The Derivative Payoff Bias

Abstract

Most U.S. equity index derivatives expire at the market open on the 3^{rd} Friday of each month. We show that equity prices at the open on 3^{rd} Fridays are systematically biased upward and fully reverse by midday. Thus, call and futures payoffs are inflated while put payoffs are deflated, transferring approximately $2.5 billion annually. This bias stems from predictable changes in option dealers' inventory delta. The aggregate delta of dealers' option positions drifts down into 3^{rd} Friday derivative expiry, generating an incentive to buy equities. Dealer delta drift predicts overnight equity returns into 3^{rd} Friday expirations, and no other days.

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S&P 500 index options constitute the largest equity index derivatives market globally. A significant fraction of these contracts are "a.m.-settled", meaning they expire on the morning of the 3^{rd} Friday of each month, with payoffs determined by the opening trade prices of index component stocks. This makes the 3^{rd} Friday open a critical moment, as these prices determine the distribution of wealth across market participants.

We document a systematic distortion in equity index prices around this settlement event, which we dub the Third Friday Price Spike (3FPS): the S&P 500 stock price index drifts upward from the close on the preceding Thursday to the 3^{rd} Friday open, precisely when the SOQ[1] is fixed, then fully reverses by midday 3^{rd} Friday. This tent-shaped price pattern is economically large (an average spike of 11 basis points per event), statistically significant, *only* seen on 3^{rd} Friday option expiry days, and highly persistent over our sample (1992 to 2023).

The economic consequences of the 3FPS are substantial. Option payoffs are calculated from a biased SOQ, which results in: (*i*) a higher payoff for in-the-money calls; (*ii*) some calls that would have expired out-of-the-money now expire in-the-money; (*iii*) a lower payoff for in-the-money puts; and (*iv*) some puts that would have expired in-the-money now expire out-of-the-money. Since index options are cash settled and option payoffs are a zero-sum game, there is a systematic wealth transfer across market participants.

We quantify the wealth transfer by comparing actual option payoffs at expiry to counterfactual payoffs based on the S&P 500 opening price that would have resulted from an average non-expiry overnight return. The bias is most pronounced for at-the-money options, where call payoffs are systematically inflated and put payoffs systematically deflated. Aggregating across all expiring S&P 500 options yields an estimated wealth transfer of approximately $2.5 billion per year, even before accounting for other affected contracts such as futures, futures options, and options on related indices.

What explains the 3FPS in U.S. equities and the resulting derivative payoff bias? We propose a novel channel based on predictable changes in option dealers' hedging demand. Due to persistent demand imbalances, dealers are typically short out-of-the-money (OTM) put options. Being short

[1] The Special Opening Quotation (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.

a put with negative delta gives dealers positive equity exposure - exposure that vanishes as the put's delta drifts toward zero near expiry. To remain hedged, dealers must buy equities, generating buying pressure precisely when the SOQ is determined. We construct a measure of this predictable hedging demand - the dealer delta drift (DDD) - and show it has strong predictive power for overnight returns into 3^{rd} Friday settlements.

Central to this mechanism is the acute sensitivity of Δ to the passage of time near expiration. As the 3^{rd} Friday settlement approaches, Δ converges toward its terminal values of -1, 0, or 1 with increasing intensity - even in the complete absence of shocks to the underlying. This acceleration is sharpest overnight, precisely when dealers' hedging instruments are least liquid. We design a set of tests evaluating whether this expected Δ drift in dealers' inventories, and the hedge-adjustment trades it induces, can plausibly generate the systematic overnight price pressures observed in the 3FPS.

First, we establish the existence of price pressures by studying order imbalances in the E-mini S&P 500 futures contract, the primary hedging instrument for SPX options. If the 3FPS is the result of option dealers' hedge-adjustment trades, then we expect to see order imbalances in dealers' major hedge instruments. Around 3^{rd} Friday, order imbalances display the same pattern as the 3FPS: positive and significant overnight, then significantly more negative intraday.

Second, we show that dealers' aggregate Δ drifts *downward* into expiration, creating incentives to buy equities. Using CBOE Open-Close Volume files, we estimate daily dealer positions across all S&P 500 options. Consistent with prior evidence (e.g., Garleanu, Pedersen, and Poteshman, 2009), dealers are predominantly short out-of-the-money puts. These puts typically expire worthless, so their Δ drifts from negative values toward zero - but because dealers are short, their aggregate Δ drifts downward.

Our third test directly relates the DDD to realized market-wide price movements. Regressing overnight S&P 500 returns on the DDD, we show that more negative values of the drift predict larger positive overnight returns into the SOQ. The effect is both statistically and economically significant - a striking result given the well-known difficulty of predicting returns at high frequency. Importantly, the relationship is absent on non-expiry days, weekends, and other settlement windows, confirming that it is specific to the 3^{rd} Friday a.m. expiration context.

Our final test further exploits variation in dealer positioning to assess whether the direction of the DDD accounts for the sign of the 3FPS. We sort expiry days by the sign of the DDD and show that the direction of predicted hedging demand determines the sign of overnight market returns. When the DDD is negative, implying net equity purchases, the overnight S&P 500 return averages 16 basis points. In contrast, when DDD is positive, implying that dealers should sell equity exposure, the overnight return is slightly negative on non-quarterly expiries.

Collectively, these analyses provide strong evidence that predictable changes in dealers' inventory risk lead to hedge-adjustment trades, which create overnight buying pressure in equity markets, distorting opening prices and the SOQ, thereby systematically biasing derivative payoffs in the illiquid a.m. settlement window.[2]

We conclude by discussing the broader implications of the 3FPS, including the emergence of vast trade in zero-day-to-expiration options, the possibility of predatory trading and/or market manipulation, and implications for regulation and settlement design.

Related Literature: Our paper contributes to several strands of the literature. First, we add to the early work on option-expiration effects. Early studies such as Stoll and Whaley (1991) and Hancock (1993) documented limited price distortions from moving option settlement to market open, but their evidence builds upon only a few years of data when the options market was relatively small. More recent research emphasizes the role of derivative-market frictions in shaping underlying prices. 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 portion of return volatility and jump probability in individual stocks. We extend this literature by documenting a new and persistent price distortion at the index level and estimating significant wealth-transfer implications.

Second, we contribute to research on intermediary hedging and inventory risk arising from option markets. Baltussen, Da, Lammers, and Martens (2021) show that Γ-hedging practices of

[2] The Online Appendix further investigates a set of potential alternative explanations drawn from the extant literature: fundamental shocks (overnight news, earnings, and macro announcements) and "pinning" - the phenomenon whereby underlying prices tend to cluster around their nearest strikes on expiration days. A battery of empirical tests fails to find support for these explanations.

option market makers drive intraday momentum around market-close times. Krohn, Mueller, and Whelan (2024) document prolonged intraday reversals in spot currency markets driven by dealers' inventory management. In addition, Adams, Dim, Eraker, Fontaine, Ornthanalai, and Vilkov (2025) and Vasquez, Amaya, Pearson, and Garcia-Ares (2025) find relatively balanced intermediary positions in p.m.-settled 0DTE S&P 500 options. We study intermediary positions in a.m.-settled 3^{rd} Friday S&P 500 options, where positions are imbalanced, and show that predictable Δ-hedging generates price pressures into expiry.

Third, we speak to the literature on intraday price pressures and predictable return patterns. Boyarchenko, Larsen, and Whelan (2023) show that U.S. equity returns are large and positive overnight around the opening of European markets, driven by the inventory management of exchange-based market makers. Furthermore, Gao, Han, Li, and Zhou (2018) show that price pressures from, among others, option market makers drive intraday momentum in equity markets. 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), while Baltussen, Da, and Soebhag (2025) find strong intraday reversals in individual stock returns related to price pressures from retail investors. We show that even in the most liquid equity-index derivative market, predictable market-wide return patterns arise in the window when settlement values are fixed, raising questions about settlement design.

I. Data and Market Background

A. Option Markets and Settlement Practices

Options on the S&P 500 index started trading on the Chicago Board Options Exchange (CBOE) on July 1^{st}, 1983 and quickly became a popular product. Today, S&P 500 options are the world's most traded index options, with robust liquidity and trading volume at various expiration and strike prices. Below, we highlight key settlement practices of the S&P 500 derivatives market, while the Online Appendix (OA) offers a more extensive description of S&P 500 option markets, as well as S&P 500 futures and Exchange Traded Funds (ETFs).

Standard S&P 500 (SPX) options expire on the 3^{rd} Friday of each month, with settlement prices originally based on the official closing price on the expiration day. Driven by concerns about dealer inventory management, on June 18^{th}, 1987, the Securities and Exchange Commission (SEC), the Commodity Futures Trading Commission (CFTC), the Chicago Mercantile Exchange (CME), and the Chicago Board Options Exchange (CBOE) changed their reference point for S&P 500 settlement prices from p.m. (i.e., market close) to a.m. settlement (i.e., market open).[3]

Since June 1987, the settlement price of quarterly S&P 500 index options has been calculated on 3^{rd} Friday mornings via the Special Opening Quotation (SOQ), and settlement is delivered in cash instead of stocks.[4] As of November 20^{th}, 1992, all monthly S&P 500 options also settle on the SOQ, motivating the use of November 1992 as the primary starting date in our study. Furthermore, trading in expiring options ceases at the market close on Thursday before expiration - that is, 17 hours and 15 minutes before settlement values are determined. This 17:15-hour window corresponds to the period from the 4:15 p.m. Thursday option close to the 9:30 a.m. Friday market open.[5] Related, since June 1987, S&P 500 futures also expire into the SOQ.

The SOQ is calculated as the market-value-weighted sum of stocks in the S&P 500 and their first reported trade price on their primary listing exchange. The SOQ is typically published 30–45 minutes after the market open, as it can only be calculated once all constituent stocks have opened for trading. 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, while less liquid stocks may take several minutes to open. Therefore, the SOQ is composed of single-stock trade prices at different points in time.

Besides the monthly a.m.-settled S&P 500 options, the CBOE has introduced additional S&P

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

[4] In cases where the 3^{rd} Friday is not a trading day, expiration occurs on the immediately preceding business day, most commonly a Thursday.

[5] In 2025, the SEC approved a CBOE rule change to extend trading in expiring a.m.-settled index options from Thursday close to five minutes before the market open on the 3^{rd} Friday. The change aims to reduce overnight exposure around settlement. See CBOE Regulatory Notice #56357 (2025).

500 option classes with different settlement conventions over time. Notably, p.m.-settled options were reintroduced in 2007 under the SEC's PM Option Expiration Pilot Program. These include (i) options expiring on the last business day of a calendar month, (ii) weekly options introduced in 2010, and (iii) monthly options expiring on the 3^{rd} Friday introduced in 2011, as well as the more recent zero-day (0DTE) options expiring daily.[6]

Figure 1 displays the monthly average dollar open interest (in billions) in S&P 500 options with 3^{rd} Friday expiry and a.m. settlement versus p.m.-settled options between January 1996 (the start date of our option open interest data) and December 2023. We observe a substantial market size in the a.m.-settled S&P 500 options, rising from about \$5 billion in 1996 to more than \$200 billion towards the end of our sample. Since around 2015, p.m.-settled options have gained prominence, but their size remains a fraction of the a.m.-settled SPX contracts.

[INSERT FIGURE 1 HERE]

B. Data

Our analysis combines data from multiple sources. From Bloomberg, we obtain daily S&P 500 index closing prices and SOQ values over the sample from November 1992 to December 2023.[7] 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 and offer prices, trade prices, and volumes. The sampling of tick-level data follows standard practices.

From the CBOE, we use the Open–Close Volume Summary dataset as of January 1996, which provides daily buy and sell volumes in S&P 500 options by participant type. We focus on positions in standard monthly contracts that expire on 3^{rd} Fridays and therefore exclude weekly (SPXW) and 0DTE S&P 500 index options. From January 1996 to December 2010, volumes are separated into "firms" and "customers," leaving "market makers" as the residual. From January 2011 to December 2023, the residual to "firms" and "customers" is further disaggregated by the CBOE

[6]Related, options on front-contract S&P 500 futures trade on the quarterly expiry calendar and expire into the SOQ, while non-quarterly (serial) options on S&P 500 futures are p.m.-settled at the close value of the underlying futures contract. In addition, in 2005, the CBOE introduced option contracts on the SPDR ETF. As ETFs are traded like common stocks, SPDR options have the same features as individual U.S. stock options; that is, they settle on the 3^{rd} Friday of the month at the closing price of that day.

[7]Bloomberg ticker SPXM until 2006 and ticker SPXSET afterwards.

into "professional customers," "broker dealers," and "market makers." For consistency, we define "market maker" trades as the residual to "firms" and "customers" across the entire sample, following Pan and Poteshman (2006) and Ni, Pearson, Poteshman, and White (2021). In what follows, we use the terms "market makers" and "dealers" interchangeably.

OptionMetrics provides end-of-day S&P 500 option data, which we use to calculate exposures to Greeks such as delta, gamma, and charm. Throughout, we scale open interest by the contract multiplier of 100 to express exposures in index units. In line with standard derivatives research practice, we exclude the expiration days of September 2001, September 2008, and October 2008 from all datasets used in the main analysis. Our findings are robust to including these dates.

II. The Third Friday Price Spike

In this section, we study equity returns around 3^{rd} Friday option expiration. We find that the S&P 500 drifts up on average by about 11 basis points from Thursday close to 3^{rd} Friday open, and subsequently fully reverts, with overnight returns showing strong predictive power for the subsequent intraday reversal. This Third Friday Price Spike is remarkably persistent during our 31-year sample period, while we find no corresponding price spike around p.m.-settled options.

A. The Third Friday Price Spike

We begin our analyses by computing overnight equity returns, as

$$\text{Return}_t^{\text{SOQ}} = \log(\text{SOQ}_t) - \log(\text{SPX}_{t-1}^{\text{close}}), \tag{1}$$

where SOQ is the S&P 500 Special Opening Quotation and $\text{SPX}^{\text{close}}$ is the closing value of the S&P 500 index. We compute intraday returns as $\log(\text{SPX}_t^{\text{close}}) - \log(\text{SOQ}_t)$.

Table I reports average returns in basis points and corresponding t-statistics over the period November 1992 to December 2023. We show results for trading periods around monthly 3^{rd} Friday settlement dates, the control group of other trading days, and the differences between 3^{rd} Friday returns versus the control group.[8] Panel (a) uses returns on all other trading days as the control group, while Panel (b) uses only Fridays that are not 3^{rd} Fridays as the control group, thereby isolating the expiration effect from any general Friday seasonal pattern.

On expiry days, 3^{rd} Thursday overnight returns are abnormally large and *positive*, equal to 10.6 bps with a t-statistic of 3.00. This compares to near-zero and insignificant average overnight returns on other days, consistent with efficient overnight pricing. The difference between overnight returns on 3^{rd} Thursdays and other days is statistically significant (t-statistic = 2.36): equity prices drift upward overnight before 3^{rd} Friday expirations. Panel (b) shows no comparable effect on non-expiry Fridays, underscoring that the bias is tied to option settlement rather than a weekly seasonal pattern.

Intraday returns on 3^{rd} Fridays are also abnormally large but *negative*, equal to -15.6 bps (t-statistic = -3.31). On other days, average intraday returns are positive but insignificant. The difference is on average -17.48 bps (t-statistic = -3.12). Again, using non-expiry Fridays as the control group yields similar results.

[INSERT TABLE I HERE]

Next, we study returns in the S&P 500 futures market to further examine the behavior of returns overnight and intraday. Futures intraday returns are computed from 5-minute volume-weighted average (VWAP) prices on E-mini futures.[9] Our futures sample spans January 2003 to December 2023, as liquid overnight trading in the E-mini began around 2003 (see the OA for more details around overnight trading).

Figure 2 shows the results. The solid black line displays cumulative 5-minute returns between 4:00 p.m. on 3^{rd} Thursdays (left-hand side of the x-axis) and 4:00 p.m. 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

[8] 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.

[9] We use the front-month futures contract and roll into the next-to-maturity contract when it becomes more liquid, typically a few days before quarterly expiry. This reflects typical rolling behavior but does not capture the SOQ on quarterly futures settlement dates. However, results are very similar when using the expiring futures contract until its expiry.

cumulative return in the active futures contract is equal to 12 bps, which completely reverses by noon. Thus, S&P 500 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 on the 3^{rd} Friday. This aligns with the pattern in index prices reported in Table I. To highlight the surprising nature of this pattern, consider the unconditional intraday return profile across all days (dotted line) which displays no reversal patterns and shows that overnight returns on 3^{rd} Thursdays are an order of magnitude larger than what should be expected unconditionally.

[INSERT FIGURE 2 HERE]

Taken together, S&P 500 index and futures prices drift up overnight before 3^{rd} Friday option expiry and revert intraday. We dub this empirical regularity the Third Friday Price Spike (3FPS). The 3FPS is economically large and statistically robust, both in absolute terms and relative to general overnight effects.

B. Third Friday Overnight-Intraday Reversal

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. To demonstrate a formal link between overnight returns in advance of 3^{rd} Friday a.m. settlements and subsequent intraday returns, we estimate a reversal regression of intraday futures returns on preceding overnight returns. We consider cumulative intraday intervals (9:30–9:35, 9:40, . . . , 4:00 p.m.), and measure overnight returns from prior close to open. Figure 3 shows the results. Panel (a) displays results for 3^{rd} Fridays and Panel (b) for all other days. Error bars represent 95% confidence intervals computed via block bootstrap.[10]

The predictive slope coefficient is strongly negative and significant on 3^{rd} Fridays up to noon, as evident from the gray bars in Panel (a). Coefficients are sizable (about -0.3), with (unreported) R^2 values near 10%, which is large given the high-frequency nature of the regressions. After noon,

[10]We use a block bootstrap approach 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 reversal effect weakens and becomes insignificant, consistent with Figure 2. In contrast, on other days reversal coefficients are small and insignificant (Panel (b)). These findings imply that large overnight returns are systematically reversed intraday up to noon, but *only* on 3^{rd} Friday expirations. In sum, S&P 500 prices exhibit a tent-shaped reversal pattern unique to 3^{rd} Fridays.

[INSERT FIGURE 3 HERE]

C. Persistence of the 3FPS

We next examine the persistence of overnight drift and intraday reversal around 3^{rd} Fridays. We consider two trading strategies and evaluate cumulative returns over time. The first buys the S&P 500 at the 3^{rd} Thursday close and sells at the SOQ on the 3^{rd} Friday, capturing the overnight return. The second shorts the S&P 500 at the 3^{rd} Friday open via the SOQ and closes at the 3^{rd} Friday close, capturing the intraday reversal. Figure 4 shows the resulting cumulative returns since November 1992. The solid line shows that overnight returns on 3^{rd} Thursdays have cumulated over most of our sample, except for a contraction over the 2000 to 2002 period. The dotted line shows 3^{rd} Friday intraday returns cumulated similarly, with a more pronounced increase recently. Overall, we conclude the 3FPS pattern is generally present throughout our sample period and not driven by particular subperiods.

[INSERT FIGURE 4 HERE]

D. P.M.-Settled Options

Next, we evaluate whether the bias documented above is a general feature of index option settlement. Besides the monthly a.m.-settled S&P 500 options, the CBOE has introduced S&P 500 options with other settlement practices over time, as outlined in the previous section. 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[11], and

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

more recently, zero-day-to-expiration (0DTE) options expiring daily. As shown in the previous section, 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. This raises the question: is a similar pattern of pre-expiry drift and subsequent (causal) reversal present around p.m. settlement?

Table II repeats the earlier analysis for the subsample when p.m.-settled options were traded (i.e., September 2011 onward), and also includes weekend returns (3^{rd} Friday close to Monday open). The 3^{rd} Thursday overnight drift remains strong at 10.08 bps (t-statistic = 2.20), with a reversal of -15.59 bps intraday (t-statistic = -2.35). In contrast, the weekend return from Friday close to Monday open - spanning the p.m. settlement window - shows no significant upward drift or reversal: -13.05 bps (t-statistic = -1.65). Thus, the 3FPS is confined to the 3^{rd} Friday a.m. settlement window, with no analogous spike-and-reversal pattern around p.m. settlements. The bias is isolated to contracts that expire into the SOQ and is not a general feature of index option settlement.

[INSERT TABLE II HERE]

SOQ prices on expiry Fridays are systematically biased upward relative to prior close prices. This regularity forms the basis for our subsequent analysis of payoff biases and wealth transfers.

III. The Payoff Bias in Equity Index Options

The consequences of the 3FPS are substantial: persistent positive overnight equity returns into the 3^{rd} Friday market open bias the payoffs of all U.S. equity derivatives that have monthly 3^{rd} Friday a.m. expiry. Because option payoffs are determined from a systematically upward biased SOQ, call payoffs are skewed upward, while put payoffs are skewed downward. This distortion alters settlement outcomes: in-the-money calls receive higher payouts, some out-of-the-money calls expire in-the-money, in-the-money puts lose value, and some puts that would have finished in-the-money expire worthless. As index options are cash-settled and payoffs constitute a zero-sum game, these biases generate systematic wealth transfers between option writers and buyers. Importantly, the impact extends beyond S&P 500 options to other equity index derivatives with 3^{rd} Friday a.m. expiry, including futures, futures options, and indices that share constituents such as the DJIA or Nasdaq 100.

A. *The Wealth Transfer from Biased Payoffs*

We quantify the wealth transfer by comparing actual option payoffs at expiry to counterfactual payoffs. We consider a.m.-settled S&P 500 options only and, as a result, our estimates should be interpreted as a lower bound on the total wealth transfer.[12]

Actual payoffs are calculated from the 3^{rd} Friday SOQ. Counterfactual payoffs replace the SOQ with the 3^{rd} Thursday S&P 500 closing price multiplied by the average non-expiry overnight S&P 500 return (equal to 1.00013, see Table I). Throughout, "counterfactual" therefore refers to Thursday's close scaled by the average non-expiry overnight return. The sample runs from January 1996 to August 2023, covering all expiring S&P 500 options with positive open interest. Because the average non-expiry overnight return is economically negligible (1.3 basis points), our wealth transfer estimates are virtually unchanged when using the Thursday closing price directly as the counterfactual.

Table III shows the results. S&P 500 call options paid off $8.314 billion on the average 3^{rd} Friday morning. Had their settlement been determined from the counterfactual open price, they would have paid off $8.150 billion. The difference of $163 million per month represents the wealth transfer from call option writers to call option buyers. Similarly, S&P 500 put options paid off $3.195 billion on the average 3^{rd} Friday morning, versus a counterfactual of $3.237 billion, yielding a wealth transfer from put option buyers to put option writers of $42 million per month. The sum of the wealth transfers in call and put options, multiplied by 12 (expiries per year), yields a wealth transfer of approximately $2.5 billion annually.

[INSERT TABLE III HERE]

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

B. Is the Payoff Bias Priced Into Options?

A natural question is whether sophisticated market participants anticipate the 3FPS and price it into options at the 3^{rd} Thursday close. If so, the payoff bias would represent compensation for bearing overnight risk rather than a market inefficiency. To test this, we examine option *returns* at expiry using tradable Thursday close midquotes.

We compare expiring S&P 500 options' actual returns into expiry to counterfactual returns. Actual expiry returns are calculated from options' mid-quotes at the 3^{rd} Thursday close to their final payoff at the 3^{rd} Friday open. Counterfactual returns are calculated from options' mid-quotes at the 3^{rd} Thursday close to a hypothetical final payoff based on the counterfactual open price defined above. The counterfactual return thus represents the option's overnight return absent the 3FPS. If the 3FPS were fully anticipated and priced into Thursday's option quotes, actual and counterfactual returns would converge.

We consider only expiring S&P 500 options with valid midquote data at Thursday close and restrict to options with moneyness between 0.5 and 1.5. Findings are reported by moneyness buckets: in-the-money (moneyness below 0.99 for calls, above 1.01 for puts), at-the-money (moneyness between 0.99 and 1.01), and out-of-the-money (moneyness above 1.01 for calls, below 0.99 for puts).

Table IV shows the results. Panel (a) reports biases in option returns in percentages; Panel (b) translates these into dollar terms. In line with the overnight equity price drift into the 3^{rd} Friday expiry, call option returns are biased upward and put option returns downward. The bias is most pronounced for at-the-money options: the average realized call (put) return equals -1.1% (-43.2%), whereas the average counterfactual expiry return for at-the-money call (put) options is -21.1% (-30.7%). Thus, at-the-money call returns are about 20.0 percentage points *less negative* than the counterfactual, while at-the-money put returns are about 12.5 percentage points *more negative*.

Panel (b) translates these biases into dollars by multiplying returns by options' lagged dollar open interest. The sum of the biases yields a wealth transfer of $1.5 billion per year - smaller than the payoff-based estimate because the return analysis excludes deep out-of-the-money options that lack valid midquote data.

The key finding is that option returns at expiry are systematically biased: call returns exceed their counterfactual values and put returns fall short. This demonstrates that the 3FPS is not fully priced into options at the 3^{rd} Thursday close. While the return-based wealth transfer ($1.5 billion) is smaller than the payoff-based estimate ($2.5 billion) - partly because the return analysis excludes deep out-of-the-money options, and partly because some participants may partially anticipate the bias - the residual pricing gap remains economically large.

[INSERT TABLE IV HERE]

IV. A Possible Explanation: Option Dealers' Inventory Hedging

This section investigates whether predictable dealer hedging demand can account for the Third Friday Price Spike (3FPS). Dealers Δ-hedge their option inventories by taking an offsetting position in the underlying index, or in close substitutes such as S&P 500 futures (see, for example, Ni, Pearson, Poteshman, and White (2021)). A distinctive feature of a.m.-settled index options is that trading in the expiring contracts ceases at the close on the 3^{rd} Thursday, while payoffs are determined at the 3^{rd} Friday open. As a result, dealers' positions in expiring options are effectively fixed over the 17:15-hour settlement window, yet the options' Δ continues to evolve mechanically as time passes and Δ converges to its terminal values $\{-1, 0, 1\}$. Even absent movements in the underlying, this predictable *Delta Drift* changes dealers' aggregate equity exposure and can induce systematic hedge-adjustment trades in the overnight period, when liquidity is relatively thin.

To quantify these predictable hedge-adjustment incentives, we develop our main measure - the projected dealer delta drift (DDD) - which summarizes the likely change in dealers' net-Δ from the 3^{rd} Thursday close to the 3^{rd} Friday open. The measure combines estimated dealer positions in each expiring contract, with a projection of each contract's Δ into settlement. This construction is designed to capture the mechanical component of Δ-evolution close to expiry without relying heavily on a particular option-pricing model or the unstable behavior of higher-order Greeks in the final hours before expiration.

We proceed as follows. Subsection A documents order-imbalance patterns in equity futures around a.m. expirations, which are consistent with temporary price pressure. Subsection B derives the effect of the passage of time on options' Δ (i.e., Charm) and motivates why the implied hedging demand is concentrated immediately before settlement. Subsection C estimates dealers' option inventory immediately before option expiry. Subsection D constructs our main prediction variable, the projected dealer delta drift. Subsection E shows that the DDD predicts the 3FPS. The OA evaluates prominent alternative explanations - including fundamental-news shocks and strike "pinning" - and finds little support for these channels.

A. Equity Price Pressures around Option Expiry

First, we establish the existence of equity price pressure by studying order imbalances. From the perspective of inventory-risk models, the ideal empirical measure of order imbalance would be the net-inventory held by market makers. As these are not observable, we use E-mini S&P 500 futures - the primary hedging instrument for SPX options - and follow Boyarchenko, Larsen, and Whelan (2023) to measure order imbalance by *signed volume*, i.e., the number of buyer-initiated minus seller-initiated contracts traded.[13] Table V contains summary statistics for all days and 3^{rd} Fridays over the sample where we have liquid overnight futures contracts (January 2003 to December 2023), split by the overnight window (Panel (a)) and the intraday window (Panel (b)).

Measured over all days, signed volume is close to zero overnight (-0.14, t-statistic $= -1.07$) but negative intraday (-1.75, t-statistic $= -3.60$), consistent with the view that futures are primarily used for hedging. By contrast, on 3^{rd} Fridays order imbalances are materially different. Overnight they are significant and *positive* (2.63, t-statistic $= 3.59$), whereas intraday they turn an order of magnitude more *negative* (-11.26, t-statistic $= -5.38$). This corresponds to an overnight order imbalance of about \$274 million, which is sizable relative to typical overnight trading imbalances.[14]

Because quarterly "Triple Witching" dates (March, June, September, December) are known to feature unusually large futures and index-arbitrage activity, one might worry that the overnight imbalance is driven by those dates alone. To address this, we estimate signed volumes separately

[13] Conceptually representing dollar order imbalances for consistency with inventory-risk models, we compute signed volume in number of contracts as each contract represents a fixed dollar exposure of $50 \times$ index level.

[14] Computed as $2.63 \times 1000 \times 50\times$ an average SPX level of 2,083 over the 2003–2023 period.

for quarterly and non-quarterly 3^{rd} Fridays.[15] We find the same pattern both on Triple Witching days and on other expiry days: positive overnight order imbalances that are followed by large negative intraday imbalances. Hence, the price-pressure pattern is not a by-product of unusual Triple Witching Day activity but a general feature of a.m.-settled 3^{rd} Fridays. These results are consistent with a price-pressure-based explanation.

[INSERT TABLE V HERE]

B. Options' Charm: The Sensitivity of Delta to the Passage of Time

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 the expected change of options' delta:

$$\frac{1}{dt} E_t^{\mathbb{P}}[d\Delta_t] = \mu S_t \Gamma_t + \frac{1}{2}\sigma^2 S_t^2 \mathcal{S}_t + \mathcal{C}_t, \tag{2}$$

where Gamma $= \Gamma = \frac{\partial^2 V}{\partial S^2} = \frac{\partial \Delta}{\partial S}$, Speed $= \mathcal{S} = \frac{\partial^3 V}{\partial S^3} = \frac{\partial \Gamma}{\partial S}$, and Charm $= \mathcal{C} = \frac{\partial \Delta}{\partial t}$. Gamma is the rate of change of Δ with respect to the price of the underlying. Gamma-induced option dealer trades, and the resulting equity price pressure, are studied in Baltussen, Da, Lammers, and Martens (2021). "Speed" ($\mathcal{S}$) is the rate of change of Γ with respect to the price of the underlying.

"Charm" ($\mathcal{C}$), the focus of this section, is the rate of change of Δ with respect to the passage of time. Ignoring the index dividend yield, for a European option, the Black-Scholes $\mathcal{C}$ is given by

$$\mathcal{C}_t = \frac{\partial \Delta}{\partial t} = -\frac{\partial \Delta}{\partial \tau} = -\frac{\partial^2 V}{\partial S \partial \tau} = \frac{\partial \Theta}{\partial S} \tag{3}$$

$$= \phi(d_1)\left(\frac{d_1}{2\tau} - \frac{r + \sigma^2/2}{\sigma\sqrt{\tau}}\right) \tag{4}$$

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 period; or (b) when options are near expiration since the magnitude of $\mathcal{C}$ increases quickly as time-to-maturity (τ) goes to zero. Unlike Γ and $\mathcal{S}$, exposures to $\mathcal{C}$ imply that, to maintain their Δ-hedge, dealers need to adjust their hedge with the passage of time, even if there is no movement in the underlying. Importantly, the

[15] See Barclay, Hendershott, and Jones (2008) for evidence on large liquidity shocks on Triple Witching days.

effect of $\mathcal{C}$ spikes into expiration, as demonstrated below. This point is well understood among practitioners, who often refer to this phenomenon as "delta bleed". Yet, the time drift in options' Δ has received little attention in the academic literature.

Figure 5 illustrates Charm for two hypothetical options. Panel (a) plots the Δ of a hypothetical call option over the 48 hours before expiry, as time $\tau \to 0$. Panel (b) contains a hypothetical put. The dotted line represents an in-the-money (ITM) option and the solid line an out-of-the-money (OTM) option. Upon expiry, the Δ of a call (put) option will be either 1 (-1) (i.e., the option expires in-the-money) or 0 (i.e., the option expires out-of-the-money). The slope of these lines is $\mathcal{C}$, measuring the rate at which Δ changes due to the passage of time, and thus the rate at which option dealers must trade in stocks to adjust their hedges. As the figure illustrates, $\mathcal{C}$ is negligible for options with many days to expiry, but $\mathcal{C}$ spikes as options near expiry. The Δ of an option drifts due to the passage of time, and especially so immediately before option expiry.

[INSERT FIGURE 5 HERE]

Panel (c) displays the properties of $\mathcal{C}$ for options with $\tau = 48$ and $\tau =$ 17:15 hours until expiry. The horizontal axis is plotted in terms of moneyness ($\log \frac{S_t}{K}$). For different levels of moneyness, the effect of $\mathcal{C}$ for deep ITM and OTM options is effectively zero, since their Δ is already 0 or 1, leaving little room for further drift. However, for options that are close to the money, the effect of $\mathcal{C}$ can be large. The Δ of just OTM calls is dragged rapidly towards 0 (negative $\mathcal{C}$), while the Δ of just ITM calls is dragged rapidly towards 1 (positive $\mathcal{C}$). The intuition for puts is symmetric: The Δ of OTM puts drifts from negative values (say, -0.4) toward 0, while the Δ of ITM puts drifts from intermediate values (say, -0.6) toward -1.

To summarize this subsection, options' Δ drifts to 0 or 1 (for calls) and 0 or -1 (for puts) as the option approaches expiration, even if the price of the underlying does not change. This effect is especially strong for options that are close to the money, since their Δ's are approximately 0.5 (-0.5) and so have a long way to drift. As a consequence of options' Δ-drift, option dealers' inventory Δ drifts into option expiry, too. This drift occurs even if dealers are initially fully Δ-hedged and even if the options have ceased trading. We turn to option dealers' inventory positions next.

C. Dealers' Option Position Before Option Expiry

We examine the positions of option market makers in S&P 500 index options, with a particular focus on 3^{rd} Thursday close positions and the expected drift in their net-Δ position. We exploit the CBOE Open-Close Volume files to estimate option dealers' inventory. Section I describes the data. For every S&P 500 option on every day since 1996, the CBOE Open-Close Volume files show the number of options bought and sold by the market maker sector. Cumulating these trades yields an estimate of dealers' net-position, i.e., an estimate of the number of options that dealers are long minus the number of options that dealers are short, for every S&P 500 option on every day. Since we do not observe dealers' starting inventory in January 1996, we use a six-month burn-in period that allows the initial option positions to expire. Hence, our sample of dealer positions is July 1996 to December 2023. Our results are robust to the choice of initialization period.

While our data on S&P 500 options are comprehensive, we do not observe dealers' position in other derivatives. For example, equity futures options also settle into the SOQ on Triple Witching days. To address the additional noise introduced by these days, we report the results of our predictive regressions both for the full set of expiration days and for the cleaner subsample of non-quarterly dates.

Table VI documents the dealer position in a.m.-settled S&P 500 options. Panel (a) column 1 shows that, on an average day, dealers' net-position in calls is -0.16 million. Column 2 shows that on an average 3^{rd} Thursday, immediately before option expiry, dealers' net-position in expiring calls is -0.87 million. In contrast, dealers' average position in puts is -16.82 million generally, and -19.02 million into expiry. This shows that dealers' long and short positions in calls are of about equal magnitude, yielding a net-position close to zero, while dealers' short position in puts exceeds their long position, resulting in a large negative net-position. These positions reveal systematic demand imbalances, consistent with evidence in Garleanu, Pedersen, and Poteshman (2009) and Golez and Jackwerth (2012).

The aggregate number of options in dealers' portfolio does not reveal their risk exposures without accounting for options' moneyness, time to expiry, the expected equity return volatility, and many more aspects. The subsequent columns address this via the three aggregate risk measures:

net-Δ, net-Γ, and net-$\mathcal{C}$.

[INSERT TABLE VI HERE]

Column 4 shows that dealers' net-position in expiring calls carries an aggregate Δ of 2.27 million, and the dealer put position carries a Δ of 2.41 million.[16] Both these exposures are calculated as the sum-product of the dealer position across options and the respective options' Δ.[17] To offset this Δ-exposure from options, dealers would short 4.68 million units of the S&P 500. As the options expire, the option Δ disappears from dealers' inventory and dealers can be expected to trade out of their stock position. However, we find below that such expiring Δ-hedge trades do not predict the 3FPS. This is consistent with the level unwind being anticipated by the market and executed during Friday's liquid regular-hours session, where ample liquidity absorbs the trades with minimal price impact. In contrast, the delta *drift* generates an exposure change over the 17:15-hour overnight window - when expiring options have already ceased trading and equity liquidity is thin - creating scope for price pressure.

Column 6 shows that dealers carry a negative inventory Γ from expiring options into option expiry. As a result, positive equity price changes would make dealers' Δ more negative (via their negative Γ exposure), incentivizing them to buy stocks to remain hedged. However, similar to the amount of expiring Δ, we find that option dealer inventory Γ does not predict the 3FPS. Also note that dealers' inventory Γ does not differ substantially between all days (column 5) and expiry days (column 6), which is inconsistent with the 3FPS occurring only into expiry days.

Column 8 shows that dealers carry substantial negative net-$\mathcal{C}$ from their options inventory immediately before option expiry. A $\mathcal{C}$ of -31.38 million implies that dealers' inventory Δ drifts *down* with the passage of time, when measured at the 3^{rd} Thursday close. To offset this drift, dealers have an incentive to buy stocks into option expiry, which can explain the 3FPS. In the next subsection, we construct a direct measure of the projected delta drift (DDD), which averages -60k index units over the 17:15-hour overnight window - equivalent to approximately $-3,500$

[16] Call options have positive Δ. Therefore, one would expect a short call position to carry an aggregate negative Δ. Here, however, long and short positions differ along the dimensions of moneyness and time to expiry in such a way that an aggregate short call position carries an aggregate positive Δ.

[17] Figure A.3 in the Online Appendix displays time series plots of dealer net-Δ and net-Γ.

index units per hour. Another attractive property of $\mathcal{C}$ becomes clear when comparing column 8 with column 7, which displays dealer option $\mathcal{C}$ on an average day of the sample. $\mathcal{C}$ is much more pronounced ahead of option expiry, potentially explaining why the 3FPS is specific to option expiry days.

D. The Projected Option Dealer Delta Drift (DDD)

Next, we introduce a new measure, the projected option *dealer delta drift*. Delta drift captures the predictable change in options' Δs over the settlement window that arises purely from the passage of time. It therefore serves as a proxy for the integrated Charm exposure of expiring options between the 3^{rd} Thursday close and the 3^{rd} Friday open (a 17:15-hour window). We construct delta drift by projecting each contract's Δ from the 3^{rd} Thursday close toward its terminal value at expiry (-1, 0, or 1), using the options' moneyness at 3^{rd} Thursday close, adjusted for the positive expected overnight equity index return. This approach avoids committing to a specific option-pricing model and is less sensitive to the extreme curvature of higher-order Greeks as time-to-expiry approaches zero.

We compute DDD as the change in dealers' net-Δ from expiring options between the 3^{rd} Thursday close and the 3^{rd} Friday open. Let $q_{i,t}$ denote dealers' net-position in expiring option i at the 3^{rd} Thursday close, and let $\Delta_{i,t}^{\text{Thu}}$ denote the option's delta at that time. Dealers' net-Δ exposure at the 3^{rd} Thursday close is $\Delta_t^{\text{Thu}} = \sum_i q_{i,t}\, \Delta_{i,t}^{\text{Thu}}$. We then form projected deltas at the 3^{rd} Friday open, $\widetilde{\Delta}_{i,t}^{\text{Fri}}$, and the corresponding projected net-Δ exposure $\widetilde{\Delta}_t^{\text{Fri}} = \sum_i q_{i,t}\, \widetilde{\Delta}_{i,t}^{\text{Fri}}$. Our projected dealer delta drift is defined as

$$\text{DDD}_t = \widetilde{\Delta}_t^{\text{Fri}} - \Delta_t^{\text{Thu}}. \tag{5}$$

Because expiring options cease trading at the 3^{rd} Thursday close, dealers' positions in these contracts are identical at both times; the only object that requires estimation is $\widetilde{\Delta}_{i,t}^{\text{Fri}}$.

To estimate $\widetilde{\Delta}_{i,t}^{\text{Fri}}$, we adopt a simple classification rule based on terminal deltas. At expiry, a call has $\Delta = 1$ if it finishes in-the-money (ITM) and $\Delta = 0$ otherwise; a put has $\Delta = -1$ if it finishes ITM and $\Delta = 0$ otherwise. We assume that moneyness at the 3^{rd} Thursday close determines moneyness at expiration, with a small adjustment for the expected overnight drift in the index. Let S_t^{Thu} denote the S&P 500 level at the 3^{rd} Thursday close and let $\bar{r}^{ON} = 1.3$ bps denote the average close-to-open log return on non-expiry days. We classify a call with strike K as expiring ITM if $K < S_t^{\text{Thu}} \exp(\bar{r}^{ON})$ and as expiring OTM otherwise. Analogously, we classify a put as expiring ITM if $K > S_t^{\text{Thu}} \exp(\bar{r}^{ON})$ and as expiring OTM otherwise. We then set $\widetilde{\Delta}_{i,t}^{\text{Fri}} = 1$ (0) for ITM (OTM) calls and $\widetilde{\Delta}_{i,t}^{\text{Fri}} = -1$ (0) for ITM (OTM) puts. The DDD defined in equation (5) measures the *total* projected Δ-change over the 17:15-hour overnight window before a.m. expiry. This is the quantity used in the predictive regressions (Tables VII and VIII). For non-expiry days and weekends, the same construction applies with the appropriate time-to-expiry horizon. When we visualize DDD across all days in Figure 6, we rescale to a per-hour rate (dividing by hours to expiry) so that magnitudes are comparable across options with different maturities.

Panel (b) of Table VI shows our calculation of the projected Δ-drift in dealers' option position quantitatively. Column 1 shows the current inventory-Δ at the 3^{rd} Thursday close, with calculation and results equivalent to column 4 in Panel (a). Dealers carry a Δ-position of 4.68 million in expiring options before option expiry. Column 2 shows that the expected dealer inventory Δ 17:15 hours later is 4.62 million. The difference of $-60{,}000$ is the projected dealer Δ drift (DDD).

The DDD of $-60{,}000$ shows that dealers' net-Δ positions systematically decline overnight before option expiry. In economic terms, this exposure implies the need to purchase approximately \$111 million of S&P 500 exposure overnight.[18] This quantity amounts to roughly 40% of the typical signed order imbalance of about \$274 million observed ahead of 3^{rd} Friday settlements. Whether this magnitude of hedging flow is sufficient to generate the observed 11 basis point price impact depends on overnight price elasticity. Overnight equity markets are substantially less liquid than regular-hours trading, with larger price impacts per unit of order flow (Boyarchenko, Larsen, and Whelan, 2023; Barclay and Hendershott, 2003). The predictability regressions in Table VIII provide direct evidence that DDD-implied flows are large enough to move prices: a one standard deviation change in the projected drift predicts overnight index returns with an R^2 above 1%, which is economically significant at this horizon.

[18] Computed as -60,000 times the average S&P 500 price level of 1,854.

Figure 6 shows DDD over all days in our sample. In this figure, we express DDD as a rate (index units per hour) by dividing the total projected delta change by hours to expiry, to make the magnitude of the Δ drift comparable for options with different times to expiry. The red dots highlight expiry dates and reveal that the dealer delta drift is both more extreme and more negative on 3^{rd} Thursdays than on other days, with most expiry observations well below zero. Moreover, there is substantial variability that we exploit in our next tests. Option dealers' inventories predictably drift overnight prior to a.m. settlement, requiring offsetting purchases of S&P 500 equities, or related products, to restore Δ-neutrality of dealers' inventory.

[INSERT FIGURE 6 HERE]

We next examine the drivers of dealers' delta drift by regressing DDD on contemporaneous Greek exposures. Table VII reports the results for all 3^{rd} Friday expiries, non-quarterly expiries (unaffected by Triple Witching activity), weekends, and non-expiry days. All variables are standardized to zero mean and unit variance. Block bootstrapped standard errors are in round brackets and Newey-West t-statistics with three lags are in square brackets. The estimates show that projected Δ changes are tightly linked to net-$\mathcal{C}$: Across specifications, we see that a one standard deviation increase in Dealer $\mathcal{C}$ is on average associated with a ~ 0.6 standard deviation increase in the projected dealer delta drift.

The R^2 values, while substantial, indicate that end-of-day Greek exposures alone do not fully capture the dealer delta drift. This is what we should expect: our proxy is designed to approximate the total change in Δ over the 17:15-hour overnight interval, which requires integrating the instantaneous change described in equation (2). During this window, the Greeks themselves evolve non-linearly, particularly near expiry, when $\mathcal{C}$ and Γ exhibit strong curvature. A linear regression based solely on Thursday close Greek values cannot fully capture these path-dependent dynamics, motivating our direct proxy for the integrated overnight Δ-change.

[INSERT TABLE VII HERE]

E. Predictability Regressions

To test the Δ-hedging explanation for the 3FPS, we test whether time series variation in the projected dealer delta drift predicts overnight S&P 500 returns on 3^{rd} Fridays. Table VIII reports the results of a predictability regression of overnight returns on lagged dealer positions measured at the previous day's close. Panel (a) uses index returns from close to the SOQ, while Panel (b) uses S&P 500 futures returns (standard contract through September 1997, E-mini thereafter). The sample is July 1996 to December 2023.

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

In the univariate specification in Panel (a), the coefficient on the dealer delta drift is economically large and statistically significant. A more negative delta drift is associated with higher overnight returns into the 3^{rd} Friday expiry. Specifically, a one standard deviation increase in the projected drift predicts a 0.12-standard-deviation reduction in the 3FPS, with an R^2 of 1.03%, which is sizable given the short 17:15-hour horizon. Unreported multivariate specifications that additionally control for the expiring dealer Δ level and short-term price-pressure proxies (VIX index, TED spread) leave the effect unchanged.

To verify that the result is not driven by the unusually high activity on Triple Witching Days, we repeat the analysis for the subset of non-quarterly expiries (columns 3-4). The coefficients remain significant and of similar or greater magnitude, confirming that predictability is not specific to quarterly expirations. Column 5 shows the results for S&P 500 returns over weekends, as predicted by dealer positions at Friday close.[19] Over weekends, the passage of time is largest (more than 2.5 days elapse), but DDD is relatively small due to its maturity dependence. Accordingly, we find little predictability over weekends, consistent with our finding that equity price pressures occur around option expiry, not over weekends.

In column 6 we consider all non-expiry days. Similar to weekends, DDD is small on average over non-expiry days and we find no systematic bias in equity open prices. Thus, we expect not to find return predictability over non-expiry days. As expected, on non-expiry days there is no

[19] Note that projecting the dealer delta drift over weekends requires expanding the time window from 17:15 hours to 2 days and 17:15 hours.

significant predictable variation in overnight returns arising from dealers' delta drift. Both point estimates and R^2 are close to zero. Thus, we conclude that the impact of DDD is confined to periods close to a.m. option expiry, where we observe the 3FPS and biased derivative payoffs. Panel (b) confirms that the results are nearly identical when using futures returns.[20] Overall, the evidence shows that dealers' expected net-Δ change measured at the 3^{rd} Thursday close reliably forecasts S&P 500 overnight returns into the SOQ and, by extension, explains the recurring 3FPS pattern.

Finally, we examine the conditional impact of dealers' delta drift on the 3FPS via sorting. We divide expiry days into two groups, based on the sign of DDD, as measured at the 3^{rd} Thursday close. Panel (a) of Figure 7 presents the results for all 3^{rd} Friday expiries, while Panel (b) focuses on non-quarterly expiries.

[INSERT FIGURE 7 HERE]

Consistent with the regression evidence, we find a negative relation between the projected dealer delta drift and subsequent overnight equity returns. When DDD is negative, indicating a dealer incentive to buy stocks into option expiry, the average overnight S&P 500 return is 16 bps, compared with only 2 bps when DDD is positive (Panel (a)). Restricting the sample to non-quarterly expiries, where market activity is less dominated by futures and related contract settlements, strengthens the pattern. Overnight returns average 16 bps when DDD is negative, but turn negative at -3 bps when DDD is positive (Panel (b)). Put differently, the 3FPS is positive on average because dealers' net-Δ change is typically negative, but the spike can flip sign when their net-Δ change turns positive.

We conclude that dealers' Δ-hedging is the most plausible mechanism behind the 3FPS and the resulting derivative payoff bias. Option market makers' hedging requirements generate systematic equity price pressures around option expiry: a mechanical downward time drift in dealers' inventory Δ creates buying pressure in the relatively illiquid overnight window before a.m. expiry, which

[20] In addition, unreported robustness tests using the post-2010 CBOE "market maker" classification produce nearly identical results, confirming that our findings do not depend on how dealer positions are identified. In our main specification we identify market makers as the counterparty to "customers" and "firms".

pushes equity prices upward. These gains subsequently reverse intraday, producing recurring price spikes in equities and persistent payoff biases in cash-settled index derivatives.

F. Discussion and Potential Implications

Our findings have several important implications. First, the evidence that dealers' Δ-hedging affects prices around option expiry suggests that the rapid growth of zero-day-to-expiration (0DTE) options could bias equity prices around the daily close. Delta drift is largest for near-expiry contracts, raising the possibility that 0DTE activity may increasingly shape intraday price behavior. At present, this channel appears limited: Adams, Dim, Eraker, Fontaine, Ornthanalai, and Vilkov (2025) document that 0DTE order flow is relatively balanced, which mitigates predictable hedging pressures. If order flow in 0DTE options were to become one-sided, the Δ drift in these contracts could generate price pressure around p.m. settlements, analogous to the mechanism we document for a.m.-settled SPX options, where order flow has long been persistently unbalanced. Nonetheless, any such effects would likely be attenuated by the much higher liquidity during regular trading hours compared to the relatively illiquid overnight window that amplifies the 3FPS.

Second, our finding that equity returns are predictable around the a.m. option settlement opens possibilities for predatory trading - trading that exploits the needs of others to change their positions. Investors who are informed about dealers' delta drift 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, underlying price pressures that impact derivatives prices give rise to the possibility of market manipulation, 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 generates a year-end reversal in single stocks. 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). All three conditions 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.

Fourth, we contribute to the growing literature documenting predictable price patterns that persist in large and liquid markets. Hartzmark and Solomon (2025) provide a striking recent example: they show that predictable uninformed cash flows from dividend reinvestment forecast aggregate market returns, with top-quintile dividend payment days generating returns four times higher than the lowest quintile, despite the payment dates being announced weeks in advance. They estimate a market-level price multiplier of 1.9, with effects strengthening when reinvestment is high and liquidity is low. Like the dividend-day effect, the 3FPS persists over our 31-year sample in equities, equity futures, and equity options, raising fundamental questions about why sophisticated investors do not arbitrage these patterns away. Limits to arbitrage remain a puzzling yet fruitful frontier for the asset pricing literature.

Several frictions may help explain this persistence. Transaction costs in option markets, particularly for large positions needed to profit from expiration effects, may deter arbitrage activity. However, while transaction costs might explain why traders do not eliminate the pattern, they do not explain why option mid-quotes, which should reflect fair value, fail to fully adjust. Additionally, managing overnight exposures into option expiration requires sophisticated trading infrastructure and demands substantial balance-sheet capacity, particularly around quarterly Triple Witching days when volumes spike.

Regardless of whether the derivative payoff bias is priced into options ex-ante and regardless of the frictions that prevent full option price adjustment, the 3FPS generates economically significant and recurring distortions in a.m. derivative payoffs. More broadly, the alignment of large-scale derivative settlements with the relatively illiquid market open warrants scrutiny from exchanges and regulators. In light of the large and growing size of derivatives markets, the quest to decipher puzzles of this type is a first-order question for future research.

V. Conclusions

Each month, when U.S. equity index derivatives settle via the S&P 500 Special Opening Quotation (SOQ), the index opens on average about 11 basis points above its prior close and fully reverses by midday. This predictable Third Friday Price Spike (3FPS) occurs only on expiry days with a.m. settlement and extends to futures markets. Because derivative payoffs are determined from these biased opening prices, call option payoffs are inflated, put option payoffs deflated, and we estimate approximately $2.5 billion in wealth is redistributed between investors in S&P 500 index options alone each year.

We trace this bias to the hedging behavior of option dealers. As expiration approaches, the passage of time alone causes dealers' aggregate inventory Δ to drift systematically downward, forcing overnight equity purchases to maintain Δ-neutral portfolios. This projected Δ drift predicts the magnitude and timing of the 3FPS, is absent outside a.m. settlement windows, and remains robust across multiple specifications. By documenting how mechanical hedging needs move market-wide prices during periods of limited liquidity, our findings suggest that the alignment of derivative expirations with thin trading windows warrants scrutiny from exchanges and regulators.

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VI. Tables

	Option Expiry Days		Control Group			
	I. Th_{close} to 3^{rd} Fr_{open}	II. 3^{rd} Fr_{open} to 3^{rd} Fr_{close}	III. Close to Open	IV. Open to Close	I. - III.	II. - IV.
	Panel (a) Control Group: Non-Expiry Days					
mean	10.61	-15.57	1.30	1.92	9.31	-17.48
t-stat	3.00	-3.31	1.47	1.56	2.36	-3.12
	Panel (b) Control Group: Non-Expiry Fridays					
mean	10.61	-15.57	0.62	3.46	9.99	-19.03
t-stat	3.00	-3.31	0.28	1.18	2.25	-3.25

Table I. S&P 500 Returns around 3^{rd} Fridays

This table reports average S&P 500 returns and associated t-statistics. Columns 1 and 2 show returns around 3^{rd} Fridays, columns 3 and 4 show returns for the control group. Columns 5 and 6 show the difference of means between 3^{rd} Friday returns and control group returns. In Panel (a), the control group consists of all days that are not 3^{rd} Fridays; in Panel (b), the control group consists of all Fridays that are not 3^{rd} Fridays. Returns are computed from closing prices and the Special Opening Quotation. Returns are in basis points. The sample period is November 1992 to December 2023.

	Th_{close} to 3^{rd} Fr_{open}	3^{rd} Fr_{open} to 3^{rd} Fr_{close}	3^{rd} Fr_{close} to Mo_{open}
mean	10.08	-15.59	-13.05
t-stat	2.20	-2.35	-1.65

Table II. S&P 500 Returns around 3^{rd} Fridays, Post-2011

This table reports average S&P 500 returns and associated t-statistics. Column 1 shows returns from Thursday close to the 3^{rd} Friday open, column 2 shows returns from the 3^{rd} Friday open to the 3^{rd} Friday close, and column 3 shows returns from the 3^{rd} Friday close to Monday open. Returns are computed from closing prices and the Special Opening Quotation. Returns are in basis points. The sample period runs from September 2011, when p.m.-settled 3^{rd} Friday options were reintroduced, to December 2023.

	Payoffs		
	I. Actual	II. Counterfactual	I. - II.
Sum Calls ($ mn., rounded)	8,314	8,150	163
Sum Puts	3,195	3,237	-42
Sum abs(I. - II.)			205

Table III. S&P 500 Option Payoffs on 3^{rd} Fridays

This table shows actual and counterfactual S&P 500 option payoffs. Row 1 contains calls, row 2 contains puts. Column 1 shows the mean monthly payoff from expiring SPX options. The monthly payoff is calculated as the sum-product of each option's payoff and the respective option's open interest. Option payoffs are determined on 3^{rd} Fridays via the Special Opening Quotation. Column 2 shows the mean counterfactual option payoff, where options' counterfactual payoff is calculated at the 3^{rd} Thursday close via S&P 500 equity trade prices adjusted for the average non-expiry overnight return. Column 3 displays the difference between actual and counterfactual payoffs, and row 3 displays the sum of the absolute differences. All numbers are in millions of dollars. The sample period is January 1996 to August 2023.

	Actual		Counterfactual	
	Calls	Puts	Calls	Puts
	Panel (a) Returns (%)			
In the money	1.1	-2.9	-0.2	-0.7
At the money	-1.1	-43.2	-21.1	-30.7
Out of the money	-75.5	-99.0	-80.6	-98.8
	Panel (b) Returns ($ mil.)			
In the money	124.7	-52.6	54.4	-21.2
At the money	3.0	-14.6	-9.0	-7.4
Out of the money	-4.1	-13.6	-4.2	-13.4
Sum	123.6	-80.7	41.2	-41.9

Table IV. S&P 500 Option Returns into 3^{rd} Fridays

This table shows summary statistics for S&P 500 option returns into expiry. Columns 1 and 2 of Panel (a) report average (net) returns of expiring S&P 500 options from Thursday close to their final payoff on the 3^{rd} Friday open. Columns 3 and 4 report counterfactual returns, calculated via a hypothetical 3^{rd} Friday SOQ, which is based on the unconditional non-expiry overnight S&P 500 return. Panel (b) reports average returns in millions of dollars, calculated as $Dollar\ Return = Return \cdot Lagged\ Dollar\ Open\ Interest$. 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 classified oppositely. Options are sorted into a moneyness bucket at Thursday close and equally weighted within each bucket. The sample period is January 1996 to August 2023.

Days:	Non-Expiry	Expiry	Qtr Expiry	Non-Qtr Expiry
		Panel (a): Overnight		
mean	-0.14	2.63	4.23	1.83
t-stat	-1.07	3.59	3.26	2.08
		Panel (b): Intraday		
mean	-1.75	-11.26	-14.04	-9.88
t-stat	-3.60	-5.38	-4.16	-3.74

Table V. Order Imbalances in S&P 500 Futures

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 4:15 p.m. and 9:30 a.m.). Panel (b) contains the average signed volume intraday (i.e., between 9:30 a.m. and 4:00 p.m.). The columns 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 January 2003 to December 2023.

Panel (a)

	Net No. (mn.)		Net Delta (mn.)		Net Gamma (k.)		Net Charm (mn.)	
Days:	1. All	2. Exp	3. All	4. Exp	5. All	6. Exp	7. All	8. Exp
Calls	-0.16	-0.87	2.40	2.27	13.98	21.24	7.43	28.49
Puts	-16.82	-19.02	2.62	2.41	-35.37	-48.81	-15.12	-59.88
Sum	-16.98	-19.89	5.02	4.68	-21.39	-27.57	-7.69	-31.38

Panel (b)

	1. Net Delta at Th_{close}	2. Projected Net Delta at Fr_{open}	2. - 1. Projected Dealer Delta Drift (DDD)	t-stat
Calls	2.27	2.32	0.05	1.17
Puts	2.41	2.30	-0.11	-2.79
Sum	4.68	4.62	-0.06	-2.37

Table VI. Dealers' Position in S&P 500 Options

This table reports dealer positions in a.m.-settled 3^{rd} Friday options. Row 1 shows the average dealer position in calls, row 2 shows the average dealer position in puts, row 3 shows the sum. In Panel (a), Net Number is in millions of option contracts. Net Delta, Net Gamma, and Net Charm are in index units (i.e., scaled by the 100× option multiplier), expressed in millions (mn.) or thousands (k). Net Greeks are calculated as the sum-product of dealers' net-number across options and the respective options' Greek risk measure. The "All" columns show the average position across all a.m.-settled S&P 500 options on all days. "Expiry" columns show the average position across expiring options on the day (Thursday) before their monthly expiry. In Panel (b), column 1 shows the dealer net-Δ in expiring options on the day (Thursday) before their monthly expiry. Column 2 reports the dealer net-Δ expected at the 3^{rd} Friday open, assuming no changes other than the passage of time. Column 3 shows the difference, the dealer delta drift, and column 4 shows the associated t-statistic. The sample period is July 1996 to December 2023.

	1. Expiry All	2. Expiry All	3. Expiry Non-Qtr.	4. Expiry Non-Qtr.	5. Weekend	6. Non-Expiry
Dealer Charm	0.56	0.57	0.57	0.56	0.33	0.45
	(0.06)	(0.06)	(0.07)	(0.08)	(0.11)	(0.03)
	[11.38]	[11.43]	[7.41]	[7.80]	[2.90]	[12.25]
Dealer Gamma	-0.04	-0.05	-0.06	-0.06		0.06
	(0.08)	(0.09)	(0.09)	(0.09)		(0.02)
	[-0.50]	[-0.70]	[-0.64]	[-0.63]		[2.65]
Expiring Dealer Delta		-0.09		0.02		
		(0.07)		(0.08)		
		[-1.39]		[0.26]		
$R^2(\%)$	30.63	31.25	31.82	31.55	11.68	20.79

Table VII. Regressing the Projected Dealer Delta Drift on Greeks

This table displays estimates from regressing the projected dealer delta drift (DDD) on contemporaneous dealer Greek risk measures. Columns 1 and 2 contain dealer positions at 3^{rd} Thursday close, columns 3 and 4 include only non-quarterly 3^{rd} Thursdays, column 5 contains positions on any Friday close, and column 6 includes only Thursdays that do not precede an option expiry. All variables are standardized to zero mean and unit variance. Block bootstrapped standard errors are in round brackets. Newey-West t-statistics with 3 lags are in square brackets. The adjusted R^2 is multiplied by 100. The sample period is July 1996 to December 2023.

	1. Expiry All	2. Expiry All	3. Expiry Non-Qtr.	4. Expiry Non-Qtr.	5. Weekend	6. Non-Expiry
Panel (a): Predicting index returns						
Dealer Delta Drift	-0.12	-0.11	-0.17	-0.17	-0.05	0.02
	(0.06)	(0.06)	(0.07)	(0.07)	(0.04)	(0.02)
	[-2.04]	[-2.04]	[-2.71]	[-2.83]	[-1.04]	[0.96]
Expiring Dealer Delta		0.03		0.07		
		(0.06)		(0.09)		
		[0.56]		[0.91]		
$R^2(\%)$	1.03	0.83	2.31	2.31	0.17	0.01
Panel (b): Predicting index futures returns						
Dealer Delta Drift	-0.09	-0.08	-0.15	-0.16	-0.06	0.01
	(0.05)	(0.05)	(0.07)	(0.06)	(0.04)	(0.02)
	[-1.84]	[-1.83]	[-2.69]	[-2.81]	[-1.33]	[0.55]
Expiring Dealer Delta		0.03		0.09		
		(0.06)		(0.08)		
		[0.47]		[1.17]		
$R^2(\%)$	0.43	0.20	1.84	2.26	0.35	-0.01

Table VIII. Regressing S&P 500 Returns on the Dealer Delta Drift

This table displays estimates from regressing the overnight return of the S&P 500 on lagged dealer positions. In Panel (a), returns are computed from closing prices to the Special Opening Quotation. In Panel (b), returns are computed from the futures mid-quote at close to the mid-quote at open. Columns 1 and 2 contain returns from Thursday close to 3^{rd} Friday open, columns 3 and 4 include only non-quarterly 3^{rd} Fridays, column 5 contains returns from Friday close to Monday open, and column 6 includes only returns that are not into a 3^{rd} Friday. All variables are standardized to zero mean and unit variance. Block bootstrapped standard errors are in round brackets. Newey-West t-statistics with 3 lags are in square brackets. The adjusted R^2 is multiplied by 100. The sample period for Panels (a) and (b) is July 1996 to December 2023.

VII. Figures

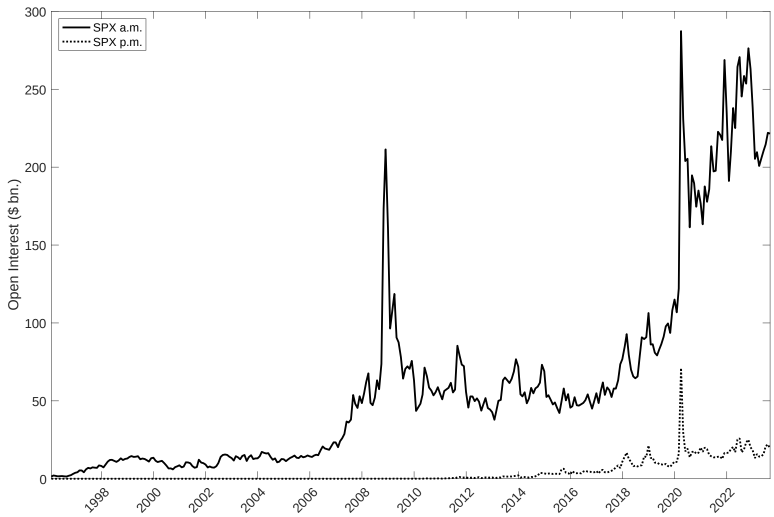


Figure 1. S&P 500 Option Market Size

This figure displays the monthly average open interest (in billion dollars) of S&P 500 options with a.m. (solid line) and p.m. (dotted line) settlement. The sample period is January 1996 to December 2023.

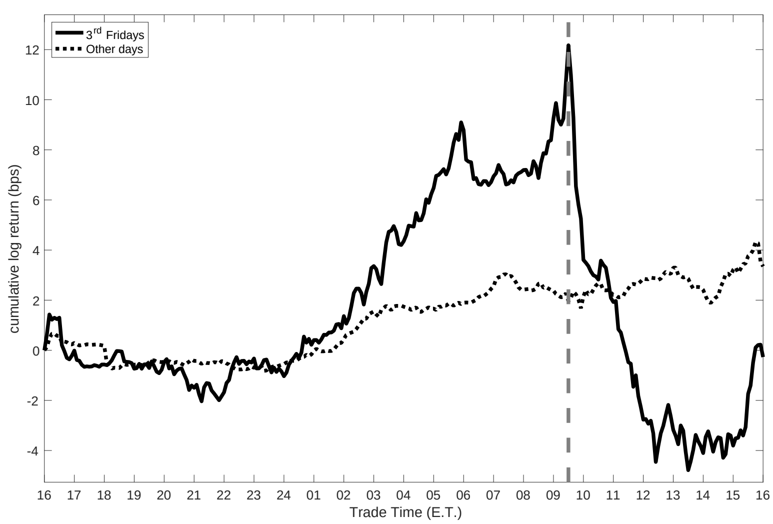
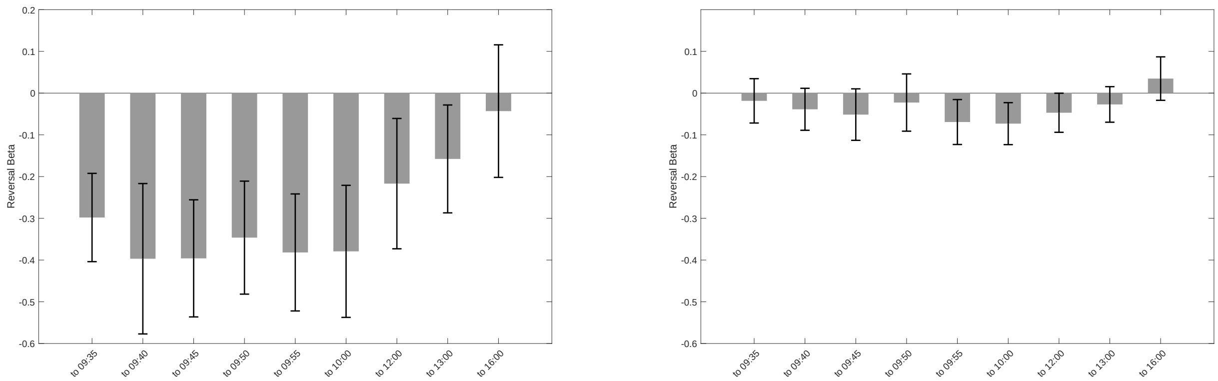


Figure 2. The 3^{rd} Friday Price Spike in S&P 500 E-mini Futures

The solid black line plots average cumulative 5-minute log returns of S&P 500 E-mini futures around 3^{rd} Friday market open (9:30 a.m., dashed vertical line). The dotted line plots cumulative returns on all other days. The vertical axis is in basis points and the horizontal axis is time of day in Eastern Time. The sample period is January 2003 to December 2023.



(a) Expiry Days **(b)** Other Days

Figure 3. Regressing intraday S&P 500 returns on preceding night returns
This figure displays the betas and associated confidence intervals from regressing intraday S&P 500 returns on preceding overnight S&P 500 returns. Returns are measured from S&P 500 futures trade prices. The LHS returns are measured from 9:30 to 9:35, 9:40, 9:45, etc. The figure bars represent this expanding window of LHS returns from left to right. The RHS return is measured from the preceding equity close to open. Panel (a) displays results around 9:30 a.m. on 3^{rd} Fridays, Panel (b) displays results for all other days. The regression includes an intercept. The error bars show the 95% confidence intervals, via bootstrapped standard errors. The sample period is January 2003 to December 2023.

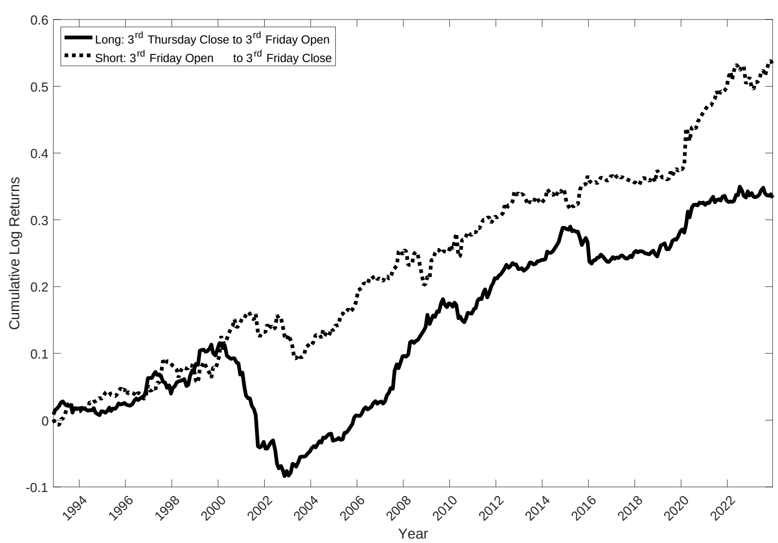
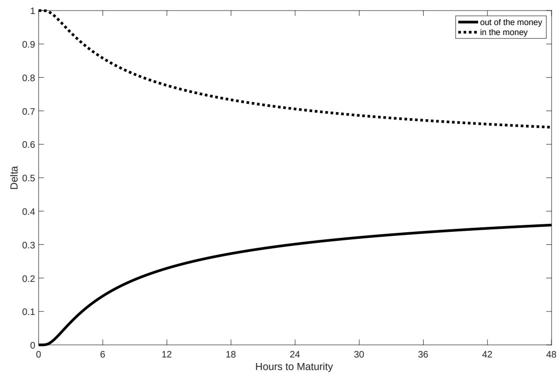
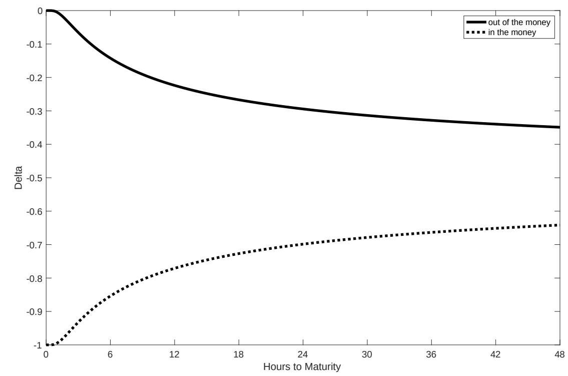


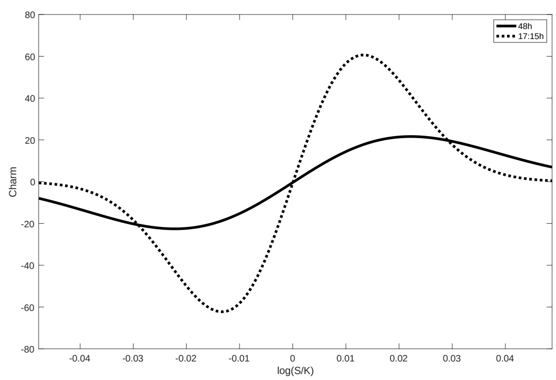
Figure 4. The 3^{rd} Friday Price Spike, Cumulative
The solid line shows cumulative log returns from a *long* position from 3^{rd} Thursday close to 3^{rd} Friday open. The dotted line shows cumulative log returns from a *short* position from 3^{rd} Friday open to 3^{rd} Friday close. To compute returns, we use the SPX close price at close and the Special Opening Quotation at open. The sample period is November 1992 to December 2023.



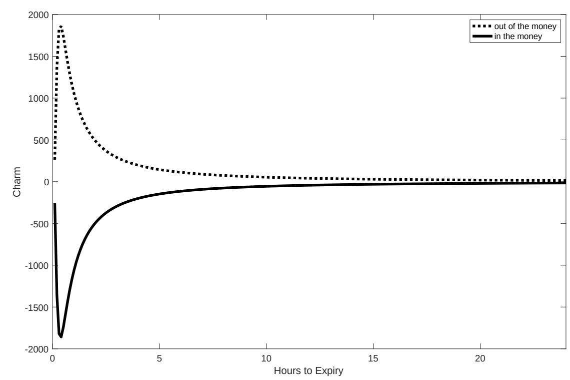
(a) Call Delta



(b) Put Delta



(c) Charm by Moneyness



(d) Charm by Time to Expiry

Figure 5. Illustration: Option Charm

This figure displays the behavior of option "Charm", i.e., the change in delta from changes in time to expiry. Panels (a) and (b) show the Black-Scholes delta for European options with an underlying price of 3000, 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-the-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 puts with strikes 2990 and 3010.

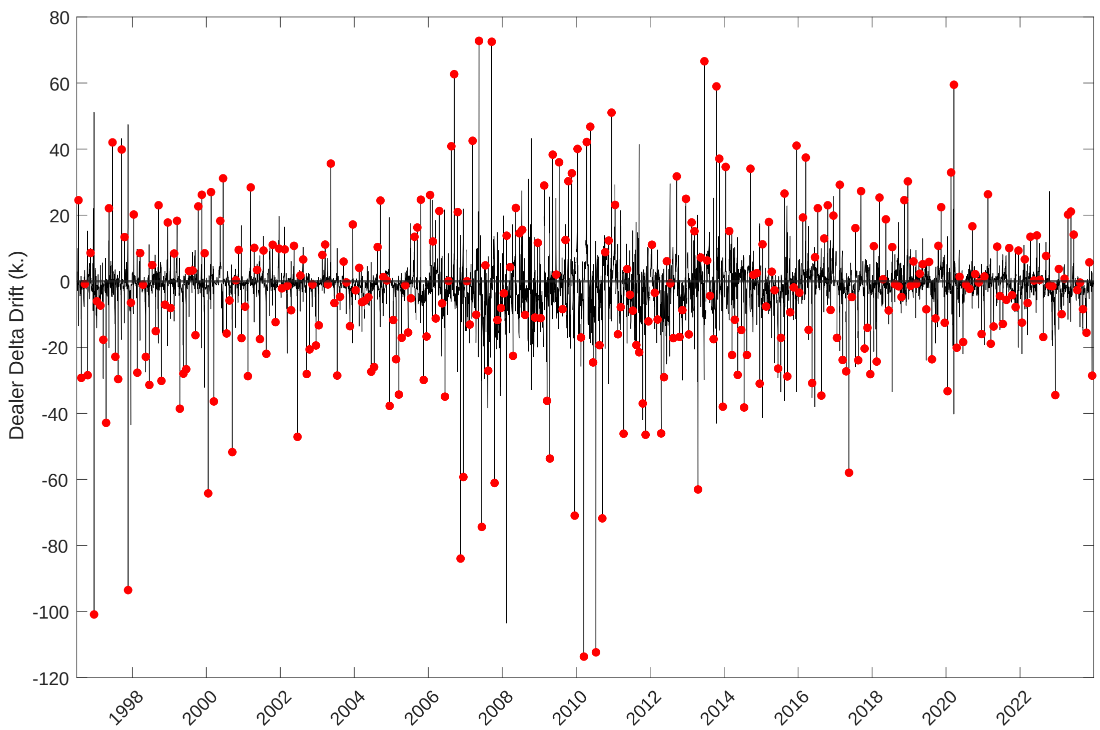
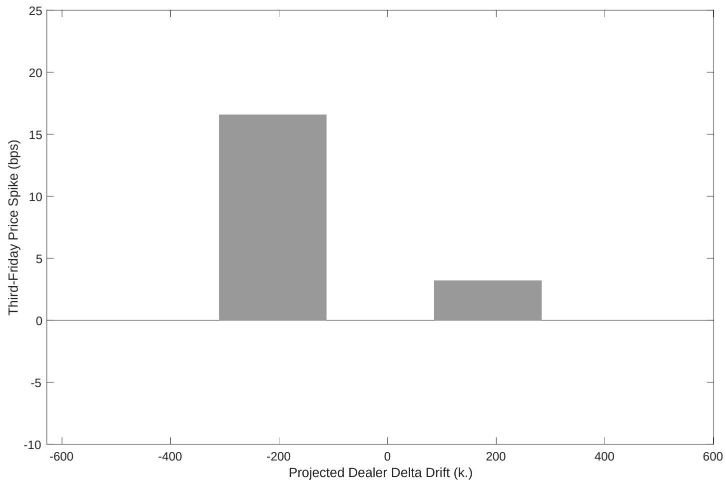
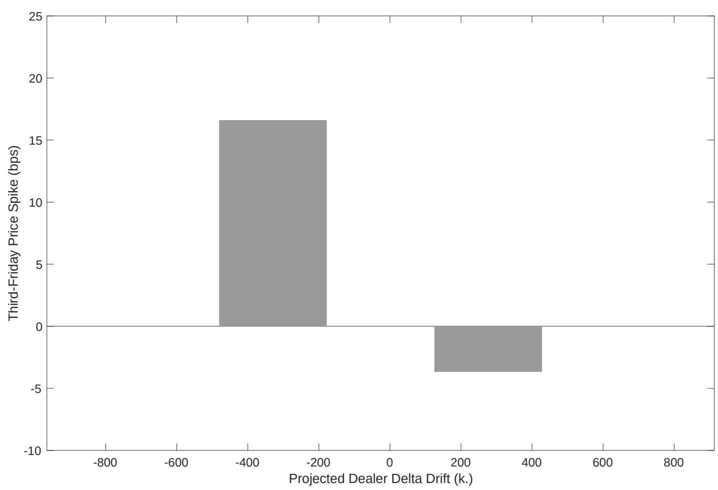


Figure 6. The Projected Dealer Delta Drift (Hourly Rate)

This figure plots the projected dealer delta drift (DDD) expressed as a *rate* (index units per hour), to make the magnitude comparable across options with different times to expiry. Specifically, we divide the total projected change in dealers' net-Δ by hours to expiry. (In contrast, Tables VI–VIII report the *total* DDD over the 17:15-hour overnight window, which averages approximately -60k index units on expiry days, corresponding to roughly $-3{,}500$ index units per hour.) We estimate the DDD as the sum-product of dealer net positions across options at option market close and the respective options' projected delta change until expiry, as described in Section IV. We consider a.m.-settled 3^{rd} Friday S&P 500 options that are first to expire. The red dots mark every month's 3^{rd} Thursday, highlighting the hourly rate of projected dealer hedging demand into the 3^{rd} Friday option expiry. The sample period is July 1996 to December 2023.



(a) Expiry Days



(b) Non-Qtr Expiry Days

Figure 7. Sorting Expiry Days by the Projected Dealer Delta Drift

This figure displays the 3^{rd} Friday Price Spike in the S&P 500 by the ex-ante delta drift in option dealers' inventory. S&P 500 returns are measured from 3^{rd} Thursday close prices to the SOQ at 3^{rd} Friday open. The dealer delta drift is measured at 3^{rd} Thursday close. We sort expiry days by the sign of the dealer delta drift and report means of dealer delta drift and subsequent S&P 500 returns. Panel (a) contains 3^{rd} Fridays, while Panel (b) contains only non-quarterly 3^{rd} Fridays. The sample period is July 1996 to December 2023.

The Derivative Payoff Bias

Online Appendix

This Online Appendix (OA) contains further details on U.S. equity derivatives markets and additional analyses on the derivative payoff bias. Section A.1 contains a more extensive discussion of relevant U.S. equity index market details. Section A.2 contains details of alternative potential explanations of the Third Friday Price Spike (3FPS), which we find rejected in the data. Sections A.3 and A.4 contain supplementary tables and figures.

A.1. Further Market Details

A. Equity Futures and Indices

The S&P 500 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 21^{st}, 1982, with one futures contract initially offering an exposure of 500 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 3^{rd}, 1997. Contracts since follow a quarterly expiry schedule, expiring the 3^{rd} Friday of the March-June-September-December cycle.[21] By far the 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 3^{rd} Thursday, after which settlement prices were determined based on the close price of the 3^{rd} Friday. Driven by worries about settlement effects, it was decided to change settlement to a Special Opening Quotation (SOQ, explained in detail later) as of June 18^{th}, 1987, computed at the 3^{rd} Friday market open time.[22]

Trading took place both by open outcry and electronically during U.S. regular trading hours concurrently with the cash market plus a 15-minute settlement window after the close of the cash market (i.e., 9:30 a.m. - 4:15 p.m. 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 on the 3^{rd} 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 into the SOQ, this means futures holders run overnight settlement risk relative to their last traded Thursday price.

Further, as of September 9^{th}, 1997, E-mini futures on the SPX commenced trading, offering the same characteristics as the regular contract with two main exceptions. First, the contract offers an exposure equal to 50 times the index. Second, trading takes place only on the CME Globex platform which facilitates global trade for most hours of the day, five days a week. Exact

[21] When the 3^{rd} Friday is a holiday, expiry is the latest business day before the 3^{rd} Friday, commonly the preceding Thursday.

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

trading times on the CME Globex platform have changed over time: until July 2003, trading started at 1:00 a.m., but afterward the trading day was extended to almost 24 hours a day to allow for greater access and flexibility for market participants around the world. Hence, the mini contracts facilitated easier trading and offered greater flexibility to trade around the clock. Since their introduction, the standard contracts were quickly surpassed in terms of traded volume by their mini versions, and as of September 17^{th}, 2021, the standard-size SPX futures have been delisted.

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. 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, and 1992, respectively.[23] These contracts also had E-mini contracts introduced and shared similar trading hours and settlement procedures (i.e., 3^{rd} Friday expiries based on a Special Opening Quotation and settlement in cash).[24]

Further, Exchange Traded Funds (ETFs) commenced trading as of January 29^{th}, 1993, on the S&P 500 index, with the Standard & Poor's Depositary Receipts (ticker: SPY) ETF being one of the largest ETFs in the world today. 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

Options on the SPX started trading on the Chicago Board Options Exchange (CBOE) on July 1^{st}, 1983 and quickly became a popular product. Today, SPX options are the world's most traded index options, with robust liquidity and trading volume at various expiration and strike prices. Following the futures practice, standard SPX options expire on the 3^{rd} Friday of each month, with settlement prices originally based on the official closing price on the expiration day. On June 18^{th}, 1987, the reference point was changed for S&P 500 settlement prices from p.m. (i.e., market close) to a.m. settlement (i.e., market open) for the quarterly index options.[25] Settlement also changed from delivery in stocks to delivery in cash. As of November 20^{th}, 1992, all monthly S&P 500 options also settle on the SOQ, motivating the use of November 1992 as the primary starting date in our study. Trading in expiring options ceases at the market close on Thursday before expiration - 17 hours and 15 minutes before settlement values are determined.

Besides SPX index options, options on SP futures have traded actively since January 28^{th}, 1983 on the CME. These options are American style (i.e., they can be exercised early), refer to one underlying futures contract, trade with strike prices $5 apart, and are effectively cash-settled.[26]

[23] A multitude of futures were launched on other U.S. equity indices as well, 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.

[24] The exception was the S&P 100 futures contract, which continued to settle at the close of the 3^{rd} Friday. However, this contract comes with relatively little trading activity.

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

[26] At settlement, in-the-money futures options deliver the underlying futures contract; because the futures expire at the same time and are cash-settled, the ultimate payoff of the option is effectively settled in cash.

As of June 1987, SP futures options that expire on the quarterly cycle follow the same 3^{rd} Friday settlement calendar as the futures themselves and expire into the SOQ. Further, starting in June 1987 SP futures options are also available with expiry dates in months outside the quarterly futures expiry calendar. Importantly, whereas the quarterly SP options are a.m.-settled, the serial monthly options are p.m.-settled based on the close value of the underlying futures contract. As of 1997, S&P 500 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.

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 options; they are American style, refer to 100 units of the underlying ETF (which is denominated at 10% of the value of the S&P 500 index itself), and are not cash-settled but instead settle via physical delivery of ETFs. ETF options expire on the 3^{rd} Friday of the month at the close price of that day. ETF options trade about the same hours as the underlying ETF; in the case of the SPDR, this is 9:30 a.m. to 4:15 p.m. E.T.

Johnson, Liang, and Liu (2018) show that SPX options have most option activity, followed by SP options and SPDR ETF options, with OTM put options being the most prominent position type. In addition, options on the SPX and other U.S. indices also trade over-the-counter (OTC). Johnson, Liang, and Liu (2018) show their size to be about half that of the listed market, while sharing a similar trend in option activity.

The CBOE has introduced a diverse array of SPX option products over time. Standard a.m.-settled SPX index options with monthly 3^{rd} Friday expiry have been the dominant contract for most of our sample and are central to our analysis. P.m.-settled options were reintroduced in 2007 under the SEC's PM Option Expiration Pilot Program, initially with expirations on the last business day of the calendar month, followed by weekly options in 2010, monthly options expiring on the 3^{rd} Friday in 2011, and, more recently, contracts expiring on a daily basis. For most of the period we study, however, open interest and trading activity remain concentrated in the a.m.-settled 3^{rd} Friday contracts, with p.m.-settled and zero-day (0DTE) contracts only becoming sizable toward the end of the sample. Table A.1 summarizes the key contract specifications.

C. Overnight Trading

Because SPX derivatives settle into the SOQ, while trading halts the prior evening, market participants face overnight risk. Instruments to manage this exposure expanded meaningfully in the early 2000s, with E-mini S&P 500 futures quickly becoming the primary vehicle for overnight index hedging. Introduced in 1997 on CME Globex, E-mini futures enabled electronic trading nearly 24 hours a day, and by the mid-2000s dominated overnight SPX risk management. The share of overnight futures volume rose from about 3% in the late 1990s to roughly 25% by the end of our sample.

Pre-market equity trading also deepened over this period. Platforms such as Instinet and, later, Nasdaq and NYSE pre-market sessions facilitated stock and ETF trading before 9:30 a.m., with the SPY ETF - launched in 1993 - emerging as the key instrument for accessing SPX exposure outside regular hours. Despite these developments, overnight equity markets remain substantially less liquid than daytime trading, with overnight volume comprising only a small fraction of total daily volume (see Boyarchenko, Larsen, and Whelan, 2023).

It is important to note that overnight futures trading is not a necessary condition for the 3FPS. The SOQ-based price spike is present across our full sample from November 1992 (Table I,

Figure 4), well before liquid overnight E-mini trading emerged. Dealers can transmit hedging demand to the SOQ through multiple channels, including market-on-open orders in constituent stocks, pre-market equity trading, and orders routed through designated market makers at the opening auction. E-mini futures provide a convenient instrument for measuring overnight order imbalances from 2003 onward, but the underlying hedging incentive from delta drift exists whenever a.m.-settled options are outstanding, regardless of whether overnight futures liquidity is available.

D. *The SOQ*

As outlined above, 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&P 500 (SPX) settlement prices from p.m. to a.m. settlement. The primary motive for this change was concern 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.

The SOQ is calculated by applying index weights to the first reported trade price (the opening price) of each constituent stock on its primary listing exchange. Hence, the SOQ can only be calculated once all constituent stocks have opened for trading. The SOQ is typically published 30-45 minutes after market open. It is possible, but increasingly rare, that stocks in the index do not trade immediately at market open, 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 are determined by their Designated Market Maker (DMM) and the procedure differs by primary listing exchange. On the NYSE, for example, orders can be entered and canceled from 6:30 a.m. until 9:30 a.m. Between 8:00 a.m. and 9:30 a.m. imbalances are reported every second if there is a change in imbalance from the previous second. At 9:30 a.m. DMMs automatically open a security for trading if the security's 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 a.m.

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 stock's weight in the SPX. Less liquid stocks might not have opened for trading 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 composed 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 stocks 2 and 3's previous close prices. 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 is 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. Rejected Explanations of the 3FPS

In this section, we present results on potential explanations of the 3FPS that we rule out: shocks from the arrival of fundamental information (overnight news from firm-specific or macro announcements), 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 the 3^{rd} Thursday and open on the 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).[27]

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 drive the 3FPS, 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

$$ES_{i,t} = \frac{A_{i,t} - F_{i,t-}}{P_{i,q-1}}, \tag{A.1}$$

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 $P_{i,q-1}$ is the stock price of the firm at the end of the preceding 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 one month prior to the announcement date. We define the daily earnings surprise of the S&P 500

[27] Approximately 95 percent of firms announce earnings outside regular trading hours, roughly equally split between firms announcing in the pre-open (between midnight and the opening bell) and post-close (between the closing bell and midnight). Pre-open, most earnings announcements are concentrated in the four hours before open. Post-close, the vast majority of earnings announcements are concentrated in the first hour after market close.

index, ES_t, as:

$$ES_t = \sum_{i \in \text{announcing}} w_{i,t-1} \times ES_{i,t} \tag{A.2}$$

where $w_{i,t-1}$ is firm i's weight in the S&P 500 index at the close of day $t-1$, and the sum is over all firms announcing earnings on day t. This construction yields weighted-average earnings surprise across announcing firms.

Figure A.1 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 especially during the financial crisis and mostly positive shocks following the financial crisis.

To examine a 3FPS explanation based on firm-specific news, we sort announcements based on being published before ("day") or after ("evening") the U.S. market closes (4:00 p.m. E.T.) 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 the 3^{rd} Friday open but revert at 9:30 a.m. until about noon. The first two columns of Table A.3 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 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.

$$\Big[\text{ INSERT FIGURE A.1 AND TABLE A.3 HERE }\Big]$$

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 overnight return before 3^{rd} Fridays on the ES_t observed during the evening period on 3^{rd} Thursdays. Table A.4 reports the results. On average 3FPS overnight returns are highly positive but unrelated to ES_t with an insignificant coefficient of -4.56 (t-statistic = -1.39).

$$\Big[\text{ INSERT TABLE A.4 HERE }\Big]$$

Hypothesis H_{02}: Overnight Macroeconomic News. We next examine whether overnight macro news released before the 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), 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 a 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.[28] These series are released on 45 (inflation) or 131 (growth) of the 3^{rd} Fridays.

[28] Common high-attention series in the Bloomberg calendar include GDP QoQ, CPI Ex Food and Energy, Industrial Production, Housing Starts, Retail Sales, and Empire Manufacturing. Only releases with Bloomberg timestamps before the 9:30 a.m. open enter our overnight announcement dummy.

We test the effect of macroeconomic announcements on the 3FPS by regressing the 3FPS 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.5 reports the results. The intercept confirms that the unconditional 3FPS is highly positive on average. The coefficients on the inflation or growth dummy variables are insignificant, indicating that 3FPS returns are not significantly different on macroeconomic announcement days compared to non-announcement days.

In sum, the 3FPS pattern 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 reject an information-based channel for the 3FPS.

[INSERT TABLE A.5 HERE]

B. Pinning

An alternative explanation is based on 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 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 unusually close to options' strike price. Stock prices may cluster near option strike prices when large at-the-money open interest and rapidly changing Δ's cause market makers' hedging trades to pull prices toward (or push them away from) the strike as expiration approaches (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 the 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 remaining in the neighborhood 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 expiration days, but are pushed away (anti-pinning) from the cost-of-carry adjusted at-the-money strike price of index options before the expiration of index options. The magnitude of this effect in the futures market is estimated at around $115 million per expiration, calculated using open interest in futures. Moreover, Golez and Jackwerth (2012) show that S&P 500 futures are more likely to be pinned from below, meaning close prices of SPX futures on the non-quarterly 3^{rd} Friday expiration days tend to be higher. Although Golez and Jackwerth (2012) do not 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. We examine the role of pinning in the 3FPS by testing whether equity prices cluster around nearby strike prices at expiration over our sample.

Hypothesis H_{03}: Expiry Price Distribution. To test for pinning, we compute the distance between equity index or futures prices at the 3^{rd} Friday open, relative to the nearest at-the-money strike price from below. Figure A.2 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 E-mini futures prices on quarterly expiration dates when both the index and futures options expire in the a.m. window (Panel (a)), (ii) the E-mini futures price on non-quarterly expiration dates when only index options expire in 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)). Since options come in strike price increments of \$5, this distance lies in the interval $[0, 5)$ and we divide it into ten bins of \$0.50 each. If equity prices follow a random walk, we would expect a uniform distribution with each bin containing approximately 10% of observations.

$\Big[$ INSERT FIGURE A.2 HERE $\Big]$

We fail to find evidence of pinning behavior in either the E-mini futures open price or the SPX SOQ on 3^{rd} Fridays. The empirical percentages generally differ little from 10 percent, with bars not systematically clustering at the ends (pinning) or middle (anti-pinning) of the distribution. Unreported Kolmogorov-Smirnov and chi-square tests confirm that none of the four distributions differs significantly from a uniform distribution.

A.3. OA 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

This table summarizes key contract specifications for S&P 500 index options, S&P 500 futures options, and S&P 500 E-mini futures. Columns describe the underlying, end-of-trading time, settlement time and method, expiration months, exercise style, strike increments, and listing exchange.

	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). In contrast, 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).

	All Days		Around 3^{rd} Fridays	
	Evening	Day	Evening	Day
mean	4.13	4.56	1.74	4.04
median	1.08	1.27	1.50	1.12
t-stat	9.10	6.56	1.03	1.36
Std	25.29	43.24	26.83	40.02

Table A.3. Earnings Announcement Surprises

This table reports average dollar-weighted earnings announcement surprises during the evening (4:00 p.m. to midnight E.T.) and during the remaining part of the day (9:30 a.m. to 4:00 p.m. 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 hundredths of basis points. Due to the availability of our earnings surprise data sample, the sample period is September 1997 to December 2020.

	S&P 500 Third Friday Price Spike	
intercept	10.23	10.27
	2.32	2.34
earnings surprise		-4.56
		-1.39
$R^2(\%)$	0.00	0.07

Table A.4. Regression: Expiry Return on Earnings Surprises

This table shows estimates from regressing the Third Friday Price Spike on earnings surprises. The 3FPS is calculated from 3^{rd} Thursday S&P 500 close prices to the 3^{rd} Friday Special Opening Quotation. 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 4:00 p.m. and midnight E.T. Every second row contains Newey-West t-statistics with 3 lags. Returns are in basis points. Earnings news is normalized to zero mean and unit variance. The adjusted R^2 is multiplied by 100. Due to the availability of our earnings surprise data sample, the sample period is September 1997 to December 2020.

	S&P 500 Third Friday Price Spike	
Intercept	12.60	12.73
	3.35	2.79
Dummy (CPI, PPI, GDP)	-14.58	
	-1.13	
Dummy (others)		-5.39
		-0.76
N	330.00	330.00
Dummy N	45.00	131.00

Table A.5. Regression: Expiry Return on Macro Announcement Dummies
This table reports estimates from regressing the Third Friday Price Spike on macro announcement dummies. The 3FPS is calculated from 3^{rd} Thursday S&P 500 close prices to the 3^{rd} Friday Special Opening Quotation. We consider 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 1 contains inflation ("cpi", "ppi", and "gdp price index") announcement dummies. Column 2 contains dummies for all other announcements. Returns are in basis points. Every second row contains Newey-West t-statistics with 3 lags. Due to the availability of our Bloomberg macro announcement data sample, the sample period is January 1996 to January 2023.

A.4. OA Figures

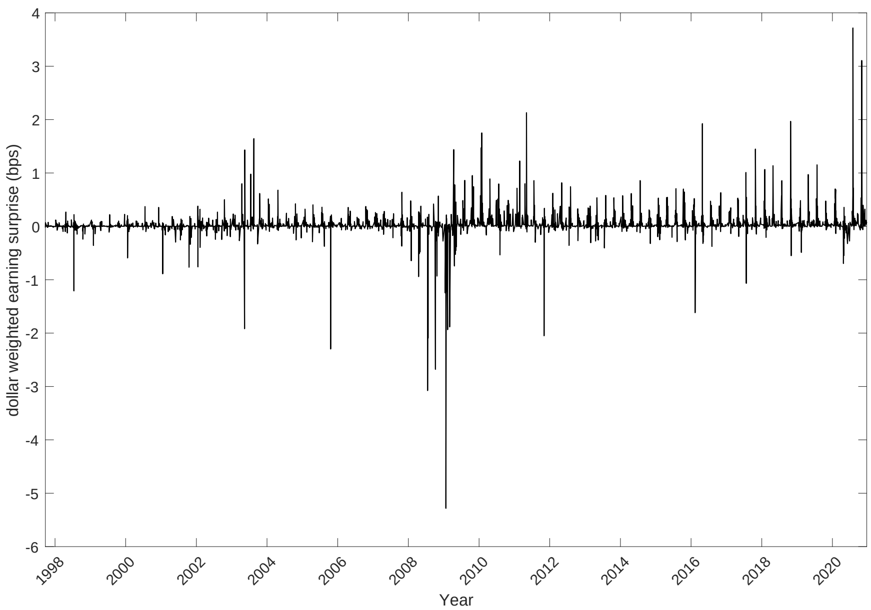
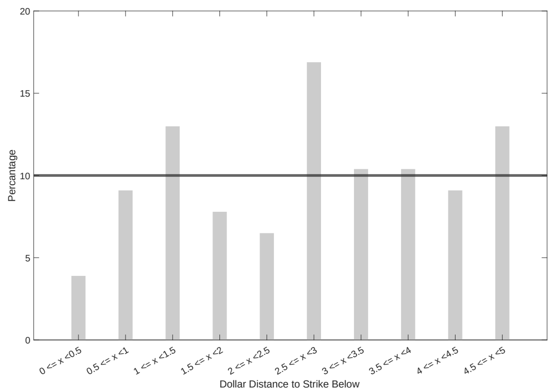
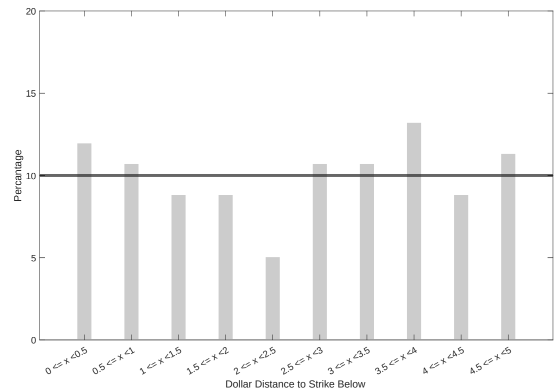


Figure A.1. Earnings Announcement Surprises

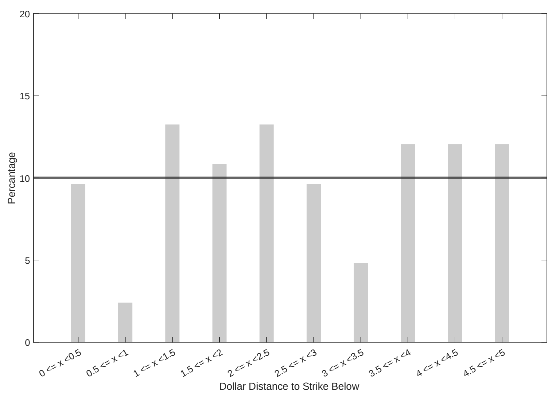
This figure displays the aggregate daily earnings announcement surprise of U.S. public companies. We calculate the earnings surprise as the sum-product of firms' earnings announcement surprises from IBES and the respective firms' lagged equity market capitalization. We consider announcements between 4:00 p.m. and midnight (E.T.). The sample period is September 1997 to December 2020.



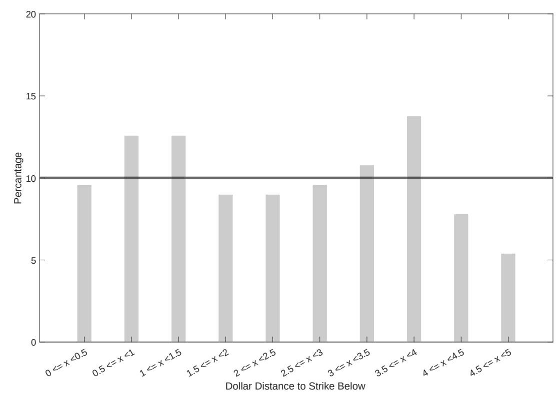
(a) Futures, Quarterly



(b) Futures, Non-Quarterly



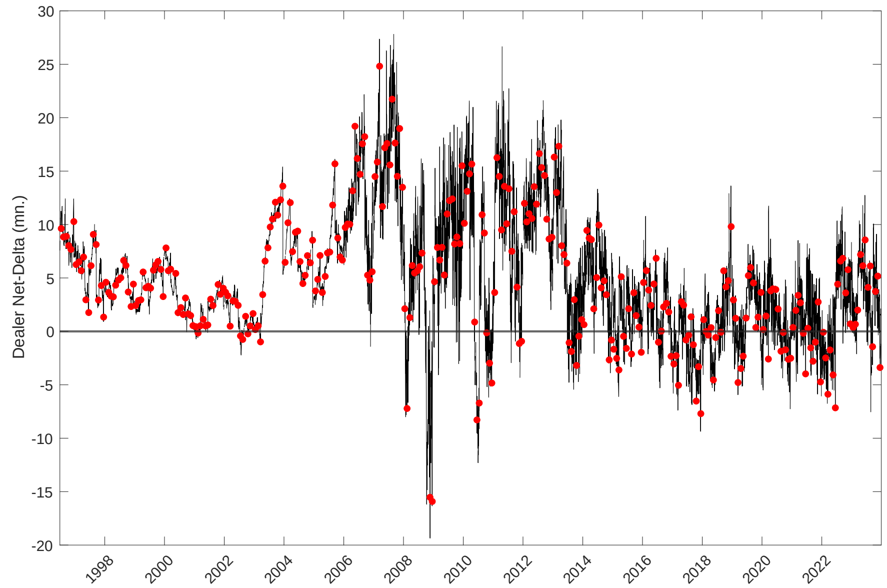
(c) Stocks, Quarterly



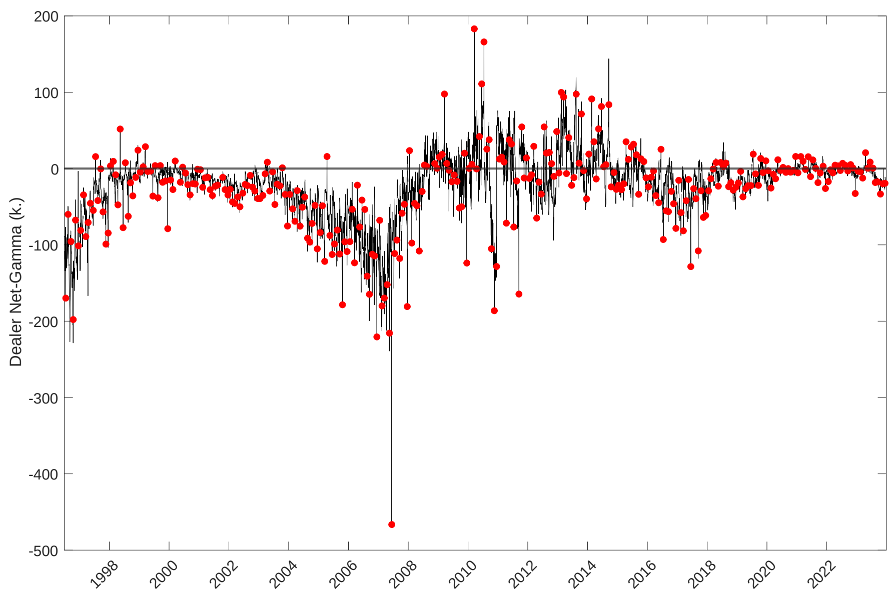
(d) Stocks, Non-Quarterly

Figure A.2. Test for Pinning in S&P 500 Stocks and E-mini Futures

This figure shows the frequency with which equity prices lie within a certain distance to the closest lower S&P 500 option strike at the 3^{rd} Friday open. Thus, the figure tests for the presence of "pinning", which is the tendency of asset prices to be abnormally close to options' strike prices at option expiry. S&P 500 option strike prices occur every $5. Panel (a) displays second-to-maturity S&P 500 E-mini futures on quarterly 3^{rd} Fridays (when first-to-maturity futures expire and become exceedingly illiquid). Panel (b) displays first-to-maturity S&P 500 E-mini futures on non-quarterly 3^{rd} Fridays (when S&P 500 E-mini futures do not expire). Panels (c) and (d) display the S&P 500 SOQ on quarterly and non-quarterly 3^{rd} Fridays, respectively. Due to the availability of liquid futures open prices, the sample period is January 2003 to December 2023.



(a) Dealer Net-Δ



(b) Dealer Net-Γ

Figure A.3. Dealer Net-Δ and Net-Γ

This figure plots the time series of dealers' aggregate net-Δ and net-Γ in a.m.-settled S&P 500 options. Panel (a) shows dealer net-Δ in millions of index units, and Panel (b) shows dealer net-Γ in thousands of index units. Net Greeks are calculated as the sum-product of dealers' net-number across options and the respective options' Greek risk measure. Black lines show values on all trading days; red dots highlight 3^{rd} Thursday values (the day before option expiry). The sample period is July 1996 to December 2023.