The Derivative Payoff Bias

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Abstract

A significant fraction of U.S. equity index derivatives expire "a.m." on the 3^{rd} Friday of each month via constituent stocks' opening trade price. We show these prices are biased upwards since the advent of overnight trading in the early 2000s. Equity prices drift up from Thursday close to 3^{rd} Friday open and revert at the point derivative payoffs are calculated. As a result, equity futures and call option payoffs are biased upwards, while put option payoffs are biased downwards, generating a wealth transfer of ∼\$3.5 billion per year in S&P 500 index options alone. Exploring explanations, we show that a novel channel ("charm") originating from market makers' hedging practices represents a plausible explanation for the derivative payoff bias.

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

JEL Classifications: G10, G12, G13, G14.

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The majority of global index derivative trading activity is concentrated in products for which the S&P 500 index (the SPX) is the underlying. Moreover, a large fraction of SPX derivative open interest is "a.m.-settled", meaning these derivatives expire on the 3^{rd} Friday of each month with payoffs determined via the index Special Opening Quotation (SOQ).[1] However, despite its importance, the SOQ and associated derivative payoffs have received little attention in the academic literature. This paper studies U.S. equity index derivative payoffs.

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 basis points (bps), which is different to the unconditional close-to-SOQ return with a high level of statistical confidence (t-statistic = 3.5). The pre-2003 sample period displays no such effect, which we argue is due to the emergence of an active yet relatively illiquid overnight market in equity futures and single stocks around that time. An illiquid overnight market allows for the possibility of price pressures to affect a.m.-derivative payoffs. We discuss potential sources of price pressure below.

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 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.[2] We dub this empirical irregularity the 3^{rd} Friday Price Spike (3FPS) and document its presence in other major U.S. equity indices with a.m. settlements like the Dow Jones Industrial Average and Nasdaq 100 indices. The 3FPS is present in almost every year since 2003 and a trading strategy exploiting the 3FPS yields sizeable profits even after accounting for transaction costs.

Importantly, the 3FPS is confined to the a.m. settlement window. Several S&P 500 option derivatives do not settle into the SOQ but instead are p.m.-settled at market close on 3^{rd} Fridays.

[1]The SOQ is calculated from the opening sales price of index component stocks on their primary listing exchange and is available only once all component stocks have traded during the regular market session after 9:30:00 Eastern Time.

[2]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.

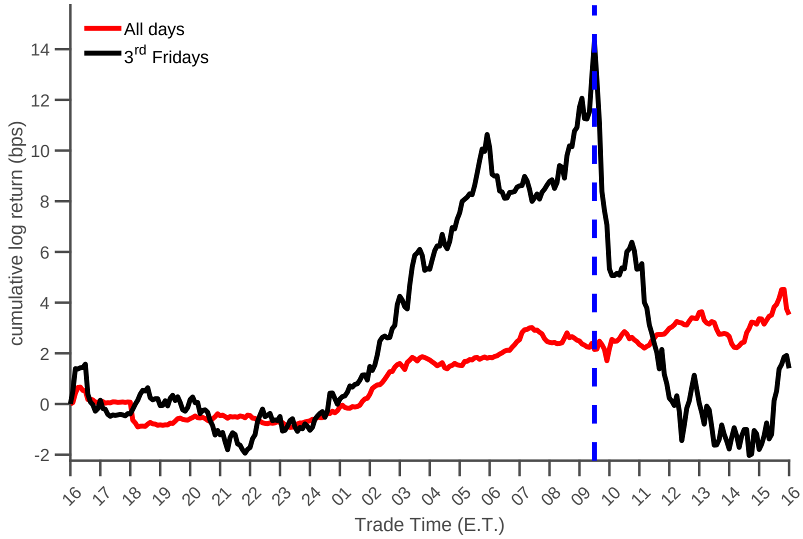

Figure 1. The 3^{rd} Friday Price Spike in S&P 500 E-mini Futures
The black line plots average cumulative 5-minute log returns of S&P 500 E-mini futures around 3^{rd} Friday market open (09:30, blue dotted line). The red line plots cumulative returns on all other days. The y-axis is in basis points and the x-axis is time of day in Eastern Time (E.T.). The sample period is 2003 to 2021.

Around the p.m. settlement window there is no corresponding pattern, highlighting the specialness of the a.m. settlement window.[3] Thus, the 3FPS is isolated in contracts that expire into the SOQ, i.e., with a.m. settlement and is 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 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?".

Addressing this question, we compute SPX index option payoffs at expiry. For counterfactual evidence, we replace the SOQ in the max operator, which determines option payoffs, with the SPX open price that would have occurred from an average non-expiry night return.[4] These calculations show that SPX call options paid off \$214 million a month, or \$2.6 billion a year, too much relative to their counterfactuals, representing a wealth transfer from call option writers to call option

[3] 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, and a.m or p.m settled S&P 500 index (SPX) options. The a.m settled options display the largest trading activity and are the most popular option contracts. Recently weekly and daily (zero-day-to-expiry; 0DTE) SPX options - options that settle in the p.m. window - have been introduced, the latter gaining substantial prominence the last years of our sample. 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 (Dim, Eraker, and Vilkov (2024)).

[4] That is, we obtain the counterfactual SPX open price on expiry days as the 3^{rd} Thursday SPX close price multiplied with 1.00013, which is the average non-expiry night return over our sample is 1.3 bps.

buyers. Similarly, SPX put options paid off ∼\$80 million a month, or \$1 billion a year, too little relative to their counterfactuals, representing a wealth transfer from put option buyers to put option writers. We interpret the sum of transfers in call and put options as the total wealth transfer of ∼\$3.5 billion per year. Testing the robustness of this finding, we compute the wealth transfer from option returns and obtain a quantitively similar estimate which, in addition, shows that the 3FPS is not priced into options at 3^{rd} Thursday close. Further, 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 sizeable option markets which are a.m. settled and also display a significant 3FPS.

What explains the bias in U.S. equity derivatives payoffs? We investigate potential explanations lifted from extant literature: 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 battery of empirical tests do not find support for these explanations and, instead, we focus on an alternative mechanism based on the hedging practices of market makers.

Motivating a price pressure-based channel, we show that (*i*) the 3FPS is stronger on days with more option expiration activity, and (*ii*) the 3FPS is also present in order imbalances which are orders of magnitude larger on expiry days compared to non-expiry days.

Exploiting option market maker (dealer) positions data, we confirm conventional wisdom that dealers face demand imbalances, since they typically hold short positions in equity index options. Resulting positions generate inventory risk, which dealers delta (Δ) hedge with offsetting positions in the underlying. If dealers have a long Δ position from expiring options they would be short the underlying and closing out their Δ-hedge into expiry might create the positive price pressure we observe. When examining net-Δ in expiring options, the relevant quantity for an unwinding Δ-hedges hypothesis, we find that dealers target their expiring option portfolio towards a zero net-Δ exposure in options alone. At expiry they do hold a small positive net-Δ position but this value is volatile around zero and displays no systematic pattern. We conclude that an "unwinding of Δ-hedges" explanation is unlikely.

Instead, we find support for a novel hedging based explanation: Charm ($\mathcal{C}$). Charm is the rate of change of option delta due to the passage of time and is most important for options that are close to expiration.[5] The intuition for $\mathcal{C}$ is as follows: Consider holding an out-of-the-money (OTM) call option that is about to expire. That options' delta is currently positive, but is dragged rapidly towards 0 over the coming hours ($\mathcal{C} < 0$), since, if nothing changes except time moving forward, the call option will expire out-of-the-money. Similarly, in-the-money (ITM) call options' delta is dragged towards 1 ($\mathcal{C} > 0$). The intuition for puts is symmetric: OTM (ITM) puts' delta is dragged towards 0 (-1). Charm can be large for options that are close to the money, while deep ITM or deep OTM options' delta is already 1, 0 or -1, so their $\mathcal{C}$ is close to 0. Thus, even if dealers have a zero net-delta 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, meaning their option delta drifts down and they need to buy equities to remain delta-hedged. This is exactly what we find. On 3^{rd} Thursdays at market close dealers, on average, have large negative net-$\mathcal{C}$, which implies they need to buy at least \$280 million worth of equities overnight to maintain a Δ-neutral position into expiry. This quantity explains the abnormal overnight \$306 million order imbalance that we document moved the market 18 bps upward on 3^{rd} Fridays.

Estimating a series of predictability regressions, we show that dealers' charm position robustly predicts the 3FPS. Considering first a univariate prediction on expiry days with net-$\mathcal{C}$ as a forecasting variable, we find an economically large, highly statistically significant (t-statistic = 2.99) negative coefficient, implying that the more negative is dealer net-$\mathcal{C}$, the more positive are overnight returns into option expiry. Moreover, we find an R^2 in this regression of 3%, which for return prediction measured over 17.5 hours is large. In a multivariate predictive regression, controlling for net-gamma (Γ) and net-Δ does not change the impact of net-$\mathcal{C}$. Consistent with our argument that an unwinding of Δ-hedges explanation is unlikely, we find the impact of net-Δ is insignificant. Additional tests confirm the impact of net-$\mathcal{C}$ on overnight returns is negligible on all non-expiry days; thus, the impact of $\mathcal{C}$ is confined to periods close to expiry, where we observe the 3^{rd} Friday Price Spike and biased derivative payoffs.

Studying "portfolio sort" type tests, we examine the conditional properties of the 3FPS. To this end, we divide our sample into terciles based on dealer net-Γ and net-$\mathcal{C}$ positions and find that overnight returns on 3^{rd} Fridays are monotonic in net-$\mathcal{C}$: the more negative is net-$\mathcal{C}$ the more positive are returns across net-Γ terciles. Moreover, overnight returns turn negative when

[5] Black-Scholes Charm is decreasing in time-to-maturity, is highly nonlinear 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.

net-$\mathcal{C}$ turns positive, consistent with the $\mathcal{C}$-hypothesis detailed above. Based on these three sets of findings, we conclude that a hedging channel due to option dealers' charm represents a plausible explanation for the 3FPS, which in turn explains the derivative payoff bias.

Concluding, we discuss broader implications of the 3FPS. First, the finding that $\mathcal{C}$-driven hedging can impact prices suggests that the surge in trading volumes of zero-day-to-expiry (0DTE) options may lead to a significant influence on intraday price dynamics. The reason is that charm is most pronounced for options with short times to expiration; thus, charm may become an increasingly important channel with the growing prevalence of 0DTE options. On the other hand, 0DTE options expire in the p.m. settlement window, a period when markets are substantially more liquid.

Second, the finding that prices are predictable before the a.m. option settlement window opens possibilities for predatory trading - trading that exploits the needs of others to change their positions. Investors aware of the overnight pricing pressures, or dealer net-$\mathcal{C}$ before the 3^{rd} Friday settlement, could anticipate the hedging trades and benefit from the resulting price pressures. Brunnermeier and Pedersen (2005) give numerous real world examples of predatory trading. Henderson, Pearson, and Wang (2020) find evidence of predatory trading around the pricing dates of structured equity products, impacting the prices of even the largest and most liquid U.S. stocks.

Third, price pressures in the underlying impacting derivatives payoffs opens up the possibility of market manipulation, since manipulators could push the underlying index price up in the period immediately preceding settlement, such that settlement prices move in the direction that benefits their position. Ni, Pearson, and Poteshman (2005) and Griffin and Shams (2018) present evidence suggesting that manipulators are active around option expiration dates for individual stocks and the VIX index. Theoretical models of manipulation identify three key factors that facilitate market manipulation: Differing price-order elasticities across markets, cash settlement, and a finite period to manipulate (Kumar and Seppi (1992) and Spatt (2014)), three conditions that are present before the a.m-settlement point. Equities trading pre-open is much less liquid than during regular trading hours with larger price impacts (Barclay and Hendershott (2003)), making the overnight window potentially suited for manipulation. Consequently, we argue that regulators should critically evaluate current settlement practices, especially settlements aligned closely with periods of illiquid trading.

Related Literature: Our paper contributes to several strands of literature, particularly to the 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 and well before the introduction of overnight equities trading. Golez and Jackwerth (2012) study the pinning of S&P 500 prices around option strike prices. Ni, Pearson, Poteshman, and White (2021) show that 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, amongst others, option market makers drives intraday momentum around market close times. Krohn, Mueller, and Whelan (2022) document prolonged intraday reversals in spot currency markets driven by inventory management practices of dealers. In addition, Dim, Eraker, and Vilkov (2024) find evidence that the charm exposure of option market makers in 0DTEs - exposure mainly present since 2020 - significantly impacts intraday volatility, although they do not focus on directional market impact. Different than these papers, we document price pressures around the a.m. expiry of S&P 500 options and offer a novel "Charm" explanation.

Our paper also contributes to literature on intraday price dynamics. Boyarchenko, Larsen, and Whelan (2023) show that U.S equity returns are large and positive overnight around the opening of European markets and driven by the inventory management of exchange trading market makers. We show that the 3FPS is unrelated to this overnight drift effect. Lou, Polk, and Skouras (2019) document strong overnight and intraday return continuation and an offsetting cross-period reversal at the individual stock level and in equity return factors (see also Bogousslavsky, 2021 and Hendershott, Livdan, and Rösch, 2020). Further, Heston, Korajczyk, and Sadka (2010) find evidence of intraday return seasonality (i.e. returns on individual stocks continue during the same half-hour intervals as during previous trading days) lasting from one day up to 40 trading days, which they argue is driven by temporary liquidity imbalances. Akin to the 3FPS, these effects show that price pressures can be systematic even in highly liquid markets.

I. Data

From Bloomberg, for the sample period 1992.1 - 2021.12 we obtain a daily S&P 500 index special opening quotation (SOQ) price.[6] Daily S&P 500 closing prices are also obtained from Bloomberg.

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

From Refinitiv, we collect 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.

From CBOE, we exploit the "Open-Close Volume Summary" dataset which provides daily buy- and sell volumes for all SPX options by option market participant sector. We focus on positions in SPX options that expire on 3^{rd} Fridays, and hence do not include the weekly (SPXW) or ODTE S&P 500 index options in our analysis. From 2006.01 to 2010.12 volumes are separated by "firms" and "customers", leaving "market makers" as the residual. From 2011.01 to 2021.12 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. We use the terms "market makers" and "dealer" interchangeably.

OptionMetrics provides us with end-of-day options data.[7] SPX options have a contract multiplier of 100. That is, one option is written on 100 units of the underlying equity index. Throughout the paper, we multiply option open interest and positions by 100, to obtain the respective measure in terms of units of the underlying. Additional details on the SPX positioning data and our calculations are reported in the Online Appendix (OA).

II. 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 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 Commod-

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

ity Futures Trading Commission(CFTC), the Chicago Mercantile Exchange (CME) and Chicago Board Options Exchange (CBOE) shifted their reference point for SPX settlement prices from p.m. (i.e., market close) to a.m. settlement (i.e., market open).[8] Since June 19th, 1987 (November 20th, 1992), the settlement price of quarterly 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 constituent stocks have opened for trading, and is typically published 30-45 minutes after market open. After the opening bell, many stocks in the index may not yet have opened due to a lack of - or imbalance between - buy and sell orders. Highly liquid, large-cap stocks usually trade close to the market opening time on their primary exchange. Less liquid stocks may take several minutes to open. Therefore, the SOQ is comprised of single stock trade prices from different points in time.[9]

Besides the monthly a.m. settled SPX options, the CBOE has introduced SPX options with other settlement practices over time. Notably, p.m.-settled options were reintroduced in 2007 with the SEC's PM Option Expiration Pilot program. Initially, these were options expiring on 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, zero-day (ODTE) options expiring daily.[10]

[8] 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.

[9] 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.

[10] 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 3^{rd} Friday of the month at the close price of that day.). The OA describes these options in more detail.

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. Overnight trading is an important tool to manage this risk.

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

[INSERT FIGURE 2 HERE]

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

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

[12] 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.

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

C. Special Opening Quotation Dynamics

Having summarized key details on settlement practices and trading, we next examine the dynamics in the SOQ. Panel (a) of figure 3 plots the (log) difference in basis points (bps) between the SOQ and the preceding closing trade price of the SPX, both obtained from Bloomberg[13]

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

[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 -

[13]In results available on request, we show the findings that follow are robust to computing closing prices from 5-minute volume weighted average prices measured between 15:55 and 16:00 Eastern time, which we compute from tick-level data obtained from Refinitiv.

the value weighted average of the SPX constituent traded prices - is systematically upward biased on 3^{rd} Fridays - when the SOQ determines derivative payoffs.

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

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 ReturnSOQ is close to zero on non-expiry Fridays, and, hence, the positive ReturnSOQ on expiry Fridays is not a reflection of a weekly (seasonal) Friday effect.

$\Big[$ INSERT TABLE I HERE $\Big]$

An interesting pattern emerges over the two sub-periods. Panel (b) shows that pre-2003 the ReturnSOQ_t (equation 1) was close to zero and insignificant on both expiry and non-expiry days (ReturnSOQ_t = -3.3 bps, t-statistic = -0.6). Panel (c) shows that post-2003 we observe a large positive ReturnSOQ_t on expiry Fridays, equal to 18.2 bps (t-statistic = 4.5) , a number that is 16.9 bps larger than on non-expiry days with a t-statistic on 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.

In summary, an economically large, statistically positive ReturnSOQ_t emerged on expiry days post 2003, coinciding with the advent of overnight trading in individual stocks and SPX futures.

The remainder of the paper documents stylized pricing facts, wealth implications, and economic explanations.

III. Pricing Bias

In this section, we study granular empirical facts about overnight and intraday returns. We compute returns on the SPX index from Bloomberg reported closing prices and the SOQ. For futures we computed intraday returns from 5-minute volume weighted average (VWAP) prices on E-mini futures.[14]

A. The Third Friday Price Spike (3FPS)

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 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. 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.

[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. 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}

[14] We use the front-month futures contract and roll into the next-to-maturity contract when it becomes more liquid, which typically occurs a few days before the quarterly futures expiry. We obtain very similar results when computing returns on quarterly settlement dates using the expiring futures contract until the moment it expires.

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]

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, the bulk which is earned in the CTO period, in line with the findings of Boyarchenko, Larsen, and Whelan (2023). 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) 3^{rd} Thursday overnight returns are abnormally large and *positive* equal to 18.2 bps, well exceeding the all day overnight return of 2.1 bps. Intraday returns on 3^{rd} Friday are also abnormally large but *negative* equal to -16.4 bps. Considering panel (b) the magnitudes of 3^{rd} Friday returns are slightly smaller but remains large, 5 times larger than its' all day counterparts, with CTO t-statistic of 3.5 and an OTC t-statistic of 2.4. Thus, the 3FPS is economically sizable and highly significant, both stand alone and relative to general overnight effects.

The 3FPS occurs nearly every year in our sample. To demonstrate its persistence, we consider a trading strategy that goes long the S&P 500 at market close, reverses into a short positions (via the SOQ) at open and closes this position at 3^{rd} Friday market close. Figure 4 displays the cumulative returns (panel a) and annual Sharpe ratio (panel b) of this trading strategy.[16] A $1 investment in 2003 grows to ~ $2.2 in 2021. The strategy earns positive returns in almost all years and annual Sharpe ratios that are generally large, with many exceeding 2. Table A.4 shows the persistence of the 3FPS in the presence of transaction costs. The 3FPS remains highly significant after transaction costs showing they have a small impact, reducing mean returns from 27 to 24 bps and t-statistics from 3.9 to 3.5.

[INSERT FIGURE 4 HERE]

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

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

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^{rd} Friday in September 2011[17], and more recently, zero-day (ODTE) options expiring daily. For most of our sample period the standard 3^{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 III repeats the analysis above for the subsample in which 3^{rd} Friday p.m. settled options were traded (i.e., 2011.09 onwards) and also includes the weekend return (Friday close to Monday open). Considering overnight Thursday and intraday 3^{rd} Friday the positive / negative return reversal pattern is also highly present over this subsample. In contrast, we find no significant weekend reversal effect as the return from Friday close to Monday open is not significantly different from zero. Hence, the 3FPS is confined to the 3^{rd} Friday a.m. settlement window with no reversal pattern existing around 3^{rd} Friday p.m. settlement. 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.

[INSERT TABLE III HERE]

C. 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

[17]See https://www.sec.gov/files/rules/sro/c2/2012/34-66140.pdf.

(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 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.[18] 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]

IV. Wealth Implications

Persistent positive overnight returns preceding 3^{rd} Fridays bias 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&P 500, the Russell 2000, the Nasdaq 100). We quantify the wealth implications induced by the derivative payoff bias and thus highlight its' economic significance. Adopting two approaches we compute (*i*) the wealth transfer from the realized payoff of SPX options, and (*ii*) the bias in realized SPX option returns. We consider a.m. settled SPX options only and, as a result, our estimates should be interpreted as a lower bound on the wealth transfer.[19]

A. Counterfactual Option Payoffs

First, we estimate a wealth transfer by comparing the realized payoff of all SPX options (calculated from 3^{rd} Friday SOQ) with a hypothetical payoff calculated from a counterfactual SPX open price. We calculate the counterfactual open price as the 3^{rd} Thursday SPX closing price multiplied by

[18] 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.

[19] Among others, we ignore futures options, options on other U.S. indices like the Nasdaq 100 and Russell 2000, and OTC options.

1.00013, which is the average non-expiry overnight S&P 500 return (see panel C of table I). 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.

The total call option settlement value is calculated as

$$SettlValue_{Calls} = \sum_{i}^{I} max(0, SOQ - K_i) \times OpenInterest_i \tag{2}$$

where I is the number of different expiring call option contracts and K is their strike price. The total put option settlement value is calculated equivalently as[20]

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

The counterfactual we consider replaces SOQ in the max operator with a counterfactual open price as outlined directly above.

Table IV shows that SPX call options paid off $10.44 billion on the average 3^{rd} Friday morning. Had their settlement been determined from the counterfactual open price, they would have paid off $10.23 billion. The difference of $214 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 $3.12 billion, yielding a wealth transfer from put option buyers to put option writers of $80 million a month. We interpret the sum of the wealth transfers in call and put options as the total wealth transfer and multiplication by 12 (expiries a year) yields our headline number of $3.5 billion annual wealth transfer.

Figure 6 displays this monthly difference in option payoffs from 3^{rd} Friday a.m. settlement versus counterfactual 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

[20]We obtain SPX options' open interest from OptionMetrics which is lagged by one day. We are not aware of an alternative data source for 3^{rd} Thursday close open interest.

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 IV are not driven by unique expiries, but are a pervasive feature of U.S. derivative markets.

[INSERT TABLE IV AND FIGURE 6 HERE]

B. Counterfactual Expiry Option Returns

Second, we show that the 3FPS does not only bias option *payoffs*, but also biases option *returns*. Biased returns do not mechanically follow from biased payoffs, since the 3FPS could be fully reflected in 3^{rd} Thursday option close prices, leading to ordinary overnight options returns into expiry. Our evidence goes against that hypothesis.

We compare expiring SPX options' actual returns into expiry to counterfactual returns and calculate actual expiry returns from options' mid-quotes at 3^{rd} Thursday close to their final payoff at 3^{rd} Friday open. Counterfactual returns are calculated from options' mid-quotes at 3^{rd} Thursday close to their counterfactual final payoff as described in subsection A. We consider only expiring SPX options and do not delta-hedge. Findings are reported by moneyness as discussed in the caption in table V.

Table V shows expiring SPX options returns into expiry. Panel A shows an average at-the-money call option returns from 3^{rd} Thursday close to 3^{rd} Friday open of 1.8%. In contrast, the average counterfactual expiry return for at-the-money call options is -33.2%. At-the-money put options experienced average returns of -51%, against counterfactual returns of -30.9%. To estimate a wealth transfer we examine option returns in dollar terms. To this end, we multiply the returns from above with options' lagged dollar open interest. Panel B of table V shows actual dollar expiry returns of call options was \$208 million against counterfactual expiry returns of \$39 million: the call return bias was \$169.6 million. Put options experienced actual expiry returns of \$-110 million against counterfactual expiry returns of \$-42 million: the put return bias was \$68.1 million. Again, we interpret the sum of the biases as the wealth transfer which is equal to \$2.8 billion per year, close to our alternative payoff estimate above. The wealth transfer estimate from option returns confirms the robustness of our wealth transfer estimate from payoffs and, in addition, shows that the 3FPS is not priced into options at 3^{rd} Thursday close.

[INSERT TABLE V HERE]

V. Potential Explanations

In this section we explore potential explanations. First, we study three candidate channels lifted from extant literatures: 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. For brevity, these analyses and extensive discussion are relegated to the OA. In this section we focus on testing a plausible alternative: price pressures generated by the inventory management of option market makers. Subsequently, we discuss the possibility of predatory trading and/or market manipulation by sophisticated investors but point out that this channel is ultimately untestable.

A. Trading Activity and Triple Witchings

To motivate an inventory management explanation we note that 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 Triple 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 VI 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-witching days, with a 3^{rd} Thursday overnight return of on average 26 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 (unreported) t-statistics equal to 3.9 and 3.3, respectively. Summarising, 3FPS effects are stronger on Triple Witching days but are also significantly present on the off-quarterly expiry days.

[INSERT TABLE VI HERE]

The results above suggests the existence of price pressure that pushes prices up overnight which revert intraday on 3^{rd} Fridays. We 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) and measure order imbalance by signed volume - the dollar volume of buyer minus seller initiated contracts traded in E-mini futures. Table VII contains summary statistics for all days and 3^{rd} Fridays.

Measured over all days signed volume is close to zero overnight and relatively small but negative intraday, consistent with the idea that futures are primarily a hedging instrument. On 3^{rd} Fridays, however, order imbalances are sizeable and positive overnight and significantly negative intraday. In terms of magnitudes, we observe an overnight order imbalance of $306 million, which relative typical overnight trading imbalances is very large.[21] Importantly, we note this was the realised trading quantity which moved the futures market 14 basis points on overnight leading into 3^{rd} Fridays, as depicted in figure 1, and it is this magnitude that we seek to explain below. Splitting 3^{rd} Fridays days into Triple Witching versus off-quarterly expirations we obtain a result directionally in-line with return magnitudes in table VI, with imbalances on Triple Witching days being larger than on off-quarterly expirations. Overall, these results are indicative of a price pressure-based explanation.

[INSERT TABLE VII HERE]

B. *Unwinding of Delta-Hedges*

Option market makers (dealers) 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 dealers 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 dealer 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 a dealer would short the

[21] Computed as $3.06 \times 1000\times$ a contract multiplier of $50\times$ an average SPX level over our sample of 2000.

[22] In practice hedging is implemented by Option Dealers in approximate replicating baskets of constituent stocks, but also in other linear derivative products like SPX futures and ETFs. Hedging trades are executed by "delta one" trading desks within equity finance or equity derivatives divisions of investment banks.

S&P 500 to obtain an approximate Δ hedge against directional moves in the S&P 500. At option expiry the dealer needs to close out their hedges, which, in our current example, means buying back the index into expiry. This could create positive price pressure and potentially explain the payoff bias that we document.

To examine a potential "unwinding Δ-hedges" explanation, we document the positions of option market makers in S&P 500 index options. 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.[23] We aggregate these daily volumes to cumulative positions for each group and compute an "representative market maker" from the residual of "firms" and "customers". The CBOE Open-Close dataset provides proprietary calculations for the first order Greeks and Γ and remaining relevant Greeks (discussed below) are computed from their Black-Scholes formula where consistent with industry practices we use option implied volatility as the input for σ.

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

[INSERT TABLE VIII HERE]

In contrast, the second column of table VIII reports *only* option positions at 3^{rd} Thursday close, which are due to expire the next morning and are therefore relevant for an unwinding Δ-hedges hypothesis. The first row shows that on average on the Thursday before option expiry dealers are short 1.52 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. Dealers 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. On 3^{rd} Thursday close, market makers have an average net delta from expiring calls (puts) of 50 thousand (20 thousand). The two lead to a total market maker net delta from

[23] In the tests which follow we allow for a 6 month burn-in period to obtain running option positions. The inclusive sample period is 2006.7 - 2020.12.

expiring options positions close to 70 thousand. Delta hedging would involve a short-position of 70 thousand units of the S&P 500 index. If market makers trade out of their potential Δ-hedges as their options positions expire, they would need to purchase approximately 70 thousand units of the index, which amounts to approximately $140 million. ($70000 \times 2000$). Thus, price pressure from expiring options' Δ-hedges represents a possible explanation of the derivative payoff bias. However, below we show that market makers expiring net-Δ position does not predict the 3FPS.

Figure 8 examines the market maker net-Δ 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 all other options (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, dealers trade such to reduce their directional exposure in options alone, ending up with a significantly reduced net-Δ in expiring options at Thursday close. This patterns stands in sharp contrast to the pattern in option positions of non-expiring options; dealers 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 towards zero in anticipation of expiring options.

Exploring this channel further, Panel (a) of figure 9 displays time-series of dealer net-Δ from expiring 3^{rd} Friday options and the red dots highlight positions at close on 3^{rd} Thursdays. While the average 3^{rd} Thursday net-Δ is positive, the time-series is volatile around zero displaying no clearly systematic variation which is difficult to reconcile with the unconditional tent-shaped return pattern from figure 1 or the 3^{rd} Friday order imbalance pattern reported in table VIII. We conclude that a simple "unwinding of Δ-hedges" is an unlikely explanation for the 3FPS.

[INSERT FIGURES 9 AND 8 HERE]

C. Expected Delta-Hedging

Next, we consider an explanation based on expected delta hedging before the derivatives settlement window. Expected hedge rebalancing by dealers equals the negative of the change in market maker Δ. Consider the Black-Scholes diffusion setting where the index follows $dS/S = \mu dt + \sigma dW^{\mathbb{P}} = rdt + \sigma dW^{\mathbb{Q}}$. An application of itô's lemma reveals

$$\frac{1}{dt} E_t^{\mathbb{P}}[d\Delta_t] = \mu S_t \Gamma_t + \frac{1}{2}\sigma^2 S_t^2 \text{Speed}_t + \text{Charm}_t \tag{4}$$

where $\Gamma = \frac{\partial^2 V}{\partial S^2} = \frac{\partial \Delta}{\partial S}$, Speed $= \frac{\partial^3 V}{\partial S^3} = \frac{\partial \Gamma}{\partial S}$, and Charm $= \frac{\partial \Delta}{\partial t}$. Γ is well known. "Speed" ($\mathcal{S}$), on the other hand, is less well known being a third order Greek defined as the rate of change of Γ with respect to the underlying. Ignoring the index dividend yield, for a European option the Black-Scholes $\mathcal{S}$ is given by

$$\mathcal{S}_t = \frac{\partial \Gamma}{\partial S} = -\frac{\Gamma}{S}\left(1 + \frac{d_1}{\sigma\sqrt{\tau}}\right) \tag{5}$$

which is identical for puts and calls and shows that $\mathcal{S}$ is proportional to Γ.

"Charm" ($\mathcal{C}$) is another higher order Greek defined as the rate of change of Δ with respect to the passage off time. Again, ignoring the index dividend yield, for a European option the Black-Scholes $\mathcal{C}$ is given by

$$\mathcal{C}_t = \frac{\partial \Delta}{\partial t} = -\frac{\partial \Delta}{\partial \tau} = -\frac{\partial^2 V}{\partial S \partial \tau} = \frac{\partial \Theta}{\partial S} \tag{6}$$

$$= \frac{1}{\sqrt{2\pi}} e^{\frac{-d_1^2}{2}} \left(\frac{d_1}{2\tau} - \frac{1}{\tau}\left(\frac{r}{\sigma} + \frac{\sigma}{2}\right)\right) \tag{7}$$

which is symmetric for puts and calls. $\mathcal{C}$ 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 dealers 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 expiry the delta of a call option will be either 1 or 0, and just before expiry as $\tau \to 0$ Charm is large. Panel (c) displays the 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 ($\log \frac{S_t}{K}$).

[INSERT FIGURE 7 HERE]

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

Since $\mathcal{S}$ is proportional to Γ one can write expected Δ rebalancing as

$$\frac{1}{dt} E_t^{\mathbb{P}}[d\Delta] = \alpha S \Gamma_t + \mathcal{C}_t \tag{8}$$

$$\alpha = \left(\mu - \frac{1}{2}\sigma^2 \left(1 + \frac{d_1}{\sigma\sqrt{\tau}} \right) \right) \tag{9}$$

so that a test of this channel only requires empirical counterparts to Γ_t and $\mathcal{C}_t$.[24]

D. Testing the Expected Delta-Hedging Channel

D.1. Market Maker Positions

Even if dealers have a close to zero net-Δ position on 3^{rd} Thursdays, as we observe empirically, if for some latent reason they are long (short) OTM (ITM) calls and long (short) ITM (OTM) puts their net-$\mathcal{C}$ would be negative and drive their net-Δ *down* overnight; thus, to maintain a Δ neutral position, dealers would buy S&P 500 component stocks (or associated products) as expiry approaches. We compute dealers net-$\mathcal{C}$ using CBOE positions data as outlined above. The final column of table VIII shows dealers indeed need to buy S&P 500 stocks overnight as expiry approaches, as they hold negative $\mathcal{C}$ on both call and put sides of their trades. More specifically, we find that at the average 3^{rd} Thursday close dealers have a net $\mathcal{C}$ position of \$-48.1 million. Thus, their inventory net-Δ from SPX option positions, expressed in dollar terms to highlight price pressure, mechanically falls by approximately \$278 million over the next 17 hours and 15 minutes.[25] That is, market makers need to purchase about \$278 million worth of U.S. equities in illiquid overnight markets to remain delta-hedged. This number is close to the 3^{rd} Friday overnight order imbalance shown in table VI of \$306 million.

Panel (b) and (c) of figure 9 displays dealer net-Γ and net-$\mathcal{C}$ for all days in 3^{rd} Friday expirations and the red dots highlight positions at close on 3^{rd} Thursdays. Panel (b) shows that, aside from the years 2006 - 2008, net-Γ oscillates around zero on expiry days. Panel (c) shows a more striking pattern; dealer net-$\mathcal{C}$ is substantially more negative than positive on expiry days relative to all

[24] Into option expiration $\lim_{\tau\to 0} \text{sign}(\alpha) = \lim_{\tau\to 0} \text{sign}\left(\mu - \frac{1}{2}\sigma^2\left(1 + \frac{\ln(S/K)}{\sigma^2\tau} + (\frac{r}{\sigma} + \frac{1}{2}\sigma)\right)\right) = -\text{sign}\left(\frac{S}{K}\right)$

[25] With the index level at an average of 2000 the calculation is $\frac{-48.1e^6 \times 2000 \times 17.5}{252 \times 24} = -278e^6$ to adjust charm to the relevant expiry horizon of 17.5 hours.

other days. The majority of the red dots are well below the zero line.

D.2. Predictability Regressions

Exploring the $\mathcal{C}$-hedging channel further we estimate predictability regression of SPX overnight returns on lagged dealer positions measured at Thursday close. Considering again equation 8 the relevant empirical quantity that should predict returns is $\int_t^{t+17.5h}(\alpha_u S_u \Gamma_u + \mathcal{C}_u)dt$. Panel (c) and (d) of figure 7 show that, even in a Black-Scholes world, $\mathcal{C}$ is highly nonlinear in time-to-maturity. Taking a practical perspective, we estimate the path of overnight $\mathcal{C}$ as $\mathbb{E}_t[\text{net}\Delta_{t+1}] - \text{net}\Delta_t$, where $\text{net}\Delta_t$ is dealers' net-delta position at market close and $\mathbb{E}_t[\text{net}\Delta_{t+1}]$ is dealers' expected net-delta position at the subsequent market open. We estimate $\mathbb{E}_t[\text{net}\Delta_{t+1}]$ equivalently to $\text{net}\Delta_t$, which is described above, only that we move τ forward by 17.5 hours when calculating options' delta. In other words, we compare dealers' actual net-delta at market close to the dealer net-delta that will materialize if nothing changes except time moving forward by 17.5 hours. Thus, we capture in one number the full overnight drift in dealer net-delta that occurs due to charm. Note also that this approach does not use forward looking information. Table IX reports regression estimates.

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 dealers' net-$\mathcal{C}$, the more positive are overnight returns. Moreover, we obtain an R^2 in this regression of 3.2% which for return prediction measured over 17.5 hours is large. Considering a multivariate prediction controlling for net-gamma (Γ) and net-Δ does not change the impact of net-$\mathcal{C}$. Consistent with our argument regarding an unwinding of Δ-hedges explanation we find the impact of net-Δ is insignificant.

Triple Witching days involve most expiry activity and the 3FPS is larger on these days. The reader might be concerned that predictability is only coming from these days. Addressing this concern, we consider only the off-quarterly expiry days. Columns 3 and 4 show point estimates and significance are similar. This result indicates that price pressure from charm-driven hedging originate from SPX options positions across expiry days, and is not specific to Triple Witching days or activity from futures contracts or futures options, which expire only on quarterly dates. Next, we consider non-expiry days for which we expect charm to have little impact due to its maturity dependence (recall that charm only becomes economically relevant very close to expiry). As expected, on non-expiry days there is no significant predictable variation in overnight returns arising from dealers' net-$\mathcal{C}$ and the R^2 is very close to zero. The final column shows there is also no effect over weekends, periods when the passage of time is the largest, but for which net-$\mathcal{C}$ is small due to maturity dependence.

[INSERT TABLE IX HERE]

D.3. Double Sorts

We examine the conditional impact of gamma versus charm on the derivative payoff bias via "portfolio" sorts. To this end, we divide our sample into nine subsamples by sorting expiry days into terciles based on dealer net-gamma and subsequently into terciles based on dealer net-charm as measured at 3^{rd} Thursday close. Table X reports the overnight effect (panel a), and resulting charm (panel b) and gamma (panel c) positions of dealers. In line with earlier results we see that the smaller (i.e., more negative) 3^{rd} Thursday charm the more positive is the overnight return. This result is monotonic and holds across gamma terciles. When charm is positive (i.e., tercile "Large") the derivatives payoff bias is close to zero across all expiries. Finally, we focus on off-quarterly expiry days only - days when markets are not impacted by the tremendous amount of futures and related derivative expiry activity - and our net-charm measure is likely to be more precise. These results are again monotonic across gamma terciles but now we see that on days with positive charm we observe a negative expiry return of between -6 to -11 bps, as one might expect from a charm-based hedging channel. Hence, the 3^{rd} Friday Price Spike is positive on average because dealer charm is negative on average, but can flip sign when dealer charm is positive. In summary, the evidence presented in this section suggests expected delta hedging due to $\mathcal{C}$ is a plausible explanation for the derivative payoff bias.[26]

[INSERT TABLE X HERE]

E. Predatory Trading and Market Manipulation

The finding that prices are predictable before the a.m. option settlement window opens possibilities for predatory trading - trading that exploits the needs of others to change their positions. Investors aware of the overnight pricing pressures or dealers net-$\mathcal{C}$ before the 3^{rd} Friday settlement could

[26] While plausible we acknowledge that charm may not be the only factor driving the derivative payoff bias. As we outline in the following other forces might be at work that could cause upward price pressures 3^{rd} Friday overnight, forces that are very hard to test.

anticipate the hedging trades and benefit from the resulting price pressures. Brunnermeier and Pedersen (2005) give numerous real world examples of predatory trading. Henderson, Pearson, and Wang (2020) find evidence of predatory trading around the pricing dates of structured equity products, impacting the prices of even the largest and most liquid U.S. stocks.

Related, underlying price pressures that impact derivatives prices gives rise to the possibility of market manipulated, as manipulators could push the underlying index price up in the period immediately preceding settlement, such that settlement prices move in the direction that benefits their positions. Ni, Pearson, and Poteshman (2005) and Griffin and Shams (2018) present evidence suggesting that manipulators are active around option expiration dates for individual stocks and the VIX index. Evidence on stock price manipulation is, for example, provided by Carhart, Kaniel, Musto, and Reed (2002) who show that fund managers inflate year-end portfolio prices through trading in order to optimize performance numbers, which generated a one time year-end reversal in single stocks - closely resembling the 3^{rd} Friday pattern documented in this paper. Theoretical models of manipulation identify three key factors that facilitate market manipulation: differing price-order elasticities across markets, cash settlement, and a finite period to manipulate (Kumar and Seppi (1992) and Spatt (2014)), three conditions present before the a.m-settlement point. Equities trading pre-open is much less liquid than during regular trading hours with larger price impacts (Barclay and Hendershott (2003)), making the overnight window potentially suited for manipulation. However, as these channels are very difficult to directly test and could, at best, be illustrated with suggestive analyses. We leave further examination of predatory trading or market manipulation channels to regulatory bodies.

VI. Conclusions

We document a significant bias in U.S. equity index derivative payoffs. On the 3^{rd} Friday of each month, when a large fraction of equity index options and other derivatives payoffs are calculated via the Special Opening Quotation (SOQ), the S&P 500 SOQ exceeds the previous day's closing price by an average of 18 basis points. This large positive return reverses intraday after derivative payoffs are calculated, giving rise to a Third Friday Price Spike (3FPS) in equity prices. This pattern has emerged alongside the rise of an active, yet relatively illiquid, overnight trading market in the early 2000s and is broadly observed across U.S. equity indices.

The Third Friday Price Spike has substantial economic consequences. It is sizable also after accounting for transaction costs, and, importantly, skews U.S. index call and put option payoffs upward and downward, respectively. We estimate that the resulting wealth transfer between option investors amounts to at least \$3.5 billion per year.

We attribute the Third Friday Price Spike to a previously undocumented price pressure channel, stemming from the hedging practices of option market makers whose positions are exposed to "charm". As expiry approaches, charm-driven adjustments to delta hedges generates price pressure that can have significant impact during the illiquid overnight period. Charm is most pronounced for options with short times to expiration that are near the money; thus, charm may become an increasingly important channel given the growing prevalence of zero-day- to-expiry options. Consequently, we argue that regulators should critically assess current settlement practices, particularly those aligned with periods of illiquid trading.

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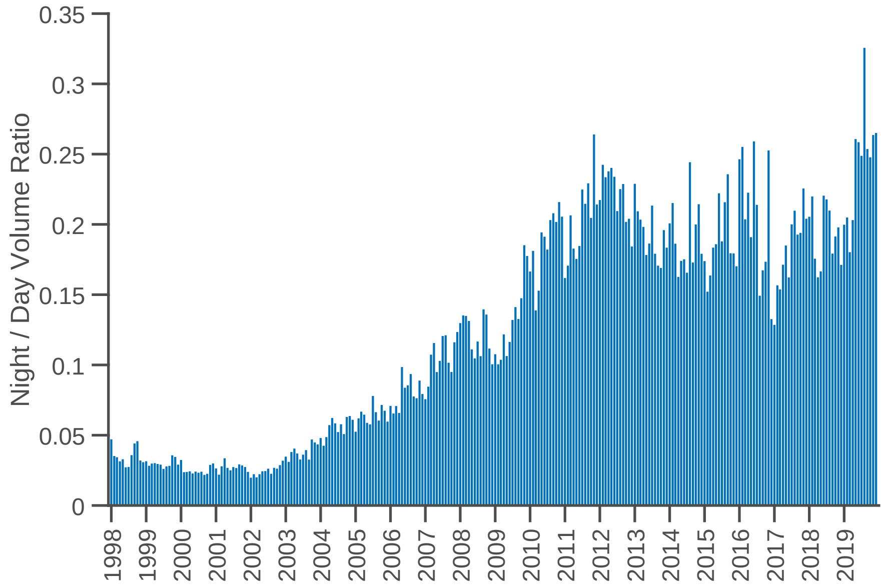
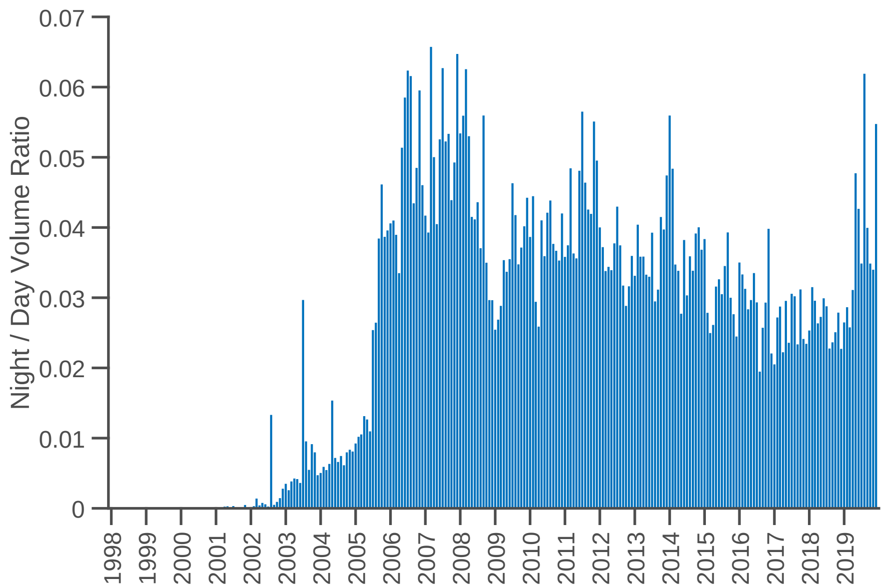
VII. Appendix: Figures



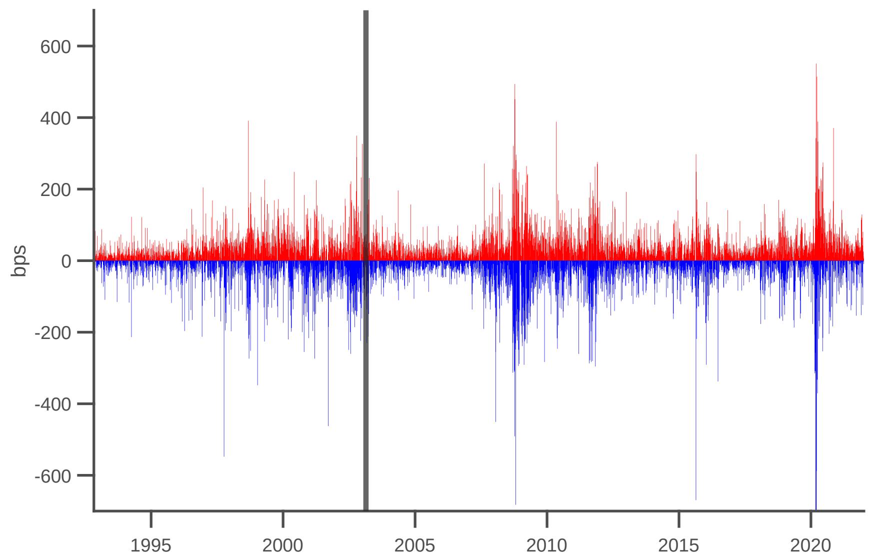
(a) Futures: ES and SP



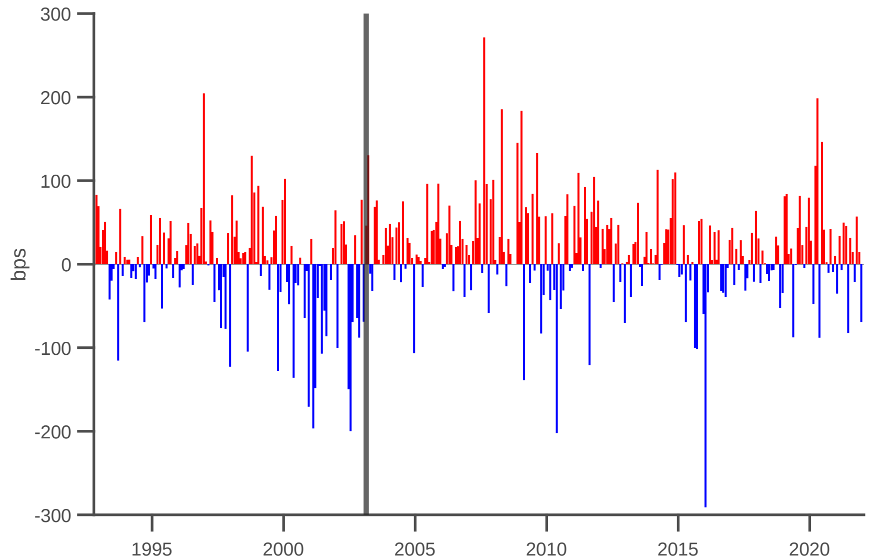
(b) ETF: SPY

Figure 2. Volume Ratios: Night vs. Day

These figures plot the ratio of trading volumes overnight (18:00 p.m. to 09:30 a.m.) to trading volumes during regular market hours (09:30 a.m. to 16:00 p.m.). Panel (a) contains the sum of regular "SP" S&P 500 futures and E-mini "ES" S&P 500 futures. Panel (b) contains the SPDR ETF (SPY). Trading volume is measured in number of contracts.



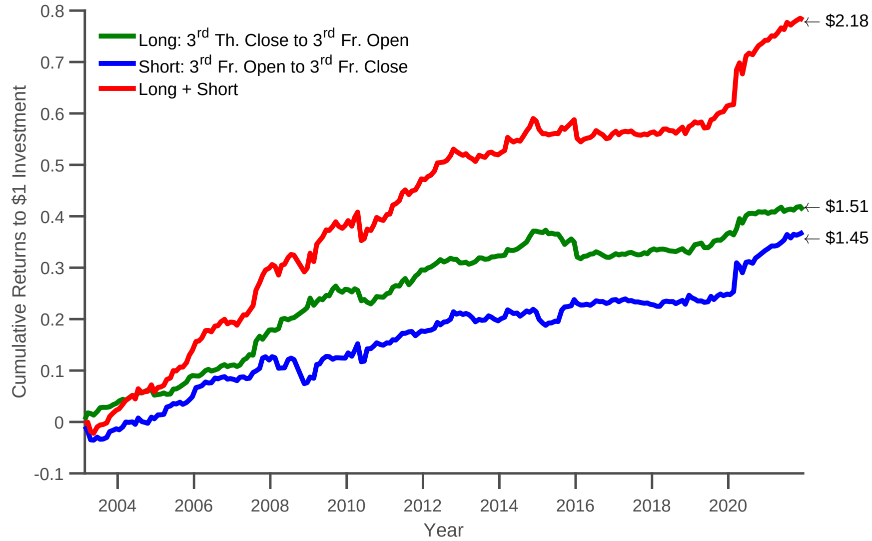
(a) All Days



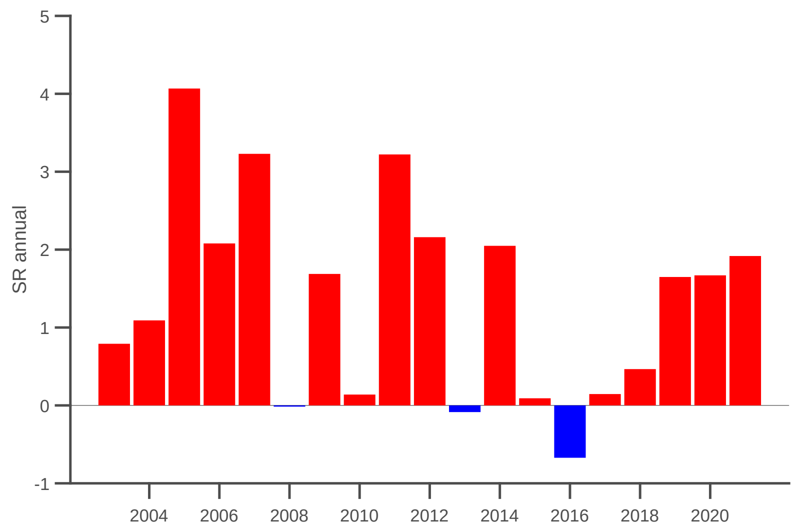
(b) 3^{rd} Fridays

Figure 3. SOQ vs. SPX Close Prices

This figure plots the times-series of returns from equation 1. Panel (a) contains all days in our sample while panel (b) contains only returns into 3^{rd} Fridays. The vertical line shows 2003.02, the start of our main sample.

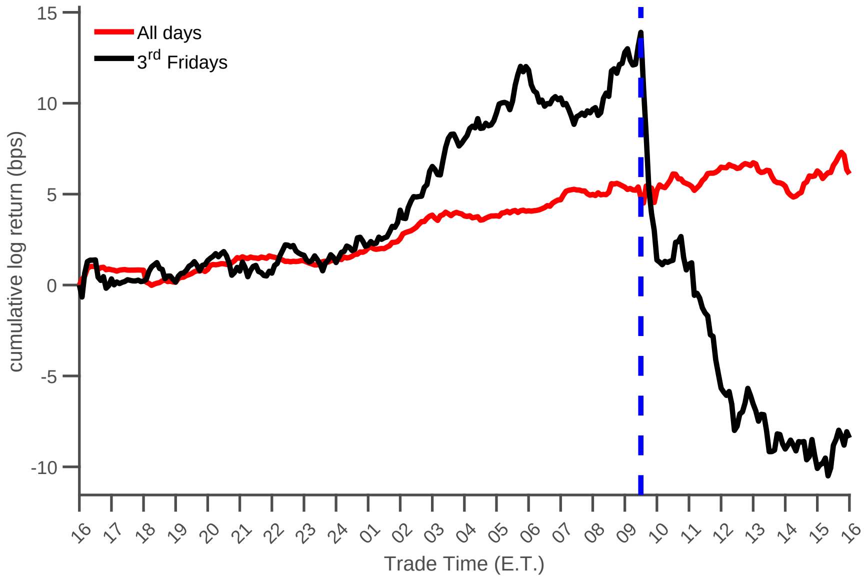


(a) Cumulative Returns

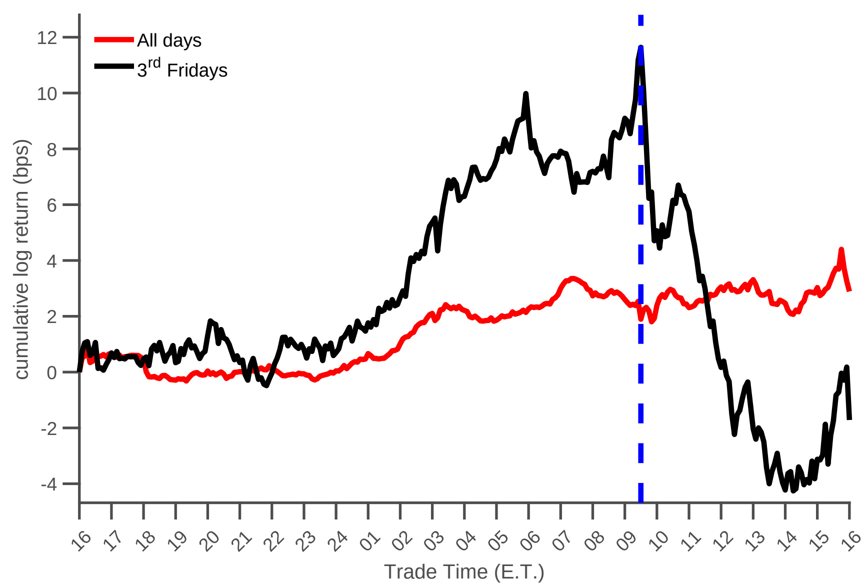


(b) Annual Sharpe Ratio

Figure 4. Trading the 3rd Friday Price Spike
In panel (a) the blue line plots the cumulative returns of the reversal strategy which goes long the S&P 500 at market close, reverses into a short positions (via the SOQ) at open and closes this position at 3rd Friday market close. Panel (b) displays the Sharpe ratio of the strategy by year.



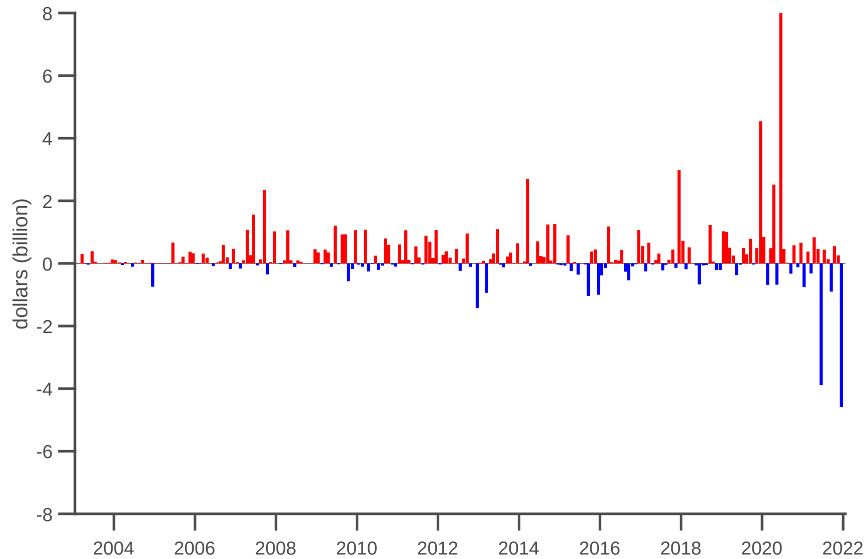
(a) Nasdaq



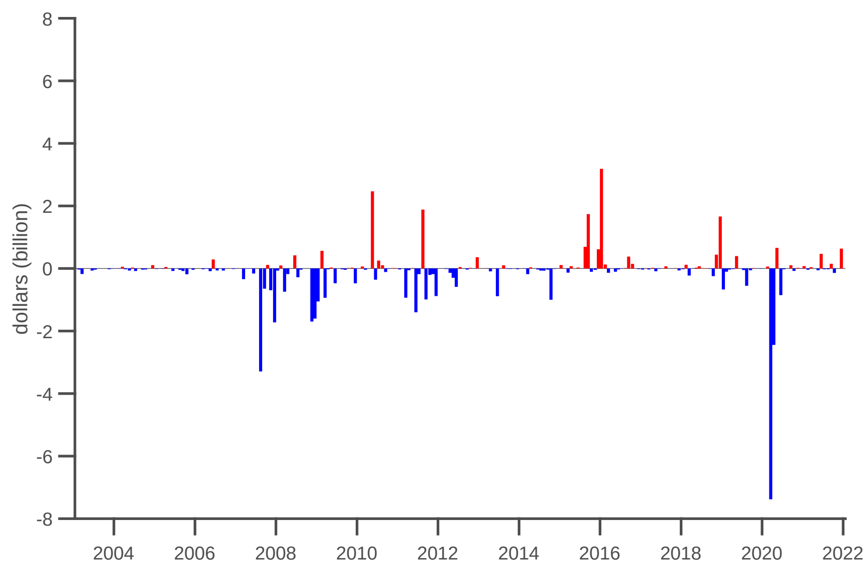
(b) Dow-Jones

Figure 5. 3^{rd} 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 3^{rd} Friday market open (09:30 a.m., 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 (E.T.).



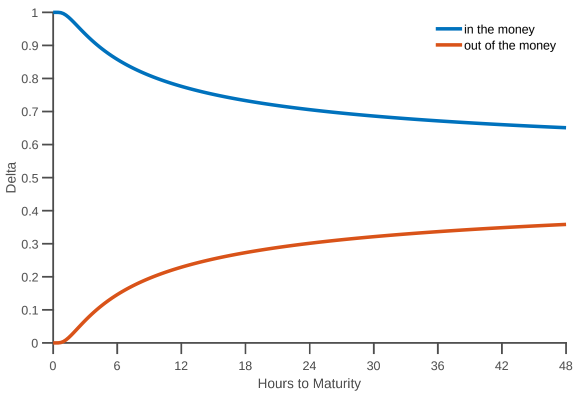
(a) Call Options



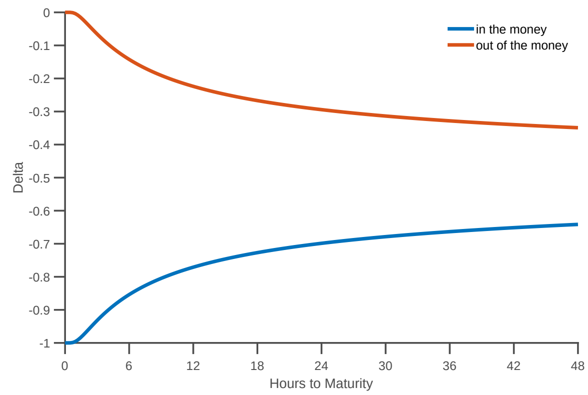
(b) Put Options

Figure 6. Wealth Transfer in SPX Options

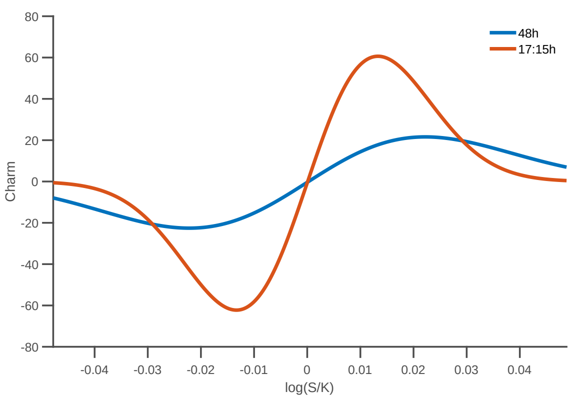
This figure displays the difference between SPX options payoffs at 3^{rd} Friday open and counterfactual payoffs. We obtain counterfactual payoffs by replacing the SOQ on expiry days with the 3^{rd} Thursday SPX close price multiplied with 1.00013, since the average non-expiry night return over our sample is 1.3 bps. Positive values are in red, negative values are in blue. Panel (a) displays call options and panel (b) displays puts.



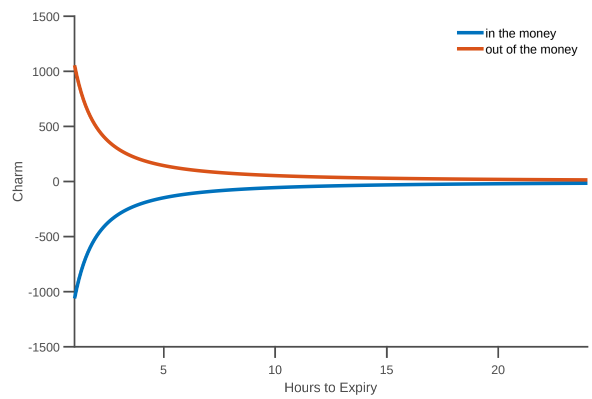
(a) Call Delta



(b) Put Delta



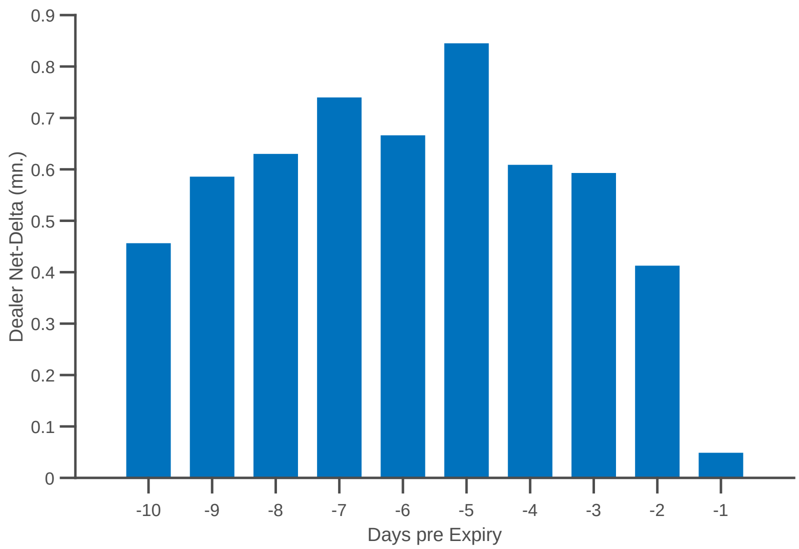
(c) Charm by Moneyness



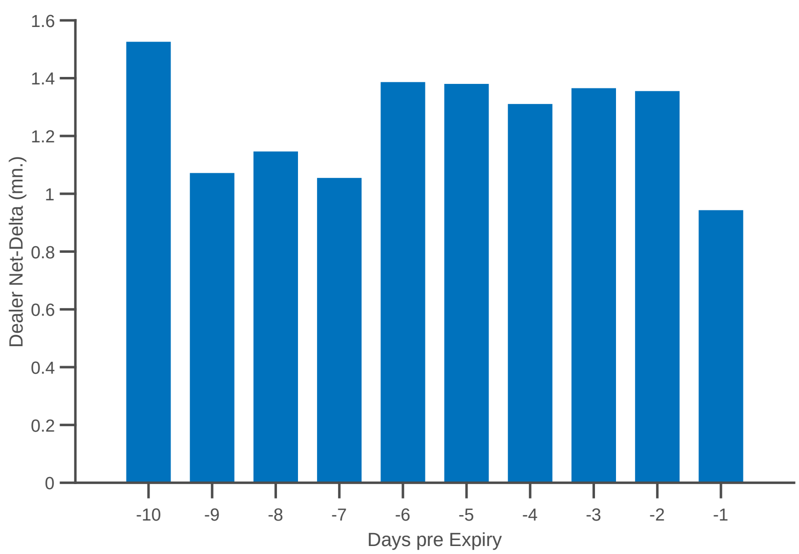
(d) Charm by Time to Expiry

Figure 7. Illustration: Option Charm

This figure displays the behaviour of option "Charm", i.e. the change in delta from changes in time to maturity. Panels (a) and (b) show the Black-Scholes delta for European options with an underlying price of 3000, an interest rate of 0, a dividend yield of 0 and an underlying volatility of 30%. For calls (puts), "in-the-money" denotes a strike of 2975 (3025) and "out-of money" denotes a strike of 3025 (2975). Panel (c) shows Black-Scholes charm for options with 48 hours and 17 hours and 15 minutes until expiry. Panel (d) shows Black-Scholes charm for put options with strikes 2990 and 3010.



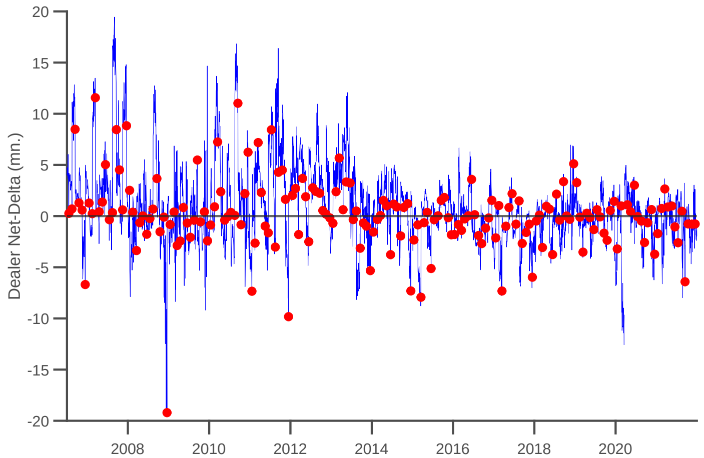
(a) Expiring Options



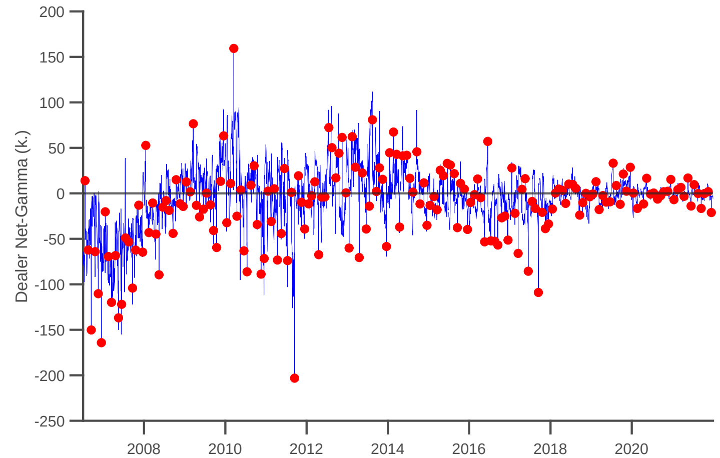
(b) Non-Expiring Options

Figure 8. Positions into Expiry: Dealers

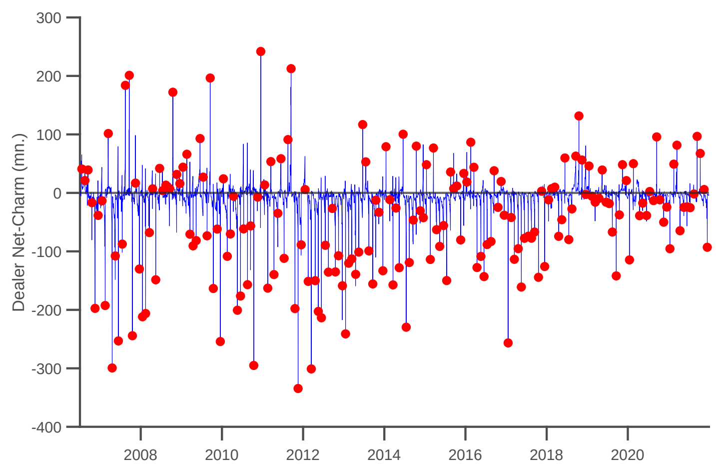
This figure reports dealer positions in a.m. settled SPX options over the 10 days before 3^{rd} Fridays. Panel (a) reports positions in expiring options. Panel (b) reports positions in longer dated options. Dealer positions and Greek calculations are described in section V. Dealer net-delta is in millions.



(a) Net-Delta



(b) Net-Gamma



(c) Net-Charm

Figure 9. Dealer Inventory Exposure from Expiring Options

The figure shows the time-series of dealer net-delta, net-gamma and net-charm across all SPX options that expire on the respective next 3^{rd} Friday. Dealer positions and Greek calculations are described in section V. Red dots indicate 3^{rd} Thursdays.

VIII. Appendix: Tables

Days:	I. Non-Expiry	II. Expiry	II. - I.	Non-Expiry 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 (b) 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 (c) Late Sample: 2003.02 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 Overnight

This table reports summary statistics for returns from equation 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. Returns are in basis points.

	All Days			Around 3^{rd} Fridays			
	Close to Open	Open to Close	Close to Close	We_{close} to Th_{open}	Th_{open} to Th_{close}	Th_{close} to Fr_{open}	Fr_{open} to Fr_{close}
				Panel (a) Index			
mean	2.12	1.46	3.57	-3.54	-0.15	18.24	-16.42
mean(24H)	2.90	5.37	3.57	-4.86	-0.55	25.01	-60.63
t-stat	2.06	1.08	2.06	-1.03	-0.02	4.53	-2.91
Std	70.86	92.88	119.63	51.53	89.30	60.40	84.71
				Panel (b) Futures			
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. S&P 500 Returns around 3^{rd} Fridays

This table reports average S&P 500 returns per trading period (first row) and per 24-hour period (second row). The *t*-statistics and return standard deviations (per period) are reported in the third and fourth rows, respectively. The first three columns show returns for all days. Subsequent columns show returns around 3^{rd} Fridays. Panel (a) computes returns from the S&P 500 index, using closing prices and the SOQ. Panel (b) computes returns via S&P 500 E-mini futures trade prices. Returns are in basis points. The sample period is 2003 to 2021.

	Around 3^{rd} Fridays		
	Th_{close} to Fr_{open}	Fr_{open} to Fr_{close}	Fr_{close} to Mo_{open}
mean	11.71	-15.66	-11.25
mean(24H)	16.07	-57.81	-4.12
t-stat	2.34	-2.27	-1.39
Std	55.83	76.71	90.28

Table III. P.M. Settlement Returns: Post 2011

This table reports average returns per trading period (first row) and per 24-hour period (second row). *t*-statistics and return standard deviations (per period) are reported in the third and fourth rows. Returns are computed for the S&P 500 index, using closing prices and the SOQ. Returns are in basis points. The sample period is 2011.9, when p.m. settled 3^{rd} Friday options were reintroduced, to 2021.12.

	Calls			Puts			
	1. Actual	2. C.F.	1.-2.=3.	4. Actual	5. C.F.	4.-5.=6.	abs(5.)+abs(6.)
mean ($ mn.)	10,441	10,227	214	3,040	3,121	-80	295
std ($ mn.)	15,691	15,574	117	12,292	12,725	-432	550

Table IV. The Payoff Bias in SPX Options

The table reports summary statistics for actual and counterfactual 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

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

where I is the number of call options and K is the strike price. Column 2 contains the counterfactual call option settlement value that is estimated by replacing the actual overnight SPX return into expiry with the average non-expiry overnight SPX return. Column 3 displays the difference. Columns 4 to 6 display put option settlement values. The put option settlement value is calculated as

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

Column 7 contains the sum of absolute differences over calls and puts. All numbers are in millions of dollars. The sample period is 2003 to 2021.

	Actual		Counterfactual	
	Calls	Puts	Calls	Puts
	Panel (a) Returns (%)			
itm	3.2	-5.7	-0.6	0.9
atm	1.8	-51.0	-33.2	-30.9
otm	-98.4	-98.1	-99.2	-97.7
	Panel (b) Returns ($ mil.)			
itm	202.4	-69.9	61.4	-16.2
atm	12.0	-24.6	-16.3	-10.6
otm	-5.7	-15.0	-5.9	-15.5
sum	208.8	-110.4	39.2	-42.3

Table V. SPX Option Returns into Expiry

This table shows summary statistics for S&P 500 index option returns into expiry. 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 counterfactual returns, calculated via a hypothetical 3^{rd} Friday SOQ based on the unconditional non-expiry overnight SPX return. Options are equally weighted across buckets. Panel (b) reports average returns in millions of dollars, calculated as $Dollar\ Return = Net\ Return \cdot Open\ Interest \cdot Price$. We measure moneyness (mnes) 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 $<= 1.5$. Returns are in percent. The sample period is 2003 to 2021.

	Around 3^{rd} Fridays				
	We_{close} to to Th_{open}	Th_{open} to to Th_{cclose}	Th_{close} to to Fr_{open}	Fr_{open} to to Fr_{close}	Fr_{close} to to Mo_{open}
	Panel (a): Quarterly Expiry				
mean	5.37	1.38	26.18	-36.76	-11.31
mean(24H)	7.36	5.09	35.91	-135.72	-4.15
t-stat	0.94	0.14	4.31	-3.54	-1.36
Std	48.88	83.43	52.58	89.95	71.98
	Panel (b): Non-Quarterly Expiry				
mean	-7.94	-0.90	14.26	-6.25	-5.05
mean(24H)	-10.89	-3.33	19.56	-23.09	-1.85
t-stat	-1.86	-0.12	2.74	-0.95	-0.66
Std	52.39	92.31	63.75	80.36	94.21

Table VI. Triple-Witchings

This table reports average returns per trading period (first row) and per 24-hour period (second row). t-statistics and return standard deviations (per period) are reported in the third and fourth rows, respectively. Returns are computed for the S&P 500 index, using closing prices and the SOQ. Returns are in basis points. The sample period is 2003 to 2021.

Days:	Non-Expiry	Expiry	Qtr Expiry	Non-Qtr Expiry
	Panel (a): Overnight			
mean	-0.02	3.06	4.64	2.28
median	0.06	2.78	3.62	2.57
t-stat	-0.12	3.00	3.39	2.47
	Panel (b): Intraday			
mean	-1.86	-12.21	-14.74	-10.95
median	-0.77	-6.97	-10.79	-3.35
t-stat	-3.48	-5.30	-3.98	-3.75

Table VII. Order Imbalances

This table reports summary statistics for the signed volume of the most liquid S&P 500 E-mini futures contract, which is usually the front month contract. Panel (a) contains the average signed volume overnight (i.e., between 16:15 p.m. and 09:30 a.m.). Panel (b) contains the average signed volume intraday (i.e., between 09:30 a.m. and 16:00 p.m.). Columns 1 to 4 show signed volume over non-expiry days, expiry days (i.e. 3^{rd} Fridays), quarterly expiry days and non-quarterly expiry days, respectively. Signed volume is the number of buyer initiated trades minus the number of seller initiated trades, in 1000s of contracts. The sample period is 2003 to 2021.

	Net Number (mn.)		Net Delta (mn.)		Net Gamma (k.)		Net Charm (mn.)	
Days:	1. All	2. Expiry	3. All	4. Expiry	5. All	6. Expiry	7. All	8. Expiry
Calls	-0.47	-1.52	2.65	0.05	9.13	8.37	6.52	32.78
Puts	-17.60	-6.33	2.53	0.02	-12.05	-21.61	-13.89	-80.88

Table VIII. Dealer Positions in SPX Options

The table reports dealer positions in a.m. settled 3^{rd} Friday (SPX) options. Row 1 (2) contains call (put) options. The columns show dealer positions as net-number, net-delta, net-gamma and net-charm in millions (mn.) or thousands (k). The "all" columns show average positions across all a.m. settled SPX options on all days. "Expiry" columns show average positions across expiring options on the day before their monthly expiry. Positions data are described in Section I and option Greeks are explained in Section V. The sample period is 2006 to 2021.

	Expiry All	Expiry All	Expiry Non-Qtr.	Expiry Non-Qtr.	Non-Expiry	Weekend
Charm	-0.18	-0.18	-0.22	-0.22	0.01	-0.02
	[0.07]	[0.07]	[0.08]	[0.08]	[0.02]	[0.04]
	(-2.99)	(-2.87)	(-2.94)	(-2.84)	(0.38)	(-0.45)
Gamma		-0.03		-0.05		
		[0.05]		[0.08]		
		(-0.55)		(-0.72)		
Delta		0.12		0.03		
		[0.08]		[0.11]		
		(1.28)		(0.24)		
R^2	3.21	4.74	4.85	5.19	0.01	0.03

Table IX. Predictability Regressions: S&P 500 Returns on Dealer Positions
We regress the overnight return of the S&P 500 equity index on lagged dealer positions. Returns are computed using closing prices to the SOQ. Columns 1 and 2 contain returns from Thursday close to 3^{rd} Friday open, columns 3 and 4 exclude quarterly expiries, column 5 considers only non-expiry days, and column 6 considers only weekend returns. Positions data are described in Section I and option Greeks are explained in Section V. Left- and right hand variables are standardized to zero mean and unit variance. Block bootstrapped standard errors are in square brackets, where the block size is chosen optimally following Patton, Politis, and White (2009). Newey-West t-statistics with 3 lags are in round brackets. R^2 is multiplied by 100. The sample period is 2006 - 2021.

	Days: Expiry			Days: Non-Qtr Expiry		
Charm:	Small	Medium	Large	Small	Medium	Large
	Panel a: S&P 500 Return (bps.)					
S Gamma	35.40	11.32	8.73	35.37	7.91	-6.31
M Gamma	31.23	9.09	-3.92	32.94	20.39	-11.24
L Gamma	36.98	19.24	1.71	18.34	21.40	-10.90
	Panel b: Charm (m.)					
S Gamma	-3.48	-0.34	3.10	-2.91	-0.23	2.72
M Gamma	-2.28	-0.34	1.23	-2.76	-0.37	1.03
L Gamma	-2.82	-0.23	1.75	-2.28	-0.01	1.60
	Panel c: Gamma (k.)					
S Gamma	-0.72	-0.49	-0.68	-0.58	-0.39	-0.53
M Gamma	-0.06	-0.07	-0.07	-0.04	-0.05	-0.04
L Gamma	0.30	0.31	0.25	0.24	0.29	0.23

Table X. Conditional Expiry Returns

This table double sorts S&P 500 returns into option expiry based on dealer net-gamma and net-charm. Returns are computed using closing prices to the SOQ. Panel (a) shows the overnight return of the S&P 500 equity index from Thursday close to 3^{rd} Friday open per subsample. Panels (b) and (c) shows dealers' net-charm and net-gamma exposure, respectively. The left panels contains all expiry days, the right panels excludes quarterly expiries. Returns are in basis points, charm is in millions and gamma is in thousands. The sample period is 2006 to 2021.

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. Contracts since follow a quarterly expiry schedule, expiring the third Friday of the March-June-September-December cycle.[27] 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.[28] 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 E.T. - 4:15pm E.T.). In September 1993, the S&P 500 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

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

[28] 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.[29]

Other U.S. equity futures share similar characteristics, with futures on the NYSE, DJIA, Nasdaq, Russell 2000, S&P 400 introduced in 1982, 1997, 1996, 1993, or 1992, respectively.[30] 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).[31]

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.[32] 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

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

[30] 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.

[31] 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.

[32] 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.[33]

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.

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.[34]

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

[33] 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.

[34] 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. CBOE Options Position Data

Figure A.2 illustrates the construction of option positions for the market maker (dealer) sector. On day t when an option is first listed, market maker' buy volume (in number of contracts) minus market maker' sell volume yields market maker' net-position in that option. On day $t+1$ market maker buys minus market maker sells yield the *change* in their position. Market maker' net position at the end of day $t+1$ is then given by their net-buys on days t and $t+1$. The hypothetical "Put 1" option in figure A.2 is listed on 21-September-2023. On that day, dealers buy (sell) a total of 80 (10) "Put 1" options, yielding an end-of-day net-position of 70 options. On 24-September-2023 dealers buy (sell) 50 (20) "Put 1" options, yielding a new end-of-day net-position of 100 options. In this way, we cumulate market maker' net position from option listing to expiry at the contract level. The sum of market maker' net positions 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 the Greek risk measures, e.g. Δ, we multiply each contract-level net-position with the respective options' Δ and subsequently sum over all available contracts to obtain the total position, which in this case would be dealers net-Δ.

[INSERT FIGURE A.2 HERE]

E. 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 II and III

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. *Small Sample Bias*

Next, we present additional evidence on return reversal. Figure A.3 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.3 HERE]

C. *Return Reversal*

The analysis so far has provided evidence that overnight returns in advance of 3^{rd} Friday a.m. settlements are systematically positive and subsequently revert intraday Friday. To demonstrate a formal link between the two sub-period returns we estimate a standard microstructure reversal regression. Overnight returns are measured from SPX trades at 16:00 to the reported SOQ the following day, and subsequent intraday returns are measured from the SOQ to the SPX traded price at 12:00. We choose for 12:00 as figure 1 reveals the overnight spike completely reverses by 12:00, and hence adding returns beyond would add noise to the reversal regression. Then we regress intraday returns on overnight returns

$$\text{Expiry:} \quad ret_{ID} = a + \underbrace{-0.32}_{[-0.46,-0.18]} ret_{ON} + \varepsilon \qquad R^2 = 12.09\% \tag{A.1}$$

$$\text{ALL DAYS:} \quad ret_{ID} = a + \underbrace{-0.10}_{[-0.16,-0.04]} ret_{ON} + \varepsilon \qquad R^2 = 1.50\% \tag{A.2}$$

on each month's 3^{rd} Thursday option expiration and all days. The regression equations report point estimates and 95% confidence intervals computed from a block bootstrap to account for a potential small-sample bias, sampling 1,000 times with the optimal block length chosen following Patton, Politis, and White (2009). 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. We repeat the analysis for all days, finding a significant reversal but with magnitudes three times smaller. In summary, the visual interpretation of unconditional tent-shaped return reversal pattern depicted in figure 1 is confirmed conditionally via predictive regressions and this pattern is special to expiry days.

D. *Trading Strategy and Transaction Costs*

Next, we present additional results on the trading strategy that exploits the reversal patterns. We consider a trade that buys ES futures at close, reverses into a short positions at open and closes this position at 3^{rd} Friday market close. Table A.4 reports summary statistics of the trading strategy. The first column considers only 3^{rd} 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 3^{rd} Fridays or 4 times a year on the quarterly expiration cycle. The last two rows A.4 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 A.4 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.5 HERE]

Table A.5 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.5 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 can 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).[35] 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.

[35] 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.

Figure A.4 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.6 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.4 AND TABLE A.6 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.7 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.7 HERE]

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.[36] 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.8 reports the

[36] 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.

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.8 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. 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.[37] 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.5 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

[37] 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.

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.5 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.9 HERE]

We test the impact of open interest in the at-the-money option strike by regressing it on the 3FPS reversal return. At-the-money open interest is defined as the number of SPX index option contracts that are within two strikes of the underlying price on the Thursday before expiry. As such, we capture the open interest on the option contracts that are would be most affected by pinning. Our sample runs from 2006 to 2019 as we utilize the CBOE high frequency option dataset that allows us the measure SPX option open interest at Thursday close.[38] To remove time trends, open interest is normalized within every year of the sample.Table A.9 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

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

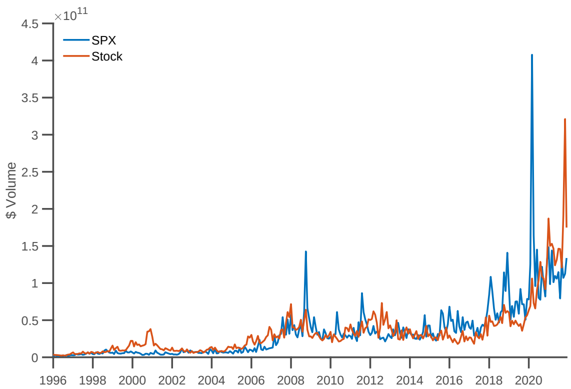
are state dependent. These theories aligns with the 3FPS when market makers absorb demand shocks overnight and offload inventories during 3^{rd} Friday trading.

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.

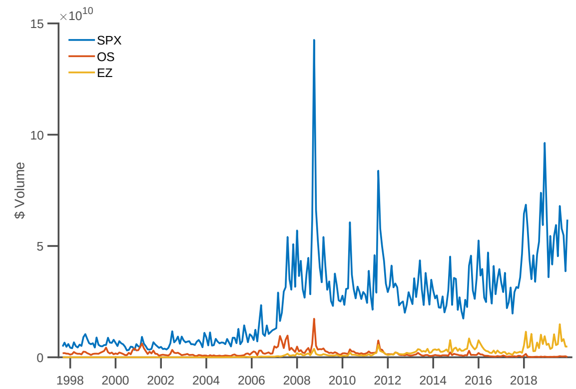
[INSERT TABLE A.10 HERE]

We test the impact of past returns by regressing it on the 3FPS reversal return. Table A.10 contains the results, revealing no significant effect of past 1-week to past 4-weeks returns on 3FPS reversal returns. Unreported analysis reveal the 3FPS reversal return is also unrelated to VIX levels or changes. Overall, we fail to find evidence supporting a link between non-fundamental shocks and 3FPS reversals.

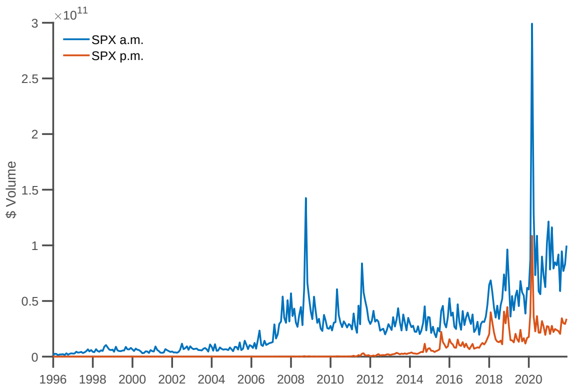
A.4. Figures



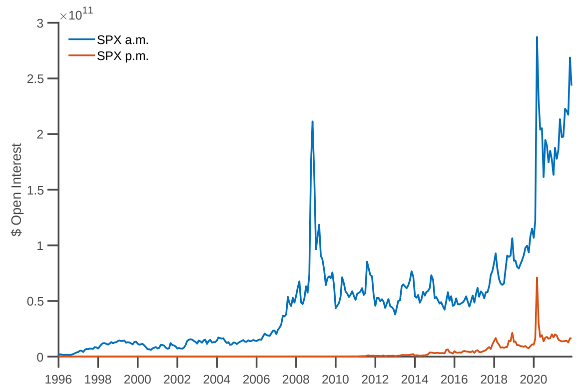
(a) Volume: Index Options vs. Stock Options



(b) Volume: Index Options vs. Futures Options



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



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

Figure A.1. SPX Option Market Size

This figure illustrates the size of the S&P 500 index (SPX) options market. Panels (a) to (c) display the monthly dollar trading volume of a.m. settled SPX options against (a) options on SPX constituent stocks, (b) S&P 500 futures options, and (c) p.m. settled SPX options. Panel (d) displays the monthly average open interest (in dollars) of SPX options with a.m. and p.m. settlement.

I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Weekday	Date			Put 1				Put 2		Sum Puts
		Dealer Buys (=DB)	Dealer Sells (DS)	Dealer Net Buy (=DB-DS)	Cumulative DNB (=CDNB1)	Dealer Buys	Dealer Sells	Dealer Net Buy	Cumulative DNB (=CDNB2)	Dealer Position (=CDNB1 + CDNB2)
Monday	18-Sep-23									
Tuesday	19-Sep-23									
Wednesday	20-Sep-23									
Thursday	21-Sep-23	80	10	70	70					70
Friday	22-Sep-23	50	20	30	100					100
Saturday	23-Sep-23				100					100
Sunday	24-Sep-23				100					100
Monday	25-Sep-23	30	110	-80	20	40	200	-160	-160	-140
Tuesday	26-Sep-23	200	10	190	210	30	150	-120	-280	-70
Wednesday	27-Sep-23	100	100	0	210	100	100	0	-280	-70
Thursday	28-Sep-23	100	100	0	210	100	100	0	-280	-70
Friday	29-Sep-23	100	100	0	210	100	100	0	-280	-70

Figure A.2. Variable Construction: Dealer Position

This figure illustrates the construction of the variable *Dealer Position* from the CBOE OpenClose files. The CBOE OpenClose Volume files contain for every day and every option contract the number of contracts bought (in column III) and the number of contracts sold (in column IV) by option dealers. The figure contains a stylized example for two option contracts (Put1 and Put2). We calculate *Dealer Net Buys* (in column V) as $DealerBuys$ minus $DealerSells$. The cumulative sum over *Dealer Net Buys* (in column VI) yields the *Dealer Net-Position*, in number of contracts.

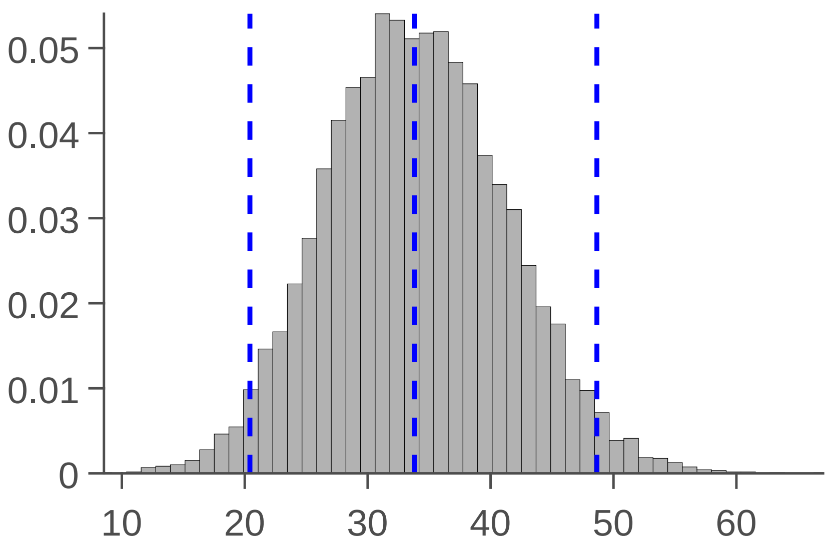


Figure A.3. Bootstrapped Expiry Reversal Return

This figure displays the block bootstrapped distribution of the 3^{rd} Friday reversal return. The reversal strategy goes long the S&P 500 at 3^{rd} Thursday close, reverses into a short positions (via the SOQ) at 3^{rd} Friday open and closes the position at 3^{rd} Friday close. 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 to 2021.

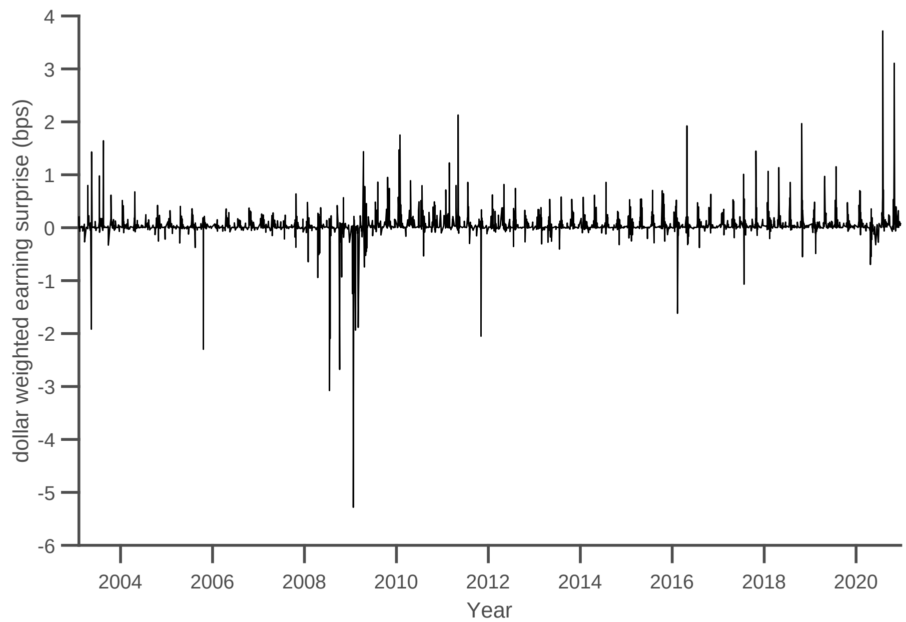
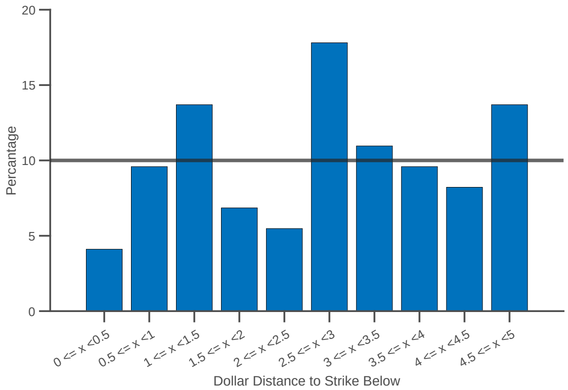
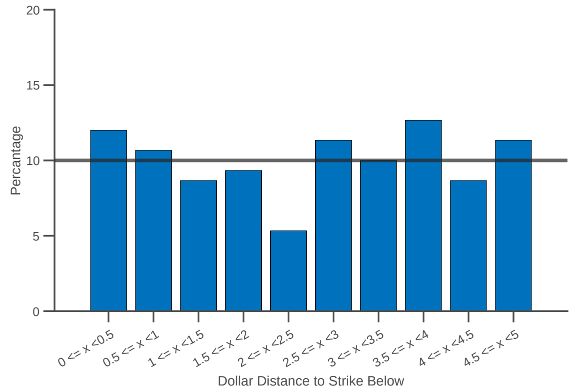


Figure A.4. Earnings Announcement Surprises

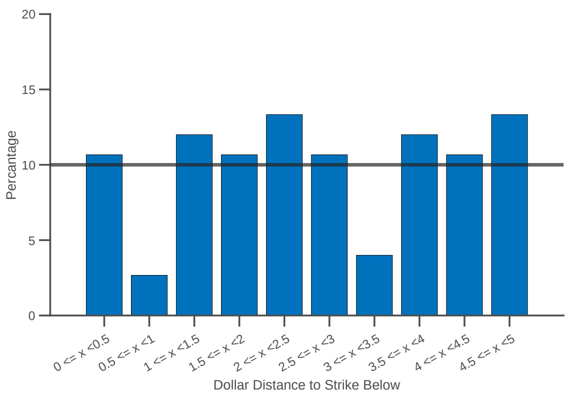
This figure displays the daily earning announcement surprise of US public companies. We calculate the earnings surprise as the sum-product of firms' earnings announcement surprises from IBES and the respective firms' lagged equity market capitalization. We consider announcements between 12:00 and 24:00 (E.T.). The sample period is 2003 to 2021.



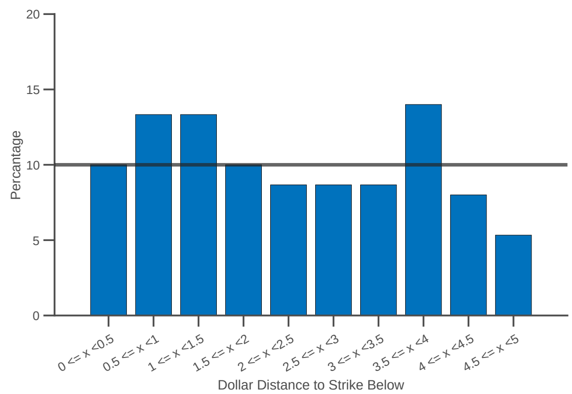
(a) ES Qtr



(b) ES Non-Qtr



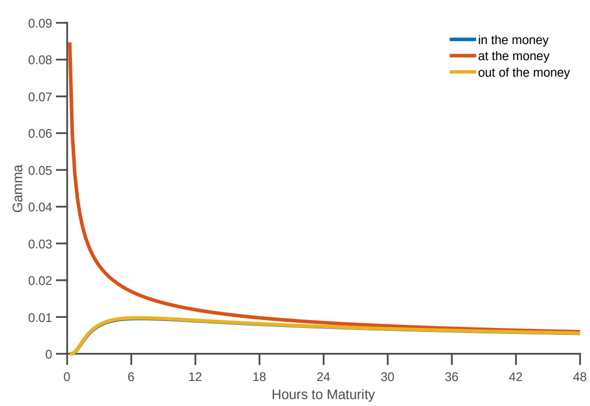
(c) SOQ Qtr



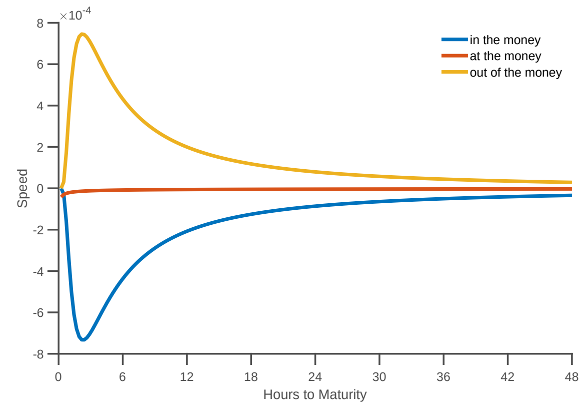
(d) SOQ Non-Qtr

Figure A.5. Distance of Equity Prices to Option Strikes at Expiry

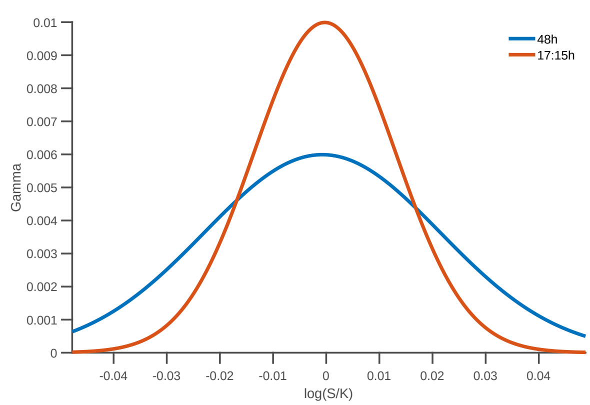
This figure shows that neither S&P 500 stocks nor associated futures contracts shows signs of "pinning" around option expiry at 3^{rd} Friday market open. Pinning is the tendency of asset prices to be abnormally close to options' strike prices. This figure shows the percentage of equity prices at 3^{rd} Friday open by distance to the closest lower SPX option strike, which occur every $5. The panels do not reveal any systematic pattern between equity prices and option strikes. Panel (a) displays second-to-maturity S&P 500 E-mini futures on quarterly 3^{rd} Fridays. Panel (b) displays first-to-maturity S&P 500 E-mini futures on non-quarterly 3^{rd} Fridays. Panels (c) and (d) displays the S&P 500 SOQ on quarterly and non-qarterly 3^{rd} Fridays, respectively. The sample period is 2003 to 2021.



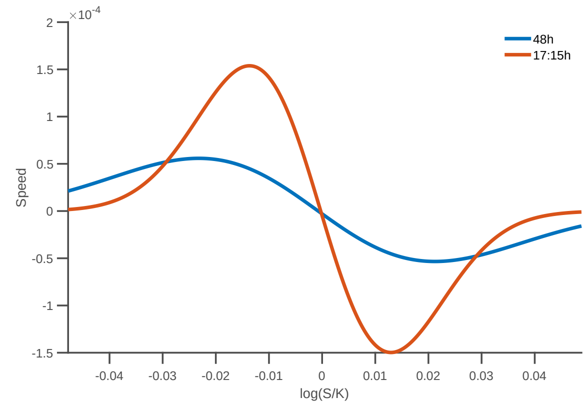
(a) Gamma by Time to Expiry



(b) Speed by Time to Expiry



(c) Gamma by Moneyness



(d) Speed by Moneyness

Figure A.6. Illustration: Option Gamma and Speed

This figure illustrates option "gamma", i.e. the change in delta from changes in the price of the underlying, and option "speed", i.e. the change in gamma from changes in the price of the underlying. Panels (a) and (b) show Black-Scholes gamma and speed for European options with an underlying price of 3000, an interest rate of 0, a dividend yield of 0 and an underlying volatility of 30%. For calls (puts), "in the money" denotes a strike of 2975 (3025), "at the money" denotes 3000 (3000) and "out of the money" denotes 3025 (2975). Panels (c) and (d) show gamma and speed for options with 48 and 17:15 hours until expiry. Gamma and Speed are identical for put and call options.

A.5. Tables

Security	S&P 500 Index Options	S&P 500 Futures Options	S&P 500 Futures
Underlying	100 x S&P 500 Index (SPX)	E-mini S&P 500 Futures (ES)	50 x S&P 500 Index
End of Trading	Th. pre 3^{rd} Fr. p.m.	3^{rd} Friday a.m.	3^{rd} Friday a.m.
Settlement	3^{rd} Friday a.m.	3^{rd} Friday a.m.	3^{rd} 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 (SOQ)
This table illustrates the calculation of the S&P 500 Special Opening Quotation (SOQ) and why the SOQ can differ from the S&P 500 opening value. Panel (a) shows an example where the SOQ ($29.3) is higher than the index opening quote ($28.3). At market open (9:30:00) only stock 1 trades on exchange. Thus, the opening index value is the (here equal-weighted) average of the opening trade price of stock 1 ($55) and the previous close prices of stocks 2 ($20) and 3 ($10). The SOQ only becomes available once all index component stocks have traded and is then calculated as the average of trade prices $55, $22 and $11. Panel (b) shows 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 Overnight - Robustness

This table shows that the results of table I are robust to the choice of breakpoint. We calculate the difference between these overnight returns into 3^{rd} Fridays and overnight returns into all other days. Within row 1, column 1 shows the average difference of returns from 1992.11 to 2002.08, column 2 extends the sample to 1992.11 to 2002.09 and so forth. Within row 3, column 1 shows the average difference of returns from 2002.08 to 2021.12, column 2 shortens the sample to 2002.09 to 2021.12 and so forth. Rows 2 and 4 show the associated Newey-West t-statistics.

Days:	Expiry	Other
Panel (a): Excluding Trade Costs		
mean	27.48	0.10
t-stat	3.94	0.06
std	104.61	112.38
SR	0.90	0.01
alpha	27.55	1.09
beta	-0.32	-0.27
Panel (b): Including Trade Costs		
mean	24.20	-3.18
t-stat	3.47	-1.90
std	104.60	112.41
SR	0.80	-0.44
alpha	24.27	-2.18
beta	-0.32	-0.27

Table A.4. Trading the 3^{rd} Friday Price Spike: Transaction Costs

This table shows that trading the 3^{rd} Friday Price Spike survives transaction costs. Column one 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. Column two reports summary statistics for the equivalent strategy on non-expiry days. Newey-West t-statistics are calculated with three lags. Sharpe ratios (SR) are annualized. Alpha and beta are from regressing reversal returns on the returns from a long-only position in S&P 500 E-mini futures. Panel (a) uses mid-quotes, panel (b) uses ask-prices for buys and bid-prices for sells. Returns are in basis points. The sample period is 2003 to 2021.

	PUT	BXM	PUT Minus BXM			
			All Days	Non-Expiry Days	Expiry Days	Non-Expiry 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.5. Option Index Returns: PUT and BXM

This table shows summary statistics for the returns of the CBOE PutWrite (PUT) and BuyWrite (BXM) indices. Mean and standard deviation are for annualized daily returns. Returns are in percent. Sharpe ratios (SR) are annualized. The columns show PUT returns, BXM return, and the difference between PUT and BXM returns on all days, non-expiry days, expiry days and non-expiry Fridays, respectively. Expiry-day returns are measured from 3^{rd} Thursday close to 3^{rd} Friday close. The sample period is 2003 to 2021.

	All Days		Around 3^{rd} 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.6. Earnings Announcement Surprises

This table reports average dollar-weighted earnings announcement surprises during the "evening" (12:00 to 24:00 E.T.) and during the rest of the "day" (09:30 to 12:00 E.T.). We calculate the earnings surprise as the sum-product of firms' earnings announcement surprises from IBES and the respective firms' lagged equity market capitalization. Columns 1 and 2 consider all days. Columns 3 and 4 consider only the evening and day surrounding the market open of the monthly 3^{rd} Friday. All numbers are in hundredth of basis points. The sample period is 2003 to 2021.

	Intercept	Slope	$R^2(\%)$
Coefficient	17.23	-0.06	0.00
t-stat	3.84	-0.01	

Table A.7. Predictive Regression: Expiry Return on Earnings Surprises

This table shows regression results from regressing the 3^{rd} Friday expiry return on the preceding earnings surprise. The expiry return is calculated as in equation 1. We calculate the earnings surprise as the sum-product of firms' earnings announcement surprises from IBES and the respective firms' lagged equity market capitalization. The earnings surprise is measured between 12:00 and 24:00. Newey-West t-statistics with 3 lags are in brackets. Returns are in basis points. Earnings news are normalized to zero mean and unit variance. The sample period is 2003 to 2021.

	Expiry Return		
Intercept	18.32	20.66	20.50
	(4.55)	(5.37)	(3.81)
Dummy		-14.24	
		(-1.10)	
Dummy			-5.46
			(-0.77)
N	225.00	225.00	225.00
Dummy N	0.00	37.00	90.00

Table A.8. Regression: Expiry Return on Macro Announcement Dummies

This table reports point estimates and t-statistics from regressions of 3^{rd} Friday expiry returns on macro announcement dummies. The expiry return is calculated as in equation 1. We consider all macro announcements listed on Bloomberg that occurred on a 3^{rd} Friday before (and including) market open. We only consider announcements with a Bloomberg attention score above 60. Column 2 contains inflation ("cpi", "ppi" and "gdp price index") announcement dummies. Column 3 contains dummies for all other announcements. Returns are in basis points. Newey-West t-statistics with 3 lags are in brackets. The sample period is 2003 - 2021.

	Expiry Return				
Intercept	16.60	16.60	16.60	16.60	16.74
	(3.32)	(3.32)	(3.31)	(3.32)	(3.32)
Atm OI		-0.53			
		(-0.12)			
Atm OI Calls			1.30		
			(0.26)		
Atm OI Puts				-1.78	
				(-0.45)	
Δ Atm OI					4.23
					(0.86)

Table A.9. Predictive Regression: Expiry Return on Option Open Interest
This table reports point estimates and t-statistics from regressing the 3^{rd} Friday expiry return on lagged S&P 500 option open interest. The expiry return is calculated as in equation 1. 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 from puts and calls, while columns 3 and 4 contains only call open interest and put open interest, respectively. Column 5 contains the change in at-the-money open interest since the last 3^{rd} Friday. Returns are in basis points. Right-hand side variables are normalized to zero mean and unit variance within every year. Newey-West t-statistics with 3 lags are in brackets. The sample period is 2006 to 2021.

	Expiry Return			
Intercept	18.19	18.19	18.19	18.19
	(4.53)	(4.48)	(4.43)	(4.48)
1 week SPX return	-1.65			
	(-0.25)			
2 week SPX return		1.35		
		(0.22)		
3 week SPX return			6.26	
			(0.90)	
4 week SPX return				5.32
				(0.75)

Table A.10. Predictive Regression: Expiry Return on the S&P 500 Return
This table reports point estimates and t-statistics from regressions of 3^{rd} Friday expiry returns on lagged S&P 500 index returns. The expiry return is calculated as in equation 1. Columns 1, 2, 3, 4 contain the regression on S&P 500 Returns over the past 1, 2, 3, 4 weeks, respectively. Returns are in basis points. Newey-West t-statistics with 3 lags are in brackets. The sample period is 2003 to 2021.