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Price Pressures and 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 always higher compared to those based on any other price of the day. The difference between these returns can reach more than 100 bps per day. Price pressures and the volatility exposure of options market makers' overnight inventory explain the results. We use an introduction of SPX night trading as a resolution of overnight uncertainty about volatility and are able to differentiate price pressure hypothesis from all other mispricing based explanations. Computing returns using first half of the day prices, where most of price discovery takes place, helps explain several anomalies in the literature 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 (EOD) closing prices as a proxy for true values.

We document that the time of the day is important while measuring option returns. 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 are robust across two time periods, 2005 to 2010, and 2011 to 2018, and are established on the cross section of equity options on S&P500 components, as well as on the level of SPX options, and thus avoid illiquidity concerns. We also find that the majority, between 75% to 85%, of net-order imbalance shocks take place earlier in a day before 12pm. As the highest trading intensity is associated with the highest price discovery, our results cast doubt on how indicative EOD prices are.

What can potentially explain these results? We hypothesise that price pressures from option end-users can have an impact on EOD prices. End-users in the individual equity options market are net sellers, and net buyers in the index options (Garleanu, Pedersen, and Poteshman (2009)). Bollen and Whaley (2004) and Garleanu et al. (2009) show that the direction of demand pressures has substantial impact on option prices. Relatedly, in the stock market, 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.

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

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[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)

end users, and asynchronous arrival rates of offsetting trades should create even stronger pressures on options market makers' inventories and cause higher distortion of EOD prices. Overwhelming literature (Jameson and Wilhelm (1992), Green and Figlewski (1999), and Battalio and Schultz (2011)) argues that inventory costs and risks are much more serious for option market makers (OMMs) than for liquidity providers in the stock market, due to hedging needs, model risk, and uncertain holding periods.

The effect of price pressures on the end of day prices should be amplified by OMMs overnight inventory exposure. While OMMs delta hedge their inventories by the end of the day, the risks associated with overnight stochastic volatility or price jumps are more difficult to hedge. Therefore, the uncertainty about overnight price volatility and OMMs overnight inventory vega exposure can contribute to EOD price deviations further from the fundamental values. This are in fact the predictions of 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).

There are of course alternative explanations of what EOD option prices can capture. The most closely related to our work is Muravyev and Ni (2020) who report significant asymmetries between options night (close-to-open) and day (open-to-close) returns. The day returns are positive while the night returns are extremely negative. The authors explain the negativity of night returns by volatility seasonality of the underlying stocks. In particular, they argue that option markets fail to realize that the night volatility is lower than the intra-day volatility and continue pricing the night volatility as high as the day volatility. Therefore, the lower night volatility of the underlying compared to the day volatility, the more negative night returns are.

Jones and Shemesh (2018) analyze longer non-trading period option returns seasonality such as weekends and holidays and find similar results. Non-traded period returns, majority of which are weekends, are extremely negative, while week-day returns are close to zero. The authors provide a slightly different explanation. The more negative weekend returns are attributed to option markets mispricing stock price variance time decay, or options theta, in the beginning of non-trading periods.

Both papers provide mispricing explanation for EOD prices at the start of non-trading periods to explain the negative non-trading period returns. Both are related to stock price volatility mispricing. The price pressures hypothesis we introduce in this paper relies on volatility risk of OMMs inventories over non-traded periods. Thus, overnight or non-trading period uncertainty about volatility is more relevant for our theory. Differentiating between overnight volatility uncertainty or mispricing hypotheses would not be possible without an exogenous event which could potentially help to resolve overnight uncertainty.

We argue that the introduction of SPX options night trading from 3am to 9:15am (ET) by CBOE on March 09, 2015 can help overnight uncertainty resolution about market volatility. There are important reasons to expect it. First, the recent literature (Bondarenko and Muravyev (2020), Boyarchenko, Larsen and Whelan (2020)) finds that majority of the US equity premium is earned over a window around the opening hours of European markets, which is between 2am and 3am (ET). Thus, the market wide price discovery takes place in the night hours in the US. Second, Bondarenko and Muravyev (2020) argue that the resolution of price uncertainty during EU-open hours contributes to price run ups in S&P E-mini futures. Importantly, the authors show that VIX future returns are positive through the Asian session, which indicates high uncertainty. This positive VIX trend stops and VIX returns start to decline before Europe opens. Subsequently, VIX returns during EU-open are highly negative which is consistent with uncertainty resolution hypothesis. Arguably, the latter should have applications for the overnight volatility uncertainty resolution on the level of OMMs inventories. This event, however, should not have applications for mispricing based explanations in EOD prices.

We test these hypotheses in several ways. First, we compare unconditionally day and night returns before and after introduction of SPX night trading for equity and SPX index options in the simple event study. The resolutions of uncertainty should reduce overnight volatility risk premium and decrease the absolute magnitudes of negative night returns. In contrast, it should have no implications for the night returns if mispricing is the main story. Supporting the resolution of uncertainty theory, the highly negative and significant night returns virtually disappear both in economic magnitudes and statistical significance right after the introduction of SPX night trading.

Consistent with volatility pricing in the options, the day returns become more negative and significant.

Second, we compare the day and night returns conditioning on OMMs overnight inventory volatility exposures, inventory vega, before and after the event. On average, OMMs hold positive inventory vega exposure in individual equity options, and negative in SPX options. This is consistent with previously reported stylized facts that end users are net sellers in the equity options and net buyers in the index, SPX, options (Garleanu et al 2009). We find that for the stock-options where OMMs accumulate excess *negative* inventory, extreme low tercile portfolios, in the sample before SPX night trading, the day returns are positive and the night returns are highly negative as in Muravyev and Ni (2020) (MN). However, in the sample after the introduction of SPX night trading, for the stock options with excess *negative* inventory, the day return is negative, but insignificant, and the night return is negative, but three times lower in absolute value compared to the pre-event sample. While this result is still qualitatively consistent with MN (2020), the difference between night and day returns is no longer significant.

Conversely, for the stock-options where OMMs accumulate excess *positive* inventory, extreme high tercile portfolios, in the sample before SPX night trading, the day return is negative and significant, and the night return is even more negative and significant. The negative day return and even more negative night return pattern is more consistent with investors requiring higher premium for the overnight uncertainty about volatility rather than volatility mispricing for this cross-section. For the period after the introduction of SPX night trading, for the stock-options where OMMs accumulate excess *positive* inventory, the night return becomes economically and statistically indistinguishable from zero, while day return becomes highly negative and significant. Moreover, the difference between the nigh and day returns flips the sign from the negative before SPX night trading to the positive after.

While these results eliminate volatility mispricing explanation, they provide an overwhelming support to price pressures hypothesis on OMMs inventories. As OMMs accumulate excess of positive vega exposures in their inventories they gradually decrease prices during the day to discourage selling pressures. The positive difference between night and day returns is the compensation to OMMs for holding overnight long positions. As OMMs accumulate negative vega inventory exposure, the negative night return is a compensation for holding overnight short volatility exposure. This overall is consistent with inventory management and price quoting market making theory of Amihud and Mendelson (1980).

We further provide a battery of tests to differentiate between volatility mispricing and price pressures hypotheses in portfolio double-sorts on OMMs inventory vega positions and day and night volatility ratio, and in cross-sectional Fama-MacBeth regressions controlling for other options and stock characteristics. We support price pressure hypothesis in the EOD prices over volatility mispricing and conclude that EOD prices can substantially deviate from the fundamental values.

Our results also have implications for Jones and Shemesh (2018) (JS) negative non-trading period return anomaly. SPX night trading does not extend to Saturdays or Sundays, but partial resolution of uncertainty can occur on Monday's early mornings before the day markets open. We therefore expect the week-end anomaly to become less robust. Consistent with expectations, we find that in the period after the introduction of SPX night trading, the weekend return in the equity call options completely disappears. It remains however in the puts. Given that it is no longer present in calls points against mispricing. It is however consistent with the non-trading period uncertainty of OMMs inventories theory.

For SPX options, similarly to JS (2018) we find no evidence of weekend effect for SPX call returns before the night trading, and strong negative weekend effect in put returns. After the introduction of SPX night trading the weekend effect in puts disappears completely and appears strongly in calls. This is again inconsistent with mispricing and is more consistent with price pressures and OMMs inventory volatility exposure over non-trading period uncertainty theory that we advocate.

Can investors benefit from generally net-selling price pressures in the equity options and OMMs decreasing the prices through the end of day to be able to mean-revert their inventories? We explore several trading strategies aimed to take advantage between intra-day and EOD price differences. A strategy that sells delta neutral straddles at 10am on Monday and buys it back at the EOD prices on Friday, earns net of trading costs annualized Sharpe ratio of 3.42 for the latest sub-period, after the introduction of SPX night trading, from March 16, 2015 through the end of 2018. For comparison, the Sharpe ratio of a similar strategy relying solely on EOD prices is much smaller, 1.42. We obtain similar results by shifting the first trade from Monday to Tuesday or Wednesday and then unwinding the position in one week. Moreover, a strategy that conditions the first trade at 10am by first observing the negative net-order flows for either call or put options, which are part of a straddle, between 9:30am and 10am., earns net of trading costs Sharpe ratio of 4. This in turn helps explain why most of trading occurs in the first half of the day in our sample.

What are implications of our results for the literature? First, we provide uniform explanation for negative non-trading period returns: (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). Both papers 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 differentiate mispricing theories from price pressure and OMMs inventory management consistent with theoretical predictions of 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, we show that continuing using end-of-day closing prices to compute option returns can lead to confusing inferences about empirical properties of options returns. In the sample, after the introduction of SPX night trading, from March 09, 2015 though the end of 2018, the general negativity of returns is driven by the weekend returns. Once we remove weekend returns, we find that all returns, whether of individual equities or SPX options, become either positive or insignificant. These results are at odds with all option returns' literature (Coval and Shumway (2001), Bakshi and Kapadia (2003a), Bakshi and Kapadia (2003b)) which shows the negative price of volatility risk in options returns.

Third, we show that if one uses earlier in the day prices, i.e. 10 am, the week-end effect becomes irrelevant. Further, 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, i.e. the volatility is priced more in the index options compared to the equity 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. Using 10 am prices instead of EOD prices, the estimates of delta hedged call, put and delta neutral straddle returns on equity options in the post-SPX night trading sample are -1.34%, -1.54%, and -1.33% respectively. For SPX options, the estimates of delta hedged call, put and delta neutral straddle returns are -1.38%, -1.46%, and -1.07% respectively. Comparing corresponding returns between equity and index options reveals very close similarities in economic magnitudes. We thus show that using 10am mid-quotes, which are least affected by the price pressures, helps to establish that volatility is priced similarly across both equity and index options.

Are we the first to bring attention to other than EOD prices? The answer is no. 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)". The authors thus use the first mid-quote after 10 am (ET) to compute option returns and establish their widely cited results. Since then the literature uses OED closing prices as that is the only price that liquidity providers conventionally provide.

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. 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.

The rest of the paper is organized as follows. Section 2 describes the data and main variable constructions. Section 3 presents main results in the paper. Section 4 provides series of tests to explain the results. Section 5 demonstrates applications of our results for the literature. Section 6 concludes.

2. 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 quotes 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 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 first 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 minutes 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.

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[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.

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%, 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. The main results however 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, 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:

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

where R_{t+1}^{Raw} 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 values of 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:

$$OIM_s = \frac{\sum_s |\Delta_s|(BuyVolume_s - SellVolume_s)}{\sum_s(BuyVolume_s + SellVolume_s)} \quad (2)$$

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. We compute net order imbalances, first on a contract level per day. We then compute the sum of imbalances or inventory on a firm level or index (SPX) level. Order imbalances are available on the intra-day level which allows us establishing trade intensity for each hour of a day.

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. Unlike order imbalances, signed trading volumes for a day are available only in the end of the day. Therefore, for OMMs inventories we can only estimate end-of-day positions.

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.

$$NetOpenInterest_{j,t} = -[OpenInterest_{j,t}^{Buy,y} - OpenInterest_{j,t}^{Sell,y}], \qquad (3)$$

where $NetOpenInterest_{j,t}$ is the net open interest of OMMs in option series j. For each underlying stock on day *t*, we compute delta and vega scaled OMMs inventories by summing over different option series as:

$$\Delta Inventory_t = \sum_{j=1}^{N_t} NetOpenInterest_{j,t} \Delta_j \qquad (4)$$

and

$$\vartheta Inventory_t = \sum_{j=1}^{N_t} NetOpenInterest_{j,t} \vartheta_j \qquad (5)$$

Where *N* is the number of option series available for trading for the underling stock and day *t*. We use delta-scaled inventory to confirm stylized facts about OMMs average inventory positions expressed in the number of underlying stocks, and we use vega scaled inventory in the main analysis to measure volatility exposure of OMMs overnight positions.

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 and effective spreads in our analysis. Quoted Spread, %QS is computed as the ask price minus bid price and divided by bid-ask mid-point. Effective spread is estimated from intra-day trades as twice absolute value of trade price minus bid-ask mid-point at the moment of trade and then scaled by the bid-ask midpoint. We compute dollar volume weighted average relative effective spread per day for each series, and then average it on the underlying stock level.

Table 1 reports summary statistics for order imbalances and OMMs delta-scaled 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 (Garleanu et al 2009), 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 2011-2018. It is interesting to note, that for calls, in 2011-2018, the average delta-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, 2011-2018, 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 delta scaled inventory level of OMMs is positive in equity options, as well as in SPX calls, and negative in SPX puts.

3. Main results

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. Both option returns and *COIM* are computed as weighted average across all contracts on a class (firm) level first, using dollar open interest from the previous day as the weight. They are 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 and intensity of price pressures on OMMs inventories during the day, as well as when the most of price discovery take place.

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 for *All* positive volume days is the most negative, -1.16%. It monotonically increases during the day, with 1pm return of -0.57%, and the daily return computed with the closing prices is close to zero, -3 bps, and is insignificant All *t*-statistics reported hereafter use Newey and West (1987) adjustment for heteroscedasticity and autocorrelation, and we interchangeably refer to delta hedged returns as returns. The daily returns computed using closing mid-points are the highest. The difference between daily returns computed using 4pm mid-quotes and 10am mid-quotes is economically large, 1.12%. The difference between daily returns computed using 3pm mid-quotes and 11am mid-quotes is still economically large, 61 bps.

It is also noticeable that relative quoted spreads %QS, which are also averaged by hour of the day to mirror the statistics for returns and cumulative imbalances, are the widest on average at the market opening, between 9:30 and 10:00 am, 9%, then drop to 8.2% on average through out the day, and increase in the last trading hour of a day to almost opening levels, 8.7%. Further, on average, 91% of COIM(t) takes place by 11am (-4.2%), before reaching the daily maximum of -4.6% by 1pm. Thus, majority of price discovery takes place before noon hours.

We observe similar differences between returns computed with 10 am and 4 pm prices, realization of *COIM*, and %QS when we only consider firm-days with *Negative*, the middle panel, or *Positive*, the bottom panel, options net-order flows. More specifically, the difference in returns is on average 100 bps, and the most of order imbalance shocks, 80% for negative and 74% for positive imbalance firm-days, come to the realization before the noon.

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, 1.06%. As straddles do not use the prices of underlying stocks, or options deltas, it suggests that this result is robust and not driven by the noise in the prices of underlying (Blume and Stambaugh (1983)), or imperfect hedge due to errors in deltas.

Further, as expected under price pressures, the returns based on 4pm prices are more negative for the cross-section of firm-days with negative OIM, and more positive for positive OIM firm-days. These differences can be high. For straddles, Panel C, for all volume days the average return is *negative* 25 bps with EOD price. On negative OIM days, it is more then twice in absolute value, -61 bps, or *positive* 26 bps on positive OIM firm-days. This difference is less pronounced in more recent sub-sample, 2011-2018, Panel F, with the straddle returns of -32 bps, -49 bps, and -13 bps for All, Negative and Positive net order flows firm-days respectively. The returns are the lowest and very similar across different net-order flows samples with 10am prices. In the second sub-sample, Panel F, straddle returns using 10am prices are identical across positive or negative net-flow firm-days, or all volume days, -1.31%.

The results for 2011-2018 sub-sample for calls and puts are presented in Panels D and E respectively, and they are qualitatively similar to those of calls and puts in the first sub-sample.

These results provide the first evidence that the time of the day to measure option returns matters, and the differences are economically large. Regardless of the direction of net order flows, or sub-period we use, the daily returns are almost monotonically increasing with the time of the day. This points to an intra-day seasonality in option prices. Further, returns based on the earlier of the day prices, and especially 10am prices, are quite similar across different net order flows sub-samples. We suggest that these prices are less distorted by price pressures on OMMs inventories which we explore in more details in the next sections.

We also provide the same analysis for the SPX index options in Table 3. As we observe these patterns on the level of S&P500 constituents, we can expect S&P500 (SPX) index to have similar regularities.

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 Calls and Puts, Panels A and B respectively. Similar to the results for individual equity options, the differences between daily returns computed using 4:15 pm mid-quotes and 10am mid-quotes are economically large, 1.35% and 1.21% for all positive volume days for calls and puts respectively. For straddles this difference is 91 bps, Panel

C. 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, and mirror those for equity options.

We also find very similar results for the second sub-sample, 2011-2018. There is however one notable exception for the quoted spreads. For SPX options, %QS increases by almost 2% at 4pm and becomes close to the opening %QS, when the equity options market closes, and then returns to pre-closing level at 4:15pm. The spreads are usually wider when uncertainty is higher. It is normal to observe wider spreads around opening as the uncertainty about valuations is higher. It looks like the closing of equity markets, or 4pm spreads are also associated with similar type of uncertainty as opening quotes.

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 those which use any other mid-quote during the day.

4. 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 or intra-day (open to close) returns. So far, we computed daily (close-to-close) returns which capture both night (close-to-open) and day (open-to-close) returns. The highest expected daily returns based on EOD prices can be consistent with the closing prices being lower compared to the morning prices on average, which should result into negative, on average, day (open-to-close) returns. This however contradicts to the results of Muravyev and Ni (2020), who find that day returns on average are positive and the night returns are highly negative. The authors explain their results with day and night volatility seasonality, as option prices fail to account for lower night volatility and price it as high as the intra-day volatility.

Alternatively, the highest expected daily returns based on EOD prices can imply lower, more negative, day, and higher, less negative, night returns which would be more consistent with price pressures on OMMs inventories hypothesis. As end users in options are net sellers (Garleanu et al 2009), then the negative price pressures, the most of which takes place in the first half of the day (see Table 2, *COIM* by hour of a day) should push prices downward for the rest of the day. This would be consistent with the standard inventory theory of market making of Amihud and Mendelson (1980), where as OMMs over-accumulate excess of positive inventory, they move prices down to discourage further selling. Therefore, the day (open-to-close) return should be negative, and the night (close-to-open) return should be either less negative or even positive since it will constitute OMMs profits of unwinding overnight long positions at higher prices next morning. The reverse is true if end-users' net buying pressure dominates, such as in the index (SPX) options. Under the buying pressure, the day return is expected to be positive or less negative, as in Muravyev and Ni (2020), and the night return to be more negative, as the latter is a premium to OMMs for holding short positions overnight. In either case, EOD prices would reflect price pressures on OMMs overnight positions and be distorted from fundamental option values. 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.

Price pressures in the options market can be even more pronounced than in the stock market (Hendershott and Menkveld (2014)) since carrying inventories imposes higher 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).

While OMMs delta hedge their positions by the end of the day, they are not immune to stochastic volatility and price jumps over the night. Therefore, from the perspective of volatility exposure of OMMs inventories, the uncertainty about overnight volatility or price jumps constitutes the highest risk due to inability to adjust delta hedges during non-trading periods. In contrast the volatility seasonality story of Muravyev and Ni (2020) suggest that option markets systematically misprice the night volatility by treating it as high as the day volatility. To separate between the two hypotheses would be impossible as they are both based on the overnight volatility risk or uncertainty about the night volatility.

To test between two hypotheses, we use an exogenous event during our sample period, an introduction of overnight SPX options trading. The night trading of SPX options cannot affect day and night volatility seasonality of underlying stocks, and if this theory is the main determinant of option valuations, then positive day and negative night option returns should not change after this event.

While introduction of SPX options by CBOE is mostly motivated by the demand of European investors[3], it can provide positive externalities to the resolution of uncertainty about market volatility during night hours. Bondarenko and Muravyev (2020) and Boyarchenko, Larsen and Whelan (2020) find that majority of the US equity premium is earned over a window around the opening hours of European markets, which is between 2am and 3am (ET). The market wide price discovery takes place in the night hours in the US. Bondarenko and Muravyev (2020) argue that the resolution of price uncertainty during EU-open hours contributes to price run ups in S&P E-mini futures. More specifically, the price uncertainty is low during US trading hours since investors keep E-mini price close to the fundamental values. The uncertainty accumulates during Asian session when major investors are asleep. The resolution of uncertainty starts with the EU-open hours when European investors need to interpret Asian news. Importantly, the authors show that VIX future returns are positive through the Asian session, which indicates high uncertainty. This positive VIX trend stops and VIX returns start to decline before Europe opens. Subsequently, VIX returns during EU-open are highly negative which is consistent with uncertainty resolution hypothesis.

Arguably, the resolution of uncertainty about market volatility is one of the main factors affecting options valuations. After the introduction of night hours, SPX contracts start trading soon after EU-open, and their prices should incorporate all relevant information about volatility and price jumps in the night. This resolution of overnight uncertainty has two testable applications. First, if the option negative night returns are a compensation for the overnight volatility risk, after introduction of SPX nigh trading they should become less negative, or zero for both, equity options

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[3] See press release https://www.bloomberg.com/professional/blog/response-overseas-demand-cboe-extends-vix-spx-options-trading-hours/

on S&P500 constituents and the SPX index itself. Second, the reduction of the night uncertainty about volatility risk of OMMs inventories should expand OMMs' inventory risk bearing capacity over the night. As a result, the day and night return patterns predicted by inventory management theories (Amihud and Mendelson 1980) should become even more apparent. More specifically, under negative price pressures from end users (Garleanu et al 2009), day returns should become more negative and night returns should become less negative, zero or even positive for equity options. For index options, where end-users are net-buyers, the reverse should be true.

We test these hypotheses in several ways. First, we compare unconditionally day and night returns before and after the introduction of SPX night trading for equity and SPX index options in the simple event study. Second, we compare the day and night returns conditioning on OMMs overnight inventory volatility exposures before and after the event. Third, we compare the day and night returns conditioning on day and night volatility ratio as in Muravyev and Ni (2020) before and after the event. Forth, we condition on both, OMMs overnight inventory volatility exposure and day/nigh volatility of underlying stocks to identify which effect dominates. Finally, we show robustness of our results in cross-sectional Fama-MacBeth regressions where we control for other option characteristics.

4.1 Event Study: Introduction of SPX night trading.

On March 9, 2015 CBOE extended trading hours of SPX options overnight from 2:00am to 8:15am Central time (CT).[4] It happens almost in the middle of our second sub-sample, 2011-2018, leaving 4-year period before and almost 4 year period after the introduction. For the rest of the analysis we therefore focus on the second sub-sample.

In the event study reported in Table 4, we isolate March 9, 2015 with one week before and one week after the introduction of SPX night trading to allow for markets to adjust. We first compute day and night returns closely around the event window with only one month of trading data before and after the introduction. While short one month pre- and post-event windows come with the

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

lower statistical power, they provide the most timely economic insights. In Panel A, our prevent window is from January 26 to March 02, 2015, and post event window is March 15 to April 17, 2015. In Panel B we expand the pre-and post- event windows to two years which allows for better statistical power, and in Panel C we present the results for the two full sub-samples of 2011-2018, before March 02, 2015 and after March 15, 2015.

We compute day and night ATM straddle returns as the focus on straddles allows to avoid capturing noise in the prices of underlying stocks or option deltas. The night, close-to-open, return is based on day *t-1* closing mid-quotes at 4pm for equity 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[5], and compute open to 11am return for 11am mid-quote, then open to 12pm return, and so on by 1-hour increment till 4pm. The 4pm return is therefore a day, open-to-close, return.

The results in Panel A stand out. There is a drastic change between day and night returns around the event window. During one month before introduction of SPX night trading, the night return is -21 bps (t=-2.19), and the day return is statistically and economically indistinguishable from zero. This is consistent with Muravyev and Ni (MN) (2020) findings. The day returns are more negative during the day, with the open-to-1pm return of -24 bps(t=-1.65). Given the sample is small, the t-statistics which are estimated using Newey and West (1987) heteroscedasticity and autocorrelation adjustment with 3 lags should be interpreted with caution. The economic magnitudes of the estimates are of importance though.

Within one month after the introduction of SPX night trading, the day and night returns flip. The day return is highly negative, -54 bps (t=-3.27), and the night return is economically and statistically indistinguishable from zero.

These changes in day and night returns are even more pronounced for the extended pre- and post-event window in Panel B. Here, before the event, the night return is -21 bps (t=-7.48), and the day return is less negative, -14 bps (t=-1.95). In contrast, after the event, the day return becomes highly negative, -26 bps (t=-3.6) and the night return is statistically and economically equivalent to zero.

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[5] The results do not change if we use 9:40 am quotes as in MN (2020), or 9:30 am quotes.

Finally, full sub-sample period analysis in Panel C reveals even more significant changes. For the period of January 01, 2011 to March 02, 2015, the night return is significantly negative, -30 bps (t=-11.28), and the day return is no different from zero statistically. In contrast, for the second sub-period, March 15, 2015 to December 31, 2018, after the introduction of SPX night trading, the day return is significantly negative, -17 bps (t=-2.76), and the nigh return becomes both statistically and economically insignificant. It is worth noting that across all three Panels, the cumulative day return decreases almost monotonically by hour of the day. This monotonic decrease in returns is especially pronounced after the introduction of SPX night trading, suggesting generally downward price drift during trading day.

These results are consistent with negative price pressures caused by generally negative net-demand for equity options by end-users (Garleanu et al 2009), and OMMs decreasing quoted mid-points through the day in order to discourage selling pressures. Consistent with the hypothesis that SPX night trading reduces uncertainty about night volatility and price jumps, the negative night returns almost disappear.

Table 5 presents a similar event study to Table 4 but for SPX index contracts. The only difference is that SPX contracts stop trading at 4:15 pm, and therefore the cumulative day return on a straddle is in the row marked 16:15. Similar to equity options, in Panel A, within a month after introduction of SPX night trading, the night return decreased in absolute value by almost a factor of two, and became statistically insignificant, -21 bps (t=-1.3). In contrast, the day return increased by a factor of two in absolute value, and is statistically significant, -40 bps (t=-2.18). Similar results are also observed for longer, two-year pre- and post-event windows in Panel B. For sub-sample analysis in Panel C, consistent with the predictions that overnight volatility premium should decrease after resolution of night uncertainty, SPX straddle night return decreases almost twice in absolute value from -38 bps (t=-7.56) before the night trading to -22 bps (t=-2.76) after the night trading. The day return, from positive, 17 bps (t=2.12) becomes negative, -18 bps (t=-1.73).

Overall, the analysis so far confirms our first hypothesis that overnight volatility premium represented by highly negative night returns substantially decreases, in absolute value, after resolution of uncertainty brought by the introduction of SPX night trading. We next look at directly how these changes in day and night returns apply given OMMs overnight inventory volatility exposure.

4.2 Day and Night Returns and Market Makers Inventory's Volatility Exposure.

Our second hypothesis relies on OMMs overnight inventory volatility risk. We therefore first estimate OMMs inventory vega (ϑ) exposure as defined in equation (5). Table 6, Panel A, presents summary statistics of $\vartheta\ Inventories$ by sub-periods, before the introduction of SPX night trading, January 01, 2011 to March 02, 2015, and after, March 15, 2015 to December 31, 2018, for individual equity options. As expected, given the stylized facts that end-users are net sellers in equity options (Garleanu et al 2009), the mean of $\vartheta\ Inventories$ is always positive. Noticeably, the mean for the second sub-period is almost twice compared to the first. This is consistent with our second hypothesis that as overnight uncertainty about volatility decreases, OMMs can expand their inventory bearing risk capacitates. The panel also reports vega-inventory levels by portfolio terciles. Here, each day, after the inventory-vega estimated on the firm level, the firms are sorted into portfolio terciles based on OMMs inventory-vega positions in the underlying stocks. Given the general positive level of vega inventory, the average of the highest tercile substantially outweighs in absolute value the average of the lowest tercile, with the medium tercile value being relatively close to zero.

Figure 1 plots the average daily inventory-vega level aggregated across all S&P500 firms in our sample. The vega scaled inventory level on average is always positive across all days in the sample. It is somewhat stable before 2015 and starts an upward trend after 2015. Thus, the aggregate levels also confirm the hypothesis that OMMs can absorb larger inventories after the introduction of SPX night trading.

We next report day and night straddle returns for two sub-samples, similar to Table 4, but separating the underlying stocks daily by vega-inventory terciles in Panels B and C. The low tercile is always associated with highly negative and high tercile with highly positive vega-inventory levels. In Panel B, before the introduction of SPX night trading, the cumulative day return by 4pm is very small and insignificant for the low and medium terciles. Consistent with the price pressure hypothesis, the day return is negative and significant for the high inventory tercile, -14 bps (t=-2.21). Consistent with the negative volatility premium hypothesis, the night returns are always highly negative and significant across all three tercile portfolios. The night return is the lowest in absolute value for the high tercile portfolio since EOD prices are lower due to the selling pressures from end-users during the day. The difference between night and day return is the smallest in absolute value for the highest tercile, -14 bps, t=-2.21, and almost twice higher for the low and medium terciles, -37 bps.

The difference between night and day returns flips the sign for the highest tercile after the introduction of SPX night trading, Panel C, 15 bps (t=2.14). Here, the night return is economically and statistically indifferent from zero, and the day return is negative, -20 bps (t=3.07). Moreover, the intra-day return almost monotonically decreases by hour of the day as intra-day prices are downward drifting under net selling pressures. The positive difference between night and day return is potentially a profit to OMMs for holding overnight long position.

On the other end, for the negative, low, inventory tercile, the cumulative day return is statistically insignificant from zero, -10 bps, although it is economically similar to open-to-11am morning return, -9 bps (t=-4.16). The night return is negative, as OMMs can unwind their negative positions at the lower prices the next morning. Overall, the results in Panel C are consistent with inventory theory of Amihud and Mendelson (1980). Under negative (positive) price pressures and OMMs accumulating excess of positive (negative) inventory, the prices drift downwards (upward or remain similar for the day), and OMMs are able to mean-revert their inventories the next day at profits. Further, consistent with the reduction in the overnight volatility premium, the night returns for Low and Medium terciles decrease by more than twice in absolute values, and the day and night return differences are no longer statistically significant for these portfolios.

We next preform a similar analysis for SPX index options in Table 7. As SPX options have only one underlying, S&P500 index, in Panel A we only present summary of $\vartheta\ Inventories$ for the whole sample, 2011-2018, and by two sub-samples, January 01, 2011 to March 02, 2015, and March 15, 2015 to December 31, 2018. Overall, the mean and median of OMMs vega-inventory is negative which is consistent with the stylized fact that end-users are net-buyers in SPX options. It might seem that the second sub-period has less negative inventory level. This is attributed to the more negative inventory levels during 2011-2012 Greek crisis, and an increased demand for the insurance against market volatility at that time. Figure 2 presents time series of the aggregate OMMs vega-inventories in SPX contracts, and shows that 2011-2012 is an outlier in terms of negative inventories.

Panels B and C present day and night straddle returns before and after the introduction of night trading respectively. We split daily inventories into positive and negative day sub-samples. In the first (second) sub-period, Panel B (Panel C), there are 963 (817) days with aggregate OMMs vega-inventories being negative, and only 68 (135) days positive. On the negative and positive days we separately compute straddle returns similar to Table 5. Interestingly, for the minority of the sample with positive inventory days, there is no significant difference between day and night returns in both sub-samples.

On the negative inventory days, in the first sub-sample, Panel B, consistent with MN (2020) we observe highly negative night, - 39 bps, t=-7.50, and positive day, 20 bps, t=2.42, returns. The difference between night and day return, - 60 bps, t=-5.94, is economically meaningful.

Consistent with the decrease in the overnight volatility premium after the introduction of SPX night trading, the night returns decrease twice in absolute value, -19 bps, t=-2.35, in the second sub-period, Panel C. The day return becomes negative, -14 bps, but insignificant. Moreover, the difference between day and night return is no longer statistically nor economically significant. These results are more aligned with price pressures on OMMs inventories even on the index level. The morning, open-to-12pm returns are negative, -19 bps, and as positive buying pressure persists, prices drift upward resulting into less negative, and insignificant, day returns. The negative night returns allow OMMs to mean-revert their negative inventories at the lower prices next morning.

4.3 Price Pressure vs. Volatility Seasonality

In this sub-section we delve further into separating price pressures on OMMs inventories versus volatility seasonality explanations for the EOD prices. If volatility seasonality is the main explanation, then an introduction of SPX night trading should have no affect on day and night returns conditioning on day and night volatility of the underlying stocks. Similar to MN (2020), for each of S&P500 components, we estimate day-night volatility ratio, $\sigma^i_{day,t}/\sigma^i_{night,t}$, where day and night ($\sigma^i_{day,t}\ and\ \sigma^i_{night,t}$) volatilities are computed as the standard deviation of open-to-close and close-to-open underlying stock returns respectively for the previous 60 days. We then split all stocks in our sample into quintile portfolios and estimate their day and night returns in Table 8 before, Panel A, and after, Panel B, introduction of SPX night trading. According the volatility seasonality hypothesis, the higher $\sigma^i_{day,t}/\sigma^i_{night,t}$ ratio is, the bigger the difference between night and day returns should be. This is because the lower night compared to the day volatility leads to higher mispricing (MN (2020), Table 7). In Panel A we confirm MN (2020) results, as the higher day-night volatility ration portfolios have on average higher in absolute value night and day return difference, -23 to -26 bps, compared to the lowest volatility ratio quintile, -16 bps, with all estimates being statistically significant.

The results in Panel B look completely opposite. After the introduction of SPX night trading, the night and day return difference for 3rd to 5th volatility quintiles becomes insignificant, and the sign flips to positive for the two lowest volatility ratio quintiles. Here, for the stocks with the highest night volatility, in the lowest $\sigma^i_{day,t}/\sigma^i_{night,t}$ quintile, the night return from – 28 bps (t=-10.84) before SPX night trading, Panel A, becomes statistically and economically close to zero, - 4bps (t=-1.25) in Panel B. This result is consistent with the resolution of uncertainty about volatility hypothesis rather than volatility seasonality and mispricing. The resolution of uncertainty should affect more the stocks with higher night volatility. The negative volatility risk premium for these stocks thus disappears, and consistent with the negative price of volatility risk, the day returns become highly negative, -26 bps (t=-3.90), compared to only -12 bps (t=-2.13) in Panel A.

This evidence also undermines volatility seasonality mispricing hypothesis for the sub-sample preceding introduction of SPX night trading. This however begs the question whether end -users net demand and subsequently OMMs inventory levels depend on day and night volatility ratio itself. In Table 9, we take extreme low and high $\vartheta\ Inventories$ terciles we analyze in Table 6, and further sort each of them into volatility ratio terciles daily. Panel A (Panel B) present the day and night straddle returns for double-sorted portfolios before (after) the introduction of SPX night trading. The results reminiscent those of MN (2020) the most are for the low, negative $\vartheta\ Inventories$ portfolio in Panel A. Here the day returns are positive but insignificant, and the night returns are highly negative, -32bps on average. However, there is no difference between day and night return differences by volatility ratio tercile. The difference between night and day returns varies from -35 bps (t=-5.12) for low day-night volatility tercile to -38 bps (t=-5.19) for high day-night volatility tercile. It suggests that the day-night volatility mispricing does not add beyond what is captured by $\vartheta\ Inventories$.

For the highest, positive $\vartheta\ Inventories$ portfolio, the results are less consistent with those of MN (2020). Here the day return is always on average negative – 14 bps across all volatility ratio tercile portfolios and is mostly statistically significant. The night return continues to be negative, and is almost twice more negative, -28 bps, and highly statistically significant. The negative day returns for the positive vega-inventory positions, which is the dominant on average OMMs position in the equity options, is inconsistent with volatility seasonality hypothesis even before the introduction of SPX night trading. It is rather consistent with the negative price pressures by end-users, and as a result a downward drift in prices during the day. Even more negative night, compared to the day, returns are consistent with the negative volatility risk premium demanded by options investors for the overnight uncertainty.

As uncertainty resolves after the introduction of SPX night trading, Panel B, for the high, positive $\vartheta\ Inventories$ portfolio, the difference between night and day returns either disappears, as for the high volatility ratio tercile, or flips the sign and becomes positive for two other terciles. The difference is the highest for the lowest day-nigh volatility ratio tercile portfolio, i.e. for the stocks with the highest night volatility, 23 bps (t=3.14). The night return completely disappeared to zero for these stocks and the negative day return -24 bps (t=-3.68) is consistent with negative net-demand pressures, and OMMs discounting the most stocks with higher night volatility. They unwind their inventory the next morning at profits.

For the negative, low $\vartheta\ Inventories$ portfolio, the day and nigh returns are not statistically different from zero after introduction of SPX night trading, Panel B, and the results are generally consistent with positive price pressures on OMMs inventories.

Overall, we find more evidence that EOD prices are mostly determined by price pressures on OMMs inventories rather than by day and night volatility seasonality mispricing before introduction of SPX night trading, and even more so after.

So far, our results are base on portfolio sorts. There however could be other stock or options characteristics which can be as important as OMMs end-of-day inventory vega exposure for EOD prices, and subsequent reversal the next morning. In Table 10 we run cross-sectional predictive

Fama-Macbeth regressions for the day t+1 night returns, measured as the close on day t to the open on day t+1, using day t values of OMMs $\vartheta\ Inventories$, day-night volatility ratio, and a set of controls such as stock returns, absolute value of stock returns, natural logarithm of stock market capitalization, options implied volatility, risk neutral skew, implied volatility spread, intra-day option imbalances on day t and day t-1, natural logarithm of option trading volume and options effective relative bid-ask spreads.

We continue using options straddles computed on the stock level similar to the previous tables to measure night returns. Similar to An, Ang, Bali, and Cakici (2014) we compute implied volatility from the daily implied volatility surface calculated by OptionMetrics. The implied volatility is the average of daily call and put implied volatilities for options with a delta of 0.5 and 30 days to maturity. Risk neutral skew is defined as in Xing, Zhang, and Zhao (2010), which is the difference between the implied volatility of out-of-the-money puts and the implied volatility of at-the-money calls. We thus estimate skewness as the difference between implied volatilities of puts with a delta of -0.2, and the average implied volatility from call contracts with an absolute value of delta of 0.5. Implied volatilities are obtained from the OptionMetrics volatility surface for options with 30 days to maturity.

The implied volatility spread is the difference between call and put implied volatilities as in Cremers and Weinbaum (2012). We calculate *IVSpread* daily for pairs of puts and calls with the same strike price and expiration date. A daily weighted average difference is calculated across option pairs using the open interest as weights. That is, for day t,

$$IVSpread_t = \sum_i w_{i,t}\left(IV_{i,t}^{Call} - IV_{i,t}^{Put}\right),$$

where i is the expiration date and strike price combination, the weight $w_{i,t}$ is the average of the put and call open interest, IV^{Call} is the implied volatility of the call and IV^{Put} is the implied volatility of the put. In calculating daily averages, option pairs are omitted if the implied volatility, option delta, open interest or option trade volume are missing, if the best bid or ask quotes are less than or equal to zero or if the ask quote is less than or equal to the bid. We omit options with absolute values of delta greater than 0.98 or less than 0.02.

We use the whole sample, 2011-2018 as the results are not quantitatively different between subsamples, and first present univariate regression results for OMMs $\vartheta\ Inventories$. Consistent with portfolio sorts, $\vartheta\ Inventories$ on day t positively and highly significantly predict next day, t+1, night return. That is the higher selling pressure from end-users, and the higher excess of OMMs inventory volatility exposure towards the end of day t decreases further EOD(t) price. The more positive night return on day t+1 is a compensation to OMMs for holding overnight volatility risk. When we add day-night volatility ratio, the coefficient on $\vartheta\ Inventories$ does not change. Consistent with MN (2020), $\sigma_{day,t}/\sigma_{night,t}$ negatively predict the night returns, and its coefficient only marginally significant in our sample. As we add other control variables, $\sigma^{i}_{day,t}/\sigma^{i}_{night,t}$ becomes insignificant, while $\vartheta\ Inventories$ remains highly significant.

Relatedly, order imbalance (OIM_intraday) on day t are significant and have the correct negative sign, i.e. the more negative day t net order flows, the lower the closing price is, and the more positive the night return is. OIM are daily shocks to the inventories, while $\vartheta\ Inventories$ is the level of inventory. $\vartheta\ Inventories$ continues to be highly significant and positive predictor of night returns after adding all other stock and options characteristics. $\sigma_{day,t}/\sigma_{night,t}$ loses its significance after control variables are added, and it flips the sign to the positive after both vega-inventory and option imbalances are added to the regressions. We therefore concluded that price pressures on OMMs inventories overnight volatility exposure captured by $\vartheta\ Inventories$ is the stronger determinant of EOD option prices, as well as day and night option returns.

Overall, this section provides ample evidence that price pressures distort EOD option prices by significant magnitudes from fundamental values. The prices reverse next morning as it shows in the differences between day and night returns. These reversals should account for potential profits to OMMs for holding overnight positions.

5. Applications of main Results

5.1 Weekend Returns

Jones and Shemesh (2018) find that option returns are significantly lower over nontrading periods, majority of which are weekends. The authors report robust evidence of economically large negative weekend 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.

The week-end return echoes negative night and positive day return before the introduction of SPX options night trading. The explanation is different though. It is not the day and night volatility seasonality but rather the time decay of the volatility over non-traded periods.

We hypothesize that the price pressures on OMMs inventories can help explain the weekend returns as well, and the economic channel works similarly to the day and night returns. To this end however, SPX options night trading does not extend over weekends. The trading begins on Monday early mornings, and thus the uncertainty about volatility can be partially, not fully, resolved before the markets open for the week. Saturdays and Sundays are still the source of uncertainty. If the volatility time decay is the main explanation of the week-end effect, then it should remain after the introduction of SPX night trading, i.e. SPX night trading cannot affect options' theta. If, in contrast, the uncertainty about market volatility and OMMs inventory exposure to the volatility risk is the first order effect, then we expect decrease of the weekend return anomaly. It can still remain for some contracts since the negative week-end return can be attributed to the negative volatility risk premium over Saturdays and Sundays, as the uncertainty is only partially resolved on Monday mornings.

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 (JS) (2018) results for the first sub-sample, January 01, 2011 to March 02, 2015, before the introduction of SPX night trading, and then for March 15, 2011 to December 31, 2018, after the introduction.

Table 11 presents the results for call and put options of S&P500 constituents. Here we switch to delta-hedged returns to keep the analysis as close as possible to the one described in JS (2018).

Consider Panel A, call returns before SPX night trading, January 01, 2011 to March 02, 2015. 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, -0.63% (t=-3.97), and positive trading period returns, 0.71% (t=4.11). The difference of -1.35% (t=-5.73) is statistically significant and economically large[6]. We therefore replicate JS (2018) results in our sample using 4pm quotes.

It is noticeable that the results are different if we compute returns using 10 am prices. Here, both non-trading and trading period returns are negative, -1.29% and -1.12% respectively, and the difference between the mean returns of -17 bps is statistically insignificant. Interestingly, the difference in non-trading and trading period returns is monotonically increases in absolute value with the hour of a day.

After the introduction of SPX night trading, March 15, 2011 to December 31, 2018, the weekend return anomaly relying on EOD prices disappears for calls. As hypothesized, the volatility risk premium should decrease due to the partial resolution of uncertainty on Monday mornings. The weekend return drops in absolute value from -0.63% (t=-3.97) before to the insignificant -0.40% (t=-0.84) after the introduction of night trading. The difference between non-trading and trading period returns is insignificant. As before, this difference is also insignificant for the returns based on 10am prices. Overall, for calls, which are the most actively traded contracts in individual equity options, the weekend anomaly disappears after the introduction of SPX night trading.

Panel B presents the result for put options. Unlike for calls, the negative effect for puts remains significant in the second sub-sample. The weekend returns based on 4pm price is -1.11% (t=-4.48), and the trading period return is only -17 bps (t=-0.79) in the first sub-sample. The difference of -

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[6] Following JS (2018), 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.

94 bps (t=-2.89) is economically large. It becomes slightly bigger in the second sub-period, -1.28% (t=-2.89). If returns are based on 10am prices, these differences are both economically and statistically indistinguishable from zero in both sub-periods.

While the week-end effect remains in puts, its disappearance in calls after the introduction of SPX night trading is inconsistent with either mispricing of options theta (JS (2018)) or day and night volatility mispricing (MN (2020)). It is more consistent with uncertainty of OMMs inventory volatility exposures over non-trading periods, and its partial resolution on Monday early mornings as SPX begins night trading.

In Table 12 we present similar analysis for SPX delta-hedged call and put options. Before the introduction of SPX night trading, for January 01, 2011 to March 02, 2015 period, similar to JS (2018) we find no evidence of week-end anomaly for SPX calls, Panel A, and strong evidence for puts, Panel B. Interestingly, for puts, the difference between nontrading and trading period returns is -1.17% (t=-3.1) for 4pm prices, and it slightly decreases in absolute value for 4:15pm prices, -84 bps (t=-1.76).

After the introduction of SPX night trading, the weekend anomaly completely vanishes for puts for March 15, 2015 to December 31, 2018 period, Panel B. Here the difference between non-trading and trading period returns based on either 4:15pm or 4pm prices is statistically insignificant.

In contrast, the weekend return appears in calls after the introduction of SPX night trading, Panel A. Here, for March 15, 2015 to December 31, 2018 subsample, the difference between nontrading and trading period returns from statistically indistinguishable from zero in the first sub-period becomes economically and statistically large, -1.78% (t=-3.49) using 4:15pm prices. It is still economically large for 4pm prices, -1.32% (t=-2.6).

These two opposite results for SPX calls and puts cannot be consistent with volatility time decay, theta, mispricing. The sudden appearance of the negative weekend returns for calls is more consistent with OMMs inventory volatility exposure to uncertainty over Saturdays and Sundays, and options investors requiring volatility risk premium. As majority of the US equity risk premium is earned during non-trading hours (Bondarenko and Muravyev (2020), Boyarchenko, Larsen and

Whelan (2020)), speculative price pressures on call options before the start of weekends can create this effect.

Overall, we conclude that week-end anomaly is more consistent with price pressures and OMMs inventory volatility risk exposure over non-trading periods.

5.2 Volatility Pricing: Equity vs Index Options. What price to use?

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.

The literature, with the exception of Coval and Shumway (2001), establishes the results based on option returns estimated with EOD 4pm prices for equity or 4:15pm prices for index options. We have shown that EOD prices are the most affected by price pressures on OMMs inventories compared to those taking place earlier in a day. We also have shown that day and night returns changed dramatically after the introduction of SPX night trading, as well as the weekend anomaly. This begs a question about whether the empirical properties of daily (24 hour) option returns change and how.

In this subsection we re-examine daily delta hedged call and put returns and returns on the straddles using different price of a day for individual equity options, Table 13, and SPX options, Table 14 for the period after the introduction of SPX night trading, from March 09, 2015 through the end of 2018. This overlaps with the second half of the 2011-2018 sample and returns reported in Table 2, Panels D, E and F for the equity, and Table 3, Panels D, E and F for SPX index options.

For the equity options, the returns reported for the 2011-2018 sample are quite similar to those for the second half of the sample in Table 13 for delta-hedged calls, Panel A, puts, Panel B, and straddle, Panel C, returns. Thus, even though the day and night returns almost flipped the signs and magnitudes in the second sub-sample, the overall 24 hour day returns are not affected. The returns based on EOD 4 pm prices are negative, and only significant for straddles, -25 bps (t=-3.2).

Next, in each panel, we remove Monday returns. Monday returns can be considered as weekend returns, from Friday close to Monday close. It is noticeable, that the overall negativity of daily returns based on 4 pm prices is driven by weekends. For calls, the return based on 4pm prices becomes positive, 16 bps (t=1.78), Panel A. It also becomes positive but insignificant for puts, Panel B, and negative and statistically indifferent from zero for straddles, Panel C. Notice that returns based on 10am or 11am prices are barely affected across all three panels.

Similar results are obtained for SPX options in Table 14. Delta hedged call, put returns or returns on straddles based on 4:15pm prices are negative but less so compared to the whole subsample (see Table 3, Panels D, E and F for calls, puts and straddles respectively). Once the weekend returns removed, returns on calls become positive but insignificant, and the return on straddle from being marginally significant -21 bps (t=-1.69) becomes both economically and statistically indistinguishable 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. Moreover, general insignificance of SPX returns, especially straddles, can point against stochastic volatility pricing in the returns of index options (Coval and Shumway (2001)).

However, the returns based on 10 am or 11 am prices are not affected by either weekend returns or sample selection. They remain highly negative and statistically significant for calls, Panel A, puts, Panel B, or straddles, Panel C. This provides further evidence that using EOD prices to compute option returns can lead to misleading results.

However, if a researcher uses 10am prices, then all returns, across trading or non-trading periods, look quite similar for both equity calls, puts and straddles, as well as for SPX options. In Table 13, delta hedged call, put and delta neutral straddle returns on equity options across all days are -1.34%, -1.54%, and -1.33% respectively. In Table 14, delta hedged call, put and delta neutral straddle returns on SPX options across all days are -1.38%, -1.46%, and -1.07% respectively. Comparing corresponding returns between equity and index options reveals very close similarities in economic magnitudes. 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 in EOD prices. Once earlier in the day prices are used, this differential pricing is elevated.

Do 10 am prices have a precedent in the literature to measure option returns? The answer is yes. 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)”. The authors use the first mid-quote after 10 am (ET) to compute option returns. For some reason, because most of data providers supply EOD closing prices, the whole option literature entirely relies on these prices. We warn that EOD prices are less indicative and can lead to false conclusion.

5.3. Trading Strategy

Do we find market frictions which is not possible to arbitrage, or market opportunity? Our analysis of day and night returns shows that intra-day prices are higher on average compared to EOD prices. To explore these differences, we analyze the following set of implementable trading strategies.

We continue maintaining delta neutral position and restrict trading in equity option straddles only. To maintain the relevance to the most recent market conditions, we start trading one week after the introduction of SPX night trading, on March 16, 2015 and through the end of 2018, the end of our sample. Our cross-section of underlying stocks remains S&P500 firms for which the daily straddle return statistics are reported in Table 13, Panel C.

Our first strategy, Strategy I, sells ATM straddles every week on Monday at 10am, and buys them back on Friday, right before the closing, 4pm. Our second strategy, Strategy II, is conditional, and it sells ATM straddles at 10am on Monday only, if we observe negative net-order flows between 9:30am and 10am for either call or put options which belong to a straddle's bundle. It then buys back the straddles on Friday right before the closing, 4pm. The third strategy, Strategy III, assumes that traders back-test their trading strategies using EOD prices generally supplied by data providers. It sells an ATM straddle right before the closing, 4pm on Monday, and buys it back right before the closing, 4pm on Friday. We then compute returns for these three strategies over one-week holding periods, and assuming that we trade only twice a week, on Mondays and Fridays. This strategy, which we call Monday-to-Friday relies on the week-end effect which we find still remains in puts (Table 11, Panel B), and EOD prices on Fridays are expected to be higher. We also analyze alternative weekly strategies by trading instead from Tuesday one week to Monday of another week, Tuesday-to-Monday, or from Wednesday of one week to Tuesday of another week, Wednesday-to-Tuesday implementations.

For each strategy we compute weekly straddle returns, round trip trading costs measured by effective spreads that an investor needs to pay per week, net straddle returns after subtracting round trip trading costs from the gross weekly straddle returns, alongside with corresponding standard deviations for the whole trading period, as well as annualized Sharpe ratios based on *net*, after trading costs, returns and assuming zero risk free rate. Table 15 reports the results.

Regardless what day of week we start trading, the strategy which relies on EOD prices only, Strategy III, has the lowest net, after trading costs, weekly returns, with economically small magnitudes. They range from 0.80% for Monday-to-Friday to 1.7% for Tuesday-to-Monday implementation. The corresponding returns for Strategy II are 2.1% and 2.5% respectively, which is almost twice higher. The annualized Sharpe ratios for Strategy I and II are always higher. The biggest difference is observed for Monday-to-Friday implementation, with Sharpe ratio of Strategy II of 3.42, and only 1.48 for Strategy III. The highest Sharpe ratio is achieved for Wednesday-to-Tuesday implementation of 4 for Strategy II, compared to 2.79 Sharpe ratio for Strategy III.

Figure 3 plots cumulative returns of each of three strategies for Monday-to-Friday implementation, and if we invest $1 on March 16th, 2015, one week after the introduction of SPX extended night hours. By the end of 2018, Strategy III returns $3.62, while Strategy I returns $16.23. Strategy II greatly outperforms the rest, resulting in the end value of $30.56. Overall, we conclude that the differences between intra-day, 10am, and EOD, 4pm, prices result in economically meaningful differences in trading opportunities.

6. Conclusion

The main message of this paper is that the time of the day to estimate option returns matters, and empirical results about properties of option returns can change dramatically depending which price a researcher uses. We show that end of day prices are distorted away from fundamental values by price pressures on OMMs inventories. They mean revert largely the next morning.

The price pressures on EOD option prices can help explaining such anomalies as negative night and positive day option returns (MN (2020)), and well as negative weekend returns (JS (2018)).

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 attributed to using EOD closing prices to compute option returns. Delta-hedged or straddle returns on equity and index options are almost *identical* if we use 10 am mid-quotes, as in Coval and Shumway (2001), and which are least affected by price pressures.

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Figure1. Aggregate end of day Option Market Makers Vega inventory exposure in the options of S&P500 constituent firms.

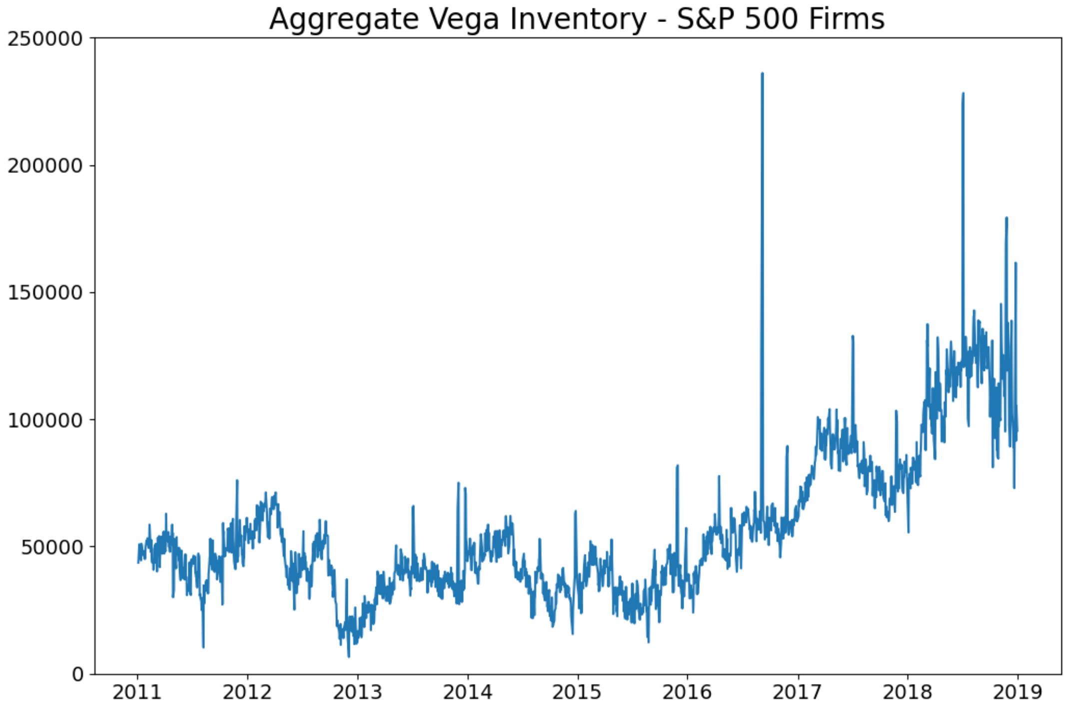

Figure 2. Aggregate end of day Option Market Makers Vega inventory exposure in the options on SPX index.

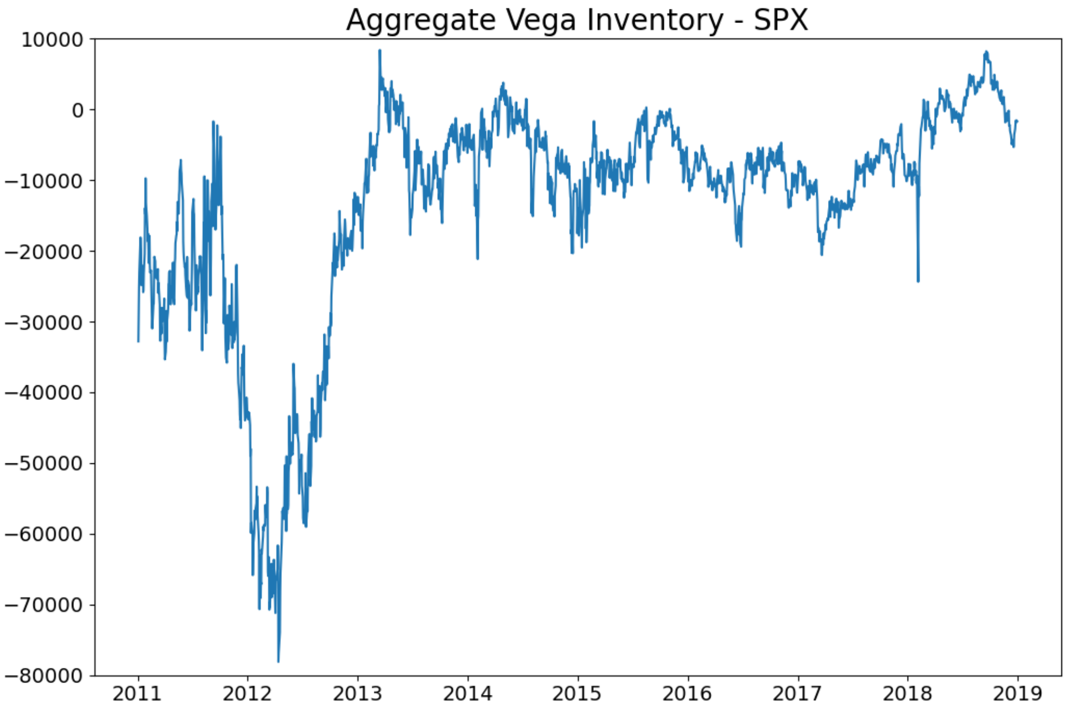

Figure 3. Cumulative returns of trading strategies relying on different prices of the day.

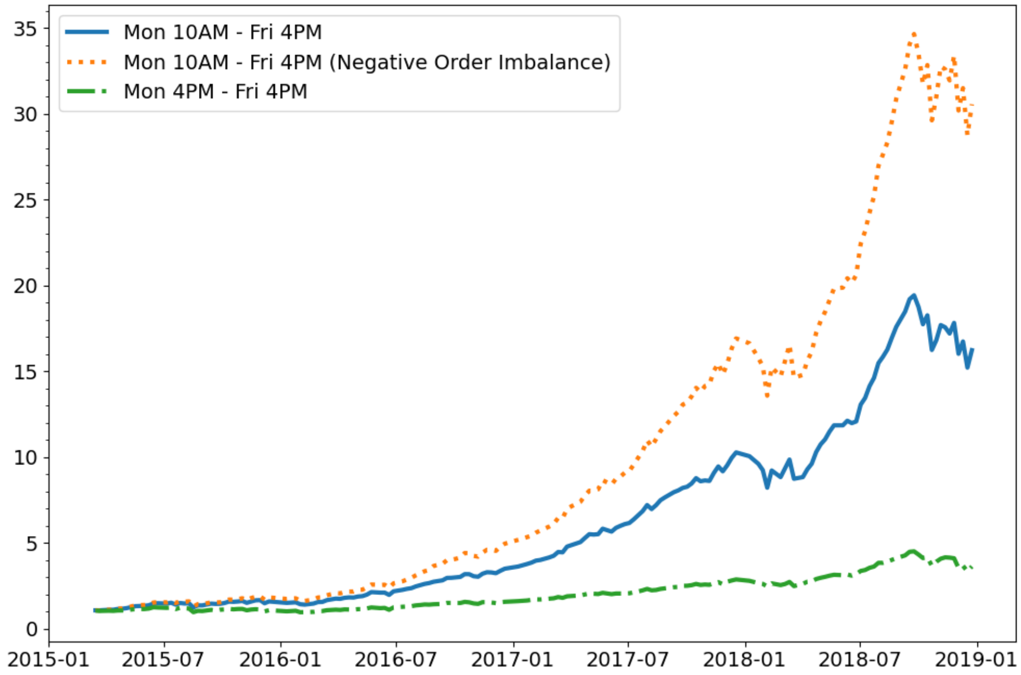

Table 1. Summary Statistics

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. Δ*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
ΔInventory	56.04	8331.15	-19514.68	77.63	16403.15
		2011-2018			
	Mean	**Stdev**	**P1**	**P50**	**P99**
OIM	-0.280	2.328	-7.503	-0.194	6.273
ΔInventory	-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
ΔInventory	217.47	7858.02	-10953.99	-2.44	14537.20
		2011-2018			
	Mean	**Stdev**	**P1**	**P50**	**P99**
OIM	-0.105	1.817	-5.597	-0.077	5.252
ΔInventory	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
ΔInventory	42282.46	36137.02	-41233.88	41180.44	141290.77
		2011-2018			
	Mean	**Stdev**	**P1**	**P50**	**P99**
OIM	-0.363	7.914	-23.167	-0.516	22.608
ΔInventory	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
ΔInventory	-33527.83	45873.22	-129806.29	-34127.11	89124.20
		2011-2018			
	Mean	**Stdev**	**P1**	**P50**	**P99**
OIM	1.064	7.566	-18.502	0.676	22.979
ΔInventory	-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 portfolios of firms 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 and West (1987) adjustment for heteroscedasticity and autocorrelations.

Panel A. Call Options, 2005-2010

time	R^O	t-stat	COIM(T)	%QS
ALL				
10:00	-0.0116	-17.37	-0.035	0.090
11:00	-0.0088	-12.87	-0.042	0.083
12:00	-0.0068	-10.34	-0.045	0.082
13:00	-0.0057	-8.54	-0.046	0.082
14:00	-0.0044	-6.40	-0.046	0.082
15:00	-0.0027	-3.83	-0.045	0.082
16:00	-0.0003	-0.48	-0.045	0.087
Negative Order Imbalances				
10:00	-0.0111	-16.15	-0.214	0.087
11:00	-0.0083	-11.77	-0.271	0.080
12:00	-0.0065	-9.57	-0.302	0.079
13:00	-0.0055	-8.09	-0.323	0.079
14:00	-0.0045	-6.33	-0.339	0.079
15:00	-0.0030	-4.24	-0.356	0.079
16:00	-0.0013	-1.82	-0.376	0.084
Positive Order Imbalances				
10:00	-0.0125	-17.32	0.183	0.087
11:00	-0.0092	-12.38	0.237	0.079
12:00	-0.0069	-9.57	0.270	0.078
13:00	-0.0055	-7.68	0.293	0.078
14:00	-0.0040	-5.4	0.314	0.078
15:00	-0.0018	-2.45	0.337	0.078
16:00	0.0013	1.7	0.363	0.082

Panel B. Put Options, 2005-2010

time	R^O	t-stat	COIM(T)	%QS
ALL				
10:00	-0.0131	-25.69	-0.019	0.084
11:00	-0.0096	-15.91	-0.022	0.077
12:00	-0.0077	-13.77	-0.024	0.076
13:00	-0.0064	-10.97	-0.024	0.076
14:00	-0.0050	-8.06	-0.024	0.076
15:00	-0.0032	-4.65	-0.023	0.077
16:00	-0.0012	-1.65	-0.023	0.082
Negative Order Imbalances				
10:00:00	-0.0126	-24.2	-0.206	0.079
11:00:00	-0.0091	-13.85	-0.257	0.073
12:00:00	-0.0074	-12.61	-0.282	0.072
13:00:00	-0.0062	-10.29	-0.299	0.072
14:00:00	-0.0050	-7.73	-0.313	0.072
15:00:00	-0.0035	-4.87	-0.329	0.072
16:00:00	-0.0022	-2.97	-0.346	0.077
Positive Order Imbalances				
10:00	-0.0137	-25.23	0.184	0.080
11:00	-0.0100	-16.94	0.234	0.074
12:00	-0.0078	-13.21	0.260	0.073
13:00	-0.0063	-10.27	0.279	0.073
14:00	-0.0046	-7.11	0.295	0.073
15:00	-0.0024	-3.4	0.313	0.073
16:00	0.0002	0.2	0.333	0.078

Panel C. Straddle, 2005-2010

time	$R^{straddle}$	t-stat
All		
10:00	-0.01308	-26.73
11:00	-0.01013	-19.82
12:00	-0.00822	-15.97
13:00	-0.00707	-13.35
14:00	-0.00592	-10.79
15:00	-0.00432	-7.47
16:00	-0.00253	-4.16
Negative Order Imbalances		
10:00	-0.01306	-26.7
11:00	-0.01091	-20.88
12:00	-0.00952	-17.96
13:00	-0.00884	-16.36
14:00	-0.00812	-14.5
15:00	-0.00709	-12.05
16:00	-0.00608	-9.86
Positive Order Imbalances		
10:00	-0.01204	-20.91
11:00	-0.00809	-13.69
12:00	-0.00552	-8.85
13:00	-0.00382	-5.87
14:00	-0.00213	-3.07
15:00	0.000066	0.09
16:00	0.002617	3.12

Panel D. Call Options, 2011-2018

time	R^{O}	t-stat	COIM(T)	%QS
ALL				
10:00	-0.0122	-22.92	-0.012	0.126
11:00	-0.0090	-17.01	-0.019	0.100
12:00	-0.0069	-12.91	-0.020	0.095
13:00	-0.0053	-10.04	-0.021	0.092
14:00	-0.0038	-6.9	-0.021	0.095
15:00	-0.0023	-3.91	-0.021	0.091
16:00	-0.0003	-0.56	-0.021	0.099
Negative Order Imbalances				
10:00	-0.0112	-20.47	-0.194	0.121
11:00	-0.0078	-14.36	-0.252	0.095
12:00	-0.0057	-10.27	-0.282	0.091
13:00	-0.0043	-7.68	-0.302	0.089
14:00	-0.0029	-4.99	-0.318	0.091
15:00	-0.0016	-2.65	-0.335	0.088
16:00	-0.0004	-0.62	-0.355	0.095
Positive Order Imbalances				
10:00	-0.0134	-24.29	0.189	0.121
11:00	-0.0102	-18.53	0.241	0.095
12:00	-0.0079	-14.25	0.271	0.090
13:00	-0.0062	-11.28	0.292	0.088
14:00	-0.0044	-7.77	0.310	0.090
15:00	-0.0026	-4.35	0.329	0.087
16:00	0.0001	0.15	0.351	0.094

Panel E. Put Options, 2011-2018

time	R^{O}	t-stat	COIM(T)	%QS
ALL				
10:00	-0.0154	-30.55	0.001	0.122
11:00	-0.0115	-23.34	-0.008	0.095
12:00	-0.0091	-17.37	-0.010	0.090
13:00	-0.0074	-13.53	-0.011	0.088
14:00	-0.0057	-9.48	-0.011	0.091
15:00	-0.0041	-6.4	-0.012	0.087
16:00	-0.0021	-2.97	-0.011	0.095
Negative Order Imbalances				
10:00	-0.0141	-27.11	-0.178	0.115
11:00	-0.0101	-19.55	-0.232	0.089
12:00	-0.0078	-14.24	-0.256	0.085
13:00	-0.0063	-11.03	-0.272	0.083
14:00	-0.0047	-7.64	-0.285	0.085
15:00	-0.0034	-5.16	-0.299	0.082
16:00	-0.0021	-2.88	-0.314	0.090
Positive Order Imbalances				
10:00	-0.0166	-32.28	0.185	0.116
11:00	-0.0127	-24.95	0.227	0.090
12:00	-0.0101	-18.64	0.249	0.086
13:00	-0.0083	-14.78	0.264	0.083
14:00	-0.0064	-10.38	0.277	0.086
15:00	-0.0046	-6.96	0.291	0.082
16:00	-0.0021	-2.84	0.308	0.091

Panel F. Straddle, 2011-2018

time	$R^{straddle}$	t-stat
All		
10:00	-0.0133	-32.83
11:00	-0.0102	-24.48
12:00	-0.0083	-19.13
13:00	-0.0070	-15.88
14:00	-0.0059	-12.8
15:00	-0.0046	-9.4
16:00	-0.0032	-6.11
Negative Order Imbalances		
10:00	-0.0131	-32.41
11:00	-0.0104	-24.87
12:00	-0.0088	-19.97
13:00	-0.0078	-17.29
14:00	-0.0069	-14.55
15:00	-0.0058	-11.51
16:00	-0.0049	-9.16
Positive Order Imbalances		
10:00	-0.0130	-33.9
11:00	-0.0097	-24.65
12:00	-0.0074	-18.32
13:00	-0.0060	-14.84
14:00	-0.0046	-10.72
15:00	-0.0031	-6.77
16:00	-0.0013	-2.57

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 the day *t*. *COIM(t)* for 10am is cumulative order imbalances between 9:30am and 10am. T-statistics are based on Newey and West (1987) adjustment for heteroscedasticity and autocorrelations.

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	-18.02	-0.005	0.064
11:00	-0.0103	-14.99	-0.016	0.046
12:00	-0.0084	-12.85	-0.018	0.045
13:00	-0.0068	-10.7	-0.018	0.045
14:00	-0.0060	-7.74	-0.020	0.049
15:00	-0.0040	-5.89	-0.021	0.046
16:00	-0.0015	-1.86	-0.020	0.061
16:15	-0.0012	-1.44	-0.021	0.048
		Negative Order Imbalances		
10:00	-0.0121	-17.55	-0.158	0.064
11:00	-0.0101	-14.61	-0.246	0.046
12:00	-0.0084	-12.7	-0.291	0.045
13:00	-0.0068	-10	-0.322	0.045
14:00	-0.0057	-8.83	-0.346	0.049
15:00	-0.0040	-6.07	-0.371	0.046
16:00	-0.0016	-2.08	-0.401	0.061
16:15	-0.0014	-1.73	-0.411	0.048
		Positive Order Imbalances		
10:00	-0.0128	-18.54	0.157	0.065
11:00	-0.0112	-15.36	0.231	0.047
12:00	-0.0091	-12.86	0.277	0.046
13:00	-0.0072	-10.45	0.310	0.046
14:00	-0.0061	-7.2	0.333	0.050
15:00	-0.0041	-5.51	0.357	0.047
16:00	-0.0012	-1.33	0.390	0.063
16:15	-0.0009	-1.04	0.399	0.049

Panel E. SPX Put Options, 2011-2018

time	R^O	t-stat	COIM(T)	%QS
		ALL		
10:00	-0.0144	-18.23	0.001	0.082
11:00	-0.0122	-16.8	0.002	0.061
12:00	-0.0107	-13.21	0.001	0.060
13:00	-0.0092	-11.66	0.001	0.059
14:00	-0.0079	-9.68	0.002	0.064
15:00	-0.0062	-6.9	0.001	0.060
16:00	-0.0037	-3.3	0.001	0.076
16:15	-0.0037	-2.64	0.001	0.063
		Negative Order Imbalances		
10:00	-0.0142	-17.73	-0.091	0.081
11:00	-0.0120	-16.35	-0.139	0.060
12:00	-0.0105	-13.1	-0.167	0.059
13:00	-0.0090	-11.46	-0.186	0.059
14:00	-0.0078	-9.63	-0.201	0.063
15:00	-0.0061	-6.72	-0.215	0.060
16:00	-0.0036	-3.14	-0.232	0.076
16:15	-0.0032	-2.27	-0.237	0.062
		Positive Order Imbalances		
10:00	-0.0151	-19.18	0.087	0.083
11:00	-0.0128	-17.25	0.138	0.062
12:00	-0.0112	-14.13	0.165	0.061
13:00	-0.0097	-11.93	0.183	0.061
14:00	-0.0083	-9.86	0.199	0.065
15:00	-0.0067	-7.19	0.212	0.061
16:00	-0.0039	-3.55	0.229	0.077
16:15	-0.0040	-2.87	0.234	0.064

Panel F. SPX Straddle, 2011-2018

time	$R^{straddle}$	t-stat
	All	
10:00	-0.0095	-17.07
11:00	-0.0083	-15.47
12:00	-0.0071	-13.19
13:00	-0.0061	-11.04
14:00	-0.0052	-9.25
15:00	-0.0040	-6.57
16:00	-0.0022	-3.02
16:15	-0.0022	-3
	Negative Order Imbalances	
10:00	-0.0099	-15.47
11:00	-0.0089	-14.42
12:00	-0.0078	-12.49
13:00	-0.0069	-10.9
14:00	-0.0059	-9.16
15:00	-0.0048	-6.92
16:00	-0.0030	-3.81
16:15	-0.0031	-3.82
	Positive Order Imbalances	
10:00	-0.0108	-16.34
11:00	-0.0090	-13.75
12:00	-0.0076	-11.6
13:00	-0.0064	-9.47
14:00	-0.0053	-7.74
15:00	-0.0035	-4.66
16:00	-0.0013	-1.46
16:15	-0.0012	-1.28

Table 4. Event Study: Day and Night, Equity Options

The table presents day and night ATM straddle returns using equity call and put options of S&P500 components for different sub-periods of 2011 – 2018 sample centered around March 09, 2015, an introduction of SPX night trading. Panel A present short, one month, pre- and post-event window, Panel B extends the windows to two years, and Panel C report sub-sample analysis . 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 and West (1987) adjustment for heteroscedasticity and autocorrelations.

Panel A. S&P500 Equity Options, short event window

January 26 2015 - March 02 2015			March 15 2015 - April 17 2015		
time	$R^{straddle}$	t-stat	time	$R^{straddle}$	t-stat
Night	-0.0021	-2.19	*Night*	-0.0010	-0.74
11:00	0.0003	0.33	11:00	-0.0019	-3.11
12:00	-0.0011	-0.83	12:00	-0.0029	-3.7
13:00	-0.0024	-1.65	13:00	-0.0033	-3.32
14:00	-0.0025	-1.55	14:00	-0.0041	-3.6
15:00	-0.0030	-1.54	15:00	-0.0049	-3.94
16:00	-0.0009	-0.27	16:00	-0.0054	-3.27

Panel B. S&P500 Equity Options, medium event window

March 09 2013 - March 02 2015			March 15 2015 - March 10 2017		
time	$R^{straddle}$	t-stat	time	$R^{straddle}$	t-stat
Night	-0.0021	-7.48	*Night*	-0.0006	-1.17
11:00	-0.0003	-1.14	11:00	-0.0008	-3
12:00	-0.0007	-1.83	12:00	-0.0014	-3.61
13:00	-0.0011	-2.42	13:00	-0.0017	-3.48
14:00	-0.0015	-2.79	14:00	-0.0020	-3.55
15:00	-0.0017	-2.92	15:00	-0.0024	-3.66
16:00	-0.0014	-1.95	16:00	-0.0026	-3.6

Panel C. S&P500 Equity Options, sub-sample analysis

January 01 2011 - March 02 2015			March 15 2015 - December 31 2018		
time	$R^{straddle}$	t-stat	time	$R^{straddle}$	t-stat
	All			All	
Night	-0.0030	-11.28	*Night*	-0.0007	-1.93
11:00	-0.0001	-0.59	11:00	-0.0007	-3.43
12:00	-0.0005	-1.41	12:00	-0.0012	-3.99
13:00	-0.0009	-2.67	13:00	-0.0015	-4.08
14:00	-0.0010	-2.59	14:00	-0.0017	-3.85
15:00	-0.0010	-2.17	15:00	-0.0020	-3.99
16:00	-0.0008	-1.33	16:00	-0.0017	-2.76

Table 5. Event Study: Day and Night Returns of SPX Options

The table presents day and night ATM straddle returns for SPX options for different sub-periods of 2011 – 2018 sample centered around March 09, 2015, an introduction of SPX night trading. Panel A present short, one month, pre- and post-event window, Panel B extends the windows to two years, and Panel C report sub-sample analysis. 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 return from 10am to 16:15. T-statistics are based on Newey and West (1987) adjustment for heteroscedasticity and autocorrelations.

Panel A. SPX Options, short event window

January 26 2015 - March 02 2015			March 15 2015 - April 17 2015		
time	$R^{straddle}$	t-stat	time	$R^{straddle}$	t-stat
Night	-0.0037	-1.81	*Night*	-0.0021	-1.3
11:00	-0.0017	-0.69	11:00	-0.0024	-1.76
12:00	-0.0057	-2.73	12:00	-0.0027	-2.37
13:00	-0.0058	-2.24	13:00	-0.0027	-2.18
14:00	-0.0045	-1.50	14:00	-0.0022	-1.7
15:00	-0.0029	-0.88	15:00	-0.0019	-1.34
16:00	0.0010	0.20	16:00	-0.0021	-0.99
16:15	-0.0022	-0.53	16:15	-0.0040	-2.18

Panel B. SPX Options, medium event window

March 09 2013 - March 02 2015			March 15 2015 - March 10 2017		
time	$R^{straddle}$	t-stat	time	$R^{straddle}$	t-stat
Night	-0.0035	-5.42	*Night*	-0.0017	-1.74
11:00	0.0002	0.51	11:00	-0.0008	-1.75
12:00	0.0000	0.07	12:00	-0.0016	-2.42
13:00	-0.0001	-0.20	13:00	-0.0010	-1.21
14:00	0.0003	0.42	14:00	-0.0001	-0.13
15:00	0.0010	1.21	15:00	-0.0004	-0.44
16:00	0.0023	2.26	16:00	-0.0017	-1.66
16:15	0.0014	1.26	16:15	-0.0023	-2.07

Panel C. SPX Options, sub-sample analysis

January 01 2011 - March 02 2015			March 15 2015 - December 31 2018		
time	$R^{straddle}$	t-stat	time	$R^{straddle}$	t-stat
Night	-0.0038	-7.56	*Night*	-0.0022	-2.76
11:00	0.0006	1.81	11:00	-0.0019	-4.32
12:00	0.0005	1.10	12:00	-0.0021	-3.33
13:00	0.0003	0.61	13:00	-0.0010	-1.34
14:00	0.0007	1.43	14:00	-0.0001	-0.19
15:00	0.0013	2.21	15:00	-0.0004	-0.53
16:00	0.0022	2.80	16:00	-0.0011	-0.99
16:15	0.0017	2.12	16:15	-0.0018	-1.73

Table 6. Day and Night Returns of Equity Options: before and after introduction of SPX night trading, conditioning on options market makers inventory Vega exposures

The table presents day and night ATM straddle returns using equity call and put options of S&P500 components for two sub-periods of 2011 – 2018 sample surrounding March 09, 2015, an introduction of SPX night trading. The returns are computed on a portfolio level conditioning on OMMs inventory vega exposure in the underlying stocks. $\vartheta\ Inventories$ are computed as described in the text, and the stocks are sorted in portfolio terciles based on the level of $\vartheta\ Inventories$ in the end of the day. Panel A presents summary statistics of $\vartheta\ Inventories$ for each tercile and sub-period. Panel B presents day and night returns for each $\vartheta\ Inventories$ tercile for the first sub-period, and Panel C for the second. 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 and West (1987) adjustment for heteroscedasticity and autocorrelations.

Panel A. Market Makers Vega Inventory Position

Mean	Low	Medium	High
January 01 2011 - March 02 2015			
16,319.17	-34,874.79	362.30	83,107.88
March 15 2015 - December 31 2018			
27,110.47	-26,362.74	303.71	105,967.35

Panel B. ϑInventory, January 01 2011 - March 02 2015

	Low		Medium		High	
time	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**
Night	-0.0033	-12.22	-0.0046	-6.94	-0.0028	-10.23
11:00	0.0002	0.84	0.0000	-0.06	-0.0003	-1.41
12:00	0.0000	-0.06	-0.0007	-1.20	-0.0007	-2.13
13:00	-0.0004	-1.02	-0.0014	-2.15	-0.0012	-3.53
14:00	-0.0003	-0.79	-0.0013	-1.79	-0.0014	-3.56
15:00	-0.0002	-0.49	-0.0015	-1.86	-0.0015	-3.08
16:00	0.0004	0.59	-0.0008	-0.85	-0.0014	-2.42
Night-Day Diff	-0.0037	-5.52	-0.0037	-3.26	-0.0014	-2.21

Panel C. ϑInventory, March 15 2015 - December 31 2018

	Low		Medium		High	
time	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**
Night	-0.0013	-3.67	-0.0020	-2.14	-0.0004	-1.20
11:00	-0.0009	-4.16	-0.0017	-2.52	-0.0006	-2.99
12:00	-0.0013	-3.79	-0.0012	-1.47	-0.0013	-3.94
13:00	-0.0014	-3.48	-0.0013	-1.38	-0.0016	-4.15
14:00	-0.0014	-2.91	-0.0018	-1.90	-0.0018	-3.96
15:00	-0.0019	-3.46	-0.0013	-1.11	-0.0021	-3.97
16:00	-0.0010	-1.44	-0.0007	-0.60	-0.0020	-3.07
Night-Day Diff	-0.0003	-0.42	-0.0013	-0.82	0.0015	2.14

Table 7. Day and Night Returns of SPX Options: before and after introduction of SPX night trading, conditioning on options market makers inventory Vega exposures

The table presents day and night ATM straddle returns of SPX index contracts for two sub-periods of 2011 – 2018 sample surrounding March 09, 2015, an introduction of SPX night trading. The returns are computed conditioning on OMMs inventory vega exposure on a daily level. $\vartheta\ Inventories$ are computed as described in the text, and returns are computed separately for days with positive and negative $\vartheta\ Inventories$ levels. Panel A presents summary statistics of $\vartheta\ Inventories$ for the sample and sub-periods. Panel B presents day and night returns for negative and positive $\vartheta\ Inventories$ levels for the first sub-period, and Panel C for the second. 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 return from 10am to 16:15. T-statistics are based on Newey and West (1987) adjustment for heteroscedasticity and autocorrelations.

Panel A. Market Makers Vega Inventory Positions

	2011-2018	2011-March 02 2015	March 15 2015-2018
Mean	-13277.67	-19618.31	-6409.84
Median	-8670.63	-13450.84	-7331.01
Std	15522.14	18763.51	5552.00

Panel B. ϑInventory, January 01 2011 - March 02 2015

	Negative			Positive	
N days	963			68	
time	**$R^{straddle}$**	**t-stat**		**$R^{straddle}$**	**t-stat**
Night	-0.0039	-7.50	*Night*	-0.0021	-1.18
11:00	0.0006	1.71	11:00	0.0006	0.69
12:00	0.0005	1.17	12:00	-0.0003	-0.28
13:00	0.0003	0.66	13:00	-0.0002	-0.16
14:00	0.0008	1.53	14:00	-0.0006	-0.34
15:00	0.0015	2.34	15:00	-0.0010	-0.63
16:00	0.0024	2.99	16:00	-0.0017	-0.75
16:15	0.0020	2.42	16:15	-0.0030	-1.54
Night-Day Diff	-0.0060	-5.94	**Night-Day Diff**	0.0010	0.35

Panel C. ϑInventory, March 15 2015 - December 31 2018

	Negative			Positive	
N days	817			135	
time	**$R^{straddle}$**	**t-stat**		**$R^{straddle}$**	**t-stat**
Night	-0.0019	-2.35	*Night*	-0.0010	-0.76
11:00	-0.0019	-4.76	11:00	-0.0024	-2.49
12:00	-0.0019	-3.38	12:00	-0.0022	-1.60
13:00	-0.0007	-0.98	13:00	-0.0015	-0.99
14:00	0.0001	0.11	14:00	-0.0017	-1.12
15:00	-0.0002	-0.27	15:00	-0.0028	-1.57
16:00	-0.0009	-0.79	16:00	-0.0037	-1.42
16:15	-0.0014	-1.15	16:15	-0.0038	-1.49
Night-Day Diff	-0.0005	-0.33	**Night-Day Diff**	0.0028	0.95

Table 8. Day and Night Returns of Equity Options: before and after introduction of SPX night trading, conditioning on day and night volatility ratio

The table presents day and night ATM straddle returns using equity call and put options of S&P500 components for two sub-periods of 2011 – 2018 sample surrounding March 09, 2015, an introduction of SPX night trading. The returns are computed on a portfolio level conditioning on day and night volatility ratio (seasonality) of the underlying stocks. The stocks are sorted in portfolio quintiles based on the day and night volatility ratio in the end of the previous day. Panel A presents day and night returns for each volatility ratio quintile for the first sub-period, and Panel B for the second. 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 and West (1987) adjustment for heteroscedasticity and autocorrelations.

Panel A. Day/Night Volatility Ratio, January 01 2011 - March 02 2015

	Low		2		3		4		High	
time	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**
Night	-0.0028	-10.84	-0.0030	-10.75	-0.0030	-10.21	-0.0031	-10.99	-0.0029	-7.25
11:00	-0.0003	-1.41	-0.0002	-0.74	-0.0001	-0.50	0.0001	0.31	-0.0002	-0.67
12:00	-0.0007	-2.15	-0.0005	-1.64	-0.0004	-1.06	-0.0003	-0.88	-0.0004	-0.96
13:00	-0.0011	-3.29	-0.0010	-2.93	-0.0008	-2.36	-0.0007	-1.92	-0.0007	-1.70
14:00	-0.0012	-3.07	-0.0011	-2.75	-0.0010	-2.33	-0.0008	-1.85	-0.0012	-2.21
15:00	-0.0014	-2.89	-0.0011	-2.21	-0.0009	-1.94	-0.0007	-1.45	-0.0011	-1.86
16:00	-0.0012	-2.13	-0.0008	-1.34	-0.0006	-1.05	-0.0005	-0.86	-0.0006	-0.83
Night-Day Diff	-0.0016	-2.56	-0.0022	-3.43	-0.0024	-3.50	-0.0026	-3.96	-0.0023	-2.82

Panel B. Day/Night Volatility Ratio, March 15 2015 - December 31 2018

	Low		2		3		4		High	
time	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**
Night	-0.0004	-1.25	-0.0002	-0.52	-0.0007	-1.73	-0.0008	-2.40	-0.0017	-4.35
11:00	-0.0010	-4.41	-0.0008	-3.61	-0.0006	-2.75	-0.0004	-1.75	-0.0004	-1.24
12:00	-0.0017	-5.28	-0.0014	-4.17	-0.0011	-3.12	-0.0008	-2.22	-0.0008	-1.92
13:00	-0.0021	-5.10	-0.0017	-4.20	-0.0015	-3.55	-0.0010	-2.40	-0.0010	-2.24
14:00	-0.0022	-4.80	-0.0018	-3.86	-0.0016	-3.29	-0.0011	-2.19	-0.0010	-2.12
15:00	-0.0027	-5.12	-0.0021	-4.01	-0.0019	-3.44	-0.0014	-2.53	-0.0014	-2.63
16:00	-0.0026	-3.90	-0.0018	-2.75	-0.0016	-2.37	-0.0010	-1.44	-0.0008	-1.17
Night-Day Diff	0.0021	2.84	0.0016	2.16	0.0009	1.17	0.0001	0.18	-0.0009	-1.20

Table 9. Day and Night Returns of Equity Options: before and after introduction of SPX night trading, conditioning on both, options market makers inventory Vega exposures and day and night volatility ratio

The table presents day and night ATM straddle returns using equity call and put options of S&P500 components for two sub-periods of 2011 – 2018 sample surrounding March 09, 2015, an introduction of SPX night trading. The returns are computed on a portfolio level conditioning on day and night volatility ratio (seasonality) of the underlying stocks. For Low and High $\vartheta\ Inventories$ terciles described in Table 7, the stocks then are sorted in portfolio terciles based on the day and night volatility ratio. Panel A presents day and night returns for each double sorted portfolio for the first sub-period, and Panel B for the second. 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 and West (1987) adjustment for heteroscedasticity and autocorrelations.

Panle A. Volatility ratio tercile portfolios before SPX night trading

January 01 2011 - March 02 2015

LOW ϑ INVENTORY TERCILE

	Low		2		High	
time	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**
Night	-0.0032	-11.12	-0.0033	-10.66	-0.0032	-9.14
11:00	0.0001	0.64	0.0002	0.94	0.0002	0.80
12:00	-0.0001	-0.25	0.0001	0.18	0.0001	0.27
13:00	-0.0004	-1.22	-0.0003	-0.70	-0.0001	-0.26
14:00	-0.0003	-0.74	-0.0003	-0.62	-0.0003	-0.57
15:00	-0.0003	-0.52	-0.0002	-0.39	-0.0001	-0.12
16:00	0.0003	0.49	0.0004	0.61	0.0006	0.90
Night-Day Diff	-0.0035	-5.12	-0.0037	-5.19	-0.0038	-5.19

HIGH ϑ INVENTORY TERCILE

	Low		2		High	
time	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**
Night	-0.0027	-9.93	-0.0028	-9.56	-0.0027	-7.52
11:00	-0.0003	-1.75	-0.0003	-1.49	-0.0002	-0.72
12:00	-0.0008	-2.48	-0.0007	-2.15	-0.0004	-1.01
13:00	-0.0013	-3.85	-0.0012	-3.58	-0.0008	-1.95
14:00	-0.0015	-3.80	-0.0014	-3.59	-0.0012	-2.38
15:00	-0.0015	-3.24	-0.0014	-3.03	-0.0013	-2.40
16:00	-0.0014	-2.53	-0.0014	-2.38	-0.0013	-1.87
Night-Day Diff	-0.0013	-2.05	-0.0015	-2.22	-0.0014	-1.91

Panle B. Volatility ratio tercile portfolios after SPX night trading

March 15 2015 - December 31 2018

LOW ϑINVENTORY TERCILE

	Low		2		High	
time	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**
Night	-0.0010	-2.50	-0.0016	-3.76	-0.0015	-2.91
11:00	-0.0011	-4.21	-0.0007	-2.49	-0.0010	-2.88
12:00	-0.0016	-4.57	-0.0007	-1.87	-0.0010	-2.00
13:00	-0.0018	-4.10	-0.0008	-1.82	-0.0010	-1.90
14:00	-0.0018	-3.56	-0.0008	-1.47	-0.0008	-1.27
15:00	-0.0025	-4.22	-0.0013	-2.07	-0.0014	-1.97
16:00	-0.0017	-2.33	-0.0002	-0.31	-0.0004	-0.51
Night-Day Diff	0.0007	0.82	-0.0014	-1.65	-0.0011	-1.21

HIGH ϑINVENTORY TERCILE

	Low		2		High	
time	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**	$R^{straddle}$	**t-stat**
Night	0.0000	-0.11	-0.0005	-1.36	-0.0011	-2.83
11:00	-0.0008	-3.76	-0.0006	-2.73	0.0000	-0.02
12:00	-0.0015	-4.61	-0.0012	-3.59	-0.0005	-1.34
13:00	-0.0018	-4.66	-0.0016	-3.91	-0.0008	-1.81
14:00	-0.0020	-4.38	-0.0017	-3.65	-0.0009	-1.91
15:00	-0.0024	-4.59	-0.0020	-3.59	-0.0012	-2.15
16:00	-0.0024	-3.68	-0.0018	-2.76	-0.0009	-1.38
Night-Day Diff	0.0023	3.14	0.0014	1.8	-0.0002	-0.21

Table 10. Predicting Night Returns with options market makers inventory Vega exposures and day and night volatility ratio

The table presents cross-sectional predictive Fama-MacBeth regressions for the night returns for January 01, 2011 to December 31, 2018. The night returns are computed for ATM straddles using equity call and put options of S&P500 components. The predictors are OMMs $\vartheta\ Inventories$, day-night volatility ratio, and a set of controls such as stock returns, absolute value of stock returns, natural logarithm of stock market capitalization, options implied volatility, risk neutral skew, implied volatility spread, intra-day option imbalances on day t and day t-1, natural logarithm of option trading volume and options effective relative bid-ask spreads. T-statistics are based on Newey and West (1987) adjustment for heteroscedasticity and autocorrelations.

	Night(R_{t+1})	Night(R_{t+1})	Night(R_{t+1})	Night(R_{t+1})
ϑInventory$_t$	0.00207***	0.00203***	0.000756***	0.0012***
	(9.06)	(9.11)	(3.44)	(5.09)
$\sigma_{day(t)}/\sigma_{nigh(t)}$		-0.00018*	-0.00001	0.0001
		(-2.02)	(-0.13)	(1.44)
StkRet$_t$			0.039378***	0.0412***
			(6.81)	(6.47)
Abs(StkRet)$_t$			0.054603***	0.0840***
			(8.07)	(10.95)
StkSize$_t$			0.00071***	0.0005***
			(12.16)	(6.01)
ImpliedVol$_t$				-0.0056***
				(-5.85)
IVSkew$_t$				0.0019
				(0.72)
IVSpread$_t$				-0.0026
				(-0.91)
OIM_Intraday$_t$				-0.0012**
				(-2.48)
OIM_Intraday$_{t-1}$				0.0002
				(0.42)
OptVolume$_t$				-0.0007***
				(-9.86)
OptEffSpread$_t$				-0.0357***
				(-10.91)
Adj. R^2	0.001	0.001	0.008	0.03

Table 11. Weekend Effect in Option Returns before and 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 two sub-periods of 2011 – 2018 sample surrounding March 09, 2015, an introduction of SPX night trading. 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, S&P500 firms

01 January 2011 - 02 March 2015				15 March 2011 - 01 December 2018			
time	Nontrading	Trading	Difference	time	Nontrading	Trading	Difference
10:00	-0.0129	-0.0112	-0.0017	10:00	-0.0158	-0.0153	-0.0005
t-stat	-10.74	-7.35	-0.90	*t-stat*	-8.12	-9.55	-0.19
11:00	-0.0091	-0.0052	-0.0039	11:00	-0.0156	-0.0098	-0.0058
t-stat	-7.67	-3.01	-1.87	*t-stat*	-9.85	-5.72	-2.5
12:00	-0.0089	0.0004	-0.0093	12:00	-0.0117	-0.0054	-0.0063
t-stat	-8.07	0.13	-2.93	*t-stat*	-4.25	-2.8	-1.9
13:00	-0.0084	-0.0002	-0.0082	13:00	-0.0142	-0.0049	-0.0093
t-stat	-7.12	-0.13	-3.72	*t-stat*	-6.96	-1.95	-2.88
14:00	-0.0076	0.0023	-0.0098	14:00	-0.0127	0.0000	-0.0127
t-stat	-5.01	1.22	-4.09	*t-stat*	-6.4	-0.01	-3.99
15:00	-0.0075	0.0041	-0.0116	15:00	-0.0111	0.0022	-0.0133
t-stat	-4.55	2.31	-4.81	*t-stat*	-4.34	1.05	-4.03
16:00	-0.0063	0.0071	-0.0135	16:00	-0.0040	0.0041	-0.0080
t-stat	-3.97	4.11	-5.73	*t-stat*	-0.84	2.11	-1.58

Panel B. Put Options, S&P500 firms

01 January 2011 - 02 March 2015				15 March 2011 - 01 December 2018			
time	Nontrading	Trading	Difference	time	Nontrading	Trading	Difference
10:00	-0.0183	-0.0167	-0.0016	10:00	-0.0189	-0.0162	-0.0026
t-stat	-14.64	-10.21	-0.76	*t-stat*	-6.81	-6.36	-0.70
11:00	-0.0172	-0.0120	-0.0052	11:00	-0.0162	-0.0118	-0.0044
t-stat	-10.47	-7.85	-2.31	*t-stat*	-6.84	-8.1	-1.58
12:00	-0.0159	-0.0098	-0.0061	12:00	-0.0144	-0.0086	-0.0058
t-stat	-11.85	-6.19	-2.91	*t-stat*	-6.77	-6.58	-2.32
13:00	-0.0145	-0.0082	-0.0063	13:00	-0.0140	-0.0063	-0.0077
t-stat	-9.01	-4.84	-2.7	*t-stat*	-7.91	-4.82	-3.51
14:00	-0.0138	-0.0058	-0.0080	14:00	-0.0131	-0.0030	-0.0101
t-stat	-8.07	-3.14	-3.2	*t-stat*	-6.44	-2	-3.95
15:00	-0.0130	-0.0039	-0.0091	15:00	-0.0109	0.0000	-0.0109
t-stat	-5.98	-2	-3.1	*t-stat*	-4.22	-0.01	-3.24
16:00	-0.0111	-0.0017	-0.0094	16:00	-0.0118	0.0010	-0.0128
t-stat	-4.48	-0.79	-2.89	*t-stat*	-2.97	0.53	-2.89

Table 12. Weekend Effect in Option Returns before and after Introduction of SPX Night Trading, 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 two sub-periods of 2011 – 2018 sample surrounding March 09, 2015, an introduction of SPX night trading. 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

01 January 2011 - 02 March 2015			
time	**Nontrading**	**Trading**	**Difference**
10:00	-0.0162	-0.0133	-0.0029
t-stat	-6.26	-9.42	-1.00
11:00	-0.0122	-0.0109	-0.0013
t-stat	-4.85	-8.52	-0.46
12:00	-0.0114	-0.0081	-0.0033
t-stat	-4.87	-5.89	-1.21
13:00	-0.0111	-0.0065	-0.0047
t-stat	-4.83	-5.23	-1.79
14:00	-0.0117	-0.0046	-0.0072
t-stat	-4.63	-3.44	-2.51
15:00	-0.0126	-0.0025	-0.0102
t-stat	-4.74	-1.9	-3.43
16:00	-0.0067	0.0002	-0.0070
t-stat	-2.14	0.15	-2
16:15	-0.0037	0.0002	-0.0039
t-stat	-1	0.1	-0.97

15 March 2011 - 01 December 2018			
time	**Nontrading**	**Trading**	**Difference**
10:00	-0.0248	-0.0151	-0.0098
	-7.74	-9.36	-2.71
11:00	-0.0229	-0.0129	-0.0100
	-8.83	-8.91	-3.33
12:00	-0.0222	-0.0098	-0.0124
	-8.78	-6.57	-4.17
13:00	-0.0221	-0.0065	-0.0156
	-8.03	-4.25	-4.93
14:00	-0.0237	-0.0041	-0.0196
	-6.7	-2.75	-5.1
15:00	-0.0192	-0.0014	-0.0178
	-4.09	-0.92	-3.61
16:00	-0.0129	0.0004	-0.0132
	-2.68	0.2	-2.6
16:15	-0.0160	0.0018	-0.0178
	-3.46	0.81	-3.49

Panel B. SPX Put Options

01 January 2011 - 02 March 2015			
time	**Nontrading**	**Trading**	**Difference**
10:00	-0.0153	-0.0147	-0.0006
t-stat	-7.34	-11.55	-0.26
11:00	-0.0148	-0.0123	-0.0025
t-stat	-6.33	-10.5	-0.95
12:00	-0.0140	-0.0101	-0.0038
t-stat	-5.45	-8.15	-1.34
13:00	-0.0146	-0.0090	-0.0057
t-stat	-6.03	-7.86	-2.14
14:00	-0.0148	-0.0071	-0.0077
t-stat	-5.11	-6.23	-2.48
15:00	-0.0171	-0.0048	-0.0123
t-stat	-7.57	-4.07	-4.89
16:00	-0.0133	-0.0016	-0.0117
t-stat	-3.81	-1.02	-3.1
16:15	-0.0110	-0.0025	-0.0084
t-stat	-2.4	-1.69	-1.76

15 March 2011 - 01 December 2018			
time	**Nontrading**	**Trading**	**Difference**
10:00	-0.0211	-0.0157	-0.0054
	-3.73	-12.45	-0.94
11:00	-0.0217	-0.0126	-0.0092
	-7.55	-9.71	-2.91
12:00	-0.0219	-0.0096	-0.0122
	-5.83	-5.91	-3
13:00	-0.0233	-0.0069	-0.0164
	-5.29	-3.78	-3.45
14:00	-0.0219	-0.0047	-0.0173
	-4.05	-2.59	-3.03
15:00	-0.0187	-0.0024	-0.0163
	-2.5	-1.29	-2.12
16:00	-0.0142	-0.0004	-0.0138
	-1.45	-0.19	-1.38
16:15	-0.0046	-0.0021	-0.0025
	-0.31	-0.97	-0.17

Table 13. Equity Option Returns after introduction of SPX night trading

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 from March 09 2015 to the end of 2018 period. R^O is a delta-hedged option return on day t. T-statistics are based on Newey and West (1987) adjustment for heteroscedasticity and autocorrelations.

Panel A. Call Options, 03/09/2015-2018

time	R^O	t-stat	time	R^O	t-stat
	ALL			No Week-ends	
10:00	-0.0134	-16.61	10:00	-0.0127	-16.35
11:00	-0.0100	-12.26	11:00	-0.0089	-10.91
12:00	-0.0075	-9.4	12:00	-0.0062	-7.97
13:00	-0.0057	-7.03	13:00	-0.0040	-5.07
14:00	-0.0039	-4.62	14:00	-0.0020	-2.56
15:00	-0.0022	-2.44	15:00	-0.0002	-0.26
16:00	-0.0002	-0.26	16:00	0.0016	1.78

Panel B. Put Options, 03/09/2015-2018

time	R^O	t-stat	time	R^O	t-stat
	ALL			No Week-ends	
10:00	-0.0156	-18.85	10:00	-0.0148	-21.62
11:00	-0.0112	-14.72	11:00	-0.0101	-15.46
12:00	-0.0085	-10.47	12:00	-0.0072	-9.85
13:00	-0.0067	-7.9	13:00	-0.0051	-6.37
14:00	-0.0045	-4.87	14:00	-0.0028	-2.95
15:00	-0.0028	-2.75	15:00	-0.0011	-1.15
16:00	-0.0008	-0.71	16:00	0.0012	1.11

Panel C. Straddle, 03/09/2015-2018

time	$R^{straddle}$	t-stat	time	$R^{straddle}$	t-stat
	All			No Week-ends	
10:00	-0.0133	-22.29	10:00	-0.0125	-21.59
11:00	-0.0101	-16.44	11:00	-0.0090	-15.54
12:00	-0.0080	-12.55	12:00	-0.0067	-11.11
13:00	-0.0065	-9.88	13:00	-0.0049	-7.81
14:00	-0.0053	-7.68	14:00	-0.0036	-5.47
15:00	-0.0038	-5.18	15:00	-0.0020	-3
16:00	-0.0025	-3.2	16:00	-0.0007	-0.96

Table 14. SPX Option Returns before and after introduction of SPX night trading

The table presents average delta hedged and straddle daily returns using different hour of a day mid-quotes for SPX call and put options from March 09 2015 to the end of 2018 period. R^O is a delta-hedged option return on day t. T-statistics are based on Newey and West (1987) adjustment for heteroscedasticity and autocorrelations.

Panel A. SPX Call Options, March 09 2015-2018

time	R^O	t-stat	time	R^O	t-stat
	ALL			No Week-ends	
10:00	-0.0138	-12.69	10:00	-0.0121	-11.09
11:00	-0.0121	-10.84	11:00	-0.0107	-9.36
12:00	-0.0099	-9.76	12:00	-0.0082	-8.11
13:00	-0.0078	-7.85	13:00	-0.0056	-5.42
14:00	-0.0062	-6.07	14:00	-0.0037	-3.39
15:00	-0.0039	-3.69	15:00	-0.0015	-1.36
16:00	-0.0014	-1.09	16:00	0.0006	0.48
16:15	-0.0013	-0.95	16:15	0.0012	0.84

Panel B. SPX Put Options, March 09 2015-2018

time	R^O	t-stat	time	R^O	t-stat
	ALL			No Week-ends	
10:00	-0.0146	-11.59	10:00	-0.0130	-12.08
11:00	-0.0125	-10.82	11:00	-0.0105	-9.44
12:00	-0.0106	-8.87	12:00	-0.0082	-6.74
13:00	-0.0090	-7.03	13:00	-0.0059	-4.39
14:00	-0.0074	-5.61	14:00	-0.0042	-3.11
15:00	-0.0053	-3.45	15:00	-0.0024	-1.67
16:00	-0.0030	-1.53	16:00	-0.0006	-0.35
16:15	-0.0032	-1.23	16:15	-0.0026	-1.23

Panel C. SPX Straddle, March 09 2015-2018

time	$R^{straddle}$	t-stat	time	$R^{straddle}$	t-stat
	All			No Week-ends	
10:00	-0.0107	-11.31	10:00	-0.0097	-11.29
11:00	-0.0095	-10.79	11:00	-0.0082	-9.54
12:00	-0.0080	-9.17	12:00	-0.0065	-7.44
13:00	-0.0067	-7.39	13:00	-0.0047	-5.07
14:00	-0.0056	-6.06	14:00	-0.0035	-3.66
15:00	-0.0040	-3.97	15:00	-0.0020	-2.04
16:00	-0.0021	-1.73	16:00	-0.0005	-0.41
16:15	-0.0021	-1.69	16:15	-0.0006	-0.56

Table 15. Trading Strategies

The table presents various specification of trading strategies based on trading at different time of the day, twice a week. Strategy I, sells ATM straddles every week on Monday at 10am, and buys them back on Friday, right before the closing, 4pm. Strategy II, is conditional, and it sells ATM straddles at 10am on Monday only, if there is negative net-order flows between 9:30am and 10am for either call or put options which belong to a straddle's bundle. It then buys back the straddles on Friday right before the closing, 4pm. Strategy III sells an ATM straddle right before the closing, 4pm on Monday, and buys it back right before the closing, 4pm on Friday. This defines weekly Monday-to-Friday implementations. Tuesday-to-Monday and Wednesday-to-Tuesday describe similar weekly implementation with the first trade is on Tuesday or Wednesday and the closing trade next Monday or Tuesday respectively. The sample period is from March 16, 2015 to December 31, 2018.

		$R^{straddle}$	Effective Spread	Net $R^{straddle}$	Sharpe ratio (annualized)
Strategy		**Monday-to-Friday**			
I	**Mean**	0.043	0.025	0.017	2.91
	Std	0.043	0.004	0.043	
II	**Mean**	0.044	0.022	0.021	3.42
	Std	0.045	0.004	0.045	
III	**Mean**	0.034	0.025	0.008	1.48
	Std	0.041	0.004	0.041	
		Tuesday-to-Monday			
I	**Mean**	0.046	0.026	0.021	2.99
	Std	0.049	0.004	0.050	
II	**Mean**	0.048	0.022	0.025	3.55
	Std	0.050	0.004	0.051	
III	**Mean**	0.042	0.026	0.017	2.54
	Std	0.047	0.004	0.048	
		Wednesday-to-Tuesday			
I	**Mean**	0.043	0.025	0.018	3.35
	Std	0.039	0.003	0.039	
II	**Mean**	0.044	0.022	0.022	4.00
	Std	0.040	0.003	0.040	
III	**Mean**	0.039	0.025	0.014	2.79
	Std	0.036	0.003	0.036	