite indices. We use the two largest ETFs, namely the Invesco S&P 500 BuyWrite ETF (\$107MM AUM as of 09/23) and the WisdomTree S&P 500 PutWrite ETF (\$103MM AUM as of 09/23). Our analysis (unreported) starts February 24, 2016, the date when returns on both ETFs are available, and confirm a sizable return gap between the ETFs that is fully explained by the intraday reversal on 3rd Fridays.

A.3. Potential Explanations That We Reject

In the main body of the paper we discuss results on two key explanations we cannot rule out. In this OA section we present results on three potential explanations that we rule out: Fundamental Shocks (overnight news, earnings, and macro announcements), non-fundamental shocks (shocks to balance sheet capacity and funding constraints), and “pinning” - the phenomenon whereby underlying prices tend to cluster around their nearest strikes on expiration days.

A. *The Arrival of Fundamental Information*

A 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).³⁹ Previous literature (see, e.g., Bernard and Thomas, 1989; Sadka, 2006, and the subsequent literature) has documented a positive (negative) drift in stock prices of individual firms following a positive (negative) earnings announcement surprise. Consequently, a significant positive arrival of earnings news 3rd Thursday 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

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

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 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

³⁹ 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.

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 A.3 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 A.7 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.

[INSERT FIGURE A.3 AND TABLE A.7 HERE]

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 A.8 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).

[INSERT TABLE A.8 HERE]

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.⁴⁰ 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

⁴⁰Common series include GDP QoQ, CPI Ex Food and Energy (CPI), Industrial Production, Housing Starts, Retail Sales, Empire Manufacturing, and University of Michigan Sentiment Index.

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 A.9 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.

[INSERT TABLE A.9 HERE]

B. 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 “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.⁴¹ 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 show 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

⁴¹These 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.

non-quarterly expiration's, and the impact of outstanding at-the-money open interest on the 3FPS.

HYPOTHESIS H_{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 A.4 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), (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%.

[INSERT FIGURE A.4 HERE]

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 with p-values all well above 20/

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.

[INSERT TABLE A.10 HERE]

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.⁴² To remove time trends, open interest is normalized within every year of the sample. Table A.10 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.

⁴²Open interest on SPX option contracts is published with one-day lag in OptionMetrics and not available for third Thursdays.

C. Price Pressure from Non-Fundamental Shocks

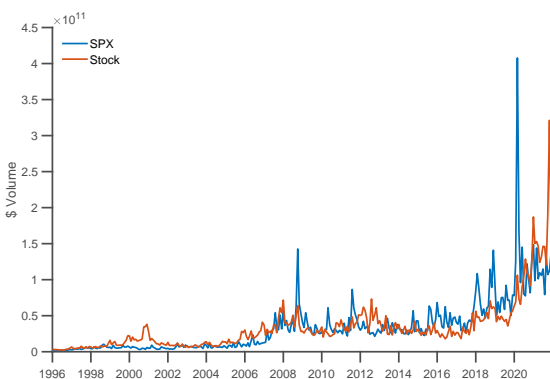
Another possible explanation is the existence of “non-fundamental” shocks that cause temporary price pressure at the index level and subsequent reversal. The market microstructure literature offers a possible explanation based on inventory management of financial intermediaries (for example, Grossman and Miller, 1988, Gromb and Vayanos, 2002, Nagel, 2012 or Brunnermeier and 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 aligns 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.

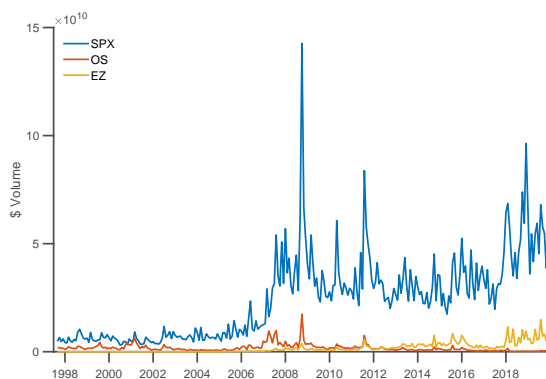
[INSERT TABLE A.11 HERE]

We test the impact of past returns by regressing it on the 3FPS reversal return. Table A.11 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.

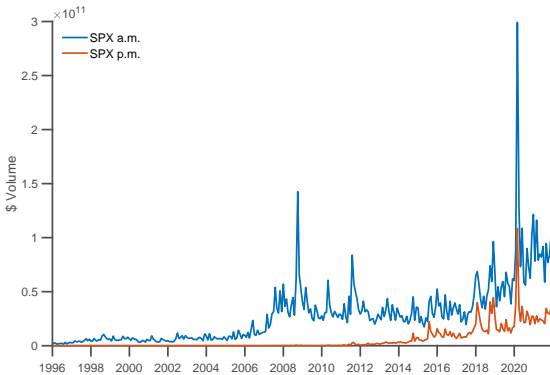
A.4. Figures



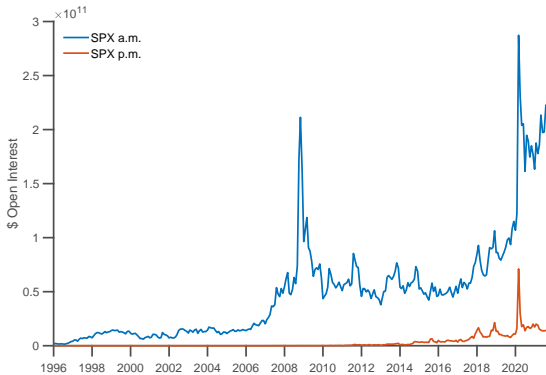
(a) Volume: Index options vs. stock options



(b) Volume: Index options vs. futures options



(c) Volume: A.m. vs. p.m. settlement



(d) Open Interest: A.m. vs. p.m. settlement

Figure A.1. SPX option market size

This figure illustrates the size of the S&P 500 index (SPX) options market. Panel a displays monthly dollar trading volume of SPX options and options on the S&P 500 constituent stocks. Panel b displays monthly dollar trading volume of SPX options and S&P 500 futures options. Panel c displays monthly dollar trading volume of SPX options with a.m. and p.m. settlement. Panel d displays monthly average dollar open interest of SPX options with a.m. and p.m. settlement. The sample period for panels a, c, d is 1996.1 - 2021.12. The sample period for panel b is 1997.9 - 2019.12.

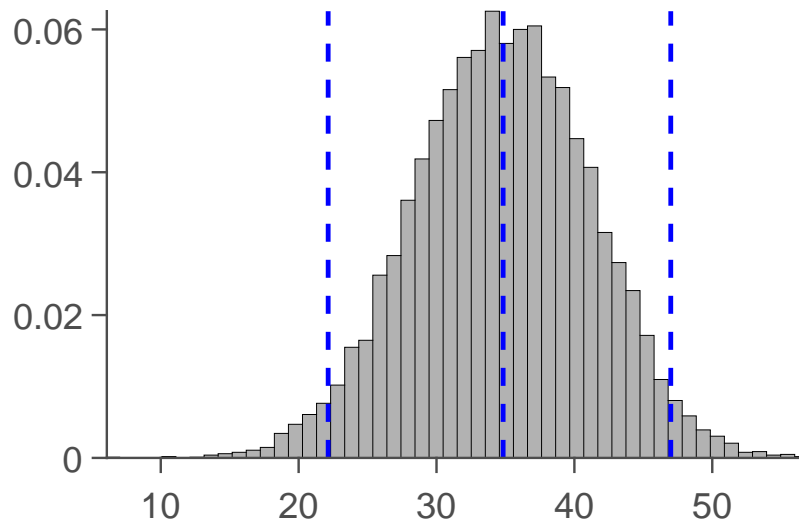


Figure A.2. Bootstrapped return differences

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.

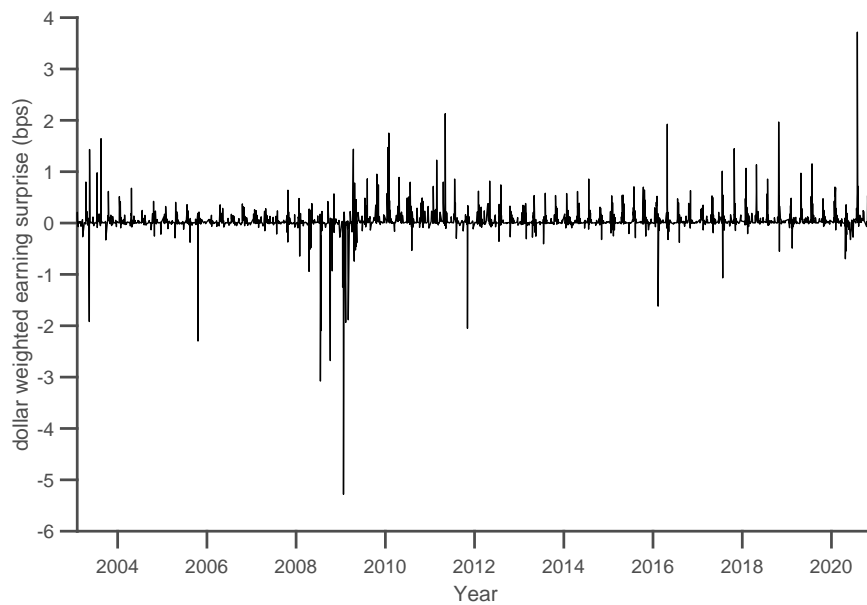


Figure A.3. Earnings Surprises from 12h to 24h

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.

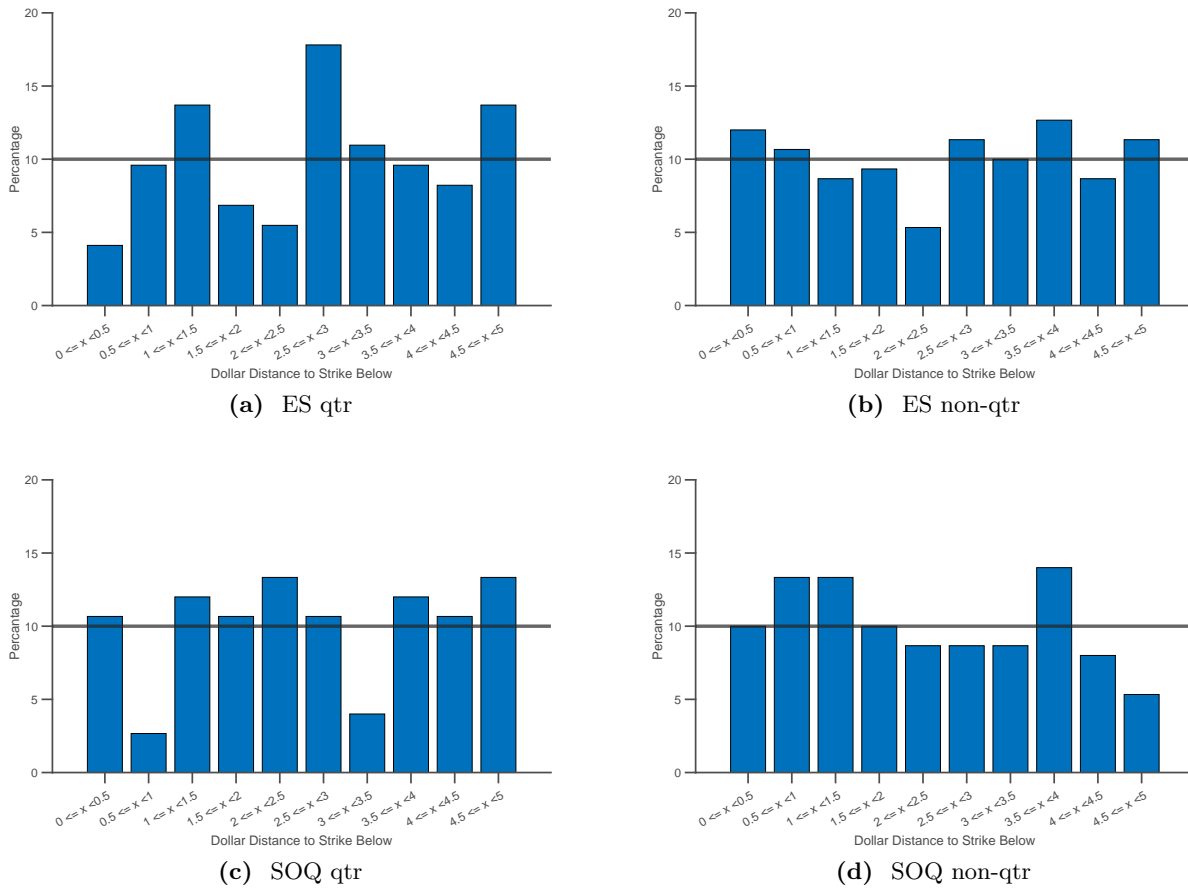


Figure A.4.

Distance of Equity Index Prices to options strike on Third Friday 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 be 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.

A.5. Tables

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

Table A.1. Contract Specifications

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

Table A.2. Illustration: The Special Opening Quotation

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

year	02	02	02	02	02	03	03	03	03	03	03	03	03
month	08	09	10	11	12	01	02	03	04	05	06	07	08
pre diff of means	-4.8	-5.1	-4.9	-5.4	-5.8	-5.2	-5.7	-5.1	-4.1	-4.1	-4.4	-3.8	-3.3
pre t-stat	-0.9	-0.0	-0.9	-1.0	-1.1	-0.0	-1.1	-0.9	-0.8	-0.8	-0.8	-0.7	-0.6
post diff of means	15.9	16.2	16.1	16.5	16.8	16.6	16.9	16.7	16.2	16.3	16.6	16.4	16.2
post t-stat	3.3	3.3	3.4	3.4	3.5	3.4	3.5	3.5	3.4	3.4	3.4	3.3	3.3

Table A.3. S&P 500 returns over night - robustness

This table shows that the results of table I are robust to the choice of breakpoint. We calculate the log return from S&P 500 close prices to the SOQ at (or shortly after) the next regular market open. We calculate the difference between these returns into OPEX days (mostly 3rd Fridays) and all other days. Rows 1 and 2 show that this difference is slightly negative and insignificant from 1992.11 to 2002.08 or any of the subsequent 12 months. Rows 3 and 4 show that this difference is highly positive and significant from 2002.08 (or any of the subsequent 12 months) to 2021.12.

	Intercept	Slope	$R^2(\%)$
PANEL A: 3 rd Fridays			
Point Estimate	-12.11	-0.32	12.09
Lower Bound	-18.70	-0.47	
Upper Bound	-5.93	-0.18	
PANEL B: All Days			
Point Estimate	1.68	-0.10	1.50
Lower Bound	0.15	-0.15	
Upper Bound	3.03	-0.04	

Table A.4. Regression: Day returns on preceding night returns

The first row reports OLS coefficients from regressing 3rd 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 3rd Thursday at 16:00 to the Special-Opening-Quotation at the subsequent market open. The intra-day return is measured from the SOQ on each month's 3rd Friday open to SPX trades on 3rd Fridays at 12:00. Returns are in basis points. The sample period is 2003.02 to 2021.12.

Days:	OPEX	Other
<i>PANEL A: Overnight</i>		
mean	1.88	0.01
median	1.72	0.04
t-stat	5.29	0.15
<i>PANEL B: Intraday</i>		
mean	-0.89	-0.01
median	-0.55	-0.08
t-stat	-4.55	-0.11

Table A.5. 3rd Friday order imbalances

This table reports summary statistics for the relative signed volume of the most liquid S&P 500 E-mini futures contract around 3rd Friday option expiration. Panel a contains the average signed volume overnight (i.e., between 16:15 and 09:30). Panel b contains the average signed volume intraday (i.e., between 09:30 and 16:00). Relative signed volume is the number of buyer initiated trades (in nr of contracts) as a fraction of the total number of contracts traded. The sample period is 2003.02 to 2021.12.

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

Table A.6. 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.

	All days		Around 3rd Fridays	
	evening	day	evening	day
mean	5.38	5.89	2.80	4.92
median	1.74	1.95	2.01	1.48
t-stat	9.19	6.76	1.31	1.33
Std	28.38	48.02	29.74	44.63

Table A.7. 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.

	intercept	slope	$R^2(\%)$
coeff	33.54	-6.50	0.23
t-stat	4.84	-1.22	

Table A.8. 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.

	rev ret	rev ret	rev ret
Intercept	36.49	36.82	39.61
	5.88	5.70	4.61
Dummy cpi		-1.99	
		-0.10	
Dummy gdp			-7.80
			-0.63
N	225.00	225.00	225.00
Dummy N	0.00	37.00	90.00

Table A.9. 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.

	rev ret	rev ret	rev ret	rev ret	rev ret
interc.	33.38	33.38	33.38	33.38	32.89
	4.37	4.36	4.35	4.38	4.28
atm oi		2.66			
		0.39			
atm oi calls			6.53		
			0.72		
atm oi puts				-1.82	
				-0.29	
Δ atm oi					1.32
					0.22

Table A.10. 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.

	rev ret	rev ret	rev ret	rev ret
Intercept	36.49	36.49	36.49	36.49
	5.89	5.88	5.87	5.89
Ret Undl 1w	-2.39			
	-0.18			
Ret Undl 2w		0.67		
		0.06		
Ret Undl 3w			9.45	
			0.68	
Ret Undl 4w				6.03
				0.42

Table A.11. 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.

	3 rd Friday Reversal Return				
Intercept	36.24	36.24	36.24	36.24	35.80
	(4.85)	(4.85)	(4.85)	(4.84)	(4.76)
Mm Net-Delta		6.19			
		(0.79)			
Mm Net-Delta Calls			4.80		
			(0.86)		
Mm Net-Delta Puts				3.27	
				(0.46)	
Mm Net-Delta Diff					8.01
					(0.79)

Table A.12. Regression: 3rd Friday return on Market Maker positions

We regress 3rd Friday reversal returns on preceding market maker net delta. The reversal strategy is long the S&P 500 from Thursday close to Friday open and short from Friday open to Friday noon (12:00). Pro-Customer positions are the sum-product of their positions across expiring SPX options and the respective options' Greek at market close (16:15). Independent variables are normalized to zero mean and unit variance. Returns are in basis points. Robust t-statistics are in parentheses. The sample period is 2006.1 to 2020.12.

	3 rd Friday Reversal Return				
Intercept	21.37	21.37	21.37	21.37	20.60
	(2.80)	(2.80)	(2.81)	(2.78)	(2.71)
Pc Net-Delta		5.55			
		(1.03)			
Pc Net-Delta Calls			4.95		
			(1.07)		
Pc Net-Delta Puts				2.66	
				(0.26)	
Pc Net-Delta Diff					12.59
					(2.17)

Table A.13. Regression: 3rd Friday return on Pro-Customer positions

We regress 3rd Friday reversal returns on preceding pro-customer net delta. The reversal strategy is long the S&P 500 from Thursday close to Friday open and short from Friday open to Friday noon (12:00). Pro-Customer positions are the sum-product of their positions across expiring SPX options and the respective options' Greek at market close (16:15). Independent variables are normalized to zero mean and unit variance. Returns are in basis points. Robust t-statistics are in parentheses. The sample period is 2011.1 to 2020.12.

	3 rd Friday Reversal Return				
Intercept	21.37 (2.80)	21.37 (2.80)	21.37 (2.81)	21.37 (2.80)	20.60 (2.69)
Mm-Net-Charm x Pc-Net-Delta		-5.69 (-1.38)			
Mm-Net-Charm x Pc-Net-Delta-Calls			-6.06 (-1.57)		
Mm-Net-Charm x Pc-Net-Delta-Puts				0.63 (0.11)	
Mm-Net-Charm x Pc-Net-Delta-Diff					-4.56 (-1.41)

Table A.14. Regression: 3rd Friday return on interacted positions

We regress 3rd Friday reversal returns on the interaction of preceding market maker net charm and pro customer net delta. The reversal strategy is long the S&P 500 from Thursday close to Friday open and short from Friday open to Friday noon (12:00). Market-Maker positions are the sum-product of their positions across outstanding SPX options and the respective options' Greek at market close (16:15). For Pro-Customer positions we consider only expiring options. Independent variables are normalized to zero mean and unit variance. Returns are in basis points. Robust t-statistics are in parentheses. The sample period is 2011.1 to 2020.12.