Price Pressures and Noise in Option Returns

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Abstract

Delta-hedged option and straddle returns on S&P500 Index and equity options computed using end-of-day closing prices are biased upward. The bias can reach more than 100 bps per day and is attributed to overnight inventory risk. An introduction of SPX options night trading enables hedging of overnight positions and as a result, negative night and positive day option returns flip the signs. Liquidity providers' 'preferred' inventory level, and the aversion to unbounded downside risk by options writers explain the results. Using intra-day, instead of closing prices helps explain several anomalies and establish identical volatility pricing across equity and index options.

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1. Introduction.

Option markets have grown dramatically over past decades both in trading volumes and in number of transactions per day. The rising popularity of option contracts among investors led to voluminous academic research on understanding how financial markets price these assets, and what inferences about underlying stocks we can make from option implied risk neutral measures or variance risk premiums.[1] To this date, while measuring option pay offs, estimating risk neutral moments or variance risk premiums, the literature almost entirely relies on end-of-day closing prices as a proxy for true values.

Blume and Stambaugh (1983) demonstrate that microstructure noise, attributed to bid-ask spreads, in end-of-day stock prices impart an upward bias in daily stock returns. The magnitude of the bias is approximately equal to the variance of noise. Asparouhova, Bessembinder, and Kalcheva (2010, 2013) show that this bias propagates in intercept and slope coefficients obtained in any ordinary least squares regression which uses stock returns as the dependent variable, and also creates significant biases in *monthly* portfolios mean returns. The literature also suggests other sources of noise than bid-ask bounce. Hendershott and Menkveld (2014) show that transitory price pressures on market maker inventories in the stock market cause significant deviations from asset's fundamental values and result in return reversals. These deviations are at least as large in magnitudes as bid-ask spreads.

This paper documents the noise in end-of-day options closing bid-ask mid-points. Closing prices are more reflective of the overnight price risk associated with a non-zero inventory state rather than fundamental market values of assets at which most of transactions takes place during the day. These prices reverse the next morning. However, using end of day closing mid-quotes to compute option returns leads to economically large biases. Both *daily* delta-hedged returns and delta-neutral straddle returns, computed for example using 10am, 11am or 12 pm mid-quotes are *more* than 100 bps, 90 bps, or 70 bps respectively lower compared to those obtained with conventionally used 4pm closing mid-quotes for equity options, or 4:15pm for S&P500 (SPX) index options. These results come with an important observation that majority, about 80%, of options' net-order imbalances and trading volumes occurs before 12pm. Our results are robust across two time

[1] See, for instance, Coval and Shumway (2001), Bakshi and Kapadia (2003a), Bakshi and Kapadia (2003b), Bakshi, Kapadia, and Madan (2003), Bollen and Whaley (2004), Dennis and Mayhew (2002), Dennis, Mayhew, and Stivers (2006), Driessen, Maenhout, and Vilkov (2009), Bollerslev, Tauchen, and Zhou (2009)

periods, 2005 to 2010, and 2011 to 2018, and our cross section of equity options is composed of most liquid underlying stocks - S&P500 components. The results are consistently observed across call and put delta-hedged returns, and especially for straddles, as the latter eliminates potential biases due to a noise in the prices of the underlying (Blume and Stambaugh (1983)).

The source of noise that we document is price pressures, or temporary deviations of prices from fundamental values. Traditionally, the risk averse intermediary charges a price impact for temporary holding the position if the offsetting trade has not arrived (Glosten and Milgrom (1985)) and use the price pressures to mean-revert their inventories. Options market is, however, more unbalanced and complex due to its zero net-supply nature compared to stocks. Lower price elasticity of liquidity demand, negative average net demand by end users, and asynchronous arrival rates of offsetting trades should create even stronger pressures on options market makers' inventories.

End-users in the options market are net sellers (Garleanu, Pedersen, and Poteshman (2009)). Writing an option, call or put, exposes a trader to unlimited downside risk and especially during non-trading periods such as nights or weekends. Delta-hedging reduces this risk, but inability to hedge perfectly (Garleanu et al. (2009)) or continuously during non-trading hours does not eliminate it. While this should not have any effect in Black and Sholes (1973) world, Bollen and Whaley (2004) and Garleanu et al. (2009) show that demand pressures have substantial impact on option prices. As holding short position is extremely risky, investors have incentives to cover it before the end of trading day which can create positive demand pressures on the late afternoon and especially closing prices. Alternatively, investors who keep their short positions open overnight or during the weekends should demand some additional compensation for the downside risk they face. This argument also applies to option market makers who can hold short overnight inventory positions. In both cases, providing inability to hedge overnight risk, these compensations should come in the form of negative non-trading period returns, i.e. higher end-of-day closing prices compared to all other intra-day prices and lower next day opening prices.

We first test the hypothesis of unbounded downside risk of option writers which rises over non-traded periods. This hypothesis is introduced by Chen and Singal (2003) who argue that the weekend effect in the stock market, or the tendency of stock returns to be lower over the weekends, is driven by short sellers rushing to close their short positions on Fridays. Holding short positions over non-trading periods and inability to hedge them exposes short sellers to unbounded downside risk. The authors show that the introduction of options on a firm's stocks leads to the disappearance of the weekend effect for those firms. Options provide a hedging instrument for non-trading periods to decrease short sellers' downside risk and thus eliminate positive price pressures on Fridays.

The majority of our sample, 2005-2014, does not have any overnight hedging instruments except futures. Hedging with futures is extremely expensive and rarely used. However, in the second half of our second sample, 2011-2018, on March 9, 2015, CBOE introduced over-night trading of SPX options from 3am to 9:15am (ET). Options market makers (hereafter OMMs) widely use SPX index options to hedge their inventories in equity options. As overnight hedging becomes available, unbounded downside risk and premiums investors demand in the form of higher end-of-day prices should decrease or disappear, as predicted by Chen and Singal (2003) hypothesis. That is exactly what we find in 2015-2018 data.

To measure intra-day dynamics of option returns and subsequent reversals, we compute cumulative intra-day returns and night returns respectively. We use at-the-money straddle returns to avoid capturing the noise due to prices of underlying stocks. Similar to Muravyev and Ni (2020), we find highly significant negative night returns for equity (SPX) options, -37 bps (-49 bps), and positive intra-day returns, 11 bps (25 bps) for 2005-2010 sub-sample. Muravyev and Ni (2020) explain their results with day and night volatility seasonality and options market failing to recognize it. These results however are also consistent with the options writers' unbonded downside risk hypothesis. The positive intra-day returns are the premiums for the risk of holding short positions overnight, and the negative night returns are the rewards.

To explicitly test Chen and Singal (2003) hypothesis, we repeat the analysis for 2011-2014, no night hedging sample, as a placebo sample, and for 2015-2018 as a test sample, where the night hedging is available. Similar to Muravyev and Ni (2020), for 2011-2014 sample, for equity (SPX) options we find negative night returns, -32 bps (-42 bps), and very small negative, -7 bps, intra-day returns for equity, and positive, 22 bps, returns for SPX options. However, for the test sample, 2015-2018, the results are almost opposite. The night return for equity options is very small and negative, - 7 bps, while intra-day return is substantially more negative, -16 bps. For SPX options the night and day returns become similar, -20 bps and -19 bps respectively. These results reflect night returns for all non-trading periods, weekends and weekdays. SPX night trading and thus overnight hedging is available only during weekdays, Mondays to Fridays, and not on weekends. Jones and Shemesh (2018) report significantly negative and economically large weekend option returns compared to all other weekdays. When we exclude weekend returns, the night returns for equity options become *positive*, 3 bps. The intra-day return is negative, -10 bps. Therefore, the night and day returns flip the signs as overnight hedging becomes available which is consistent with Chen and Singal (2003) hypothesis. As options writers can hedge unbounded downside overnight risk, the end of day prices no longer incorporate positive premium, and hence intra-day cumulative returns become negative. The positive night returns are a compensation to OMMs for holding positive inventories over non-trading periods.

We also demonstrate how OMMs inventory management practices look like post 2015. Using signed CBOE/ISE Open/Close options buy/sell volumes originated by end users, similar to Ni, Pearson, Poteshman, and White (2020), we estimate options market makers inventories on a stock or index level. We confirm that in individual equity options OMMs hold on average positive inventories, and negative inventories in SPX put options. To measure demand pressures on OMMs inventories, we estimate options net order flows from intra-day transactions and quotes.

For the cross-section of stock options where OMMs accumulate extreme positive (top 20%) inventory, the intraday return is even more negative, -13 bps, and it almost monotonically decreases through the day due to negative net-demand pressures from end users. The night return is more positive, 8 bps. This positive night return is a compensation to OMMs for overnight holding and hedging costs of their inventories. Moreover, consistent with inventory theories (Amihud and Mendelson (1980)) intra-day option mid-points monotonically move downwards through the day under net selling pressures in post-2015 sample.

For the cross-section of stock options where OMMs accumulate extreme negative (bottom 20%) inventory, the intraday return increases sharply towards the end of day to -2 bps, but statistically indistinguishable from zero. The night return for these options is negative, -6 bps, which serves as a compensation to OMMs for holding negative inventory overnight. This return is substantially smaller than in placebo sample, -28 bps, as the ability to hedge in the night decreases the risk premium on the short positions.

We replicate similar tests for SPX options, and find no significant intra-day or night returns for extreme positive or negative OMMs inventories. This is in contrast to placebo sample, where we find negative night and positive intra-day returns for both positive and negative inventory contracts. As the night trading is available, intra-day or night SPX straddle returns are no longer statistically different from zero on extreme inventory days as these positions can be unwound during the night hours.

Therefore, for pre- 2015 sample, higher end-of-day closing prices compared to intra-day prices, and positive intra-day and negative night (Muravyev and Ni (2020)) or negative week-end (Jones and Shemesh (2018)) option returns are attributed to unbounded downside risk of option writers hypothesis. For post-2015 sample, when this friction can be hedged away, our results are consistent with the theory of "preferred" inventory position, and downward monotonicity of bid-ask prices of Amihud and Mendelson (1980). According to the theory, liquidity providers will *decrease* quoted mid-points and widen bid-ask spreads if they over-accumulate *positive* inventories, or *increase* quoted midpoints and widen the bid-ask spreads if they over-accumulate *negative* inventories compared to their preferred inventory level (Amihud and Mendelson (1980), Figure 3). That is exactly what we find in the post-2015 data.

What are implications of our results for the literature? First, we provide uniform explanation for negative non-trading period returns reported in the literature: (i) negative night and positive day returns of Muravyev and Ni (2020), and (ii) negative weekend returns and less negative or close to zero weekday returns of Jones and Shemesh (2018). Jones and Shemesh (2018) eliminate the possibility of aversion to downside risk over non-traded periods in favor of excessive rate of time decay, option's theta, right before non-traded periods. Muravyev and Ni (2020) eliminate the possibility of demand pressures on end-of-day quotes in favor of day and night volatility seasonality. Both papers mainly end their samples before 2015. Having an exogenous event in our more recent sample, such as an introduction of SPX night trading, allows us to explain both effects with the aversion to unbounded downside risk by option writers over non-traded periods. We also establish that in the post-2015 sample liquidity providers in options markets behave as predicted by Amihud and Mendelson (1980) model. To the best of our knowledge, we are the first to provide an empirical support for this model which incorporates both, decline (increase) in quoted mid-points under excessive positive (negative) inventory pressures on liquidity providers and widening of bid-ask spreads at the same time.

Second, continuing using end-of-day closing prices to compute option returns will lead to false discoveries of new anomalies. We first show that for post-2015 period, Jones and Shemesh (2018) weekend return is still negative and significant, while delta-hedged call and put returns across all weekdays become positive. This can be seen as an anomaly since due to volatility pricing option returns are normally negative, as we observe in before-2015 sample. We further show that taking out week-ends and holidays returns, and using closing end-of-day prices to compute returns for 2015-2018 sub-sample, will result in: (i) positive and significant daily delta-hedged equity options call returns, 17 bps; (ii) positive and significant daily delta-hedged equity options put returns, 10 bps; (iii) insignificantly different from zero daily delta hedged returns on SPX calls, puts, and straddles. These results are at odds with all option returns' literature (Coval and Shumway (2001), Bakshi and Kapadia (2003a), Bakshi and Kapadia (2003b)). They can however be explained by positive night returns during weekdays which contribute to overall positivity of 24-hour daily returns.

Third, we want to bring attention to the fact that options market structure changed with the introduction of SPX night trading after 2015. This change affects the magnitudes of option returns obtained from the closing prices. For example, using end of day closing prices to compute daily returns and excluding weekends, delta hedged equity call (put) return is 17 (11) bps in 2015-2018. Compare it to call (put) returns of 6 bps (-17 bps) in 2011-2014 sub-period. Alternatively, the average straddle return is -8 bps in 2015-2018 vs. -24 bps in 2011-2014. However, using 10am or 11am mid-quote to compute daily returns results in similar estimates regardless the sub-sample we use. For example, whether we include or exclude the weekends, delta hedged call, put or delta-neutral straddle returns using 10am mid-quotes are -1.3%, -1.6% and -1.16% for equity options respectively, or -1.5%, -1.6%, and -1.16% for SPX index options respectively. We also find that the difference between non-trading and trading period returns (Jones and Shemesh (2018)) becomes economically small or evaporates if one uses 10am mid-quotes instead of closing prices.

Fourth, as can be seen from the above return estimates with 10am mid-quotes, there does not seem to be any significant difference between the returns on individual equity and index options as both are similarly negative. Coval and Shumway (2001) and Bakshi and Kapadia (2003a) find that volatility is negatively priced in index options. Bakshi and Kapadia (2003b) find that that delta-hedged equity option returns are only a small fraction of returns on index options. Driessen, Maenhout, and Vilkov (2009) find that volatility is not priced in equity options which are the components of the S&P 100 Index. These results are puzzling since the return on a basket (the index) is a value-weighted return on its components. Both Bakshi and Kapadia (2003b) and Driessen, Maenhout, and Vilkov (2009) use end of day closing prices to establish their results. We show that using 10am mid-quotes, which are least affected by the microstructure noise, helps to establish that volatility is priced similarly across both equity and index options.

Finally, we suggest using 10 am (or 12 pm) quotes to avoid discoveries of false anomalies. To the best of our knowledge, only one paper in the literature uses 10am mid-quotes to estimate option returns before us. In the seminal paper, Coval and Shumway (2001) write: "For each option, we identify the first bid-ask quote after 9 a.m. Central Standard Time (CST)". They thus use the first mid-quote after 10 am (ET) to compute option returns. While the authors do not explain the rational behind the mid-quote selection, we find it very intuitive. We show that between 75 to 85% of order imbalances and thus overall trading volume takes place before 11am or 12pm at most. Therefore, between 10am and 12pm mid-quotes reflect most actively traded prices. We also show that quotes in the late afternoon and at the closing are mostly affected by the noise associated with overnight inventory risk management, and they reverse the next morning. When liquidity providers have limited risk bearing capacity, and when short-run intra-day liquidity supply is not perfectly elastic, price pressures on market makers' inventories can move prices away from true, fundamental, values by the end of trading day. While we establish our results in the option market, they can be extended to any asset class characterized by price discreteness, nonsynchronous trading, illiquidity, and persistent demand pressures.

The rest of the paper is organized as follows. Section 2 discusses the economics of noise in options market in more details and overviews related literature. Section 3 describes the data and main variable constructions. Section 4 presents main results in the paper. Section 5 provides series of tests to explain the results. Section 6 concludes.

2. Economics of Noise in Options Market and Related Literature.

This paper is related to the literature on micro-structure effects that generate noise in returns, and stylized facts about option returns.

Noise.

Blume and Stambaugh (1983) show that stock returns computed using closing daily prices are biased upward and this bias is approximately proportional to the variance of bid-ask spreads. The bias is the highest for small stocks, where bid-ask spreads are wider, and almost negligible for large stocks with narrower spreads. They propose to use buy-and-hold portfolio approach based on compounded returns to eliminate the bias.

Asparouhova, Bessembinder, and Kalcheva (2010) further explore empirical asset pricing applications of Blume and Stambaugh (1983) bias. They find that standard regression-based tests of whether average return contains illiquidity premium in stocks are biased towards finding the premium. Asparouhova, Bessembinder, and Kalcheva (2013) argue that noise can introduce sever biases in mean returns and regression-based tests not only in daily but monthly data as well. Duarte, Jones and Wang (2020) find that delta-hedged option returns computed using end-of-day closing prices are also upward biased due to large bid-ask spreads. The authors adjust end-of-day options closing prices and deltas for the magnitudes of bid-ask spreads and adapt Asparouhova, Bessembinder, and Kalcheva (2010) methodologies for the options market structure.

A few papers in stock market literature suggest that noise can be originated from other sources than bid-ask spreads. Hendershott and Menkveld (2014) show that stock prices are distorted by price pressures. Market makers use these price pressures to mean revert their inventories and this results in return reversals. The authors find that the average size of price pressures is 49 bps with a half life of 0.92 days. For the quintile of largest stocks, the price pressure is 17 bps with a half life of 0.54 days, and for the quintile of smallest stocks it is 118 bps with a half life of 2.11 days. They suggest that the price pressure that an intermediary charges per unit of inventory is an alternative to the bid-ask spread. Given that institutional investors care more about the marginal pressure rather than bid-ask spreads, it makes it more attractive and relevant measure of liquidity. Hendershott, Menkveld, Praz and Seasholes (2018) demonstrate similar source of noise which arises from dynamic interaction between fast and slow traders and market makers' inventories.

They show that deviations from fundamental values, pricing errors or noise, can persist once fast (attentive) investors want to trade quickly on fundamental shocks, market makers have to provide liquidity to these trades, then further adjust prices to attract opposite side of trades, and delayed arrival of slow (inattentive) investors to offset market makers accumulated inventories. The price pressure occurs when the fast traders create negative/positive price impacts, market makers absorb their demand pressures and maintain the prices at below/above fundamental values expecting for slower traders to arrive and offset their inventories at close to fundamental prices. This results in either fast or slow returns reversals depending on how fast the slow trader arrival rate is. Calibrating their model to the data, the authors show that this dynamic generates a pricing error for a typical NYSE stock with a standard deviation of 2.9 percentage points and a half-life of 3 weeks. Moreover, these pricing errors account for 27% of daily and 19% of monthly idiosyncratic return variance.

Similar to Hendershott and Menkveld (2014) we identify noise due to price pressures in options market. End-users in options market are net sellers. Writing an option exposes an investor to unbounded downside risk and more so during non-trading periods. Writing a call is associated with unlimited positive pay off to option buyer if the stock price increases sharply. Delta-hedging helps to reduce potential losses to an option writer. However, given that delta-hedging is not perfect (Garleanu et al (2009), Cetin et al (2006)) and especially costly for illiquid contracts (Christoffersen et al (2018)), this risk cannot be eliminated. Downside risk of writing a put is bounded by magnitudes of stock price and often can exceed prices of puts. However, the downside of delta-hedged written put position becomes unbounded since it involves short-selling a stock.

In the stock market, Chen and Singal (2003) show that the weekend effect, the tendency of stock returns to be low over weekends, is explained by the unbounded downside risk of short sellers over non-trading periods. Because of inability to hedge or rebalance their short positions over weekends, and thus higher downside risk exposure, short sellers prefer to close them on Fridays. Once options trading becomes available, short-sellers gain access to hedging downside risk over non-trading periods, and as a result, for the optionable firms the week-end effect disappears.

Given that downside risk is even higher for option writers, the overnight hedging is not available, and the evidence that demand pressures move option prices from the fundamental values (Bollen and Whaley (2004) and Garleanu et al. (2009)) one can expect end-of-day temporary price pressures similar to Chen and Singal (2003) findings.

The unbounded downside risk hypothesis is also applicable to OMMs inventory risk management practices. If OMMs are net sellers, and accumulate excess of negative inventories, they face the same downside risks as end-users and would set higher end-of-day closing mid-quotes. Market microstructure literature highlights variety of costs facing market makers inventories, and how they affect their price quoting strategies. Stoll (1978), and Ho and Stoll (1981, 1983) show that as inventory increases, market makers will increase their quoted bid-ask spreads. In contrast, Amihud and Mendelson (1980) argue that market makers not only widen bid-ask spreads as the level of inventory deviates from the optimal, but also will move price mid-points. The authors advocate the ‘preferred’ inventory level by liquidity providers. In their model, summarized in Figure 3 in their paper, mid-quotes are a downward monotonic function of inventory holdings. As inventory deviates further to the positive from the preferred level, the mid-quote prices decrease sharply, as market makers try to discourage selling pressures. As inventory deviates further to the negative, mid-quote prices move sharply up to discourage buying pressures. Thus, market makers use price pressures to mean-revert their inventories.

Option Returns.

The literature on options’ returns is relatively young as the data availability was limited. Coval and Shumway (2001) find that zero beta at-the-money straddle positions on the S&P500 index produce average losses of approximately 3% per week. They first point out that stochastic volatility is priced in the returns of index options. Bakshi and Kapadia (2003a) find that delta-hedged returns on index call options are consistently negative. They theoretically and empirically show that index option prices reflect a negative market volatility premium. The negative market volatility premium is attributed to Black and Sholes implied volatilities of index options on average exceeding realized volatilities. Bakshi and Kapadia (2003b) find that Black and Sholes implied volatilities of individual equity options are also greater on average than historical return volatilities. Similar to index options, equity option prices too embed negative market volatility risk premium. However, this premium is much smaller than for the index options.

Driessen, Maenhout, and Vilkov (2009) analyze options on S&P 100 index and options on its individual components. The authors formally show that individual options, unlike index options, do not embed negative variance risk premium, and emphasize that the challenge in option pricing is to explain the differences between expected index and individual option returns. They argue that index options are more expensive and thus earn lower returns because, unlike individual options, they offer a hedge against correlation increases during market downturns. Therefore, the correlation risk premium is priced in index and not in individual options.

While negative option returns are generally expected, several papers establish that the negative sign is mainly driven by non-trading period returns. Muravyev and Ni (2020) document economically large negative option night returns, and significant and positive day returns. The authors suggest that option prices fail to reflect day and night volatility seasonality. As intra-day volatility is higher than overnight volatility, option prices understate intraday and overstate night volatility. Jones and Shemesh (2018) find economically large negative weekend and holidays returns, and less negative or close to zero weekday returns. They suggest that options market systematically misprices stock price variance time decay, options' theta, which increases right before non-traded periods. The core of the argument is French (1984) who demonstrates that if market participants do not account for the deterministic link between trading time and volatility, then option implied volatilities will tend to be too high just prior to nontrading periods.

Both papers show that the negative sign in option returns is mainly driven by non-trading periods. This can be seen as an anomaly compared to all the previous literature advocating negative variance risk premium in option returns.

3. Data and Construction of Main Variables.

The main options data are from Chicago Board Options Exchange (CBOE)/LiveVol. They include two data sets: trades data with all intraday transactions for each options series, time stamped prices and volumes; and quotes which include 1 min snapshots of best bids and offers (NBBOs) during a trading day for each series. The quote data also include synchronous NBBOs for the underlying stocks at the time of option quotes. The data cover the period 2005 to 2018, and, when merged together and after imposing filters described below, exceed 200 TB in size.

Trades data are merged with quotes by timestamps to sign the trades using tick rule. If a trade occurs above bid-ask midpoint it is classified as a buy, and if it is below bid-ask midpoint, as a sell. If a trade takes place at the midpoint, we look at the previous midpoint or trade whichever comes first as a benchmark to sign the trade. If the previous midpoint is the same, we search for the first different midpoint to sign the trade. The signed buy and sell transactions are used to compute net order imbalances.

We use OpionMetrics, CRSP and Compustat data as well. CRSP/Compustat provide identifiers for S&P500 index constituents. We use equity options on S&P500 firms as they are substantially more liquid compared to the rest of CRSP universe. We identify these firms on the daily bases[2]. We also separately analyze S&P500 (SPX) index options.

From OptionMetrics we fist use end-of-day bid-ask quotes. We cross-check 4pm (16:00) closing quotes from LiveVol and OptionMetrics to confirm that the data match. We then use OptionMetrics option contracts identifiers (optionid's) and security identifiers (secid's) to merge with CRSP permno's to identify equity options on S&P500 firms in LiveVol data. We merge LiveVol and OptionMetrics data by ticker, cp_flag (Call or Put), time to expiration, strike price and date.

We also use OptionMetrics deltas which are computed accounting for a possibility of an early exercise. Open interest data are provided by both OptionMetrics and LiveVol and they are identical. In the main analysis we compute delta hedged and delta-neutral straddle returns for the following intraday quotes from day *t* to day *t+1*: 10 am(10:00), 11am (11:00), 12pm (12:00), 1pm (13:00), 2pm (14:00), 3pm (15:00) and closing quotes at 4pm (16:00). As SPX market closes 15 min after equity options, for index options we use closing quotes at 4:15 pm (16:15).

For options contracts we impose the following filters. As we measure returns from one day to another, we require a contract to be traded two consecutive calendar days. Contracts with extreme deltas are deleted, and we retain only those with absolute values of delta between 0.02 and 0.98. Equity option quotes with dollar quoted spreads greater than $3 are deleted. We also delete illiquid options contracts with daily dollar volume weighted effective relative spreads greater than 70%,

[2] The results for S&P500 firms are the most conservative. When we analyze all stock options, the economic magnitudes of all estimates become even bigger.

and options with mid-point quoted prices below 50 cents. Finally, we exclude options contracts which violate obvious no-arbitrage bounds: for calls, the price must be less than the current stock price, for puts it must be less than the strike. To control for possible data entry errors in synchronous bid-ask quotes of underlying stocks, stock quotes with quoted bid-ask spreads greater than 99 cents are deleted. Contracts with less than 10 days left to expiration are also eliminated. Overall, the results are not sensitive to these filters.

We do the analysis for two sub-periods separately, 2005 to 2010, and 2011 to 2018 for two reasons. First, most of the literature analyzes the first sub-period which allows us to cross-check stylized facts. The second sub-period does not include 2008-2009 financial crisis and is characterized by higher overall options market liquidity, and trading activity. Second, analyzing two periods is also for computational feasibility. Even after all filters, the first sub-period data exceeds 1.2 billion observations, and the second sub-period over 1.5 billion observations.

The main variables we use are delta-hedged option returns, returns on straddles, option order imbalances, and OMMs inventory levels. Similar to Christoffersen et al (2018) delta hedged options returns are defined as:

$$R^{O}_{t+1,n} = R^{Raw}_{t+1,n} - R^{S}_{t+1} S_t \frac{\Delta_{t,n}}{O_{t,n}}$$

where R^{Raw}_{t+1} is the daily raw rate of return on option *n*. The option delta $\Delta_{t,n}$ is computed by OptionMetrics using the Cox, Ross, and Rubinstein (1979) binomial tree model, thus allowing for early exercise, and further assuming a constant dividend yield. For each intra-day option quote we also have a synchronous stock NBBO quotes. We therefore use quoted stock mid-point as a stock price, *S*.

To avoid capturing noise in the prices of underlying stocks (Blume and Stambaugh (1983)) and possible mismeasurement of deltas (Cetin et al (2006)) or model risk (Green and Figlewski (1999)), we also use straddle returns. Straddle returns are computed for each pair of at-the-money call and put options on the same underlying, with the same strike price and time to expiration. At-the-moneyness is defined as in Bollen and Whaley (2004) for absolute deltas between 0.375 and 0.625.

Options delta-hedged and straddle returns are computed on a contract level first. We then compute weighted average returns on a firm level across contracts, using dollar open interest from the previous day as a weight.

Order imbalances are computed as:

$$OIM_s = \frac{\sum_s |\Delta_s|(BuyVolume_s - SellVolume_s)}{\sum_s(BuyVolume_s + SellVolume_s)}$$

where *s* denotes option series, call or put. *Buy* and *Sell* volumes are signed in intra-day trading data using the tick rule, and $|\Delta_s|$ is an absolute value of option delta.

To compute OMMs inventories we use the data on signed trading volumes for various groups of customers obtained from the Chicago Board Options Exchange (CBOE) and the International Securities Exchange (ISE). Since ISE data begin only in 2005, we start the whole sample from 01/01/2005.

We follow Ni, Pearson, Poteshman, and White (2020) methodology who use similar data to infer OMMs inventory positions. CBOE/ISE Open/Close data contain eight categories of volume for each option series at the close of every trade day: open buy, open sell, close buy and close sell by public investors classified as customers and firm proprietary traders. For each option series, we cumulate the buy and sell trades of the public customers and firm proprietary traders to estimate the long and short open interests of the two groups of customers, and then estimate the net market maker position as the negative of the sum of the public customer and firm proprietary trader open interests. Thus, for each option series for the period of 2005 to 2018, we estimate buy and sell open interest by cumulating the CBOE and ISE open buy, close sell, open sell and close buy volumes as follows:

$$OpenInterest_{j,t}^{Buy,y} = OpenInterest_{j,t-1}^{Buy,y} + Volume_{j,t}^{OpenBuy,y} - Volume_{j,t}^{CloseSell,y},$$

$$OpenInterest_{j,t}^{Sell,y} = OpenInterest_{j,t-1}^{Sell,y} + Volume_{j,t}^{OpenSell,y} - Volume_{j,t}^{CloseBuy,y},$$

where $Volume_{j,t}^{OpenBuy,y}$ and $Volume_{j,t}^{OpenSell,y}$ are volumes from investor class *y* to establish new purchased and written positions, and $Volume_{j,t}^{CloseBuy,y}$ and $Volume_{j,t}^{CloseSell,y}$ are volumes to close existing written and purchased positions, respectively. The OMMs inventory is estimated as net open interest taken with the opposite sign.

$$NetOpenInterest_{j,t} = -[OpenInterest_{j,t}^{Buy,y} - OpenInterest_{j,t}^{Sell,y}],$$

where $NetOpenInterest_{j,t}$ is the net open interest scaled by option contracts deltas (and thus expressed in units of stocks) of OMMs in option series j. We thus obtained delta scaled *Inventory* levels.

We compute net order imbalances, and OMMs inventories first on a contract level per day. We then compute the sum of imbalances or inventory on a firm level or index (SPX) level. For equity contracts CBOE and ISE data cover about 66% of overall trading volume in the US. For SPX contracts which exclusively trade at CBOE, we have 100% coverage.

We also use percentage quoted spreads in our analysis (%QS), computed as the ask price minus bid price and divided by bid-ask mid-point. Figure 1 presents %QS dynamics for all equity options by 10 min snapshots throughout the day for 2005-2010 and 2011-2018 sub-periods. For each 10-min interval, starting at 10:00 am, of a trading day we compute the average %QS across all 1 min NBBOs snapshots for each contract. We then average these estimates across all contracts with the quotes available. The relative quoted spread pattern is an asymmetric U-shape throughout the day. The spreads are wider at the opening, then they are almost monotonically decrease towards the end of the day, and then, in the last 10 min, between 3:50pm and 4pm, %QS disproportionally jump up. This pattern is consistent with inventory management practices of market makers who widen the spreads once inventory costs increase (Stoll (1978), Ho and Stoll (1981, 1983), Amihud and Mendelson (1980)). Figure 1 provides the first evidence that in options market quoted spreads abruptly widen right before the market closes.

Table 1 reports summary statistics for order imbalances and OMMs inventories for equity options Calls, Panel A, and Puts, Panel B, and SPX index call options, Panel C, and put options Panel D for both sub-periods, 2005-2010 and 2011-2018.

We confirm stylized facts reported in the previous literature. As end-users of individual equity contracts are net-sellers, we observe across both calls and puts, Panels A and B, the negative net order flows, *OIM*. The negative net demand pressures result in overall positive on average OMMs inventory positions in equity options in 2005-2010, and for puts in 2010-2018. It is interesting to note, that for calls, in 2010-2018, the average inventory level becomes negative, -94.93. The median however remains highly positive, 33.71, implying negative skew in calls inventory distribution for 2011-2018. The negative average inventory is driven by 2011-2014 sub-period. After introduction of SPX night trading in March 2015, which we discuss in more details below, for 2015-2018 sub-sample the average call inventory is positive, 34.15, and the median remains positive, 29.57.

For SPX options, OMMs hold positive inventory only in calls, Panel C, where end-users are net sellers. Since end-users are normally net buyers of SPX puts, and especially in the second sub-period, 2010-2018, where we observe significant positive net order imbalances, OMMs hold substantial negative inventories.

Overall, the results are consistent with positive net demand pressures by end users for SPX puts, and negative net demand pressures for equity options (Garleanu et al 2009). The average inventory level of OMMs is positive in equity options, as well as in SPX calls, and negative in SPX puts.

4. Main results: End of Day Bias in Option Returns

We compute delta hedged daily 24-hour call, put and straddle returns using different hour mid-quotes during a trading day: 10am, 11am, 12pm, 1pm, 2pm, 3pm, and the closing 4pm mid-quote for equity and 4:15pm mid-quotes for SPX index options. Table 2 presents the results for S&P500 firms' equity options, and Table 3 for SPX index options. For call and put returns we also report cumulative by hour order imbalances, *COIM*, and percentage quoted spreads, %QS, in the end of each time interval. *COIM* is computed as weighted average across all contracts on a class (firm) level first, using dollar open interest from the previous day as the weight. It is then averaged across all firms on a portfolio level. For 10am, the *COIM* is estimated from 9:30am to 10am interval. The cumulative imbalances for 11am are estimated by adding together 9:30am to 10am, and 10am to 11am imbalances. We repeat this procedure throughout the end of a day by hour and use cumulative order imbalances to characterize the dynamics of price pressures on OMMs inventories during the day.

Table 2, Panel A reports daily delta-hedged returns for Calls for the first sub-period. The first panel presents the results for *All*, *Positive* and *Negative*, order imbalance days. *All* includes all positive volume days. *Positive* are portfolios of firms with strictly positive options net order flows for day *t*. *Negative* are portfolios of firms with strictly negative options net order flows for day *t*.

The morning, 10am, return is the most negative, -1.25%. It monotonically increases during the day, with 1pm return of -0.63%, and the daily return computed with the closing prices is close to zero, -8 bps. All t-statistics reported hereafter use Newey West standard errors adjusted for 22 lags, and we interchangeably refer to delta hedged returns as returns. The magnitudes of t-stats are high as we have very large samples with tens of millions of observations in each portfolio. As all returns are significant, the daily return computed using closing mid-points is the highest. The difference between daily returns computed using 4pm mid-quotes and 10am mid-quotes is economically large, 1.17%. The difference between daily returns computed using 3pm mid-quotes and 11am mid-quotes is still economically large, 63 bps. This is the first evidence of significant upward bias coming from using late afternoon, and especially closing prices. It is also noticeable that %QS jump by 50 bps at the closing compared to the rest of the day, and majority of *COIM* takes place by 11 am, leaving OMMs the rest of the day to balance their inventories before the market closes.

We observe similar returns, *COIM*, %QS patterns when we only consider firm-days with *Negative*, the middle panel, or *Positive*, the bottom panel, options net-order imbalances. The only difference is that for *Positive* imbalance firm-days, the difference between daily returns computed using 4pm mid-quotes and 10am mid-quotes is even bigger, 1.42%. Moreover, for positive or negative order imbalance firm-days, more than 70% of net-order flow shocks takes place before 11am. The results are similar for puts in Panel B, and for Straddles in Panel C. For ATM straddles, the difference between daily returns computed using 4pm mid-quotes and 10am mid-quotes is as big as for delta-hedged returns, 1.07%. As straddles do not use the prices of underlying stocks, or options deltas, the result suggest that the bias we document is not attributed to the noise in the prices of underlying (Blume and Stambaugh (1983)), or imperfect hedge due to errors in deltas.

The results for 2011-2018 sub-sample are presented in Panels D, E and F and are similar to 2005-2010 sub-sample. There is one noticeable observation: %QS often jump by almost 1% at the closing, at 4pm. Therefore, the inventory management considerations normally reflected in wider bid-ask spreads (Stoll (1978), Ho and Stoll (1981, 1983), and Amihud and Mendelson (1980)) increase substantially right before the non-trading periods.

Table 3 presents similar statistics for SPX index options. For the first sub-period, Panels A, B and C present results for delta hedged SPX calls, puts, and ATM SPX straddles respectively. Consider SPX Put options, Panel B. Similar to the results for individual equity options, the difference between daily returns computed using 4:15 pm mid-quotes and 10am mid-quotes is economically large, 1.21% for all positive volume days. For straddles this difference is 91 bps. Given that SPX contracts are the most liquid options, compared to equity options, and we still obtain these big differences in returns, we conclude that our results are not driven by option's illiquidity. The results are similar for positive or negative imbalance days.

We also find very similar results for the second sub-sample, 2011-2018 with one notable exception. For SPX options, %QS jumps up by almost 2% at 4pm, when the equity options market closes, and then returns to pre-closing level at 4:15pm. This is the first evidence that OMMs inventories in equity and index options are linked, as OMMs often use SPX options to hedge their positions in equity options.

Overall, we document that for individual equity options and options on SPX index, daily returns computed using closing mid-quotes are always higher, and by significant magnitudes, compared to what the returns would be if we use any other mid-quote during the day. We also document that majority of options imbalances take place before noon, and that the closing quoted bid-ask spreads are always wider compared to earlier trading hours. In the next two sections we show that the upward bias in returns based on closing mid-points is due to quoted prices distortions attributed to non-traded periods non-zero inventory states of market participants.

5. What can explain these patterns in returns?

The results reported in the previous section call for more detailed analysis of intra-day option price dynamics under different demand pressures. The logical conclusion is that at the market closing, not only %QS jumps up but also quoted mid-points themselves change substantially. What are potential sources behind mid-point change and wider bid-ask spread before non-trading periods?

First, widening of quoted bid-ask spreads is expected since carrying inventories imposes significant costs on OMMs. Jameson and Wilhelm (1992), Green and Figlewski (1999), and Battalio and Schultz (2011) argue that inventory costs and risks are much more serious for option market makers than for liquidity providers in stock markets, due to hedging needs, model risk, and uncertain holding periods. In option markets, market makers also incur hedging and rebalancing costs when they are unable to quickly resell illiquid series (Leland 1985; George and Longstaff 1993; de Fontnouvelle, Fishe, and Harris 2003; Engle and Neri 2010). Overall, holding options inventories is more expensive compared to the stocks. Therefore, the inventory effect on bid-ask spreads (Amihud and Mendelson 1980; Stoll 1978; Ho and Stoll 1981, 1983) should be even more applicable in the options market, and especially before non-trading periods where continuous hedging is not available.

If there is a positive buying pressure, and OMMs have already accumulated negative inventory positions, to decrease net buying order flows they need to increase mid-point quoted prices. On the negative order imbalance days which prevail on average (Garleanu et al (2009)), OMMs are net buyers, and hence hold positive inventories (Table 1). As positive inventory increases, OMMs need to decrease quoted mid-points to discourage selling pressure and attract offsetting trades. Therefore, for the cross-section of options where OMMs over-accumulate positive inventories, we expect to see a *downward* drift in intra-day option returns towards the end of day. For the cross-section of options where OMMs over-accumulate negative inventories, we expect to see an *upward* drift in intra-day option returns towards the end of day. While both are consistent with inventory management practices theoretically argued by Amihud and Mendelson (1980), the former is in conflict with the aversion to unbounded downside risk of option writers' hypothesis. Since option writers have a greater aversion to downside risk during non-trading periods (Cheng and Singal (2003)), they would require higher closing prices if overnight hedging is not available. However, once overnight hedging is available, options writers no longer should require the downside risk premium, and option prices should continue to fall under net selling pressure through the end of the day towards the market closing. In the next section we test these hypotheses.

5.1 Day and Night Option Returns and Market Makers Inventories

The analysis in this section is similar to Muravyev and Ni (MN) (2020). We do not follow the authors directly, as we only adopt their methodology for our hypotheses' tests. We only use ATM straddle returns to avoid capturing noise in the prices of underlying stocks or option deltas. Similar to the authors, our night return, close-to-open return, is based on day *t-1* closing mid-quotes at 4pm for equity options and 4:15 pm for SPX options, and day *t* opening mid-quotes. Our day return is *intra-day* cumulative by hour of a day return. More specifically, we use 10am mid-quote as an opening quote[3], and compute open to 11am return for 11am mid-quote, then open to 12pm return, and so on by 1-hour increment till 4pm for equity and 4:15pm for SPX options. Open-to-close will result in a cumulative intra-day return for a given trading day. These returns will allow us to trace mid-quote drifts compared to the opening mid-quotes under different demand pressures on OMMs inventories through the end of trading day.[4]

Table 4 present results for returns on ATM straddles for S&P500 firms' equity options for 2005-2010 which is the majority of MN (2020) sample in Panel A, and more recent, 2011-2018 sub-sample in Panel B.

Consider first Panel A. We confirm MN (2020) results that the night return is negative, -37 bps, and the cumulative intra-day return is positive, 11 bps. We also split cross-section of stock options where OMMs accumulate extreme (top 20%) positive and extreme (bottom 20%) negative inventory, where inventory is ranked daily on overall firm/class levels. For cross-section of firms where OMMs accumulate excess of negative inventory, which also implies significant buying pressure from end-users, we find even higher cumulative day return, 24 bps. The cumulative return trends upward almost monotonically through the day which is consistent with inventory management quoting practices of Amihud and Mendelson (1980). The night return is negative which compensates OMMs for the overnight inventory risk of the short positions. For positive inventory cross-section, where end-users are net-sellers, Amihud and Mendelson (1980) hypothesis predicts a downward trend in intra-day cumulative returns. Instead, the intra-day cumulative return is rather flat at around zero, while the night return is still negative, -37 bps. This however is consistent with unbounded downside risk hypothesis of Chen and Singal (2003) where options sellers demand a compensation for non-trading period risk in terms of higher closing prices. The negative night return is thus a premium to option writers for holding overnight positions. According to Chen and Singal (2003) hypothesis, when a hedging instrument becomes available to hedge non-trading period unbounded down-side risk, the option writers should no longer require the premium. This brings us to the second sub-sample, 2011-2018, Panel B.

[3] The results do not change if we use 9:40 am quotes as in MN (2020), or 9:30 am quotes.
[4] The end-users net order flows, and OMMs inventory levels are highly negatively correlated. We therefore choose to directly focus on the inventories.

In the middle of the second sample, in March 2015, CBOE introduced SPX options night hours trading, which enables option writers to hedge overnight risk. Subsequently, the results for this subsample begin to look differently from those for 2005-2010.

For all positive volume days, the cumulative intraday return is no longer positive, but negative, -12 bps, and comparable in magnitudes to the night return of -19 bps. As expected according to Amihud and Mendelson (1980) theory, on excess positive inventory days, the intraday cumulative return almost monotonically decreases, and is more negative, -18 bps, compared to the corresponding night returns, -14 bps. On excess negative inventory days, the cumulative intra-day returns jump up by the end of day, and remains negative but small, -2 bps, while the night return is negative, -24 bps.

Therefore, on this sub-sample, with the night hedging available, the OMMs inventory management practices and quoting strategies look more as predicted by Amihud and Mendelson (1980).

Table 5 repeats the analysis of Table 4 for SPX index options where we find similar results between sub-periods to those for equity options.

5.2 Introduction of SPX Night Trading

On March 9, 2015 CBOE extended traded hours for SPX options from 2:00am to 8:15am Central time (CT).[5] This provides ideal exogenous event in our sample to test overnight inventory risk explanation of our results. We further split the second period, 2011 to 2018, in two sub-periods, 2011 to 2014, where overnight hedging is not available, we call it the placebo sample, and 2015 to 2018, the test sample where the night hedging is available. Our numerous conversations with option market makers confirm that they use SPX options substantially to hedge their equity option positions.

Table 6 reports the results for S&P500 equity options. In general, the main results of MN (2020) are replicated for 2011-2014 placebo sample, Panel A. For the test sample, 2015-2018, Panel B, these results change. For all positive-volume days, the night return is economically small, -7 bps, while intra-day cumulative returns are substantially more negative, -16 bps. Consistent with Amihud and Mendelson (1980) theory, on excess positive inventory days, the intraday cumulative

[5] See press release http://ir.cboe.com/press-releases/2015/feb-06-2015.aspx

return almost monotonically decreases, and is more negative, -20 bps, compared to the corresponding negligible night returns, -3 bps. On excess negative inventory days, the cumulative intra-day returns jump up by the end of day, and remains negative but small, -9 bps, and somewhat similar night return is negative, -13 bps.

Table 6 results account for the possibility to hedge during weekdays, Monday to Friday. SPX options do not trade over weekends or holidays, and hence unlimited downside risk of options writers still remains unhedgable during longer non-trading periods. Weekend and holidays returns are still treated as overnight returns and are part of the sample. Jones and Shemesh (JS) (2018) find that option returns are significantly lower over nontrading periods, majority of which are weekends. We address the weekend returns in the next sub-section.

In Table 7 we adjust the sample for weekend returns. To make sure that trading frequency does not influence our conclusions, as in JS (2018) we only retain contracts which traded all five days during a week. The week-end return, as in JS (2018) is measured from Friday close to Monday close, where Monday is considered as the end of week-end period. After imposing 5-day per week of positive trading volume filter on the sample in Table 6, we next withdraw the week-end returns, or Mondays, from the sample, and repeat the analysis. For the placebo sample, 2011-2014, Panel A, we still observe MN (2020) negative night and close to zero or positive day return. For the test sample, Panel B, the day and nigh returns flip the signs. The night return is now positive, 3 bps, and the intra-day return is negative, -10 bps. Consistent with Amihud and Mendelson (1980) theory, on excess positive inventory days, the intraday cumulative return almost monotonically decreases, and is more negative, -13 bps, while the night return is positive, 8 bps. The positive night return is a compensation to OMMs for positive overnight inventory hedging costs and risks. On excess negative inventory days, the cumulative intra-day returns jump up by the end of day and are statistically indistinguishable from zero. The night return is small and negative, -6 bps to compensate OMMs for holding negative overnight positions.

Tables 8 and 9 repeat the analysis of Tables 6 and 7 for SPX index options. We find similar results for SPX options, except when we delete weekend returns in Table 9, Panel B, the night and intra-day returns on SPX straddles for extreme positive or negative inventory portfolios are generally insignificant. We also observe that for the post-2015 sample about 15% of SPX afternoon volume migrates into the night hours. Given that SPX continues trading in the night, insignificant straddle returns in the extreme OMMs inventory contracts are not surprising.

5.3 Weekend Returns

Jones and Shemesh (2018) find that option returns are significantly lower over nontrading periods, majority of which are weekends. Since SPX options night trading does not extend over weekends, the weekend returns can be treated as a counterfactual to our results. We pursue two objectives. First, given that unbounded downside risk in the end of Fridays cannot be hedged on Saturdays and Sundays even for 2015-2018, we should observe negative weekend returns. Second, given structural change in the options markets in 2015, there is no evidence in the literature yet about how post-2015 returns look like for weekdays. JS (2018) for example find puzzling that Wednesday and Thursday returns in their sample are positive. In the light of our results, given that the night return is no longer highly negative as reported before (MN (2020)), but actually is positive, one can expect that all weekday returns can be positive overall. This will also imply that if one does not account for weekend returns, the average across all days negative sign for options returns can be totally attributed to the negative weekend return.

To compare weekend returns with day of week returns, similar to Jones and Shemesh (2018) we choose only contracts which traded all five days during a week, and the week-end return is measured from Friday close to Monday close, where Monday is considered as the end of non-trading period.

We first replicate Jones and Shemesh (2018) results for two sub-samples, 2005-2010, and 2011-2018, in Table 10, and then separately for our test sample, 2015-2018 in Table 11 for S&P500 firms' equity options.

Consider Table 10, Panel A, call returns for 2005-2010. The first two columns compare non-trading period returns versus trading period returns, where non-trading and trading return estimates are pooled together. The delta-hedged returns are first computed on a contract level, then value-weighted return is computed on a class level using previous day dollar open interest as a weight, and then averaged on a portfolio level across all stocks. Similar to JS (2018), using 4 pm quote, we find significant negative non-trading period returns, -0.84%, and positive trading period returns, 0.11%. The difference of -0.95% is statistically significant and economically large[6]. Similar to JS (2018) we also obtain the highest negative return on Monday, -0.82%, with all other days of the week having lower in absolute values returns. As in JS (2018), we find that Wednesday and Thursday returns are positive, with Friday returns being the second most negative return of the week. We therefore replicate JS (2018) results in our sample using 4pm quotes.

The results are different if we compute returns using 10 am quotes. Here, both non-trading and trading period returns are negative, -1.68% and -1.28% respectively, and the difference between mean returns of -40 bps is statistically significant. As the sample size is large, most of t-statistics are significant.

For 10 am quote, compared to 4 pm quote, the difference in returns between non-trading vs trading periods decreases by more than a factor of 2 in absolute value (from -95 bps to -40 bps). The absolute value of the dereference is monotonically increases with the hour of a day. These results are consistent with the noise in end of day prices which we document earlier.

For 10 am quotes, Monday returns are no longer the most negative as for 4 pm quotes. As negative return is also observed on Wednesdays, -1.64%. Qualitatively similar results are also observed in more recent, 2011-2018 period for calls, Panel B. For 4pm quote, the difference between non-trading and trading period returns is -92 bps, and it drops (in absolute value) to -21 bps for 10 am quote. Monday returns are the most negative for the week with 4 pm quote, and Tuesday with 10 am quote.

For puts, Panels C and D, we find qualitatively similar results as well. The difference in returns between non-trading and trading periods is -0.82% and -1.05% for the first and second sub-periods respectively with 4pm quotes. For 10 am quotes this difference drops (in absolute value) to -0.15% and -0.23% respectively. These differences, while significant, are not as meaningful economically. Therefore, the negative weekend effect is rather attributed to the end-of-day noise caused by price pressures.

[6] Similar to mean returns t-statistics, we also use Newey West standard errors adjustment with 22 lags to compute t-statistics for differences in means.

In Table 11, for post-2015 sample with the night SPX hedging available, we confirm our second hypothesis. The weekday returns for 4pm mid-quotes are all positive or insignificantly different from zero for calls, Panel A, and puts, Panel B.

Tables 12 and 13 present similar analysis for SPX options, where we find qualitatively similar but much weaker results. As in JS (2018) the results are weak for calls for 2005-2010, Panel A. They get stronger in 2011-2018, Panel B. For puts, using 4:15pm closing mid-points, the difference between the negative weekend and positive trading period returns is high, -2.22% for the first sub-sample, 2005-2010, Panel C. This difference flips the sign however, and becomes positive, 0.36%, for the second sub-period, Panel D. This surprising change in the sign between non-trading and trading periods for SPX puts is driven by 2015-2018 sub-period, when SPX night trading becomes available. Table 13, Panel B, demonstrates that for delta-hedged returns based on 4:15pm mid-quotes, the non-trading period return is positive, 0.21%, but insignificant, while the trading period return is negative, -0.68%, and highly significant. This *positive* difference is even larger, 0.89%, than in Table 12, Panel D. Thus, the weekend return for SPX puts, similar to the negative night and positive day returns of MN (2020), too flips the sign.

It is interesting to note that for 4pm mid-quotes, which are synchronous with the equity options market closing, the difference between trading and non-trading periods is *negative*, -0.95%. Only 15 minutes separate these two opposite results from each other. Perhaps buying pressures by OMMs to hedge their long 4pm positions in equity options with SPX puts on Fridays is responsible for the results. This however provides another evidence how price pressures and OMMs inventory management practices can distort asset values even for the most liquid contracts. For SPX puts, the prices mean-revert within 15 minutes after equity options market closes.

5.4 False Discoveries Using End of Day Closing Prices.

In this section we present examples of discovering false anomalies in options returns in more recent data after introduction of SPX night trading. We continue retaining contracts which trade all five days per week and removing weekend returns. Table 14 presents 24-hour daily delta hedged returns for calls, puts and ATM straddles for S&P500 firms' equity options for 2015-2018, vs 2011-2014 subsamples.

Compare delta-hedged call returns in Panel A, 2015-2018, vs Panel D, 2011-2014. For SPX night trading sample, Panel A, the call return, using 4pm mid-quotes, is abnormally positive, 17 bps, while it is almost zero for 2011-2014 sub-sample. Similarly, put returns are positive in 2015-2018, Panel B, 11 bps, while they are negative in 2011-2014, Panel E, -17 bps. The straddle return is very small and negative, - 9 bps, in 2015-2017 (Panel C), while it is -24 bps in 2011-2014 (Panel D).

Table 15 computes similar statistics for SPX options. The results for SPX options look even more different between sub-periods. Delta-hedged call and put returns, or delta-neutral straddle returns in 2015-2018, Panels A, B and C respectively, are all insignificantly different from zero. Positive signs for call returns could be seen as an anomaly. Bakshi and Kapadia (2003a) suggest that because of market volatility risk pricing in index options, non-negative delta hedged payoffs cannot exist.

However, if a researcher uses 10am mid-quotes, then all returns, across trading or non-trading periods, look quite similar for both equity calls and puts, as well as SPX options. In Table 14, delta hedged call, put and delta neutral straddle returns on equity options in 2015-2018 are -1.33%, -1.60%, and -1.16% respectively. They are very similar in magnitudes compared to those in 2011-2014.

In Table 15, delta hedged call, put and delta neutral straddle returns on SPX options in 2015-2018 are -1.51%, -1.61%, and -1.16% respectively, and they are similar in magnitudes compared to those in 2011-2014.

Moreover, comparing the returns based on 10 am mid-points between equity and index (SPX) options, it is quite noticeable that they are similar in magnitudes. In our sample, the delta-hedged put and the delta-neutral straddle equity and index option returns are identical. The differential pricing of variance risk premium between individual equity and index options has been a long standing puzzle in the option literature (Bakshi and Kapadia (2003b) and Driessen, Maenhout, and Vilkov (2009)). We show that these puzzling results are attributed to price pressures.

6. Conclusion

The main message of this paper is that end of day closing midpoints in options market are noisy and mean-revert the next morning. This noise is attributed to non-zero inventory levels of OMMs who use price pressures to mean-revert their inventories and unbounded downside risk of option writers over non-trading periods. Delta-hedged and delta-neutral straddle equity and index option returns computed using closing prices contain large biases reaching more than 1% per day.

The noise in the end of day option prices explains negative night and positive day returns (MN (2020)), and well as negative weekend returns (JS (2018)). Aversion to unbounded downside risk over non-trading periods of option writers drives an upward bias in the closing prices. The negative non-trading period returns are rewards for holding short positions unhedged. As the hedging becomes available via introduction of SPX night trading in March 2015, the negative night and positive day returns (MN (2020)) flip the signs, as well as the negative non-trading and positive trading period returns for SPX puts (JS (2018)) flip the signs too. Therefore, negative non-trading period returns as premiums for downside risk exposure largely disappear once this risk can be hedged away.

In post-2015 period, the day returns are negative and night returns are positive. The negative day returns are consistent with an average net selling pressures by options end-user, and OMMs thus holding positive inventories on average. Similar to Hendershott and Menkveld (2014) results in the stock market, OMMs use price pressures to mean-revert their inventories. The positive night return is a compensation to OMMs for holding long positions overnight.

Finally, we show that differential pricing of volatility risk between individual equity and index options (Bakshi and Kapadia (2003b) and Driessen, Maenhout, and Vilkov (2009)) is completely explained by the noise in closing prices. Delta-hedged or straddle returns on equity and index options are *identical* if we use 10 am mid-quotes, as in Coval and Shumway (2001), and which are least affected by noise.

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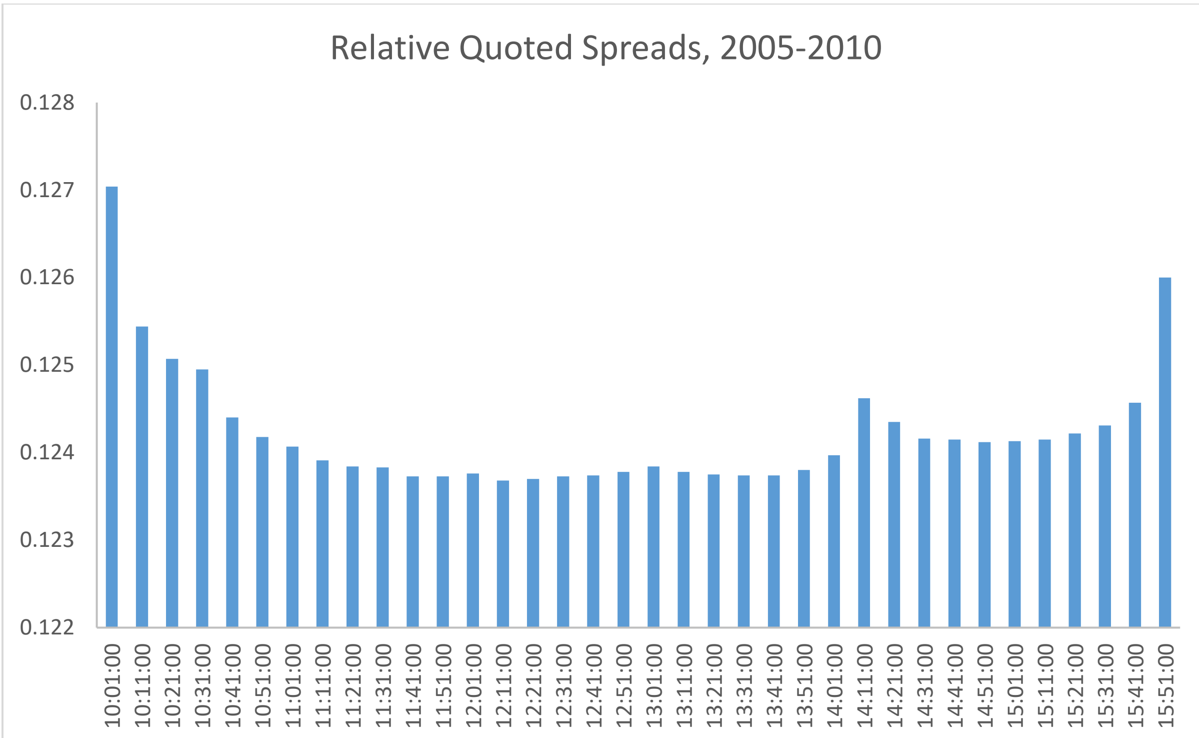
Figure1. Relative Quoted Bid-Ask Spreads averaged by 10-min intervals of trading day.



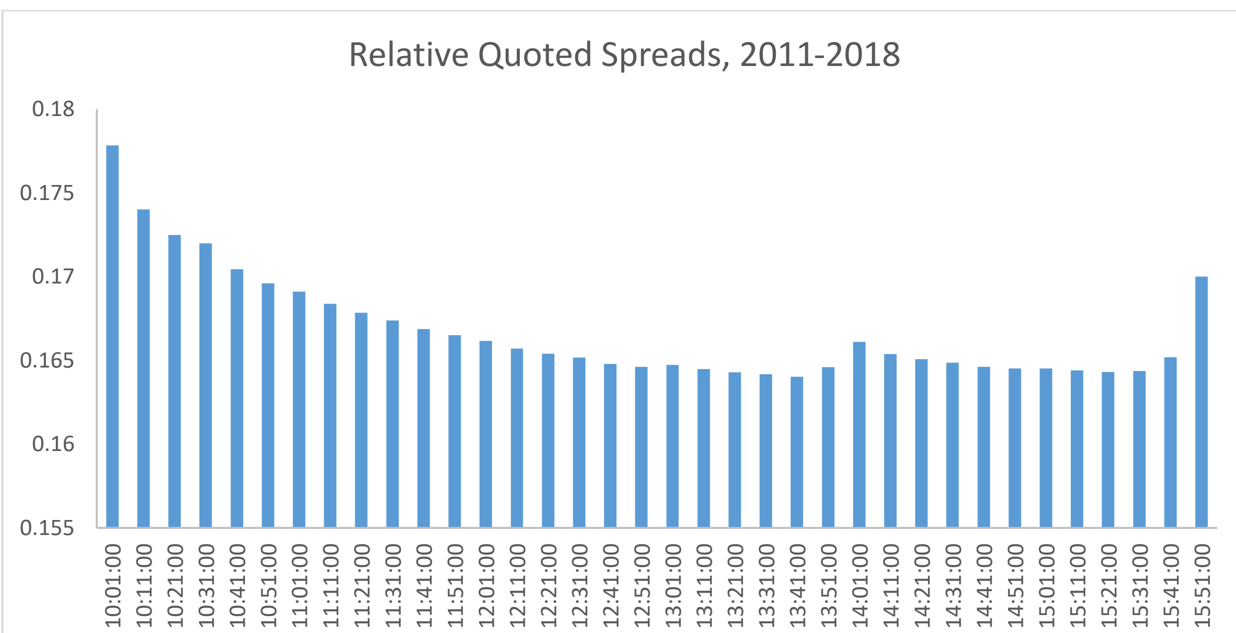


Table 1. Summary Statistics

The table reports daily summary statistics for call, Panel A, and put, Panel B, options of S&P500 components for 2005 to 2010, and 2011 – 2018 subperiods, and for SPX index call and put options in Panels C and D respectively. *OIM* are option net order imbalances computed from intraday transactions where buy or sell trades are signed using tick rule. *Inventory* is option market makers delta-scaled inventory level.

Panel A. Calls SP500 equity options

	Mean	Stdev	P1	P50	P99
2005-2010					
OIM	-0.335	1.698	-5.434	-0.271	4.224
Inventory	56.04	8331.15	-19514.68	77.63	16403.15
2011-2018					
OIM	-0.280	2.328	-7.503	-0.194	6.273
Inventory	-94.93	6810.11	-15147.77	33.71	12194.53

Panel B. Puts SP500 equity options

	Mean	Stdev	P1	P50	P99
2005-2010					
OIM	-0.110	1.334	-3.976	-0.098	3.548
Inventory	217.47	7858.02	-10953.99	-2.44	14537.20
2011-2018					
OIM	-0.105	1.817	-5.597	-0.077	5.252
Inventory	706.55	5900.47	-3598.18	6.38	18351.63

Panel D. Calls SPX options

	Mean	Stdev	P1	P50	P99
2005-2010					
OIM	-0.834	3.532	-10.148	-0.815	7.356
Inventory	42282.46	36137.02	-41233.88	41180.44	141290.77
2011-2018					
OIM	-0.363	7.914	-23.167	-0.516	22.608
Inventory	24302.81	35991.63	-31771.17	16773.95	146966.74

Panel E. Puts SPX options

	Mean	Stdev	P1	P50	P99
2005-2010					
OIM	-0.126	3.610	-9.802	0.045	8.157
Inventory	-33527.83	45873.22	-129806.29	-34127.11	89124.20
2011-2018					
OIM	1.064	7.566	-18.502	0.676	22.979
Inventory	-13804.52	27016.79	-99745.65	-9106.79	33683.86

Table 2. Equity Option Returns

The table presents average portfolio delta hedged and straddle daily returns using different hour of a day mid-quotes for call and put options of S&P500 components for 2005 to 2010, and 2011 – 2018 subperiods. R^O is a delta-hedged option return on day t. *COIM(t)* is cumulative options net order imbalance on day t for a given hour of a day. *All* reports hourly statistics without conditioning on net order flows. *Negative (Positive) Order Imbalances* report hourly statistics for portfolio sorted on *OIM(t)<0 (OIM(t)>0)* for that day *t*. *COIM(t)* for 10am is cumulative order imbalances between 9:30am and 10am. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Call Options, 2005-2010

time	R^O	t-stat	COIM(T)	%QS
		ALL		
10:00	-0.0125	-110.50	-0.035	0.090
11:00	-0.0095	-86.47	-0.042	0.083
12:00	-0.0074	-69.51	-0.045	0.082
13:00	-0.0063	-58.41	-0.046	0.082
14:00	-0.0050	-46.50	-0.046	0.082
15:00	-0.0032	-29.26	-0.045	0.082
16:00	-0.0008	-6.78	-0.045	0.087
		Negative Order Imbalances		
10:00	-0.0119	-86.63	-0.214	0.087
11:00	-0.0090	-68.02	-0.271	0.080
12:00	-0.0070	-54.17	-0.302	0.079
13:00	-0.0060	-45.95	-0.323	0.079
14:00	-0.0049	-37.22	-0.339	0.079
15:00	-0.0034	-25.73	-0.356	0.079
16:00	-0.0016	-11.76	-0.376	0.084
		Positive Order Imbalances		
10:00	-0.0136	-103.5	0.183	0.087
11:00	-0.0101	-77.69	0.237	0.079
12:00	-0.0078	-60.37	0.270	0.078
13:00	-0.0063	-49.18	0.293	0.078
14:00	-0.0048	-38.89	0.314	0.078
15:00	-0.0026	-20.13	0.337	0.078
16:00	0.0006	4.43	0.363	0.082

Panel B. Put Options, 2005-2010

time	R^O	t-stat	COIM(T)	%QS
		ALL		
10:00	-0.0134	-92.72	-0.019	0.084
11:00	-0.0100	-71.21	-0.022	0.077
12:00	-0.0078	-56	-0.024	0.076
13:00	-0.0065	-46.78	-0.024	0.076
14:00	-0.0051	-37.02	-0.024	0.076
15:00	-0.0034	-23.67	-0.023	0.077
16:00	-0.0012	-7.98	-0.023	0.082
		Negative Order Imbalances		
10:00:00	-0.0130	-83.45	-0.206	0.079
11:00:00	-0.0096	-63.14	-0.257	0.073
12:00:00	-0.0076	-49.77	-0.282	0.072
13:00:00	-0.0065	-42.65	-0.299	0.072
14:00:00	-0.0053	-35.05	-0.313	0.072
15:00:00	-0.0039	-25.05	-0.329	0.072
16:00:00	-0.0025	-15.23	-0.346	0.077
		Positive Order Imbalances		
10:00	-0.0139	-84.48	0.184	0.080
11:00	-0.0102	-64.43	0.234	0.074
12:00	-0.0078	-49.04	0.260	0.073
13:00	-0.0061	-38.57	0.279	0.073
14:00	-0.0044	-27.86	0.295	0.073
15:00	-0.0023	-13.83	0.313	0.073
16:00	0.0006	3.33	0.333	0.078

Panel C. Straddle, 2005-2010

time	$R^{straddle}$	t-stat
	All	
10:00	-0.01334	-164.62
11:00	-0.01034	-132.23
12:00	-0.00842	-108.28
13:00	-0.00724	-93
14:00	-0.0061	-76.67
15:00	-0.00456	-55.45
16:00	-0.00267	-29.93
	Negative Order Imbalances	
10:00	-0.01343	-122.39
11:00	-0.01133	-106.56
12:00	-0.00999	-94.28
13:00	-0.00928	-86.47
14:00	-0.00862	-78.98
15:00	-0.00768	-67.63
16:00	-0.00658	-54.08
	Positive Order Imbalances	
10:00	-0.01199	-100.34
11:00	-0.00798	-68.14
12:00	-0.00535	-45.6
13:00	-0.00365	-30.83
14:00	-0.00199	-16.4
15:00	0.000148	1.16
16:00	0.002756	19.95

Panel D. Call Options, 2011-2018

time	R^O	t-stat	COIM(T)	%QS
		ALL		
10:00	-0.0128	-117.9	-0.012	0.126
11:00	-0.0095	-100.4	-0.019	0.100
12:00	-0.0072	-76.21	-0.020	0.095
13:00	-0.0056	-61.06	-0.021	0.092
14:00	-0.0041	-42.05	-0.021	0.095
15:00	-0.0025	-24.94	-0.021	0.091
16:00	-0.0007	-6.64	-0.021	0.099
		Negative Order Imbalances		
10:00	-0.0119	-109.2	-0.194	0.121
11:00	-0.0083	-77.22	-0.252	0.095
12:00	-0.0060	-56.37	-0.282	0.091
13:00	-0.0045	-41.33	-0.302	0.089
14:00	-0.0032	-28.06	-0.318	0.091
15:00	-0.0018	-15.76	-0.335	0.088
16:00	-0.0006	-4.89	-0.355	0.095
		Positive Order Imbalances		
10:00	-0.0141	-116.3	0.189	0.121
11:00	-0.0108	-99.52	0.241	0.095
12:00	-0.0083	-78.05	0.271	0.090
13:00	-0.0066	-64.03	0.292	0.088
14:00	-0.0048	-43.4	0.310	0.090
15:00	-0.0029	-27.13	0.329	0.087
16:00	-0.0004	-3.72	0.351	0.094

Panel E. Put Options, 201-2018

time	R^O	t-stat	COIM(T)	%QS
		ALL		
10:00	-0.0155	-135.22	0.001	0.122
11:00	-0.0115	-110.49	-0.008	0.095
12:00	-0.0091	-89.09	-0.010	0.090
13:00	-0.0073	-71.96	-0.011	0.088
14:00	-0.0057	-53.1	-0.011	0.091
15:00	-0.0041	-37.61	-0.012	0.087
16:00	-0.0021	-18.9	-0.011	0.095
		Negative Order Imbalances		
10:00	-0.0141	-112.57	-0.178	0.115
11:00	-0.0102	-85.15	-0.232	0.089
12:00	-0.0079	-68.19	-0.256	0.085
13:00	-0.0063	-55.33	-0.272	0.083
14:00	-0.0048	-40.81	-0.285	0.085
15:00	-0.0034	-29.17	-0.299	0.082
16:00	-0.0022	-17.59	-0.314	0.090
		Positive Order Imbalances		
10:00	-0.0166	-130.9	0.185	0.116
11:00	-0.0125	-109.21	0.227	0.090
12:00	-0.0099	-87.61	0.249	0.086
13:00	-0.0081	-70.67	0.264	0.083
14:00	-0.0062	-53.17	0.277	0.086
15:00	-0.0043	-35.78	0.291	0.082
16:00	-0.0018	-14.11	0.308	0.091

Panel F. Straddle, 2011-2018

time	$R^{straddle}$	t-stat
	All	
10:00	-0.0134	-213.74
11:00	-0.0103	-171.81
12:00	-0.0084	-140.03
13:00	-0.0071	-117.45
14:00	-0.0060	-96.29
15:00	-0.0046	-73.5
16:00	-0.0032	-49.58
	Negative Order Imbalances	
10:00	-0.0131	-159.44
11:00	-0.0104	-129.74
12:00	-0.0088	-108.17
13:00	-0.0078	-94.43
14:00	-0.0069	-81.36
15:00	-0.0058	-66.95
16:00	-0.0050	-55.51
	Positive Order Imbalances	
10:00	-0.0131	-147.28
11:00	-0.0097	-111.47
12:00	-0.0074	-84.2
13:00	-0.0060	-68.06
14:00	-0.0046	-50.56
15:00	-0.0031	-33.16
16:00	-0.0012	-12.87

Table 3. SPX Option Returns

The table presents average portfolio delta hedged and straddle daily returns using different hour of a day mid-quotes for call and put options on S&P500 (SPX) index for 2005 to 2010, and 2011 – 2018 subperiods. R^O is a delta-hedged option return on day t. *COIM(t)* is cumulative options net order imbalance on day t for a given hour of a day. *All* reports hourly statistics without conditioning on net order flows. *Negative (Positive) Order Imbalances* report hourly statistics for portfolio sorted on *OIM(t)<0 (OIM(t)>0)* for that day *t*. *COIM(t)* for 10am is cumulative order imbalances between 9:30am and 10am. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SPX Call Options, 2005-2010

time	R^O	t-stat	COIM(T)	%QS
		ALL		
10:00	-0.0168	-14.71	-0.018	0.063
11:00	-0.0152	-13.04	-0.022	0.063
12:00	-0.0144	-10.11	-0.019	0.062
13:00	-0.0129	-10.92	-0.020	0.062
14:00	-0.0111	-8	-0.019	0.062
15:00	-0.0070	-5.55	-0.020	0.062
16:00	-0.0030	-1.8	-0.023	0.063
16:15	-0.0033	-1.96	-0.023	0.062
		Negative Order Imbalances		
10:00	-0.0164	-14.77	-0.145	0.064
11:00	-0.0149	-11.47	-0.223	0.063
12:00	-0.0128	-11.4	-0.267	0.062
13:00	-0.0117	-10.08	-0.294	0.063
14:00	-0.0097	-8.63	-0.316	0.063
15:00	-0.0063	-5.01	-0.340	0.062
16:00	-0.0015	-0.9	-0.370	0.062
16:15	-0.0021	-1.25	-0.378	0.062
		Positive Order Imbalances		
10:00	-0.0179	-15.42	0.122	0.065
11:00	-0.0173	-11.6	0.199	0.064
12:00	-0.0163	-10.29	0.252	0.064
13:00	-0.0140	-11.47	0.282	0.063
14:00	-0.0125	-8.15	0.308	0.063
15:00	-0.0095	-7.69	0.332	0.063
16:00	-0.0054	-3.43	0.357	0.065
16:15	-0.0050	-3.03	0.367	0.064

Panel B. SPX Put Options, 2005-2010

time	R^O	t-stat	COIM(T)	%QS
		ALL		
10:00	-0.0126	-17.62	-0.009	0.077
11:00	-0.0105	-14.26	-0.006	0.073
12:00	-0.0091	-12.74	-0.008	0.073
13:00	-0.0078	-8.37	-0.007	0.072
14:00	-0.0068	-8.09	-0.006	0.072
15:00	-0.0039	-3.3	-0.004	0.072
16:00	-0.0011	-0.82	-0.003	0.072
16:15	-0.0005	-0.33	-0.004	0.072
		Negative Order Imbalances		
10:00	-0.0122	-17.2	-0.097	0.078
11:00	-0.0104	-14.3	-0.151	0.074
12:00	-0.0087	-11.86	-0.185	0.073
13:00	-0.0080	-9.81	-0.204	0.073
14:00	-0.0067	-7.69	-0.220	0.073
15:00	-0.0037	-3.02	-0.236	0.073
16:00	-0.0010	-0.73	-0.253	0.073
16:15	-0.0008	-0.51	-0.260	0.072
		Positive Order Imbalances		
10:00	-0.0139	-14.41	0.083	0.079
11:00	-0.0113	-14.13	0.143	0.074
12:00	-0.0099	-12.92	0.173	0.074
13:00	-0.0084	-8.9	0.196	0.074
14:00	-0.0073	-8.37	0.213	0.074
15:00	-0.0044	-3.67	0.233	0.073
16:00	-0.0014	-1.04	0.253	0.073
16:15	-0.0008	-0.49	0.259	0.072

Panel C. SPX Straddle, 2005-2010

time	$R^{straddle}$	t-stat
	All	
10:00	-0.0115	-19.52
11:00	-0.0099	-16.73
12:00	-0.0084	-13.68
13:00	-0.0080	-12.46
14:00	-0.0068	-9.9
15:00	-0.0049	-6.18
16:00	-0.0022	-2.36
16:15	-0.0024	-2.49
	Negative Order Imbalances	
10:00	-0.0130	-16.56
11:00	-0.0111	-13.72
12:00	-0.0096	-11.39
13:00	-0.0090	-9.9
14:00	-0.0074	-7.52
15:00	-0.0048	-3.82
16:00	-0.0023	-1.58
16:15	-0.0025	-1.66
	Positive Order Imbalances	
10:00	-0.0139	-16.49
11:00	-0.0114	-13.33
12:00	-0.0090	-9.31
13:00	-0.0081	-8.48
14:00	-0.0066	-7.19
15:00	-0.0039	-3.17
16:00	-0.0011	-0.85
16:15	-0.0014	-1.05

Panel D. SPX Call Options, 2011-2018

time	R^O	t-stat	COIM(T)	%QS
		ALL		
10:00	-0.0120	-16.69	-0.005	0.064
11:00	-0.0105	-14.3	-0.016	0.046
12:00	-0.0084	-12.77	-0.018	0.045
13:00	-0.0067	-10.93	-0.018	0.045
14:00	-0.0060	-8.18	-0.020	0.049
15:00	-0.0042	-5.54	-0.021	0.046
16:00	-0.0019	-2.29	-0.020	0.061
16:15	-0.0015	-1.79	-0.021	0.048
		Negative Order Imbalances		
10:00	-0.0120	-16.7	-0.158	0.064
11:00	-0.0103	-14.27	-0.246	0.046
12:00	-0.0082	-12.45	-0.291	0.045
13:00	-0.0066	-10.19	-0.322	0.045
14:00	-0.0055	-8.94	-0.346	0.049
15:00	-0.0038	-6.23	-0.371	0.046
16:00	-0.0019	-2.41	-0.401	0.061
16:15	-0.0015	-1.88	-0.411	0.048
		Positive Order Imbalances		
10:00	-0.0126	-16.71	0.157	0.065
11:00	-0.0110	-14.52	0.231	0.047
12:00	-0.0090	-12.91	0.277	0.046
13:00	-0.0073	-11.41	0.310	0.046
14:00	-0.0063	-8.12	0.333	0.050
15:00	-0.0046	-5.94	0.357	0.047
16:00	-0.0017	-1.86	0.390	0.063
16:15	-0.0015	-1.64	0.399	0.049

Panel E. SPX Put Options, 2011-2018

time	R^O	t-stat	COIM(T)	%QS
		ALL		
10:00	-0.0143	-18.25	0.001	0.082
11:00	-0.0122	-16.51	0.002	0.061
12:00	-0.0105	-13.18	0.001	0.060
13:00	-0.0091	-11.76	0.001	0.059
14:00	-0.0079	-10.1	0.002	0.064
15:00	-0.0063	-6.94	0.001	0.060
16:00	-0.0042	-3.31	0.001	0.076
16:15	-0.0039	-2.73	0.001	0.063
		Negative Order Imbalances		
10:00	-0.0140	-17.53	-0.091	0.081
11:00	-0.0117	-16.38	-0.139	0.060
12:00	-0.0102	-13.33	-0.167	0.059
13:00	-0.0090	-11.83	-0.186	0.059
14:00	-0.0077	-9.96	-0.201	0.063
15:00	-0.0060	-6.63	-0.215	0.060
16:00	-0.0040	-3.05	-0.232	0.076
16:15	-0.0031	-2.11	-0.237	0.062
		Positive Order Imbalances		
10:00	-0.0150	-19.5	0.087	0.083
11:00	-0.0129	-17.19	0.138	0.062
12:00	-0.0110	-14.16	0.165	0.061
13:00	-0.0095	-11.81	0.183	0.061
14:00	-0.0083	-10.25	0.199	0.065
15:00	-0.0068	-7.27	0.212	0.061
16:00	-0.0041	-3.43	0.229	0.077
16:15	-0.0042	-2.99	0.234	0.064

Panel F. SPX Straddle, 2011-2018

time	$R^{straddle}$	t-stat
	All	
10:00	-0.0095	-16.66
11:00	-0.0083	-15.12
12:00	-0.0071	-13.38
13:00	-0.0061	-11.22
14:00	-0.0053	-9.65
15:00	-0.0041	-6.8
16:00	-0.0022	-2.9
16:15	-0.0023	-2.85
	Negative Order Imbalances	
10:00	-0.0098	-15.71
11:00	-0.0087	-14.31
12:00	-0.0076	-12.69
13:00	-0.0068	-11.12
14:00	-0.0057	-9.24
15:00	-0.0046	-6.85
16:00	-0.0027	-3.31
16:15	-0.0027	-3.25
	Positive Order Imbalances	
10:00	-0.0107	-16.47
11:00	-0.0090	-14.72
12:00	-0.0076	-12.7
13:00	-0.0064	-10.5
14:00	-0.0054	-8.73
15:00	-0.0036	-5.3
16:00	-0.0015	-1.68
16:15	-0.0015	-1.58

Table 4. Day and Night Returns, Equity Options

The table presents day and night ATM straddle returns for equity call and put options of S&P500 components for 2005 to 2010, and 2011 – 2018 subperiods. *All* refers to all positive volume days. *Negative* (*Positive*) Inventory is identified on a class/firm level on day *t* as the bottom 20% (top 20%) of option market makers inventory holdings. The *Night*, close-to-open, return is computed using day *t-1* close mid-point and day *t* opening mid-point. The other returns reported in each panel are *intra-day* cumulative returns. 11 am return is measured from 10 am to 11am., and 4pm return is the cumulative return from 10am to 16:00. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SP500 Equity Options, 2005-2010			Panel B. SP500 Equity Options, 2011-2018		
time	$R^{straddle}$	**t-stat**	**time**	$R^{straddle}$	**t-stat**
All			**All**		
Night	-0.0037	-71.66	*Night*	-0.0019	-41.52
11:00	0.0005	16.05	11:00	-0.0004	-13.19
12:00	0.0004	10.31	12:00	-0.0008	-21.96
13:00	0.0003	5.45	13:00	-0.0012	-29.34
14:00	0.0003	6.03	14:00	-0.0013	-29.28
15:00	0.0006	9.65	15:00	-0.0015	-29.4
16:00	0.0011	14.87	16:00	-0.0012	-21.26
Positive Inventory			**Positive Inventory**		
Night	-0.0037	-53.89	*Night*	-0.0014	-25.98
11:00	0.0002	4.9	11:00	-0.0004	-11.68
12:00	0.0000	-0.33	12:00	-0.0010	-21.34
13:00	-0.0003	-5.21	13:00	-0.0014	-27.79
14:00	-0.0003	-4.6	14:00	-0.0016	-28.95
15:00	-0.0002	-1.88	15:00	-0.0018	-29.58
16:00	0.0000	-0.22	16:00	-0.0018	-26.27
Negative Inventory			**Negative Inventory**		
Night	-0.0035	-42.34	*Night*	-0.0024	-28.42
11:00	0.0009	16.43	11:00	-0.0003	-6.38
12:00	0.0010	14.27	12:00	-0.0006	-8.65
13:00	0.0009	11.93	13:00	-0.0009	-11.62
14:00	0.0011	12.59	14:00	-0.0009	-10.36
15:00	0.0015	15.17	15:00	-0.0009	-10.01
16:00	0.0024	20.01	16:00	-0.0002	-2.04

Table 5. Day and Night Returns of SPX Options

The table presents day and night ATM straddle returns for SPX options for 2005 to 2010, and 2011 – 2018 subperiods. *All* refers to all positive volume days. *Negative* (*Positive*) Inventory is identified on day *t* as the bottom 20% (top 20%) of options market makers inventory holdings. The *Night*, close-to-open, return is computed using day *t-1* close mid-point and day *t* opening mid-point. The other returns reported in each panel are *intra-day* cumulative returns. 11 am return is measured from 10 am to 11am., and 4:15pm return is the cumulative returns from 10am to 16:15. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SPX Options, 2005-2010

time	$R^{straddle}$	t-stat
All		
Night	-0.0049	-12.43
11:00	-0.0002	-0.65
12:00	-0.0003	-0.73
13:00	-0.0002	-0.56
14:00	0.0000	0.06
15:00	0.0012	1.87
16:00	0.0027	3.35
16:15	0.0025	3.04
Positive Inventory		
Night	-0.0043	-7.81
11:00	-0.0002	-0.57
12:00	0.0001	0.18
13:00	0.0003	0.48
14:00	0.0006	0.98
15:00	0.0020	2.43
16:00	0.0034	3.33
16:15	0.0032	2.92
Negative Inventory		
Night	-0.0061	-11.02
11:00	0.0003	0.77
12:00	0.0001	0.17
13:00	-0.0004	-0.75
14:00	-0.0003	-0.48
15:00	0.0011	1.29
16:00	0.0027	2.61
16:15	0.0024	2.28

Panel B. SPX Options, 2011-2018

time	$R^{straddle}$	t-stat
All		
Night	-0.0033	-7.98
11:00	-0.0003	-0.82
12:00	-0.0004	-0.83
13:00	-0.0001	-0.25
14:00	0.0006	1.34
15:00	0.0010	1.75
16:00	0.0013	1.54
16:15	0.0006	0.7
Positive Inventory		
Night	-0.0030	-5.73
11:00	-0.0001	-0.18
12:00	0.0000	0.02
13:00	0.0002	0.44
14:00	0.0011	1.89
15:00	0.0012	1.79
16:00	0.0015	1.56
16:15	0.0008	0.89
Negative Inventory		
Night	-0.0030	-6.83
11:00	0.0002	0.78
12:00	0.0000	0.03
13:00	0.0002	0.56
14:00	0.0009	2
15:00	0.0012	2.08
16:00	0.0015	2.11
16:15	0.0009	1.17

Table 6. Day and Night Returns of Equity Options, before and after introduction of SPX night trading

The table presents day and night ATM straddle returns for equity call and put options of S&P500 components for 2005 to 2010, and 2011 – 2018 subperiods. *All* refers to all positive volume days. *Negative* (*Positive*) Inventory is identified on a class/firm level on day *t* as the bottom 20% (top 20%) of option market makers inventory holdings. The *Night*, close-to-open, return is computed using day *t-1* close mid-point and day *t* opening mid-point. The other returns reported in each panel are *intra-day* cumulative returns. 11 am return is measured from 10 am to 11am., and 4pm return is the cumulative return from 10am to 16:00. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SP500 Equity Options, 2011-2014

time	$R^{straddle}$	t-stat
	All	
Night	-0.0032	-53.46
11:00	-0.0001	-3.49
12:00	-0.0004	-9.12
13:00	-0.0009	-16.39
14:00	-0.0010	-17.04
15:00	-0.0010	-14.93
16:00	-0.0007	-10.02
	Positive Inventory	
Night	-0.0029	-39.19
11:00	-0.0003	-6.66
12:00	-0.0008	-12.77
13:00	-0.0012	-18.01
14:00	-0.0014	-19.66
15:00	-0.0014	-17.95
16:00	-0.0015	-16.62
	Negative Inventory	
Night	-0.0032	-31.35
11:00	0.0001	1.43
12:00	-0.0001	-0.72
13:00	-0.0004	-4.75
14:00	-0.0004	-3.98
15:00	-0.0003	-2.64
16:00	0.0003	2.45

Panel B. SP500 Equity Options, 2015-2018

time	$R^{straddle}$	t-stat
	All	
Night	-0.0007	-9.9
11:00	-0.0007	-14.06
12:00	-0.0012	-20.98
13:00	-0.0015	-24.56
14:00	-0.0016	-23.92
15:00	-0.0019	-25.87
16:00	-0.0016	-19.39
	Positive Inventory	
Night	-0.0003	-3.33
11:00	-0.0005	-9.63
12:00	-0.0011	-17.16
13:00	-0.0016	-21.3
14:00	-0.0018	-21.52
15:00	-0.0021	-23.59
16:00	-0.0020	-20.45
	Negative Inventory	
Night	-0.0013	-9.74
11:00	-0.0009	-9.96
12:00	-0.0012	-11.32
13:00	-0.0014	-11.6
14:00	-0.0014	-10.75
15:00	-0.0017	-11.57
16:00	-0.0009	-5.48

Table 7. Day and Night Returns of Equity Options, before and after introduction of SPX night trading: No Weekends

The table presents day and night ATM straddle returns for equity call and put options of S&P500 components for 2005 to 2010, and 2011 – 2018 subperiods. *All* refers to all positive volume days. *Negative* (*Positive*) Inventory is identified on a class/firm level on day *t* as the bottom 20% (top 20%) of option market makers inventory holdings. The *Night*, close-to-open, return is computed using day *t-1* close mid-point and day *t* opening mid-point. The other returns reported in each panel are *intra-day* cumulative returns. 11 am return is measured from 10 am to 11am., and 4pm return is the cumulative return from 10am to 16:00. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SP500 Equity Options, 2011-2014

time	$R^{straddle}$	t-stat
All		
Night	-0.0026	-28.05
11:00	0.0002	2.86
12:00	0.0000	0.21
13:00	-0.0003	-3.84
14:00	-0.0003	-2.92
15:00	0.0000	-0.31
16:00	0.0001	0.6
Positive Inventory		
Night	-0.0023	-19.92
11:00	0.0001	1.39
12:00	-0.0001	-1.5
13:00	-0.0005	-4.88
14:00	-0.0005	-4.76
15:00	-0.0003	-2.61
16:00	-0.0004	-2.84
Negative Inventory		
Night	-0.0028	-17.62
11:00	0.0002	2.25
12:00	0.0003	1.95
13:00	0.0000	-0.13
14:00	0.0002	1.08
15:00	0.0004	2.22
16:00	0.0008	4.04

Panel B. SP500 Equity Options, 2015-2018

time	$R^{straddle}$	t-stat
All		
Night	0.0003	2.95
11:00	-0.0002	-2.33
12:00	-0.0006	-6.87
13:00	-0.0008	-8.08
14:00	-0.0009	-8.49
15:00	-0.0013	-11.53
16:00	-0.0010	-7.96
Positive Inventory		
Night	0.0008	6.15
11:00	-0.0001	-1.23
12:00	-0.0006	-5.92
13:00	-0.0009	-7.96
14:00	-0.0010	-7.91
15:00	-0.0014	-10.36
16:00	-0.0013	-8.51
Negative Inventory		
Night	-0.0006	-2.71
11:00	-0.0003	-2.38
12:00	-0.0005	-3.07
13:00	-0.0004	-2.14
14:00	-0.0005	-2.52
15:00	-0.0010	-4.06
16:00	-0.0002	-0.88

Table 8. Day and Night Returns of SPX Options, before and after introduction of SPX night trading

The table presents day and night ATM straddle returns for SPX options for 2005 to 2010, and 2011 – 2018 subperiods. *All* refers to all positive volume days. *Negative* (*Positive*) Inventory is identified on day *t* as the bottom 20% (top 20%) of options market makers inventory holdings. The *Night*, close-to-open, return is computed using day *t-1* close mid-point and day *t* opening mid-point. The other returns reported in each panel are *intra-day* cumulative returns. 11 am return is measured from 10 am to 11am., and 4:15pm return is the cumulative returns from 10am to 16:15. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SPX Options, 2011-2014

time	$R^{straddle}$	t-stat
All		
Night	-0.0042	-9.29
11:00	0.0008	2.17
12:00	0.0008	1.48
13:00	0.0007	1.33
14:00	0.0012	2.02
15:00	0.0020	2.55
16:00	0.0028	2.56
16:15	0.0022	2.03
Positive Inventory		
Night	-0.0036	-4.96
11:00	0.0007	1.28
12:00	0.0010	1.42
13:00	0.0007	0.97
14:00	0.0016	2.05
15:00	0.0025	2.78
16:00	0.0034	2.88
16:15	0.0027	2.41
Negative Inventory		
Night	-0.0039	-7.15
11:00	0.0009	2.36
12:00	0.0006	0.88
13:00	0.0003	0.66
14:00	0.0009	1.5
15:00	0.0014	1.83
16:00	0.0022	2.31
16:15	0.0017	1.76

Panel B. SPX Options, 2015-2018

time	$R^{straddle}$	t-stat
All		
Night	-0.0020	-2.68
11:00	-0.0019	-4.44
12:00	-0.0022	-3.78
13:00	-0.0013	-1.87
14:00	-0.0003	-0.48
15:00	-0.0005	-0.78
16:00	-0.0010	-0.91
16:15	-0.0019	-1.84
Positive Inventory		
Night	-0.0022	-2.99
11:00	-0.0012	-2.72
12:00	-0.0015	-2.43
13:00	-0.0005	-0.58
14:00	0.0004	0.43
15:00	-0.0007	-0.76
16:00	-0.0014	-1
16:15	-0.0020	-1.44
Negative Inventory		
Night	-0.0017	-2.57
11:00	-0.0007	-1.77
12:00	-0.0008	-1.18
13:00	0.0001	0.15
14:00	0.0011	1.32
15:00	0.0008	1.02
16:00	0.0005	0.45
16:15	-0.0004	-0.32

Table 9. Day and Night Returns of SPX Options, before and after introduction of SPX night trading: No Weekends

The table presents day and night ATM straddle returns for SPX options for 2005 to 2010, and 2011 – 2018 subperiods. *All* refers to all positive volume days. *Negative* (*Positive*) Inventory is identified on day *t* as the bottom 20% (top 20%) of options market makers inventory holdings. The *Night*, close-to-open, return is computed using day *t-1* close mid-point and day *t* opening mid-point. The other returns reported in each panel are *intra-day* cumulative returns. 11 am return is measured from 10 am to 11am., and 4:15pm return is the cumulative returns from 10am to 16:15. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SPX Options, 2011-2014

time	$R^{straddle}$	t-stat
All		
Night	-0.0037	-5.54
11:00	0.0011	2.09
12:00	0.0012	1.35
13:00	0.0011	1.53
14:00	0.0020	2.63
15:00	0.0033	3.7
16:00	0.0045	3.23
16:15	0.0035	2.52
Positive Inventory		
Night	-0.0030	-2.64
11:00	0.0012	1.9
12:00	0.0014	1.52
13:00	0.0015	1.42
14:00	0.0026	2.59
15:00	0.0043	3.43
16:00	0.0055	3.29
16:15	0.0048	3.15
Negative Inventory		
Night	-0.0043	-5.66
11:00	0.0011	1.61
12:00	0.0009	0.79
13:00	0.0010	0.97
14:00	0.0016	1.62
15:00	0.0029	2.83
16:00	0.0045	3.06
16:15	0.0035	2.41

Panel B. SPX Options, 2015-2018

time	$R^{straddle}$	t-stat
All		
Night	-0.0026	-2.65
11:00	-0.0009	-1.64
12:00	-0.0007	-0.93
13:00	0.0011	1.05
14:00	0.0023	2.08
15:00	0.0013	1.25
16:00	0.0016	0.95
16:15	0.0001	0.09
Positive Inventory		
Night	-0.0024	-1.76
11:00	-0.0001	-0.11
12:00	0.0000	-0.01
13:00	0.0015	1.18
14:00	0.0026	1.84
15:00	0.0004	0.31
16:00	0.0007	0.33
16:15	-0.0009	-0.47
Negative Inventory		
Night	-0.0013	-1.12
11:00	0.0003	0.39
12:00	0.0004	0.47
13:00	0.0019	1.59
14:00	0.0033	2.5
15:00	0.0024	1.9
16:00	0.0028	1.36
16:15	0.0011	0.63

Table 10. Weekend Effect in Option Returns, Equity Options

The table presents average portfolio delta hedged daily returns using different hour of a day mid-quotes for call and put options of S&P500 components for 2005 to 2010, and 2011 – 2018 subperiods. Nontrading period is defined as weekends, from Friday close to Monday close, and Monday is the end of nontrading period. Trading periods are all other weekdays, Tuesday to Friday. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Call Options, SP500 firms, 2005 - 2010

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0168	-0.0128	-0.0040	-0.0168	-0.0138	-0.0164	-0.0098	-0.0117
	-45.89	-74.19	-9.95	-45.72	-38.46	-46.22	-35.38	-36.46
11:00	-0.0150	-0.0087	-0.0063	-0.0149	-0.0097	-0.0119	-0.0049	-0.0091
	-42.87	-56.15	-16.42	-41.09	-29.12	-41.14	-18.32	-29.67
12:00	-0.0132	-0.0062	-0.0071	-0.0132	-0.0078	-0.0085	-0.0020	-0.0071
	-40.86	-39.82	-19.73	-40.70	-23.56	-28.01	-7.87	-24.54
13:00	-0.0124	-0.0048	-0.0076	-0.0122	-0.0069	-0.0061	0.0004	-0.0079
	-39.58	-28.51	-21.52	-35.58	-20.87	-20.84	1.29	-23.87
14:00	-0.0118	-0.0031	-0.0087	-0.0116	-0.0064	-0.0041	0.0006	-0.0039
	-37.23	-19.24	-24.43	-35.87	-18.75	-13.60	2.24	-13.70
15:00	-0.0106	-0.0014	-0.0092	-0.0105	-0.0046	-0.0013	0.0035	-0.0044
	-30.23	-8.44	-23.98	-29.87	-12.57	-4.24	12.37	-15.93
16:00	-0.0084	0.0011	-0.0095	-0.0082	-0.0017	0.0020	0.0050	-0.0025
	-24.05	6.4	-24.39	-23.17	-4.30	6.54	16.92	-8.00

Panel B. Call Options, SP500 firms, 2011 - 2018

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0150	-0.0129	-0.0021	-0.0150	-0.0152	-0.0121	-0.0114	-0.0126
	-39.22	-77.58	-4.92	-39.44	-51.52	-42.34	-37.54	-31.71
11:00	-0.0124	-0.0088	-0.0035	-0.0123	-0.0109	-0.0076	-0.0077	-0.0094
	-35.13	-57.47	-9.2	-35.11	-39.00	-29.54	-25.98	-26.30
12:00	-0.0115	-0.0058	-0.0057	-0.0115	-0.0080	-0.0046	-0.0046	-0.0068
	-36.11	-35.44	-15.99	-35.99	-27.57	-17.92	-15.87	-18.80
13:00	-0.0113	-0.0039	-0.0074	-0.0113	-0.0057	-0.0027	-0.0032	-0.0043
	-35.04	-22.84	-20.31	-33.12	-20.04	-10.38	-11.29	-11.77
14:00	-0.0105	-0.0023	-0.0082	-0.0104	-0.0040	-0.0008	-0.0011	-0.0044
	-33.02	-16.1	-23.35	-32.74	-14.16	-2.89	-3.60	-15.26
15:00	-0.0097	-0.0003	-0.0094	-0.0096	-0.0028	0.0004	0.0027	-0.0026
	-30.16	-1.94	-26.26	-29.31	-10.10	1.60	9.45	-6.87
16:00	-0.0077	0.0015	-0.0092	-0.0076	-0.0011	0.0033	0.0039	-0.0016
	-26.05	9.8	-27.63	-25.50	-4.02	12.21	13.42	-4.22

Panel C. Put Options, SP500 firms, 2005 - 2010

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0173	-0.0159	-0.0015	-0.0171	-0.0178	-0.0176	-0.0126	-0.0164
	-29.79	-70.06	-2.36	-29.27	-33.23	-50.31	-39.36	-31.81
11:00	-0.0150	-0.0108	-0.0043	-0.0149	-0.0128	-0.0123	-0.0075	-0.0120
	-27.86	-49.56	-7.31	-27.50	-24.75	-36.10	-25.34	-24.57
12:00	-0.0134	-0.0078	-0.0056	-0.0132	-0.0097	-0.0091	-0.0041	-0.0097
	-26.77	-36.54	-10.27	-26.09	-19.29	-26.06	-14.72	-19.82
13:00	-0.0127	-0.0059	-0.0068	-0.0125	-0.0083	-0.0073	-0.0015	-0.0079
	-26.01	-28.35	-12.74	-25.59	-17.37	-22.37	-4.95	-16.03
14:00	-0.0118	-0.0038	-0.0080	-0.0107	-0.0064	-0.0052	0.0001	-0.0062
	-24.93	-12.86	-14.37	-10.96	-13.30	-14.99	0.34	-13.96
15:00	-0.0105	-0.0014	-0.0090	-0.0094	-0.0043	-0.0024	0.0033	-0.0052
	-18.84	-4.87	-14.42	-9.51	-8.69	-6.86	10.51	-12.27
16:00	-0.0079	0.0003	-0.0082	-0.0076	-0.0020	0.0004	0.0055	-0.0045
	-14.52	1.29	-13.81	-13.78	-3.84	1.00	16.49	-8.77

Panel D. Put Options, SP500 firms, 2011 - 2018

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0184	-0.0162	-0.0023	-0.0183	-0.0181	-0.0167	-0.0149	-0.0155
	-47.20	-91.87	-5.31	-47.08	-70.92	-56.94	-39.38	-43.29
11:00	-0.0162	-0.0112	-0.0050	-0.0162	-0.0124	-0.0109	-0.0103	-0.0117
	-42.15	-70.36	-12.09	-42.34	-50.81	-40.42	-28.23	-34.91
12:00	-0.0150	-0.0081	-0.0069	-0.0150	-0.0095	-0.0076	-0.0067	-0.0091
	-40.79	-51.91	-17.24	-40.81	-39.27	-28.47	-18.45	-27.46
13:00	-0.0140	-0.0061	-0.0079	-0.0139	-0.0074	-0.0050	-0.0043	-0.0081
	-37.77	-38.76	-19.68	-37.78	-32.19	-18.11	-12.06	-24.26
14:00	-0.0132	-0.0041	-0.0091	-0.0131	-0.0049	-0.0032	-0.0026	-0.0068
	-31.62	-24.79	-20.31	-31.44	-19.98	-11.54	-7.09	-19.01
15:00	-0.0115	-0.0019	-0.0096	-0.0112	-0.0032	-0.0013	-0.0001	-0.0048
	-29.38	-11.09	-22.44	-28.61	-12.70	-4.72	-0.29	-14.01
16:00	-0.0103	0.0001	-0.0105	-0.0101	-0.0016	0.0014	0.0034	-0.0042
	-26.04	0.65	-23.97	-25.47	-6.33	4.78	8.57	-10.15

Table 11. Weekend Effect in Option Returns after Introduction of SPX Night Trading, Equity Options

The table presents average portfolio delta hedged daily returns using different hour of a day mid-quotes for call and put options of S&P500 components for 2015 – 2018 period. Nontrading period is defined as weekends, from Friday close to Monday close, and Monday is the end of nontrading period. Trading periods are all other weekdays, Tuesday to Friday. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Call Options, SP500 firms, 2015 - 2018

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0167	-0.0136	-0.0030	-0.0167	-0.0156	-0.0118	-0.0129	-0.0130
	-29.18	-52.02	-4.83	-29.45	-43.47	-29.37	-27.48	-19.16
11:00	-0.0152	-0.0090	-0.0062	-0.0151	-0.0093	-0.0087	-0.0088	-0.0087
	-31.69	-37.84	-11.64	-31.70	-26.31	-22.47	-19.03	-14.85
12:00	-0.0137	-0.0057	-0.0081	-0.0136	-0.0055	-0.0059	-0.0055	-0.0061
	-35.74	-23.84	-17.92	-34.50	-15.46	-14.70	-12.20	-10.47
13:00	-0.0136	-0.0034	-0.0102	-0.0136	-0.0032	-0.0036	-0.0041	-0.0028
	-34.18	-12.41	-21.03	-29.38	-8.86	-8.77	-9.25	-4.69
14:00	-0.0127	-0.0018	-0.0109	-0.0127	-0.0019	-0.0012	-0.0022	-0.0026
	-34.26	-8.85	-25.62	-33.36	-5.15	-2.91	-4.75	-8.39
15:00	-0.0112	0.0004	-0.0116	-0.0110	-0.0013	0.0006	0.0009	0.0004
	-28.25	1.72	-25.13	-27.01	-3.44	1.55	2.14	0.74
16:00	-0.0086	0.0020	-0.0106	-0.0085	0.0004	0.0031	0.0024	0.0009
	-26.5	8.76	-26.7	-25.79	1.15	7.28	5.46	1.58

Panel B. Put Options, SP500 firms, 2015 - 2018

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0184	-0.0158	-0.0026	-0.0182	-0.0173	-0.0153	-0.0167	-0.0148
	-37.43	-62.73	-4.71	-37.04	-49.64	-38.87	-31.56	-28.83
11:00	-0.0151	-0.0107	-0.0044	-0.0151	-0.0112	-0.0104	-0.0108	-0.0111
	-33	-49.23	-8.65	-33.30	-33.00	-28.01	-20.83	-23.00
12:00	-0.0142	-0.0073	-0.0069	-0.0141	-0.0083	-0.0067	-0.0075	-0.0074
	-31.94	-33.88	-14	-31.94	-25.26	-17.66	-14.29	-15.06
13:00	-0.0134	-0.0048	-0.0086	-0.0134	-0.0057	-0.0041	-0.0043	-0.0057
	-30.91	-22.42	-17.76	-30.92	-17.84	-10.63	-8.52	-11.72
14:00	-0.0126	-0.0028	-0.0099	-0.0124	-0.0025	-0.0022	-0.0036	-0.0041
	-22.22	-11.82	-16.05	-22.08	-7.57	-5.48	-6.95	-7.59
15:00	-0.0097	-0.0004	-0.0093	-0.0095	-0.0012	-0.0004	-0.0009	-0.0018
	-20.53	-1.77	-17.32	-19.58	-3.52	-0.86	-1.56	-3.48
16:00	-0.0092	0.0016	-0.0107	-0.0089	0.0005	0.0019	0.0027	-0.0009
	-19.14	5.76	-19.51	-18.44	1.48	4.65	4.66	-1.33

Table 12. Weekend Effect in Option Returns, SPX Options

The table presents average portfolio delta hedged daily returns using different hour of a day mid-quotes for SPX call and put options for 2005 to 2010, and 2011 – 2018 subperiods. Nontrading period is defined as weekends, from Friday close to Monday close, and Monday is the end of nontrading period. Trading periods are all other weekdays, Tuesday to Friday. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SPX Call Options, 2005 - 2010

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0162	-0.0161	0.0000	-0.0162	-0.0171	-0.0227	-0.0077	-0.0172
	-13.76	-27.55	-0.03	-13.76	-15.02	-20.23	-9.20	-16.07
11:00	-0.0193	-0.0119	-0.0073	-0.0193	-0.0125	-0.0186	-0.0040	-0.0130
	-15.02	-22.86	-5.29	-15.02	-12.86	-18.32	-4.98	-13.52
12:00	-0.0171	-0.0099	-0.0071	-0.0171	-0.0123	-0.0142	-0.0013	-0.0122
	-13.99	-21.67	-5.48	-13.99	-14.49	-14.69	-1.77	-14.58
13:00	-0.0174	-0.0086	-0.0088	-0.0174	-0.0106	-0.0127	0.0011	-0.0124
	-13.6	-18.8	-6.46	-13.60	-13.35	-14.58	1.15	-12.18
14:00	-0.0151	-0.0073	-0.0078	-0.0151	-0.0101	-0.0103	-0.0003	-0.0089
	-11.26	-16.8	-5.52	-11.26	-12.46	-13.36	-0.33	-9.82
15:00	-0.0137	-0.0046	-0.0091	-0.0137	-0.0073	-0.0073	0.0044	-0.0084
	-8.81	-11.25	-5.67	-8.81	-7.54	-10.57	4.83	-10.02
16:00	-0.0087	0.0007	-0.0094	-0.0087	-0.0030	0.0013	0.0072	-0.0027
	-4.77	1.52	-5.00	-4.77	-3.41	1.01	7.40	-3.03
16:15	-0.0027	-0.0002	-0.0025	-0.0027	-0.0096	0.0015	0.0078	-0.0011
	-1.13	-0.38	-1.00	-1.13	-5.70	1.07	7.46	-0.88

Panel B. SPX Call Options, 2011 - 2018

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0189	-0.0117	-0.0072	-0.0189	-0.0118	-0.0083	-0.0121	-0.0143
	-25.96	-43.73	-9.30	-25.97	-26.80	-15.02	-19.05	-25.87
11:00	-0.0150	-0.0096	-0.0054	-0.0150	-0.0084	-0.0067	-0.0085	-0.0146
	-24.68	-42.17	-8.28	-24.68	-21.86	-11.53	-15.63	-26.82
12:00	-0.0142	-0.0072	-0.0070	-0.0142	-0.0045	-0.0053	-0.0073	-0.0112
	-26.08	-35.89	-12.1	-26.08	-10.71	-8.88	-14.72	-21.76
13:00	-0.0146	-0.0050	-0.0096	-0.0145	-0.0017	-0.0050	-0.0031	-0.0097
	-26.64	-28.58	-16.7	-26.64	-4.43	-8.09	-5.86	-20.13
14:00	-0.0157	-0.0030	-0.0127	-0.0157	0.0012	-0.0036	-0.0012	-0.0078
	-25.01	-19.22	-19.67	-25.01	2.71	-5.75	-2.37	-15.18
15:00	-0.0136	-0.0008	-0.0129	-0.0136	0.0011	-0.0029	0.0047	-0.0057
	-20.25	-4.84	-18.64	-20.25	2.56	-5.78	7.95	-11.82
16:00	-0.0065	0.0009	-0.0074	-0.0065	0.0026	0.0030	0.0066	-0.0080
	-8.42	4.90	-9.36	-8.42	6.28	4.58	8.42	-14.01
16:15	-0.0088	0.0008	-0.0096	-0.0088	0.0048	-0.0013	0.0091	-0.0086
	-11.54	4.06	-12.20	-11.54	8.07	-2.13	11.26	-13.65

Panel C. SPX Put Options, 2005 - 2010

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0134	-0.0142	0.0007	-0.0134	-0.0201	-0.0183	-0.0062	-0.0121
	-15.86	-31.66	0.77	-15.86	-19.29	-20.59	-9.92	-15.00
11:00	-0.0155	-0.0108	-0.0047	-0.0155	-0.0164	-0.0147	-0.0032	-0.0091
	-16.45	-27.12	-4.63	-16.45	-17.54	-16.95	-5.03	-12.25
12:00	-0.0162	-0.0081	-0.0080	-0.0162	-0.0136	-0.0118	-0.0003	-0.0070
	-17.5	-22.56	-8.1	-17.50	-17.92	-15.80	-0.55	-10.81
13:00	-0.0168	-0.0069	-0.0098	-0.0168	-0.0124	-0.0113	0.0035	-0.0077
	-16.85	-19.28	-9.29	-16.85	-16.37	-16.47	4.56	-10.12
14:00	-0.0165	-0.0050	-0.0115	-0.0165	-0.0109	-0.0069	0.0006	-0.0032
	-14.31	-14.18	-9.54	-14.31	-16.43	-9.85	0.84	-4.42
15:00	-0.0150	-0.0021	-0.0128	-0.0150	-0.0078	-0.0034	0.0056	-0.0030
	-10.84	-6.26	-9.02	-10.84	-9.82	-5.28	6.92	-4.55
16:00	-0.0112	0.0040	-0.0152	-0.0112	-0.0021	0.0060	0.0092	0.0028
	-8.33	8.55	-10.69	-8.33	-2.89	4.87	12.20	3.83
16:15	-0.0159	0.0063	-0.0222	-0.0159	0.0021	0.0042	0.0083	0.0101
	-10.91	10.89	-14.15	-10.91	2.04	3.43	10.31	7.55

Panel D. SPX Put Options, 2011 - 2018

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0201	-0.0175	-0.0026	-0.0201	-0.0190	-0.0193	-0.0144	-0.0172
	-27.44	-57.25	-3.31	-27.44	-30.43	-30.13	-21.68	-32.90
11:00	-0.0189	-0.0145	-0.0045	-0.0189	-0.0146	-0.0165	-0.0111	-0.0156
	-31.18	-56.34	-6.74	-31.18	-30.31	-24.11	-18.56	-32.29
12:00	-0.0191	-0.0118	-0.0073	-0.0191	-0.0108	-0.0156	-0.0080	-0.0128
	-33.96	-50.35	-11.97	-33.96	-22.67	-23.05	-12.89	-26.43
13:00	-0.0201	-0.0094	-0.0107	-0.0201	-0.0084	-0.0140	-0.0043	-0.0108
	-30.71	-46.93	-15.66	-30.71	-19.91	-21.63	-7.89	-22.11
14:00	-0.0193	-0.0073	-0.0120	-0.0193	-0.0059	-0.0132	-0.0014	-0.0086
	-27.09	-39.44	-16.31	-27.09	-13.93	-20.35	-2.26	-17.46
15:00	-0.0173	-0.0044	-0.0129	-0.0173	-0.0068	-0.0104	0.0040	-0.0045
	-24.11	-25.74	-17.44	-24.11	-15.77	-19.37	5.99	-9.89
16:00	-0.0104	-0.0008	-0.0096	-0.0104	-0.0049	-0.0020	0.0096	-0.0057
	-11.47	-3.71	-10.34	-11.47	-11.79	-3.15	11.28	-10.64
16:15	-0.0014	-0.0050	0.0036	-0.0014	-0.0163	0.0073	-0.0009	-0.0098
	-1.14	-23.14	2.86	-1.13	-21.95	9.80	-1.23	-14.85

Table 13. Week-end Effect in Option Returns, SPX Options after Introduction of SPX night trading

The table presents average portfolio delta hedged daily returns using different hour of a day mid-quotes for SPX call and put options for 2005 to 2010, and 2011 – 2018 subperiods. Nontrading period is defined as weekends, from Friday close to Monday close, and Monday is the end of nontrading period. Trading periods are all other weekdays, Tuesday to Friday. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SPX Call Options, 2015 - 2018

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0228	-0.0132	-0.0096	-0.0228	-0.0130	-0.0117	-0.0152	-0.0130
	-21.35	-36.19	-8.49	-21.35	-21.98	-15.88	-17.73	-18.00
11:00	-0.0194	-0.0108	-0.0085	-0.0194	-0.0084	-0.0113	-0.0093	-0.0141
	-22.08	-31.44	-9.05	-22.08	-18.77	-12.94	-14.36	-19.74
12:00	-0.0180	-0.0078	-0.0103	-0.0180	-0.0025	-0.0099	-0.0081	-0.0103
	-22.3	-22	-11.63	-22.30	-5.34	-10.65	-12.96	-14.44
13:00	-0.0183	-0.0051	-0.0132	-0.0183	0.0002	-0.0095	-0.0017	-0.0091
	-22.22	-14.01	-14.63	-22.22	0.33	-9.82	-2.64	-13.13
14:00	-0.0204	-0.0026	-0.0178	-0.0204	0.0032	-0.0071	-0.0008	-0.0055
	-21.28	-7.04	-17.29	-21.28	5.07	-7.05	-1.36	-7.58
15:00	-0.0162	-0.0002	-0.0159	-0.0162	0.0022	-0.0052	0.0038	-0.0017
	-15.39	-0.7	-14.49	-15.39	3.67	-7.32	6.26	-2.53
16:00	-0.0090	0.0012	-0.0102	-0.0090	0.0036	0.0016	0.0065	-0.0063
	-7.03	3.01	-7.61	-7.03	6.95	1.76	6.84	-7.63
16:15	-0.0134	0.0007	-0.0140	-0.0134	0.0060	-0.0053	0.0079	-0.0056
	-12.71	1.56	-12.38	-12.71	7.76	-6.53	9.14	-6.66

Panel B. SPX Put Options, 2015 - 2018

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00	-0.0234	-0.0195	-0.0038	-0.0234	-0.0215	-0.0223	-0.0182	-0.0162
	-23.65	-56.47	-3.66	-23.65	-27.92	-31.43	-27.40	-27.40
11:00	-0.0228	-0.0162	-0.0066	-0.0228	-0.0142	-0.0239	-0.0120	-0.0146
	-31.17	-44.07	-8.03	-31.17	-24.22	-24.51	-19.40	-22.75
12:00	-0.0233	-0.0131	-0.0102	-0.0233	-0.0086	-0.0220	-0.0111	-0.0105
	-32.5	-36.47	-12.72	-32.50	-15.49	-23.02	-18.19	-17.25
13:00	-0.0252	-0.0096	-0.0156	-0.0252	-0.0065	-0.0199	-0.0034	-0.0084
	-32.19	-26.31	-18.01	-32.19	-11.98	-21.19	-5.45	-12.42
14:00	-0.0246	-0.0069	-0.0176	-0.0246	-0.0038	-0.0171	-0.0024	-0.0041
	-28.32	-19.38	-18.82	-28.32	-7.60	-17.99	-4.57	-6.16
15:00	-0.0181	-0.0041	-0.0140	-0.0181	-0.0091	-0.0124	0.0040	0.0013
	-17.54	-12.51	-12.95	-17.54	-15.85	-18.33	6.34	2.09
16:00	-0.0100	-0.0005	-0.0095	-0.0100	-0.0057	-0.0038	0.0114	-0.0036
	-6.88	-1.16	-6.32	-6.88	-11.66	-4.55	11.71	-4.54
16:15	0.0021	-0.0068	0.0089	0.0021	-0.0237	0.0096	-0.0009	-0.0117
	1.12	-13.04	4.5	1.12	-20.63	10.13	-1.18	-11.76

Table 14. Equity Option Returns before and after introduction of SPX night trading, No Weekends

The table presents average delta hedged and straddle daily returns using different hour of a day mid-quotes for call and put options of S&P500 components for 2011 to 2014, and 2015 – 2018 subperiods. R^O is a delta-hedged option return on day t. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Call Options, 2015-2018

time	R^O	t-stat
10:00	-0.0133	-54.36
11:00	-0.0089	-39.37
12:00	-0.0058	-25.75
13:00	-0.0034	-15.05
14:00	-0.0020	-10.49
15:00	0.0002	0.8
16:00	0.0017	7.71

Panel B. Put Options, 2015-2018

time	R^O	t-stat
10:00	-0.0160	-72.01
11:00	-0.0109	-51.4
12:00	-0.0074	-35.07
13:00	-0.0050	-23.55
14:00	-0.0031	-14.04
15:00	-0.0011	-4.63
16:00	0.0011	4.22

Panel C. Straddle, 2015-2018

time	$R^{straddle}$	t-stat
10:00	-0.0116	-82.65
11:00	-0.0084	-61.82
12:00	-0.0063	-45.93
13:00	-0.0046	-33.36
14:00	-0.0036	-25.23
15:00	-0.0022	-14.8
16:00	-0.0009	-5.97

Panel D. Call Options, 2011-2014

time	R^O	t-stat
10:00	-0.0123	-61.67
11:00	-0.0089	-47.29
12:00	-0.0063	-32.68
13:00	-0.0046	-24.63
14:00	-0.0032	-16.14
15:00	-0.0014	-6.98
16:00	0.0006	2.86

Panel E. Put Options, 2011-2014

time	R^O	t-stat
10:00	-0.0166	-72.77
11:00	-0.0118	-55.01
12:00	-0.0091	-43.52
13:00	-0.0076	-36.69
14:00	-0.0058	-27.23
15:00	-0.0038	-18.72
16:00	-0.0017	-8.14

Panel D. Straddle, 2011-2014

time	$R^{straddle}$	t-stat
10:00	-0.0123	-90.1
11:00	-0.0094	-72.26
12:00	-0.0075	-57.25
13:00	-0.0063	-48.87
14:00	-0.0052	-39.73
15:00	-0.0038	-28.36
16:00	-0.0024	-17.24

Table 15. SPX Option Returns before and after introduction of SPX night trading, No Weekends

The table presents average delta hedged and straddle daily returns using different hour of a day mid-quotes for SPX call and put options for 2011 to 2014, and 2015 – 2018 subperiods. R^O is a delta-hedged option return on day t. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Call Options, 2015-2018

time	R^O	t-stat
10:00	-0.0151	-9.84
11:00	-0.0127	-9.3
12:00	-0.0095	-6.73
13:00	-0.0064	-4.43
14:00	-0.0040	-2.83
15:00	-0.0013	-0.89
16:00	0.0007	0.43
16:15	0.0019	0.91

Panel B. Put Options, 2015-2018

time	R^O	t-stat
10:00	-0.0161	-12.82
11:00	-0.0128	-9.93
12:00	-0.0097	-6.2
13:00	-0.0072	-4.06
14:00	-0.0048	-2.79
15:00	-0.0026	-1.45
16:00	-0.0003	-0.16
16:15	-0.0021	-0.97

Panel C. Straddle, 2015-2018

time	$R^{straddle}$	t-stat
10:00	-0.0116	-11.28
11:00	-0.0094	-9.79
12:00	-0.0071	-6.6
13:00	-0.0052	-4.4
14:00	-0.0037	-3.12
15:00	-0.0020	-1.59
16:00	-0.0001	-0.1
16:15	-0.0009	-0.64

Panel D. Call Options, 2011-2014

time	R^O	t-stat
10:00	-0.0130	-10.22
11:00	-0.0107	-9.09
12:00	-0.0081	-6.27
13:00	-0.0064	-5.3
14:00	-0.0045	-3.77
15:00	-0.0024	-2.09
16:00	0.0000	0
16:15	0.0001	0.07

Panel E. Put Options, 2011-2014

time	R^O	t-stat
10:00	-0.0143	-11.25
11:00	-0.0120	-10.45
12:00	-0.0099	-8.02
13:00	-0.0087	-7.74
14:00	-0.0069	-6.07
15:00	-0.0046	-3.85
16:00	-0.0017	-1.07
16:15	-0.0026	-1.78

Panel D. Straddle, 2011-2014

time	$R^{straddle}$	t-stat
10:00	-0.0085	-9.16
11:00	-0.0070	-8.22
12:00	-0.0058	-6.17
13:00	-0.0047	-5.29
14:00	-0.0038	-4.25
15:00	-0.0023	-2.45
16:00	-0.0007	-0.52
16:15	-0.0011	-0.92