The Derivative Payoff Bias

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Abstract

A significant fraction of U.S. equity index derivatives settle "a.m" on the 3^{rd} Friday of each month via constituent stocks' opening trade price. We show that these prices are biased upward since the advent of overnight trading in the early 2000s. U.S. equity prices drift upwards from Thursday close to 3^{rd} 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, generating a wealth transfer of around $4 billion per year in SPX options alone. Exploiting options positions data, we show the most likely explanation is due to market maker hedging practices during the illiquid overnight trading period that precedes option settlement. We conclude by arguing that current settlement design generates a market inefficiency and discuss policy implications.

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 and a large fraction SPX derivative open interest is "a.m.-settled", meaning they expire on the 3^{rd} 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.

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 3^{rd} Friday of each month when index option payoffs are determined. On these days the SOQ exceeds the index closing price by an average of 18.5 basis points (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 3^{rd} Fridays. Studying 24-hour continuous trading via equity futures, we detect clear tent-shaped reversal pattern from the close of regular trading on 3^{rd} Thursdays, which peaks exactly when the SOQ is calculated on 3^{rd} Fridays and fully reverts afterward by about noon 3^{rd} Friday.[1] 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 like the Dow Jones Industrial Average and Nasdaq 100 indices. Further, it is present in almost

[1] Throughout the paper we will refer to the option expiry date as the 3^{rd} 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 3^{rd} Thursday, even though this does not have to be true.

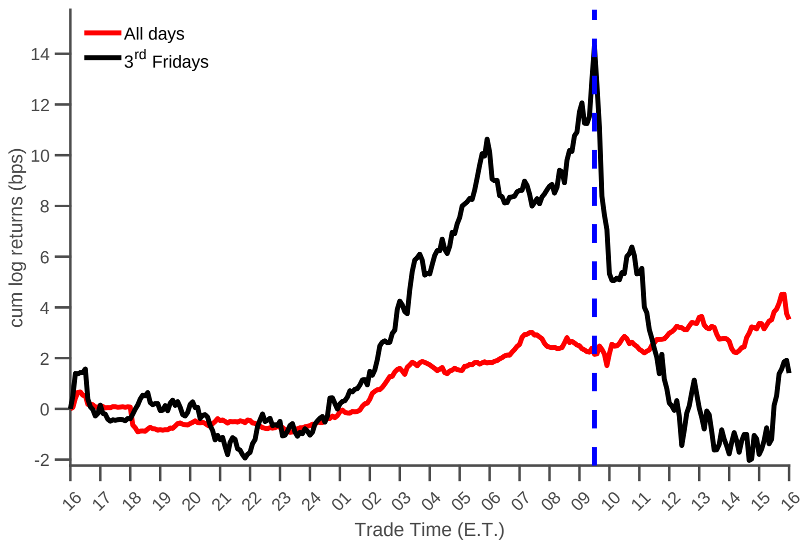

Figure 1. The 3$^{\text{rd}}$ Friday price spike in S&P 500 E-mini futures

The black line plots average cumulative 5 minute log returns of S&P 500 E-mini futures around 3$^{\text{rd}}$ 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.

every year in our sample 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 3^{rd} 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 3$^{\text{rd}}$ 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 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 3^{rd} Thursday but the 3FPS in the underlying generates price pressure in derivatives overnight. Therefore, we compare actual overnight option settlement returns with counterfactual returns that replace the time-series of realised 3FPSs with the unconditional overnight return measured across all days. Relative to their counterfactuals, we estimate overnight option returns (measured over 17 hours and 15 minutes) are: +34% for at-the-money calls and -20% for at-the-money puts.

Second, we 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 3^{rd} Thursday. These calculations show that SPX call options paid off $10.46 billion on the average 3^{rd} Friday morning. Had their settlement been determined at Thursday close, they would have paid off $10.23 billion. The difference of $230 million a month, 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 3^{rd} 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.[2]

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 detective work focuses on two plausible alternative channels: (*i*) hedging practices of option market makers; and (*ii*) market manipulation. We exploit option market maker positioning data from the CBOE to examine these channels.

Option market makers (OMMs) face demand imbalances since they are typically short index

[2]Note 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.

puts and long index calls. The resulting options positions expose OMMs to inventory risk, which they delta (Δ) hedge with offsetting positions in the underlying. To examine a potential unwinding Δ-hedges explanation, we study OMM positions in a.m settled options on all days across all maturities and show they are, in general, positive net-Δ in their call and put positions. However, remarkably, when examining net-Δ in expiring options in the week of expiration, the relevant quantity for an unwinding Δ-hedges hypothesis, we find they trade their net-Δ exposure to zero (in option positions alone). This patterns stands in sharp contrast to the pattern in option positions of non-expiring options. Thus, we conclude that a simple "unwinding of Δ-hedges" explanation cannot account for the 3FPS as there should be no need for them to trade in the overnight period preceding expiry.

Next, we consider an alternative hedging based explanation: Charm ($\mathcal{C}$) is the rate of change of OMM delta due to the passage of time and is particular important close to expiration.[3] The intuition for $\mathcal{C}$ is as follows. For deep in the money (ITM) and out-the-money (OTM) options their $\mathcal{C}$ is zero since their deltas are already either 0 or 1. For at-the-money (ATM) options the effect of charm can be large. For just OTM calls with positive sizeable delta, overnight on 3^{rd} Fridays their deltas are dragged rapidly towards 0 ($\mathcal{C} < 0$), while for just ITM calls their deltas are dragged rapidly towards 1 ($\mathcal{C} > 0$). The intuition for puts is symmetric. Thus, even if OMMs have a net-delta zero position on 3^{rd} Thursdays, if for some latent reason they are long (short) OTM (ITM) calls and long (short) ITM (OTM) puts their net Charm would be negative. This is exactly what we find, on 3^{rd} Thursday close OMMs, on average, have large negative net-$\mathcal{C}$, which we calculate implies OMMs need to buy \$50 million overnight to maintain a Δ-neutral position into expiry.

Exploring the $\mathcal{C}$-hedging channel further we estimate a predictability regression of over-night returns on the S&P 500 equity index on lagged dealer positions measured at Thursday close. Considering first a univariate prediction with net-$\mathcal{C}$ as a forecasting variable we find a economically large, statistically significant negative coefficient implying that the more negative is OMM net-$\mathcal{C}$, the more positive are overnight returns. Moreover, we find an R^2 in this regression of 1% which for return prediction measured over 17.5 hours is quite large. Considering a multivariate prediction controlling for net-gamma (Γ) and net-Δ doesn't change in the impact of net-$\mathcal{C}$. However, im-

[3] Black-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. Formally, charm is defined as $\mathcal{C}_t = -1 \times \frac{\partial \Delta}{\partial \tau}$ where Δ is the option delta and τ is time-to-maturity.

portantly, consistent with our argument regarding an unwinding of Δ-hedges explanation we find impact of net-Δ is zero. Interestingly, net-Γ is positive and significant which is consistent with the much discussed effect that Γ-hedging implies trading the underlying in the direction of price movements (Baltussen, Da, Lammers, and Martens (2021)), amplifying the effect of rebalancing due to net-$\mathcal{C}$. Therefore, we do not rule out a hedging based channel as the evidence suggests a $\mathcal{C}$ explanation is plausible.

A second possible explanation is that manipulators push the underlying index price up in the period immediately preceding settlement, and tilt their option positions to take advantage of a temporary price spike through an option position that is cash settled. A tent shaped 3FPS may be 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 which we call 'Pro' customers) 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 and it is the view of these authors, based on Occam's razor, that market manipulation channel is the least likely of the two explanations we focus on.

What then could explaining the tilting of these traders portfolios towards benefiting from the 3FPS? Predatory trading differs from manipulation and is defined as trading that induces or exploits the needs of others to reduce their positions. Brunnermeier and Pedersen (2005) give numerous real world examples of predatory trading that includes front running, which applied to our setting means that if some strategic traders had advance knowledge that OMM would be net-$\mathcal{C} < 0$ at expiration they would position themselves in expiring options with net-$\Delta > 0$. Testing this conjecture we find that in the run up to expiry dealer net-$\mathcal{C}$ is strongly negatively ($R^2 = 6\%$) correlated with Pro-customer net-Δ, that is, the more negative OMM net-$\mathcal{C}$ the more Pro-customers position their option portfolios to take average of a potential 3FPS.

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 3^{rd} 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 an empirical literature on the effects of demand pressures and intermediary inventory risks. Stoll 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. 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, Lammers, 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 3^{rd} Thursday of the month to close of regular trading hours on the 3^{rd} Friday of the month.[4]

Our paper also relates to the literatures on market manipulation, predatory trading 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 3^{rd} Friday pattern documented in this

[4]Figure A.1 in the Online Appendix (OA) compares trading volumes and open interest in 3^{rd} Friday settled single stock S&P 500 options, futures options, a.m and p.m settled SPX settled options, showing that that the a.m variety display the largest trading activity. Dim, Eraker, and Vilkov (2024) study the evolution of so-called zero-day-to-expiry (0DTE) options which settle p.m. At the end of our sample period (2021.12) 3^{rd} Friday a.m settled and 0DTE option open interest was approximately the same standing at \$250 billion per day.

paper. The empirical evidence of our study also suggests that predatory trading is at play in the run up to a.m option settlement, consistent with the theoretical framework of Brunnermeier and Pedersen (2005).

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.[5] 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 (see, for example, (Boyarchenko, Larsen, and Whelan, 2023)).

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.[6] 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.

Finally, we exploit the CBOE Open-Close dataset, which provides daily buy- and sell volumes for all SPX options by option market participant sector. From 2006.01 to 2010.12 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" over the whole sample. Terstegge (2024) provides details on the construction of option positions. To summarize briefly, on the day an option is first listed market maker buy volume (in number of contracts) minus market maker sell volume yields the market makers' net position in that option. On the next day, market maker buys minus market maker sells yield the *change* in market makers' position. Market makers' new net position is then given by yesterday's position plus today's change in position. In this way we cumulate market makers' net position from option listing to expiry at the contract level. The sum of market

[5]BB ticker SPXM until 2006 and ticker SPXSET afterwards.

[6]In 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.

makers' net position across all currently listed SPX options yields our daily baseline measure of total market maker net position. When we study market maker positions with regards to some Greek risk measure, e.g. Delta, we multiply each contract level net-position with the respective options' delta and sum over all available contracts to obtain the total position, which in this case would be market maker net delta.

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 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 3^{rd} 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).[7] Since June 19th, 1987 (November 20th, 1992), the settlement price of quarterly and monthly SPX index options has been computed on 3^{rd} 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

[7] There were particular concerns over "Triple Witching" events, occurring only four times per year on the 3^{rd} Friday of March, June, September, and December, where simultaneous expiry of futures, futures options, index options, and single stock options takes place. Market makers complained to regulators about difficulties managing imbalances due to extreme volatility and volumes on these days.

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.[8]

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.[9]

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.[10] 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

[8]At 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.

[9]Related, 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.

[10]We multiply the volume for the SP contract by 5 to make its volume comparable to the ES.

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.[11] In 1991 the Instinet system was introduced, allowing large investors to trade stocks 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

[11] Before, 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.

and preceding closing trade of the SPX

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

[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 3^{rd} 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 larger mass of red bars compared to blue bars. In other words, compared to close prices on 3^{rd} Thursdays, the SOQ - the value weighted average of the SPX constituent traded prices - appears structurally upward biased on 3^{rd} 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 3^{rd} 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 sub-periods. 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 upward biased on 3^{rd} 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 3^{rd} Friday SOQ price. To this end, we compute traded returns around *monthly* 3^{rd} 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.[12] 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 3^{rd} Fridays (right hand side of the x-axis) showing prices drift steadily up and continue drifting in early morning trade until *exactly* the 9:30

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

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.[13] Hence, SPX futures prices display a tent-shaped reversal pattern from the close of regular trading on 3^{rd} Thursdays, which peaks exactly when the SOQ is calculated on 3^{rd} Fridays and fully reverts afterward by about noon 3^{rd} 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 profile across all days (red line) which displays no reversal patterns and shows that overnight returns on 3^{rd} Fridays are an order of magnitude larger than what should be expected unconditionally.[14]

[INSERT FIGURE 1 HERE]

The 24-hour price path around 3^{rd} Fridays displays a classic reversal pattern that typically arises in models of demand for immediacy and inventory risk management. This point is discussed by numerous studies (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 (table A.4). 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 (figure A.2), and the 3FPS is not only present in returns but also shows up in order imbalances (table A.5).

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 3^{rd} Friday settlement dates (columns 4 - 7).[15] Panel (a) reports return statistics from trading the SPX closing price and the SOQ at open, and (b) are calculated from closing and opening prices for the e-mini.

[INSERT TABLE II HERE]

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

[14] Unconditional 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.

[15] The column "All days CTO" contains summary statistics for returns that includes the weekend return from Friday to Monday morning.

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 3^{rd} Friday settlement. Wednesday close to Thursday open, and Thursday open to Thursday close display returns not statistically different from zero.

The final two columns highlighted in grey display return statistics for Thursday close to Friday open and Friday open to Friday close. In panel (a) Thursday overnight returns are abnormally large and *positive* equal to 19 bps. Friday intraday returns are also abnormally large but *negative* equal to -17 bps. Considering panels (b) the magnitudes is slightly smaller but remains large, 5 times larger its all day counterparts, with a t-statistic of 3.5. The statistical difference between all day CTO returns and 3^{rd} Friday CTO returns is large with t-statistics equal to 4.9 (panel a), 3.3 (panel b) and 3.6 (panel c).

A. Triple Witchings

Most expiry activity on derivative markets takes place on the "triple witching day", the 3^{rd} 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 3^{rd} Friday quarterly (panel a) and off-quarterly expiries (panel b). Effects are stronger on the quarterly triple-witch days, with a 3^{rd} Thursday overnight return of on average 27 bps, reverting -37 bps intraday on the third Friday. Off-quarterly expiries still display a strong reversal pattern around the publication of the SOQ, equal to 14 bps overnight and -6 bps intraday. Again, the economic and statistical difference between all day CTO returns and 3^{rd} 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]

B. 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 3$^{\text{rd}}$ Friday in 2011, and more recently, zero-day (ODTE) options expiring daily. For most of our sample period the standard 3$^{\text{rd}}$ Friday expiry contracts have generally been the most liquid and largest in terms of open interest and activity, although more recently especially zero-day (0DTE) 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 a reversal pattern exists only around a.m. settlement.

[INSERT TABLE IV HERE]

C. 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 returns over time by computing their realised cumulative values. The long overnight, short intraday and reversal strategy are remarkably stable 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.[16] The strategy earns positive returns in all years except 2008, 2013 and 2016. Sharpe rations are generally large, with many exceeding 2 and some exceeding 3. Although the highest Sharpe ratios occur in the early part of our sample, the high Sharpe rations in 2019 to 2021 show that the 3^{rd} price spike is present until the end of our sample.

[INSERT FIGURE 4 HERE]

D. *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 5 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 3^{rd} 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

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

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.[17] 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 5 HERE]

V. Wealth Implications

Persistent positive overnight returns preceding 3^{rd} Fridays biases the payoffs of all U.S. equity derivatives that have monthly 3^{rd} 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 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 3^{rd} Thursday but that the 3FPS in the underlying generates price pressure in derivatives overnight, we compute the SPX index option returns into expiry. We compare actual overnight option settlement returns - as measured between 3^{rd} 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.[18] 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

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

[18] Moneyness is the underlying price divided by the strike price.

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 3^{rd} 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 an estimated wealth transfer from option returns.

[INSERT TABLE VI HERE]

The second approach we considering when estimating a wealth transfer compares the realized payoff of all SPX options (calculated from 3^{rd} Friday SOQ) with a hypothetical payoff calculated from Thursday SPX closing price.[19] The overnight return bias impacts options as follows: (*i*) a higher payoff for already in-the-money calls; (*ii*) some calls which would have expired out-of-the money without the price spike now expire in-the-money; (*iii*) a lower payoff for in-the-money puts; and (*iv*) some puts which would have expired in-of-the money now expire out-the-money. Since SPX options do not trade over night before expiry, there are no changes in option positions that we need to consider. Therefore, the hypothetical payoff from Thursday close represents a natural counterfactual.

The total call option settlement value is calculated as

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

where I is the number of different expiring call option contracts and K is their strike price. The

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

total put option settlement value is calculated equivalently as[20]

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

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 3^{rd} Friday morning. Had their settlement been determined at Thursday close, they would have paid off \$10.23 billion. The difference of \$230 million a month represents the wealth transfer from call option writers to call option buyers. Similarly, the table shows that SPX put options paid off \$3.04 billion on the average 3^{rd} Friday morning, versus a counterfactual \$2.12 billion, yielding a wealth transfer from put option buyers to put option writers of \$90 million a month.[21] We interpret the sum of the wealth transfers in call and put options as the total wealth transfer and multiplication by 12 (expiries a year) yields our headline number of \$3.8 billion annual wealth transfer.

Figure 6 displays this monthly difference in option payoffs from 3^{rd} Friday a.m. settlement versus hypothetical Thursday close settlement. Of course, not every equity return between Thursday close and Friday open represents a market inefficiency and thus not every difference between actual and hypothetical option payoffs represents a bias. However, considering call options in panel (a), it is remarkable to see that this difference (actual minus hypothetical payoff) is positive for the vast majority of option expiry days. Considering put option in panel (b), the difference is negative for the vast majority of expiry dates. Thus, the estimates in table VII are not driven by unique expiries, but are a pervasive feature of US derivatives markets.

[INSERT TABLE VII AND FIGURE 6 HERE]

VI. Potential Explanations

Next, we explore economic explanations. We first investigate three obvious candidates: Fundamental Shocks (overnight news, earnings, and macro announcements), non-fundamental shocks

[20] We obtain SPX Options data from OptionMetrics and CBOE. OptionMetrics lags open interest by one day and options drop out of the data on their expiry day. Thus, option open interest at Thursday close before OPEX cannot be observed via OptionMetrics. Therefore, we obtain open interest at Thursday close from the CBOE high-frequency SPX options data, which do not suffer from this issue. However, the cboe open-interest data contain data errors for the October 2006 and July 2007 expiry. We drop both dates from the sample wherever we need option open interest into 3^{rd} Friday OPEX.

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

(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 alternative 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).[22]

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 theirs 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.

[22] In 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.

[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 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 3^{rd} Thursday close, market makers have an average net delta from expiring calls (puts) of 60 thousand (-70 thousand).[23] 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 8 examines the market maker net delta in the 10 trading days in the run up to 3^{rd} 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 8 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

$$\mathcal{C}_t = \frac{\partial \Delta_t}{\partial t} = -\frac{\partial \Delta_t}{\partial \tau} = -\frac{\partial^2 V_t}{\partial S_t \partial \tau} = \frac{\partial \Theta_t}{\partial S_t} \tag{4}$$

[23] Most 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.

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* if there is no movement in the underlying. Panels (a) and (b) of figure 7 illustrates how the well known properties of delta for in-the-money (ITM) compared with out-the-money (OTM) options varies as time $\tau \to 0$. Upon OPEX the delta of a call option will be either 1 or 0, and just before expiry as $\tau \to 0$ 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 $MN = \log \frac{S_t}{K}$.

$\Big[$ INSERT FIGURE 7 HERE $\Big]$

Considering its effects around different levels of MN, The effect of $\mathcal{C}$ for deep ITM and OTM 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 3^{rd} 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 that 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 3^{rd} 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 3^{rd} 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 17 hours and 15 minutes.[24] Market makers would have to buy the underlying to prevent this change in directional market exposure.

Exploring the $\mathcal{C}$-hedging channel further we estimate predictability regression of over-night returns on the S&P 500 equity index on lagged dealer positions measured at Thursday close. Considering first a univariate prediction with net-$\mathcal{C}$ as a forecasting variable we find a economically

[24]The calculation is $\frac{-26e9\times17.5}{365\times24} = -52e6$, to adjust charm to the relevant expiry horizon of 17.5 hours.

large, statistically significant negative coefficient implying that the more negative is OMM net-$\mathcal{C}$, the more positive are overnight returns. Moreover, we find an R^2 in this regression of 1.5% which for return prediction measured over 17.5 hours is quite large. Considering a multivariate prediction controlling for net-gamma (Γ) and net-Δ doesn't change in the impact of net-$\mathcal{C}$. However, importantly, consistent with our argument regarding an unwinding of Δ-hedges explanation we find impact of net-Δ is zero. Interestingly, net-Γ is positive and significant which is consistent with the much discussed effect that Γ-hedging implies trading the underlying in the direction of price movements (Baltussen, Da, Lammers, and Martens (2021)), amplifying the effect of rebalancing due to net-$\mathcal{C}$. Therefore, we do not rule out a hedging based channel as the evidence suggests a $\mathcal{C}$ explanation is plausible.

[INSERT TABLE XI HERE]

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 3^{rd} 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 imme-

[25] Manipulation is more difficult for an asset with physical settlement. Suppose a manipulator pushes the price of a 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.

diately 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.

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.

[INSERT TABLE X HERE]

Table X contains the summary statistics. On average, the pro-customers are net long delta on the 3^{rd} Thursday before expiry in both calls and puts. In other words, they would benefit from a price rise overnight just before expiry. The CBOE positions data contain two further large sectors: Customers and Firms. However, it is not clear whose positions these sectors represent. Either Customers or Firms could contain investment banks that trade either for their own book or to hedge risk from some related derivative. Due to the ambiguity in Customer and Firm positions, we focus on market makers and professional customers. Interestingly, when comparing pro-customer positions from the 3^{rd} Wednesday to the 3^{rd} Thursday, we can observe that they increase their option delta Thursday intraday; thus, increasing the payoff of a overnight price spike.

[INSERT FIGURE 9 HERE]

Figure 9 further examines pro-customer net delta in the 10 trading days in the run up to 3^{rd} 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.

This finding suggests that market manipulation by professional customers is second plausible explanation. That said, a direct identification of market manipulation is challenging since the practice is inherently latent and it is the view of these authors, based on Occam's razor, that market manipulation channel is the least likely of the two explanations we focus on.

What then could explaining the tilting of these traders portfolios towards benefiting from the 3FPS? Predatory trading differs from manipulation and is defined as trading that induces or exploits the needs of others to reduce their positions. Brunnermeier and Pedersen (2005) give numerous real world examples of predatory trading that includes front running, which applied to our setting means that if some strategic traders had advance knowledge that OMM would be net-$\mathcal{C} < 0$ at expiration they would position themselves in expiring options with net-$\Delta > 0$. Testing this conjecture we find that in the run up to expiry dealer net-$\mathcal{C}$ is strong negatively correlated with Pro-customer net-Δ, that is, the more negative OMM net-$\mathcal{C}$ the more Pro-customers position their option portfolios to take average of a potential 3FPS.

[INSERT TABLE XII HERE]

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 3^{rd} 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 3^{rd} 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 3^{rd} Fridays, the point when individual stock options, non-monthly options, and SPY options already settle. As highlighted in Section III, settlement of SPX options used to be in the close of 3^{rd} 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 3^{rd} Friday a suboptimal alternative. Alternatively, settlement could be aligned to the close on 3^{rd} 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 3^{rd} 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 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.

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

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

VIII. Conclusions

We document a sizeable bias in the payoff of U.S. equity index derivatives. On the 3^{rd} 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 3^{rd} Friday p.m. settled options. A positive overnight return bias raises (lowers) S&P 500 call (put) option payoffs inducing an annual wealth transfer in the region of $4 billion per year.

We rule out a set of plausible explanations based on informational shocks, pinning, or limited risk-bearing capacity of market makers. As an alternative, we conjecture and study two plausible alternatives: (1) hedging motivates by option market makers; and (2) an explanation based on market manipulation. Both explanations rely on the existence of an illiquid trading period directly preceding payoff settlement. 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.

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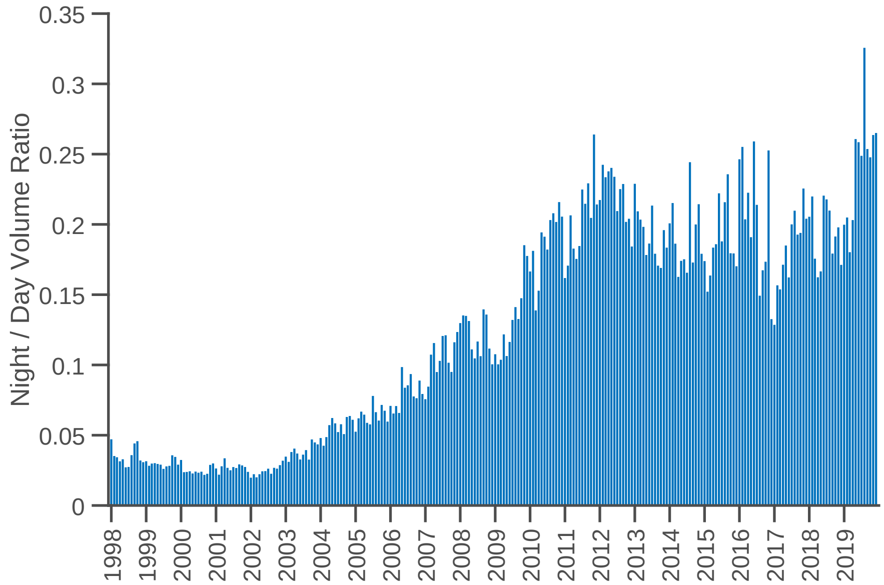
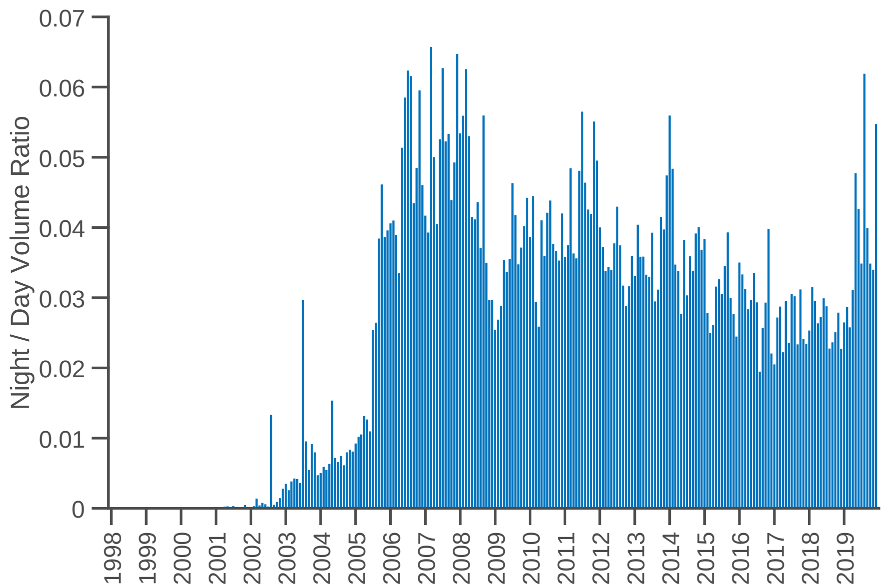
IX. Appendix: Figures



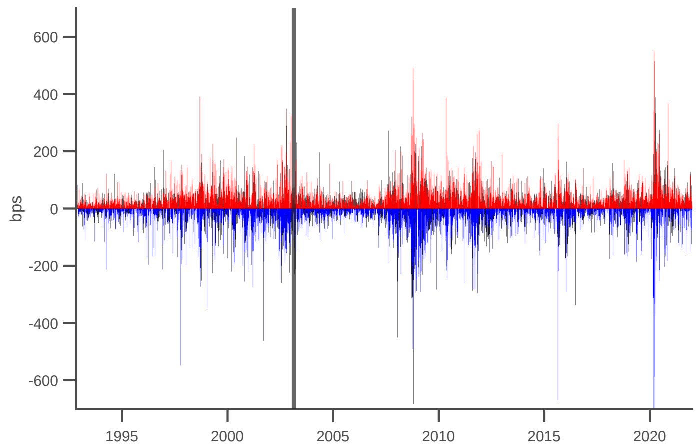
(a) Futures: ES and SP



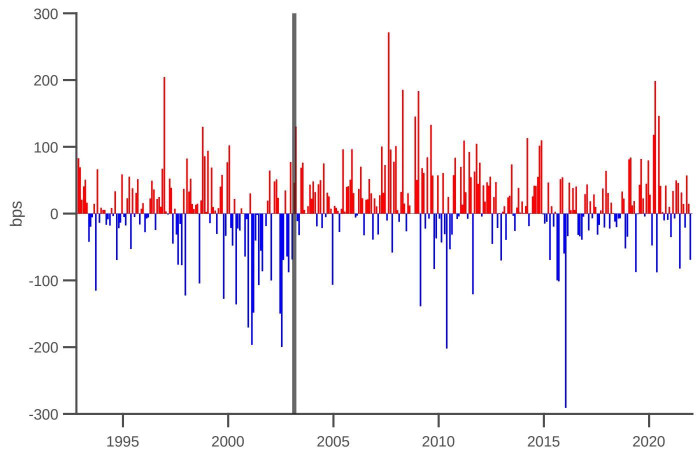
(b) ETF: SPY

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 measures 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



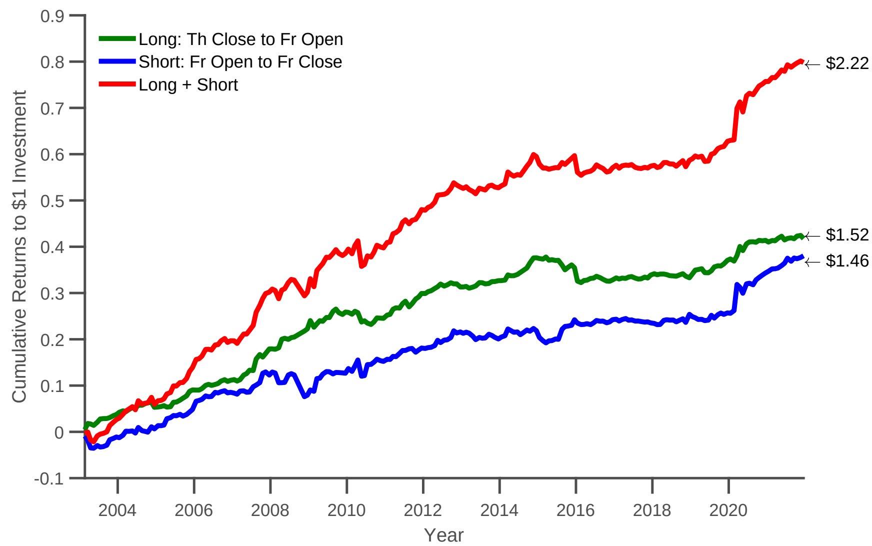
(b) OPEX Days

Figure 3. SOQ vs. SPX close prices

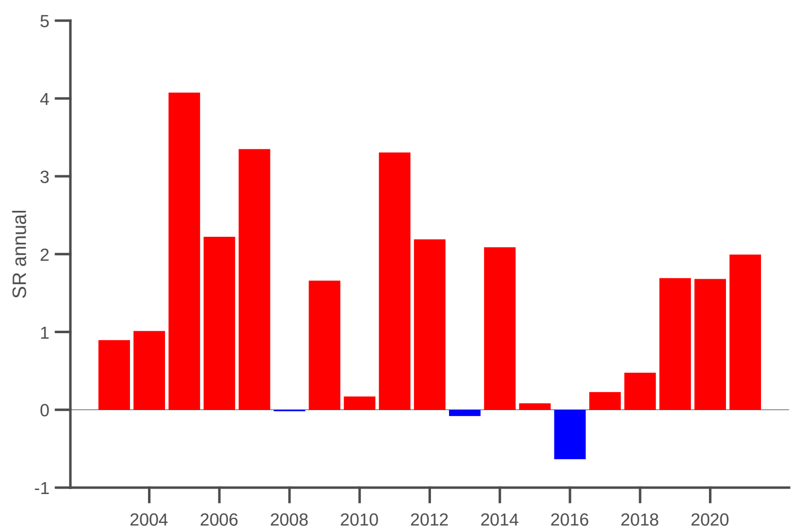
These figures plot the times-series

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

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 computet 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 3^{rd} 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.



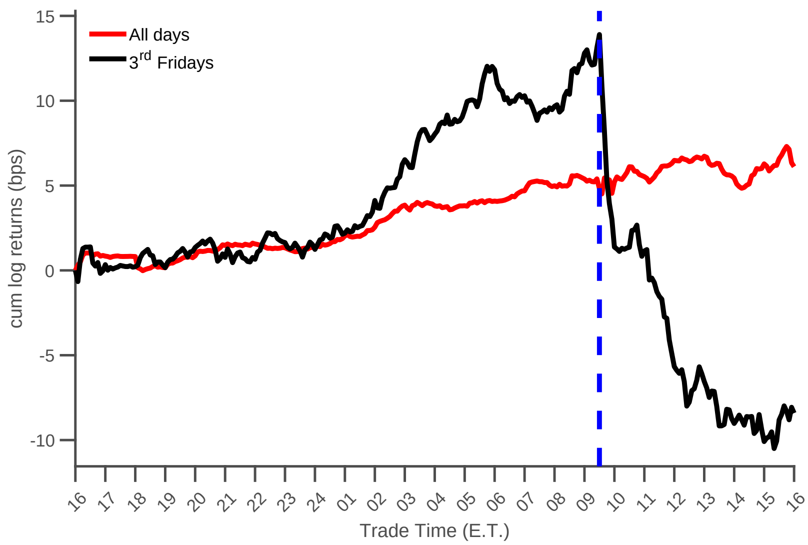
(a) Cumulative Returns



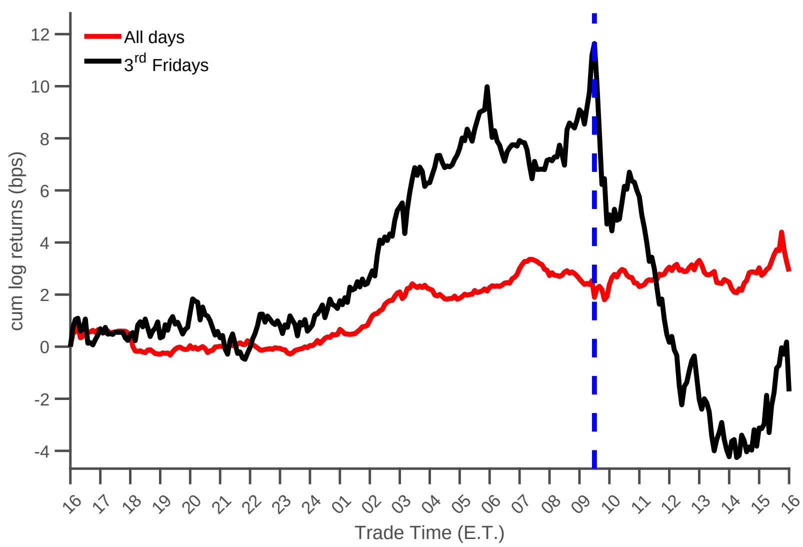
(b) Annual Sharpe Ratio

Figure 4. Trading the 3$^{\text{rd}}$ 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 3$^{\text{rd}}$ Thursday close (16:00), switch to a short position at 3$^{\text{rd}}$ Friday open via the Special Opening Quotation (at or shortly after 09:30) and close the position at 3$^{\text{rd}}$ 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.

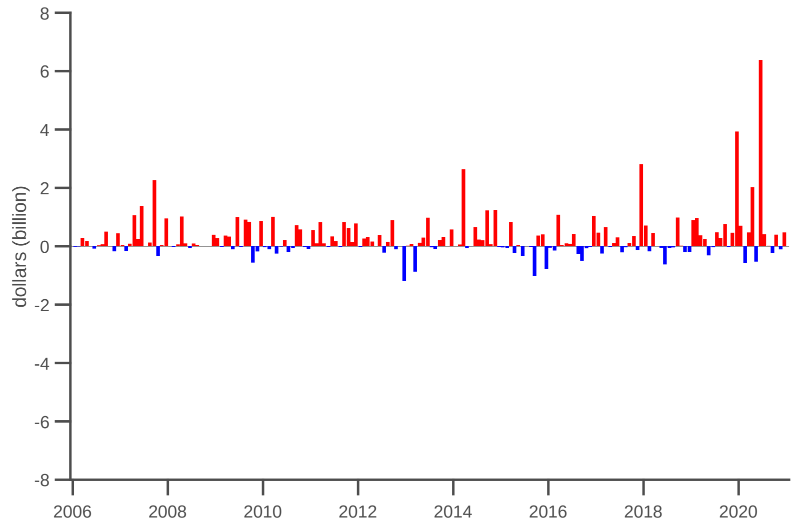


(a) Nasdaq

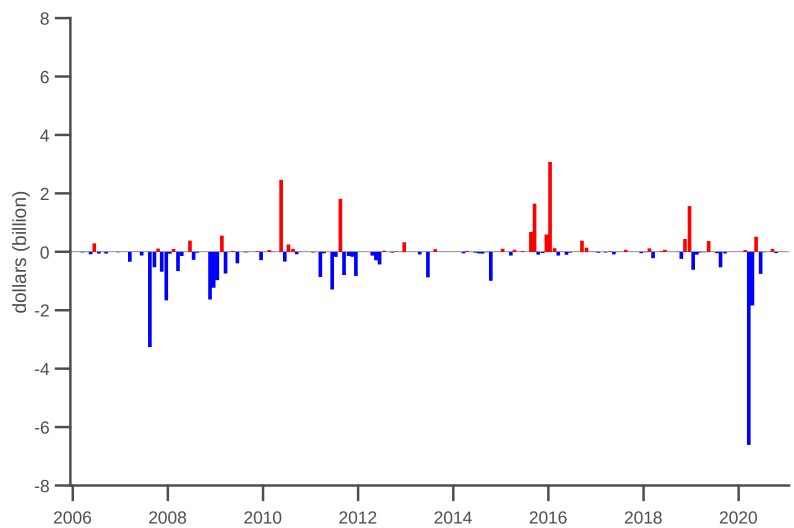


(b) Dow-Jones

Figure 5. 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.



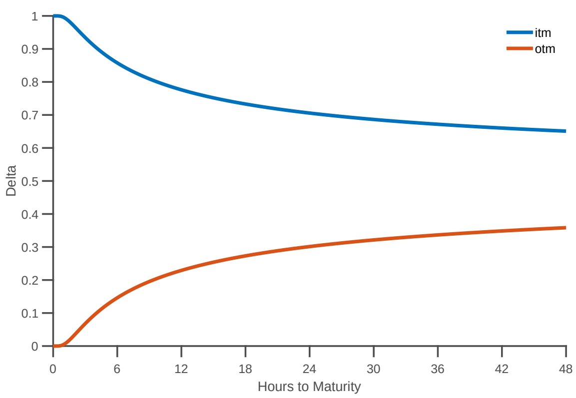
(a) Call options



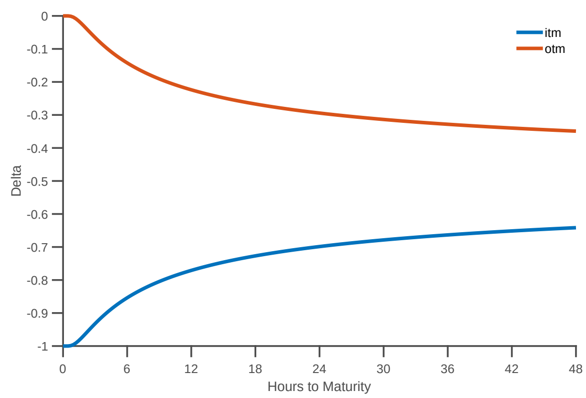
(b) Put options

Figure 6. Wealth transfer in SPX options

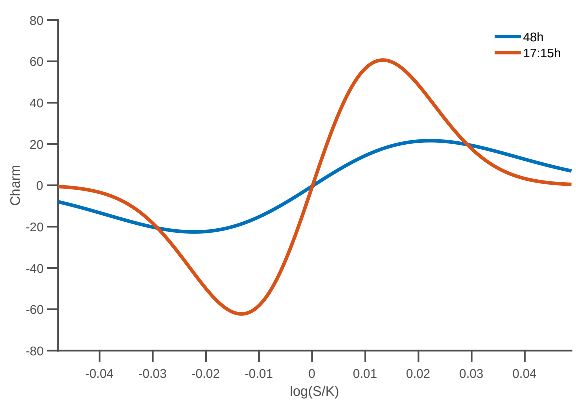
This table displays actual monthly SPX options payoffs at 3rd Friday open minus hypothetical payoffs if settlement occurred at the previous Thursday close instead. That is, the table shows the change in option payoffs due to the large positive price pressure in the S&P 500 from 3rd Thursday close to 3rd Friday open. 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.



(a) Call Delta



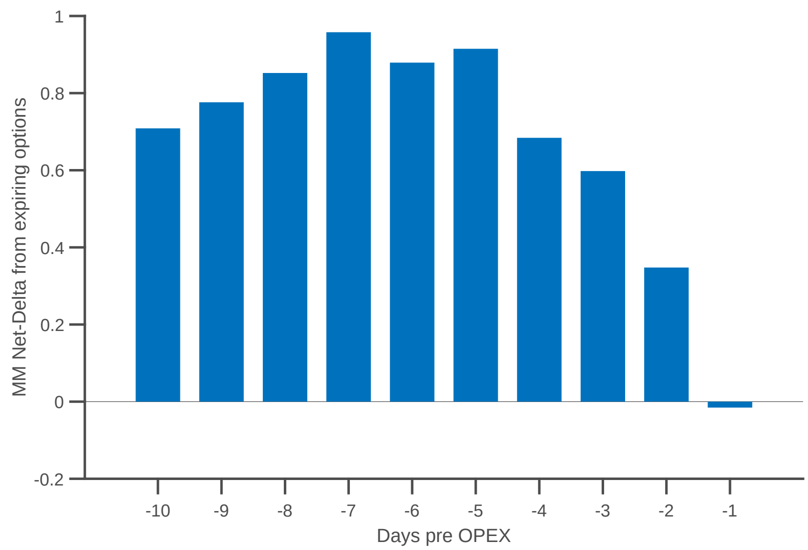
(b) Put Delta



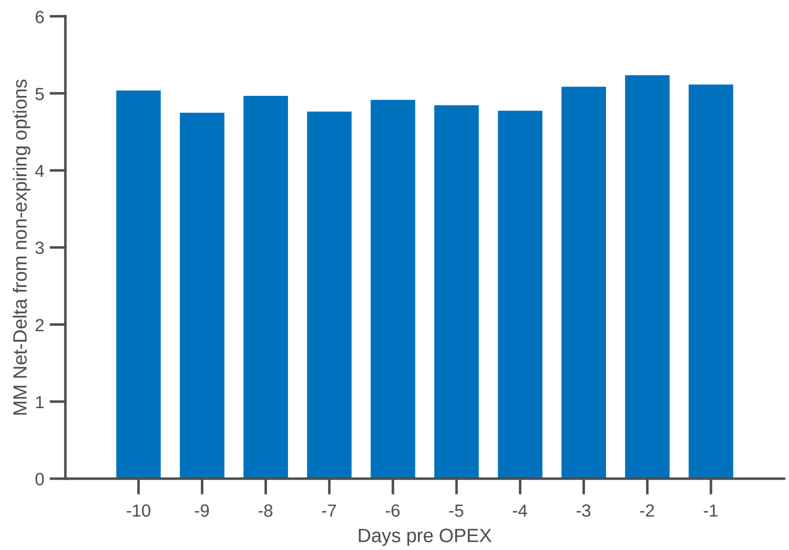
(c) Charm

Figure 7. 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 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.



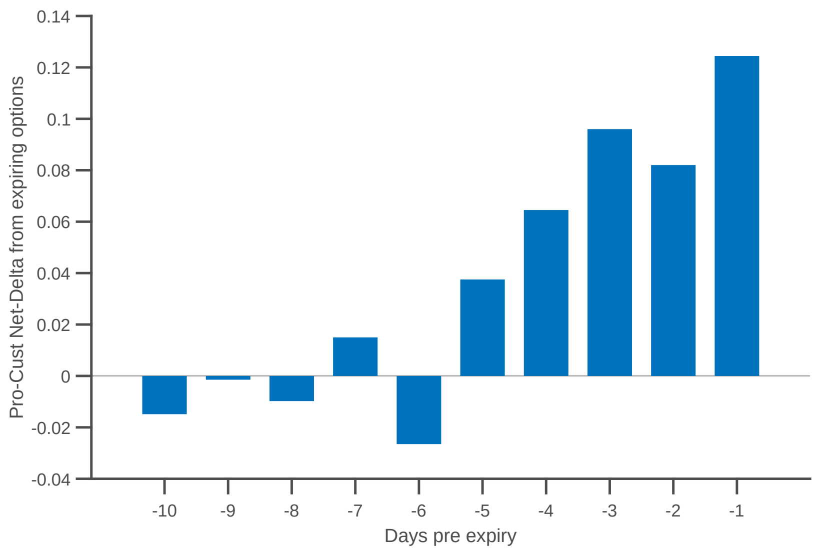
(a) Expiring options



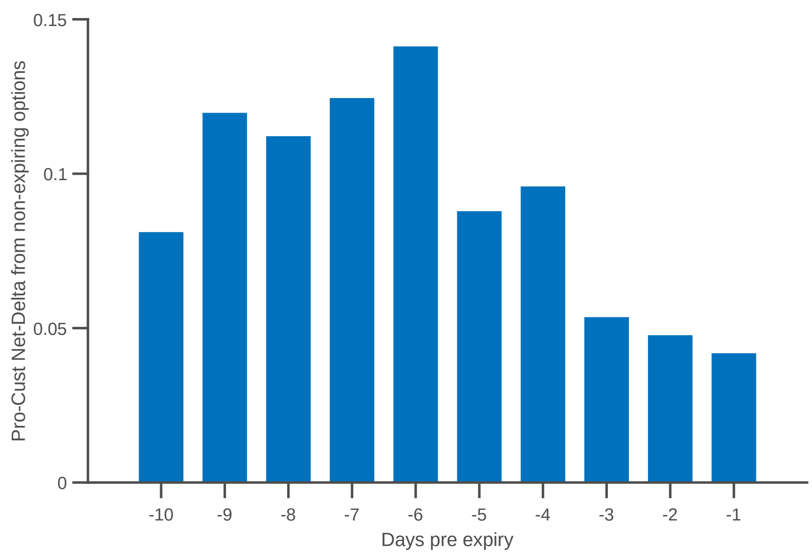
(b) Non-Expiring options

Figure 8. Positions into OPEX: Market Makers

The figure reports market maker positions in a.m. settled SPX options over the 10 days before 3^{rd} 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 9. Positions into OPEX: Pro-Customers

The figure reports professional-customer positions in a.m. settled SPX options over the 10 days before 3$^{\text{rd}}$ 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
	Panel a: *Full Sample (1992.11 to 2021.12)*			
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
	Panel C: *Early Sample (1992.11 to 2003.01)*			
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
	Panel B: *Late Sample (2003.01 to 2021.12)*			
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 3$^{\text{rd}}$ Friday of every month. Estimates are in basis points. The SOQ calculation is discussed in section III. SPX close prices are calculated on 3$^{\text{rd}}$ 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 3rd Fridays			
	CTO	OTC	CTC	We_c to Th_o	Th_o to Th_c	Th_c to Fr_o	Fr_o to Fr_c
				Panel a : SOQ / SPX			
mean	2.30	1.06	3.59	-3.17	-0.55	18.54	-16.91
mean(24H)	3.15	3.90	3.59	-4.34	-2.04	25.43	-62.42
t-stat	2.22	0.79	2.08	-0.91	-0.09	4.65	-2.99
Std	71.08	92.11	117.88	51.92	88.21	59.82	84.95
				Panel b : 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 S&P 500 E-mini futures at open and close. The sample period is 2003.2 to 2021.12.

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

Table 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 3^{rd} Friday price spike: Transaction costs

The first column reports summary statistics for a trading strategy that buys S&P 500 e-mini futures at 3^{rd} Thursday close, reverses into a short positions at 3^{rd} Friday open and closes the position at 3^{rd} 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	3.2	-5.6	-0.6	1.0
atm	1.8	-51.8	-33.1	-30.7
otm	-98.4	-98.1	-99.2	-97.7
	Panel B : Returns ($ mil.)			
itm	201.7	-70.2	60.8	-16.3
atm	11.9	-24.7	-16.4	-10.5
otm	-5.7	-15.0	-5.9	-15.5
sum	207.9	-110.9	38.5	-42.4

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 3^{rd} Thursday close to their final settlement value on 3^{rd} Friday open. Columns 3 and 4 report counter-factual returns, calculated via a hypothetical 3^{rd} 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 <= 0.99, atm if 0.99 < mnes <= 1.01 and otm if 1.01 < mnes <= 1.5. Puts are otm if 0.5 < mnes <= 0.99, atm if 0.99 < mnes <= 1.01 and itm if 1.01 < mnes <= 1.5. The total monthly wealth effect is calculated as the difference between actual and counter-factual dollar returns, summed over puts and calls. Returns are in percent. The sample period is 2003.02 to 2021.12.

	Calls			Puts			
	Fr Op	Th Cl	Diff	Fr Op	Th Cl	Diff	Σ Abs Diff
mean	7.32	7.04	0.29	2.89	2.98	-0.09	0.38
std	10.17	9.73	0.44	11.28	11.72	-0.44	0.88

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 3^{rd} friday via the SOQ. The call option settlement value is calculated as

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

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

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

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	
	3rd We	3rd Th	3rd We	3rd Th	3rd We	3rd 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	
	3rd We	3rd Th	3rd We	3rd Th
Market Maker Calls	-0.99	-1.34	0.26	0.05
Market Maker Puts	-7.00	-6.54	0.08	-0.07
Customer Calls	-1.61	-0.73	-1.50	-0.85
Customer Puts	5.48	4.70	-0.10	0.22
Firm Calls	2.60	2.08	1.23	0.80
Firm Puts	1.52	1.84	0.02	-0.15
Pro-Customer Calls	-0.27	-0.30	0.05	0.09
Pro-Customer 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.

Dependent Variable: Return Th_{close} to 3^{rd} Fr_{Open}		
Market Maker Charm	-0.10	-0.12
	[-0.19,-0.03]	[-0.04,-0.23]
Market Maker Gamma		0.15
		[0.23,0.07]
Market Maker Expiring-Delta		0.02
		[0.13,-0.10]
R^2	0.97	3.35

Table XI. Regression: S&P 500 return into Opex on Dealer Positions

We regress the over-night return of the S&P 500 equity index on lagged dealer positions. Returns are measured from thursday close to 3^{rd} friday open. Positions are measured at thursday close. Positions are as described in section A, except that all positions are divided by the number of expiring options contracts to control for the changing size of the options market and dealer sector. Left and right hand variables are standardized to zero mean and unit variance. Every second row reports block bootstrapped confidence intervals where the block size is chosen optimally following Patton, Politis, and White (2009). The sample period is 2006.1 - 2020.12. The period is shortened due to the availability of Dealer Positions.

Dependent Variable: Pro-Customer Net-Delta		
Market Maker Charm	-0.24	-0.24
	[-0.06,-0.39]	[-0.08,-0.40]
Market Maker Gamma		0.16
		[-0.07,0.35]
Market Maker Expiring-Delta		-0.04
		[0.14,-0.25]
R^2	5.61	8.28

Table XII. Regression: Pro-Customer Position on Dealer Position

We regress the option positions of professional customers on the positions of dealers. Both positions are measured at thursday close prior to the 3^{rd} friday a.m. option expiry. Positions are as described in section A. Left and right variables are standardized to zero mean and unit variance. Every second row reports block bootstrapped confidence intervals where the block size is chosen optimally following Patton, Politis, and White (2009). The sample period is 2011.1 - 2020.12. The period is shortened due to the availability of Pro-Customer Positions.

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 multiplier was $50 per index point (hence offering exposure of 5 times the index). Second, trading

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

[29] Stoll 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.

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.[30]

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.[31] 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).[32]

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.[33] 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 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, SPY options have the same features as individual U.S. stock

[30] See https://www.cmegroup.com/education/articles-and-reports/faq-conclusion-of-standard-sp-500-futures-and-options-trading.html.

[31] Since 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.

[32] The 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.

[33] At 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.

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.[34]

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 3^{rd} 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 3^{rd} Friday of the March-June-September-December cycle. Starting in June 1987, options on front-contract SPX futures trade on the quarterly expiry calendar.[35]

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 billion in 1996 to over \$100 billion a month towards the end of our sample. Next, we plot the monthly trading volume

[34] Options 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.

[35] Options on SPX futures also trade outside the quarterly expiry calendar. The OA describes these options in detail. 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 3^{rd} Friday of the month at the close price of that day.)

for SPX options versus options on the futures contracts in panel (b), showing that most volume resides in SPX options. Panels (c) and (d) illustrate that the standard 3^{rd} 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 3^{rd} Friday of March, June, September, and December. Liquidity providers and designated market makers complained to regulators that they were often unable to manage imbalances on their books due to the extreme volatility and volumes on these days.

On June 19th, 1987 an industry wide shift to a.m. settlement was actioned and the settlement price computed on 3^{rd} Friday mornings via the special opening quotation (SOQ). The SOQ is computed as follows. Index weights are computed from the opening (first reported) trade price of constituent stocks on their primary listing exchange.

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 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 Sections III and IV

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 3^{rd} 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.[36] 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]

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

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 push prices down intraday 3^{rd} 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 volumes during the 3^{rd} Thursday overnight trading window or during the 3^{rd} 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 3^{rd} 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 3^{rd} 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 3^{rd} Friday of each month). As the exact time of the SOQ is undetermined, these indices have to rely on other pre-determined procedure to enter new option positions. For these indices this is not directly at expiry but rather at noon of the expiry day. As a result the buywrite index has only a long S&P500 exposure between the SOQ and noon, while the putwrite index has no market exposure during these same window. Note that this occurs 12 times a year for about 2.5 hours. As document 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 3^{rd} Friday open to noon is of similar magnitude. We next decompose this return gap in expiry versus non-expiry days. Return differences on non-expiry days equal an insignificant -0.6% 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 3^{rd} 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 3^{rd} 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 3^{rd} Thursday and open on 3^{rd} 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).[37] 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 3^{rd} 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 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 3^{rd} 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 3^{rd} 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 3^{rd} 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 3^{rd} 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]

[37] 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.

Hypothesis H_{02}: Overnight Macroeconomic News. We next examine whether overnight news released overnight before 3^{rd} 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 3^{rd} 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 3^{rd} 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.[38] These series are released on 37 (inflation) or 90 (growth) of the 3^{rd} Fridays, mostly at 8:30 a.m., or an hour before market open. This timing seems hard to reconcile with the 3FPS pattern: a macroeconomic news-based explanation needs to explain rising equity prices from 3^{rd} 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 3^{rd} 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 3^{rd} 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 3^{rd} Friday p.m.

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

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.[39] 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 3^{rd} Friday expiration days tend to be higher. Although, Golez and Jackwerth (2012) fail to find significant evidence of pinning in the SPX SOQ on 3^{rd} Friday expiration days, pinning might cause the 3^{rd} Friday a.m. settlement prices to be biased upward and thereby explain the 3FPS effect documented above. We consider three tests to examine the role of pinning in the 3FPS: the distribution of equity prices around expiry, the difference in 3FPS on quarterly versus non-quarterly expiration's, and the impact of outstanding at-the-money open interest on the 3FPS.

HYPOTHESIS H_{03}: EXPIRY PRICE DISTRIBUTION. To examine an 3FPS explanation based on pinning we first compute the distance between equity index or futures prices in 3^{rd} 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 3^{rd} 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 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

[39] These 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.

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.[40] 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.

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 3^{rd} Friday trading.

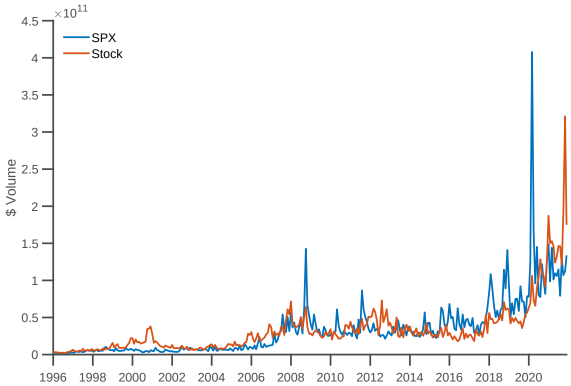
HYPOTHESIS H_{06}: FUNDING CONSTRAINTS. Models in which intermediaries are financially constrained predict that a tightening of funding constraints of market makers reduces their liquidity-provision capacity and thereby should increase price pressure effects. Funding constraints tend to tighten in times 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]

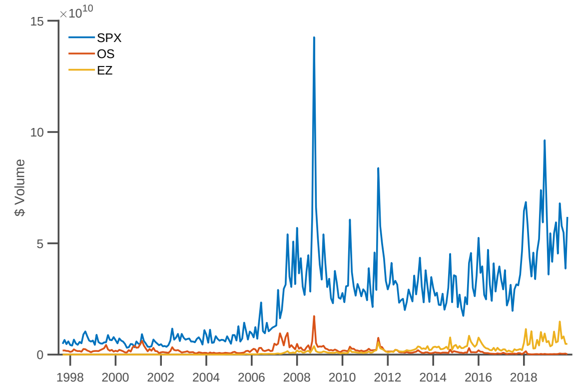
We test the impact of past returns by regressing it on the 3FPS reversal return. Table A.11 contains the results, revealing no significant effect of past 1-week to past 4-weeks returns on 3FPS reversal returns. Unreported analysis reveal the 3FPS reversal return is also unrelated to VIX levels or changes. Overall, we fail to find evidence supporting a link between non-fundamental shocks and 3FPS reversals.

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

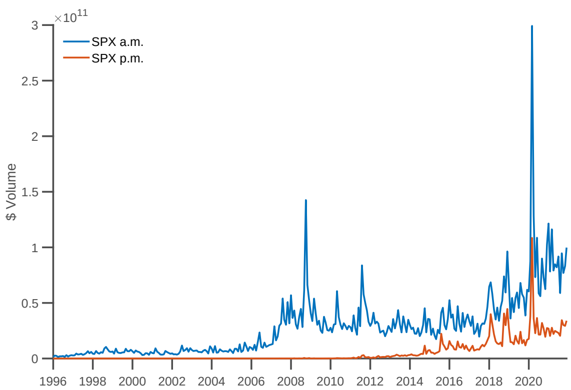
A.4. Figures



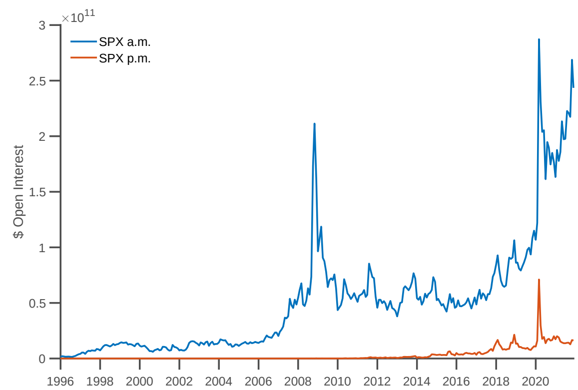
(a) Volume: Index options vs. stock options



(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.

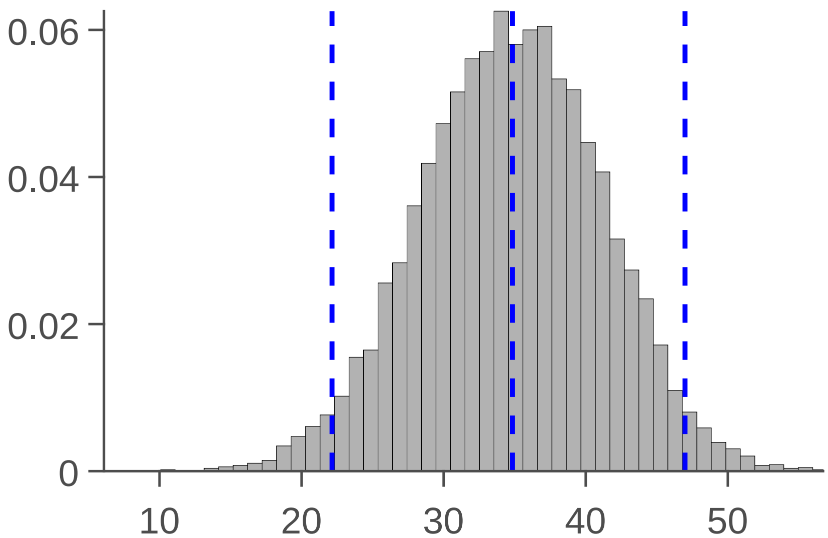


Figure A.2. Bootstrapped return differences

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.

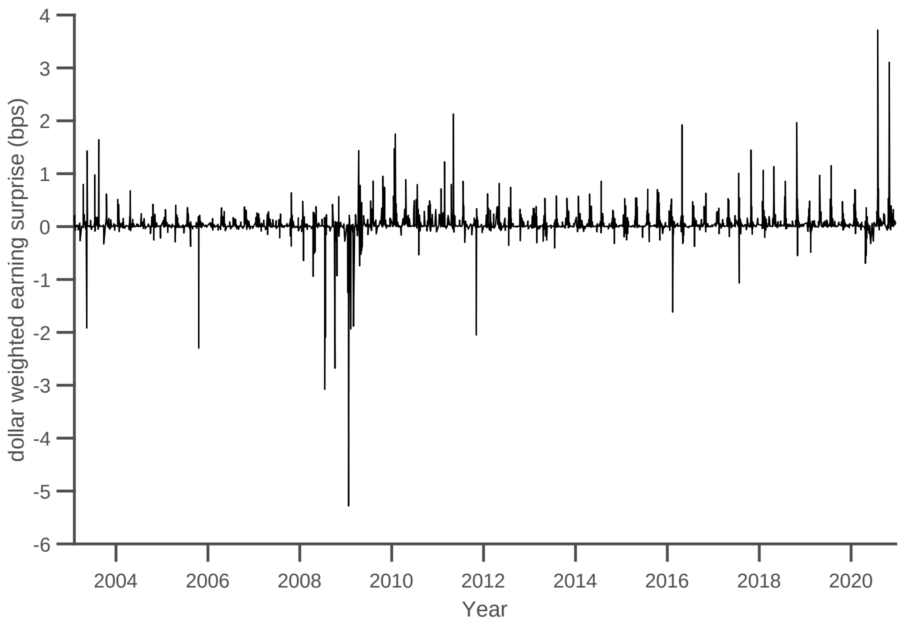
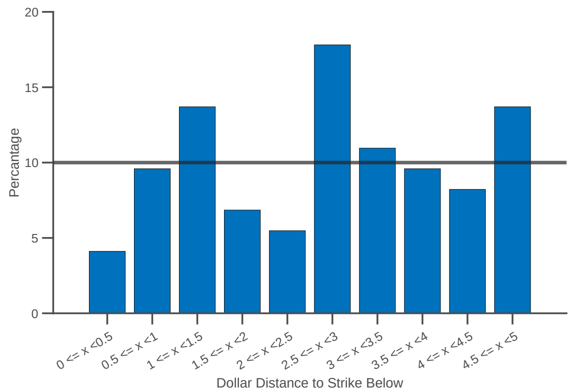
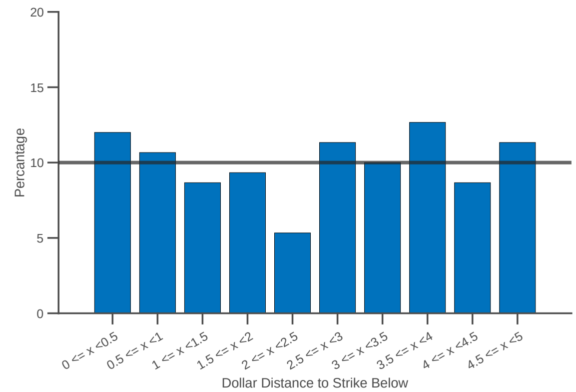


Figure A.3. Earnings Surprises from 12h to 24h

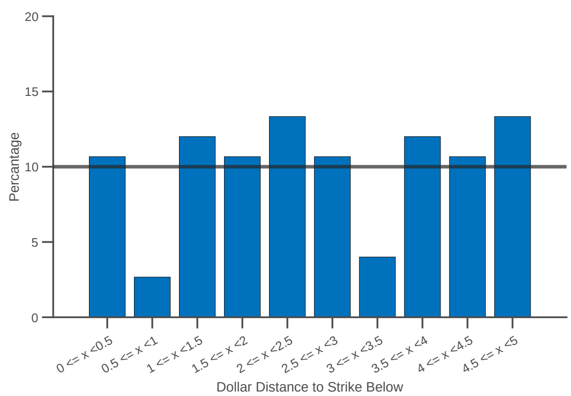
This figure displays the daily dollar-weighted earning announcement surprise of US public companies in IBES. We consider only announcements between 1200 and 2400 ET. The sample period is 2003.2 - 2021.12.



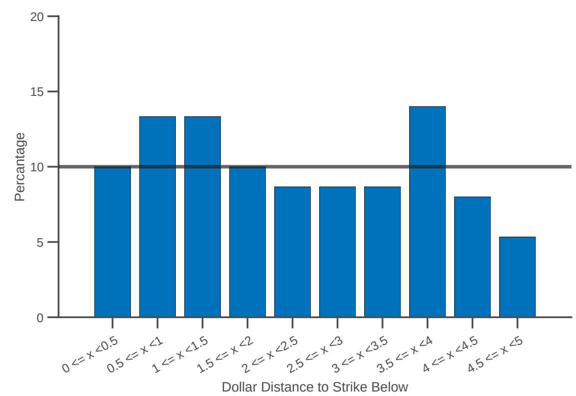
(a) ES qtr



(b) ES non-qtr



(c) SOQ qtr



(d) SOQ non-qtr

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 by at 10%. Panel a displays second-to-maturity S&P 500 e-mini futures on quarterly 3rd Fridays. Panel b displays first-to-maturity S&P 500 e-mini futures on non-quarterly 3rd Fridays. Panels c and d displays the S&P 500 SOQ on quarterly and off-qarterly 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 3^{rd} Fridays) and all other days. Rows 1 and 2 show that this difference is slighly 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 3^{rd} 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 3^{rd} 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 3^{rd} Friday open to SPX trades on 3^{rd} Fridays at 12:00. Returns are in basis points. The sample period is 2003.02 to 2021.12.

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

Table A.5. 3^{rd} **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 3^{rd} 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 occured 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.