Option Returns: Closing Prices are not What You Pay

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Abstract

We document that end-of-day equity and index options quoted bid-ask mid-points which are widely used to compute option returns, implied volatilities, and greeks, do not accurately represent trading prices for a day. Delta-hedged option returns computed using these mid-quotes are systematically higher compared to those using any other mid-quote during a day. These differences, which can reach up to 1% per day, are attributed to dynamics of option net order flows, and option market makers inventory position management. An introduction of night hours trading for SPX options allows for overnight inventory hedging and more flexible liquidity provision during day hours. Our results help explain such puzzles in the option literature as different non-trading and trading returns, or different day and night returns. Using earlier trading hour's quotes removes differential pricing of equity vs. index options, or trading vs non-trading returns, as the returns across all contracts become similarly negative.

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Introduction.

Option markets have grown dramatically over past few decades both in trading volumes and in number of transactions per day. The raising popularity of option contracts among investors has drawn attention of academic literature to examine net-pay offs option investors receive, their predictability, risks and determinants.[1] The focus of this literature is on delta-hedged option gains to account for the effect of underlying, and using end-of-day closing bid-ask mid-points as a proxy for daily option prices.

This paper documents a few stylized facts which help explain some puzzles reported by this literature. Our main result is that end of day option closing prices are not an accurate representative of intraday prices at which most of transactions take place. These last bid-ask mid-quotes of a day are used to estimate options returns, implied volatilities and greeks, and are also widely used in back testing different options trading and hedging strategies and estimating variance risk premiums and risk neutral moments. We show in the data that delta-hedged returns based on closing mid-points are highly biased upward. We argue that this bias reflects the gamma premium that options market makers (OMMs) demand for carrying their overnight, or over non-traded (e.g. week-ends) period inventory risks. The magnitude of the bias is not uniform across option contracts and depends on direction of net-order flows, negative or positive, and price pressures they create on OMMs inventories, and OMMs inventory risk bearing capacities.

Before conditioning on daily net order flows, delta-hedged option returns computed using 4pm mid-quotes are systematically higher compared to returns based on 10am, 11am, 12pm, 1pm, 2pm, or 3pm mid-quotes. The differences are economically large. For example, delta-hedged option returns based on 1pm mid-quotes are approximately 60 bps lower compared to 4pm returns for both calls and puts, for 2004 to 2010, and after the financial crisis, 2011-2017 periods. These differences only increase in magnitudes if we use earlier trading hours' mid-quotes.[2] To control

[1] Bakshi and Kapadia (2003) find that delta-hedged gains for index options are negative and interpret their results as a negative price of volatility risk. Bakshi Kapadia and Madan (2003) show that index options are more negatively skewed compared to individual equity options. Cao and Han (2013) document that delta-hedged option returns decrease monotonically with idiosyncratic volatility of the underlying stocks. Christoffersen, Goyenko, Jacobs and Karoui (2018) show that delta-hedged option returns increase in option illiquidity. Jones and Shemesh (2018) find that option returns are significantly lower over nontrading periods, majority of which are week-ends, and Muravyev and Ni (2019) document negative night and positive day delta-hedged options returns. Cao, Han, Tong and Zhan (2017) find that delta-hedged option returns are predicted by a variety of stock characteristics and firm fundamentals.

[2] If one uses 10am mid-quote, these differences exceed 1% on a daily basis.

for options trading activity, we only use options on S&P500 firms. We however find even bigger differences for SPX options, where *daily* delta-hedged returns based on 1pm mid-quotes are almost 1% lower than those based on 4pm for the first sub-period, 2004-2010, for calls and puts. For the second period, 2011-2017, this difference decreases to 54 bps for calls, and 65 bps for puts. Yet, finding these big differences in daily returns for the most liquid SPX contracts leads us further doubt how appropriate are 4 pm quotes to accurately represent investors' delta-hedged pay offs. Even one hour before closing, using 3pm mid-quotes to estimate daily option returns (vs. 4pm quotes), the last sub-period, 2010-2017, produces the differences of 25 bps and 29 bps for SPX calls and puts returns respectively, and 24 bps for equity call option returns. Overall, daily delta-hedged returns based on 4pm prices are always higher compared to any other quote during the day.[3] [4]

How do we explain lower returns during a trading day, and higher returns in the last trading hour of a day with the highest value at 4pm.? We proceed in three steps. First, we report on the dynamic of options net order flows. We confirm the results in previous literature that net order flows are negative on average for equity options and SPX calls, and largely positive for SPX put options ((Christoffersen et al (2018), Garleanu et al (2009)). It further confirms that OMMs are net buyers and therefore hold net long positions in option contracts. It also suggests that optimal or target inventory level is long position ((Amihud and Mendelson (1980). We then document the following stylized facts about dynamics of option net-order flows: (i) On average there are more days with negative rather than positive order imbalances; (ii) Negative imbalances persist, and high negative imbalance shocks on one day are more likely to remain negative the next day but less so in magnitudes; (iii) Positive imbalances do not persist from one day to another, and high positive imbalance shocks on one day are more likely to revert to modestly negative the next day; (iv) The biggest negative or positive imbalance shocks occur in the early trading hours, between 9:30am and 10am, and the second biggest shock is between 10am and 11am. By approximately 1pm option imbalances decrease almost twice in magnitudes and remain stable during the rest of a day.

[3] We also estimated 3:45pm quote based returns, and still find significant differences with 4pm returns.

[4] Interestingly, if a researcher uses 10am mid-quotes to estimate delta-hedged option returns, the differential pricing of volatility risk between equity and index options (Bakshi, Kapadia and Madan (2003)) becomes less obvious. For example, using 4pm mid-quotes, the average return on equity calls is 0.11%, and index calls is -0.33% for the last sub-period, 2011-2017, which is consistent with the stylized results in the previous literature. However, for 10 am. mid-quotes, the returns are quite similar, -1.3% and -1.46% for equity and index calls respectively.

Given these dynamics of option net order flows, liquidity providers, OMMs, have no choice but absorb the highest net imbalance shocks in the early trading hours. They then need to "work out" their books to bring their inventory positions back to target levels during the day ((Amihud and Mendelson (1980), Ho and Stoll (1981), (1983)).[5] To work their books, OMMs should increase the quoted prices on positive net order flows days, and decrease the prices on negative net order flow days (Ho and Stoll (1981)). Conditioning on the net-order flows for a day, these quoting strategies should be reflected in intra-day return.

Second, we show that OMMs do indeed work out their books to get to the target inventory level by the end of trading day. Similar to Muravyev and Ni (2019) we decompose returns into day and night returns.[6] Consistent with inventory price pressures and optimal OMMs response with price quoting strategies (Ho and Stoll (1981)), on positive imbalance days, returns increase through out the day compared to the opening mid-quote.[7] For example, for equity calls (puts) in the first sub-period, 2004-2010, the day return monotonically increases from the morning till late afternoon on positive imbalance days. The returns for calls (puts) from 9:40am to 10am are 0.17% (0.22%), from 9:40am to 1pm are 0.34% (0.50%), with the closing return, from 9:40am to 4pm, being the highest for the day 0.53% (0.79%). The subsequent night returns are -0.33% and -0.55% for call and puts respectively. Thus, positive price pressures move prices upward through out the day (Ho and Stoll (1981)). The negative night returns are positive premiums to OMMs for holding overnight short position.

The majority of observations in our sample, after volumes across contracts are aggregated on a firm level, are negative order imbalance firm-days. On these firm-days, for calls (puts) we find negative night returns, -0.22% (-0.50%), and substantially higher day returns, 0.04% (-0.04%).

[5] In the stock market, where imbalances are close to zero on average (Christoffersen et al (2018)), the costs and duration of holding inventory are lower. For large stocks, which are similar to our S&P500 stocks, Hendershott and Menkveld (2014) estimate the half life of inventory of 0.54 days, and intermediaries are able to trade out their end-of-day position in the course of next day. Inventory holding costs in options are substantially higher, as they involve delta-hedging ((Jameson and Wilhelm 1992; Engle and Neri 2010), model risk (Green and Figlewski (1999)), higher transaction uncertainty, inability to quickly re-sell illiquid series and hence higher future inventory rebalancing costs ((Leland 1985; George and Longstaff 1993; de Fontnouvelle, Fishe, and Harris 2003; Engle and Neri 2010). Overall, Jameson and Wilhelm (1992), Green and Figlewski (1999), and Battalio and Schultz (2011) argue convincingly that inventory costs and risks are much more serious for option market makers than for liquidity providers in stock markets, due to hedging needs, hedge rebalancing, model risk, and uncertain holding periods. Therefore, OMMs should have strong incentive to get back to target inventory levels by the end of day.

[6] We confirm Muravyev and Ni (2019) results of negative night and positive day returns in our sample.

[7] To avoid opening rotations, instead of 9:30am mid-quote we use 9:40am mid-quote.

Under negative net order flows, one would expect, first, day returns to monotonically decrease during the day as negative price pressures persist, and, second, to be more negative than night returns, as the latter is a compensation to OMMs for taking long overnight positions. While during the day we do observe decreasing returns, they rebound up in the last trading hour between 3pm and 4pm. We also observe similar patterns in SPX contracts on negative imbalance days. This is puzzling, as the option market seem to close at higher prices on both positive and negative net demand pressure days. While it makes sense on positive net demand pressure days, it is puzzling for negative days.

Our explanation is as follows. OMMs target inventory level is long position as selling pressures from end-users prevail on average. OMMs have limited risk bearing capacities to hold inventories overnight, or over non-trading periods. The limited risk bearing capacities or the effect of dealers' financial constraints on asset prices has been widely discussed in the literature (Brunnermeier and Pedersen (2009), Adrian, Etula, and Muir (2014)). As dealers cannot hedge excess of long position over-night, they need to partially liquidate by the end of day. Partial liquidation means selling at prices at least as high as they bought at in the morning when the net selling is the highest. This can explain why delta-hedged returns do not continue falling continuously through the end of trading hours, given that overnight hedging is not accessible.

As a counterfactual, an introduction of any instrument which would allow for overnight inventory hedging should enable dealers to expand their inventory risk bearing capacities, and avoid active, and most likely costly for them, rebalancing in last trading hour on negative net order flow days. Luckily, there is an exogenous event which takes place during our sample period. On March 9, 2015, CBOE introduced over-night trading of SPX options.[8] The night trading, between 3am and 9:15am (ET), allows overnight inventory hedge rebalancing by hedging equity option position with SPX contracts before the opening at 9:30am.

After splitting last period, 2011-2017, in two subsamples, before introduction of SPX night trading, 2011-2014, and after, 2015-2017, we obtain striking differences in intra-day, day and night returns for both equity and index options. After introduction of night trading, 2015-2017, equity call day returns are negative, -0.06%, and night returns are positive, 0.31%. Moreover, on negative net

[8] We are especially grateful to Russell Rhoads (TABB group) for bringing this to our attention

order flow days, the day return monotonically decreases from 0.11% at the opening (between 9:40am and 10am) to the lowest, -0.20%, at the closing (from 9:40am to 4pm), and the subsequent night return is positive, 0.55%. This result is consistent with OMMs being able to take lager long inventory positions at the end of the day as they can hedge the excess of overnight risk in the nigh SPX market. They thus buy at lower prices through the day and sell at higher prices at the opening next day. High positive night returns are a compensation for the risk and extra hedging costs of expanded overnight positions.

This is completely opposite to what we observe before introduction of SPX night trading, 2011-2014. Here, similar to results in Muravyev and Ni (2019), the night returns for calls are negative, -0.20%, and day return are positive, 0.18%. The results also change for SPX options. For example for SPX puts, which is the most active market in index options, before night trading, the day return is 0.48%, and the night return is -0.94%. However, after introduction of night trading, the day return is -0.39%, and night return is negative but statistically indifferent from zero.

We investigate further and observe reductions in trading volumes for SPX contracts by almost 30% during day trading hours, and at the opening (9:30am to 10am) negative or positive net order imbalances decrease by 40% to 50% after introduction of night trading. This is consistent with the significant part of SPX hedging volumes shifting to night hours. Overall, we confirm that the upward bias in delta hedged returns which use 4pm mid-quotes is attributed to OMMs pricing their risk premiums for holding overnight inventories. This risk premium is more likely to be related to changes in prices of the underlying and hence to options gamma.

In final, third step, we further confirm our inventory hedging hypothesis. SPX night trading does not extend to week-ends, and it is only available during week days. In related work, using 4pm closing prices, Jones and Shemesh (2018) document that option returns are significantly lower over non-trading periods, majority of which are week-ends. The authors argue in favor of mis-pricing due to incorrect treatment of stock price variations during non-trading periods.

We first examine whether Jones and Shemesh (2018) results are affected by computing returns using closing mid-points. Similar to authors we define week-end as Friday close to Monday close, and confirm their results. Week-end returns are highly negative while week-day returns are small and negative or close to zero for both equity and SPX options. Consistent with the authors, we also

find that Mondays, which are the end of week-ends, returns are the most negative while the rest of weekdays have either mildly negative or positive returns.

However, there is no substantial economic difference between Monday returns and the rest of week-day returns, if one uses 10am mid-quotes. For SPX options, the difference between non-trading and trading period returns becomes insignificant for 10 am mid-quotes. This difference becomes significant and monotonically increases through the rest of the day starting with 11am mid-quotes, with the highest difference at 4pm. Therefore, net order flows price pressures, and OMMs unwinding their inventories during the day can help explain different return patterns between non-trading and trading periods.

Second, as SPX options do not trade during week-ends, we have two hypotheses. First, we should observe the negative week-end effect after introduction of SPX night trading, as OMMs cannot hedge from Friday to Monday, and thus Fridays closing prices should remain biased upward even on negative demand pressure days. Second, as the night returns become more positive after introduction of night trading in SPX, and especially so for equity calls, the 24-hour return that Jones and Shemesh (2018) use in their test based on 4pm mid-quote should become more positive on week days, where overnight SPX trading is available. We confirm both predictions. After introduction of overnight trading, Monday returns for equity calls remain the most negative for week-days. The rest of week-days have either positive and significant or insignificant from zero returns.

Overall, we contribute to the literature in two important ways. First, we provide an alternative explanation for negative nigh and positive day returns (Muravyev and Ni (2019)), or highly negative non-trading period returns compared to traded periods (Jones and Shemesh (2018)). We suggest that net demand pressures by end-users and OMMs risk bearing capacity and ability or inability to hedge inventories during non-traded periods can help explain both empirical findings. Second, our results also suggest that closing prices reflect OMMs overnight or week-end inventory gamma risks rather than prices that end-users transact at during a trading day. This is important as end of day closing prices are used in almost all empirical options literature. In empirical asset pricing, estimations of variance risk premiums, and risk neutral moments like skewness and kurtosis heavily rely on end of day closing mid-quotes. Implied volatility estimates which options literature uses extensively are also based on end of day mid-quotes. Perhaps most important are

conclusions based on put-call parity violations, which are too always rely on end-of-day closing mid-quotes to infer call and put prices. Industry practitioners use these end-of-day prices to back test their trading strategies. Our results send strong warning to academic and industry community, as the closing prices are not what you really pay. From an end-user prospective these quotes are non-tradable. From OMMs prospective, these quotes reflect inventory levels risk premiums to carry over non-trading periods.

The rest of the paper is organized as follows. Section 2 describes the data and main variables construction. Section 3 compares delta hedged option returns using intra-day instead of closing mid-quotes, and conditions them on options order imbalances. Section 4 describes the dynamics of options net order flows, their effects on day and night returns, and documents how introduction of SPX night trading alleviates OMMs inventory constraints. In Section 5 we estimate week-end and week-days returns with different quotes of a day, and after introduction of SPX night trading. Section 6 concludes.

2. Data

The main options data are from CBOE/LiveVol. They include two data sets: trades data with all intraday transactions for each options series, prices, volumes and time-stamps; and quotes which include 1 min snapshots of NBBO during the trading day. The quote data include best bid and offer for option contracts as well as best bid and offer for the underlying stocks at the time of option quotes. Thus, both, option and stock quotes are synchronized. The data cover the period 2004 to 2017, and, when merged together and after imposing filters described below, exceed 200 TB in size.

Trading data are carefully 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. We therefore are able to sign all trades which we use 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[9]. We also separately analyze SPX index options.

From OptionMetrics we fist use end-of-day bid-ask quotes. We first compare 16:00:00 closing quotes from LiveVol and OptionMetrics to confirm that closing quotes from both data sets 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 returns for the following intraday quotes from day *t* to day *t+1*: 10 am(10:00:00), 11am (11:00:00), 12pm (12:00:00), 1pm (13:00:00), 2pm (14:00:00), 3pm (15:00:00) and closing quotes ate 4pm (16:00:00). To estimate close to open overnight returns, we use the quotes at 9:40am, as 9:30am opening quotes might be noisy due to opening rotations.

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 value of delta between 0.1 and 0.9. 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 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 for matched bid-ask quotes for underlying stocks, stock quotes with quoted bid-ask spreads greater than 99 cents are

[9] 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.

deleted. Overall, the results are not sensitive to these filters. Similar to previous literature we only use contracts with 14 to 180 days to maturity.

We do the analysis for two sub-periods separately, 2004 to 2010, and 2011 to 2017 for two reasons. First, most of the literature analyzed the first sub-period which allows us to cross-check stylized facts. The second sub-period does not include financial crisis and is characterized by higher overall options market liquidity, and trading activity. Second, analysing two periods is also for computational feasibility. Even after all filters, 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 and option order imbalances. Similar to Christoffersen et al (2018) delta hedged options returns are defined as:

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

where R^{Raw}_{t+1} is the daily raw rate of return on option *n*. The option delta $\Delta_{t,n}$ is computed by OptionMetrics using the Cox, Ross, and Rubinstein (1979) binomial tree model, thus allowing for early exercise, and further assuming a constant dividend yield. In sub-section 4.2 we also use Black-Sholes-Merton (BSM) model deltas which we estimate separately. For each option quote we also have a synchronous stock bid and ask quotes. We therefore use quoted stock mid-point as stock price, *S*.

Order imbalances are computed as:

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

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

We compute returns and order imbalances first on a contract level per day. We then compute the weighted average on a firm level using dollar open interest from the previous day as the weight. In the tables, we report equally weighted average portfolio estimates across all firms for each category we analyze.

Table 1 report summary statistics for delta-hedged returns and order imbalances for equity options Calls (Panels A and B) and Puts (Panels C and D). Here we obtain returns using 4pm quotes. Consistent with the results reported in the previous literature, average call returns in 2004-2010 are negative and very close to zero, - 6bps. The median is -0.6% and the standard deviation is 10.66%. Interestingly, the average call returns for the second period, 2011-2017, Panel B, is positive, 11 pbs, while the median remains negative, -64 bps.

Confirming previous results (Christoffersen et al 2018), order imbalances are negative, and more negative in the first period, -4.81%, then in the second period, -1.76 %. The first column reports the number of firm-days observations after contracts are aggregated on a firm level per day. The majority of observation across both samples are negative order imbalances days.

The last two rows of each panel report similar statistics for strictly negative and positive firm-day order imbalances days. On the negative firm-days order imbalances reach -26.56% and -22.54% for the first and second sample respectively. For the positive imbalances the corresponding numbers are 23.93% and 21.83%. Interestingly, the delta-hedged returns using 4pm quote is negative in the first sample, -0.25% for negative order imbalances days, and it is positive, 0.09% for the second sample. For the positive order imbalances, the delta hedged returns are close in magnitudes, 0.16% and 0.13% for the first and second periods respectively.

The results for puts, Panels C and D, are qualitatively similar, with the only exception as puts have negative betas, put returns are more negative than call returns. Their means range from -0.14% to -0.50% from the first period to the second, and remains negative even on positive imbalances days in the second period, -0.36% Panel D.

Table 2 presents similar summary statistics for SPX index options. Consistent with negative variance risk premium for index options, call returns are substantially more negative across both periods, Panels A and B, -0.53% and -0.33% respectively. The average order imbalances for index calls are also negative, and in the second period, panel B, they are similar in magnitude, -1.84%, to those of equity call options, -1.76%, Table 1, Panel B. SPX call returns remain negative for both negative and positive order imbalances days, and they are more negative, -0.40% for positive imbalances days in the second period, Panel B, compared to the negative imbalances firm-day observations, -0.27%. Compared to the equity options, index calls are relatively more balanced. For example, the imbalances in the second sub-period range between -11.07% to 9.36% for

negative and positive days respectively. The corresponding numbers for equity options in the second sub-period are -22.54% and 21.83% respectively. As for the equity options, there are more negative imbalance days, 965 (958) then positive, 781 (790) in the first (second) sub-period, for SPX calls.

SPX put returns, Panels C and D, are also negative, and substantially more negative on positive imbalances days, -0.21% (-0.79%) than on negative imbalance days, -0.06% (-0.15%) for the first (second) sub-period. On average, put order imbalances are close to zero, and in the second sub-period, Panel D, there are more positive, 912, rather than negative, 836, imbalance days.

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). Using 4pm quotes to compute call returns, we confirm the results of previous literature of negative variance risk premium for index options, and either close to zero or positive variance risk premium for equity options (Bakshi, Kapadia and Madan (2003)).

3. Different Intra-day Bid-Ask Midpoint Returns and Order Imbalances.

We next compute returns similar to Tables 1 and 2 but using seven mid-quotes during a trading day: 10am, 11am, 12pm, 1pm, 2pm, 3pm, and the closing 4pm mid-quote. We retain closing quotes returns for all order imbalance days from the previous tables for comparison purposes. Table 3, Panel A reports day-to-day delta-hedged returns for Calls for the first sub-period, by hour of the day. The first panel presents the results for all, positive and negative, order imbalance days. The morning, 10am, return is the most negative, -1.44%. It monotonically increases during the day, with 1pm return of -0.69%, and the closing return already reported in Table 1, Panel A, of -0.06%. All t-statistics reported hereafter use Newey West standard errors adjusted for 22 lags, and we interchangeably refer to delta hedged returns as returns. The magnitudes of t-stats are high as we have very large samples with tens of millions observations in each portfolio. As all returns are significant, the closing return would be the highest returns during the day without conditioning on order imbalances.

The next column reports cumulative, by hour, net order imbalances (*COIM(t)*), for the same day t where we compute average returns. Here, for 10am, the imbalances are estimated from 9:30am to

10am interval. The imbalances for 11am are estimated by adding together 9:30am to 10am, and 10am to 11am imbalances. We repeat this procedure through the end of a day by hour and use cumulative order imbalances as an inventory pressures on options market makers (OMMs) during the trading day. On average, the cumulative imbalances remain relatively stable during the day, ranging from -3.55% at 10am, reaching -4.95% at 1pm, and then remaining at a similar level towards the end of the day. As the imbalances are cumulative, the observed pattern suggests that the majority of inventory shocks for OMMs occur during earlier hours rather than towards late afternoon or even closing.

The next column reports cumulative order imbalances by hour on a previous, t-1, day, *COIM(t-1)*. We observe a similar order imbalances pattern as on a day t, suggesting that negative order imbalances are quite persistent from day to day. The last column reports order imbalances summed by hour on day t (non-cumulative), *1h –OIM*. The magnitudes of hourly imbalances are similar during the day, with a slightly inverted U-shape in absolute value: they are less negative on average in the first few hours during the day, -3.55% at 10am, -4.96% between 10am and 11am, then reaching the lowest at 12pm, -5.77%, and returning to -4.94% between 3pm to 4pm.

The middle panel of Panel A, Table3, present similar statistics as the top panel, but for portfolios of contracts formed on only negative cumulative order imbalances by the end of each trading hour of a day. Here, in the end of each trading hour, only contract with negative cumulative imbalances for that hour are retained. We then compute the average return for those contracts by value-weighting their individual returns on a firm level using dollar open interest from the previous day as the weight, and then the portfolio return is the average returns across all firms for that hour. Averaging on the class (firm) level first is done to decrease the impact of individual contracts as the portfolio composition can change every hour. All other variables, *COIM (t)*, *COIM(t-1)* and *1h-OIM(t)* are computed similarly.

The closing, 4pm to 4pm returns on negative imbalance day-hours is more negative, -0.17%, compared to -0.06% in the top panel. The 10am to 10am return is even more negative, -1.74%, and monotonically increases during the day, with 1pm-to-1pm return of -0.78%, and 3pm to 3pm return of -0.42%. Even the return one hour before the closing return is more than two times negative on negative imbalance days. Cumulative order imbalances, COIM(t), are decreasing during the day with the highest imbalance on the opening, between 9:30am to 10am. This is

confirmed in the last column, where hourly order imbalances are the highest in absolute value during the first few trading hours: -43.14% between 9:30am and 10am, and -34.25% between 10am and 11am. They become less negative and similar in magnitudes through the rest of the days, ranging from -28% between 11am and 12pm, to -20.7% between 3pm and 4pm. Higher negative price pressures on OMMs inventories in the earlier hours of the day may explain substantially lower returns during the first half of the day compared to the closing return. The highest negative returns at 10am on day *t* are consistent with the most negative imbalance shock between the opening and 10am on day *t*. As the imbalances decrease in magnitude, the returns are increasing while still remaining negative. High negative cumulative order imbalances (*COIM(t)*) on day *t* are preceded by smaller negative order imbalances on day *t-1*, *COIM(t-1)*.

The bottom panel reports results of a similar sorting exercise where instead of negative, we sort contracts by positive cumulative order imbalances every hour. The 10am return is -1.72% which is similar to the one for negative imbalances. The return increases monotonically during a day, with the closing, 4pm to 4pm return being positive, 0.11%. This closing positive return is the only positive return for a day, and the return one hour before, 3pm to 3pm, is still negative, -0.18% and highly significant. Similar to negative imbalances, the highest positive imbalances shocks occur in the earlier hours, 42.61% from 9:30am to 10am, and 31.17% from 10am to 11am. They then decrease substantially during the day, and remain at a similar, 15% level after 2pm. Interestingly, positive imbalances on day *t*, *COIM(t)*, are preceded by negative imbalances on day *t-1*, *COIM(t-1)*. This is the first evidence which suggests that while negative imbalances persist, positive imbalances may not.

Overall, the closing, 4pm returns for equity calls, in the first sub-period, are the highest for the day, and even with 3pm return being substantially different from the returns one hour later. This provides preliminary evidence that 4pm quotes and returns computed using those quotes may not be representative of trading quotes, and returns during trading hours. This difference is due to net order flows pressures from end-users on OMMs inventories, which are the highest early in the day, get more stable in the middle of the day, and the lowest towards the end of the day.

This pattern in call returns is even more pronounced in the last sub-sample, 2011-2017, Panel B. The closing, 4pm return for all days is positive, 0.11%, the top panel, and it is the only positive return for a day, even without conditioning on order imbalances. The nearest, 3pm return is -0.13%,

and mid-day, 1pm return is -0.48%. The difference between returns which use 1pm mid-quotes and 4pm mid-quotes is 59 bps and is highly statistically significant. If one uses 10am quotes to compute returns, this difference will be even bigger, 1.4%. These differences for daily returns are economically large and cast doubts on how representative or indicative the closing, 4pm prices are. The pattern in returns documented for 2004-2010, Panel A, remains qualitatively similar for 2011-2017 sub-sample.

Equity put option returns, Panels C and D, Table 3, exhibit similar properties to those of calls across both sub-periods. The 4pm mid-quote return is always the highest return for a day, and the 10 am mid-quote return is the lowest return for a day. The highest imbalance shocks occur in the earlier hours of the day and get more stable in magnitudes after mid-day. The difference between returns using 1pm quote and 4pm quote range from 60 bps in the first sub-sample to 55 bps in the second sub-sample for all order imbalances days.

Table 4 present similar statistics for SPX options. First, consider index call options for the first sub-period, Panel A. As for the equity options, index delta-hedged call returns present similar pattern by trading hour during the day: the 10am quote return is the lowest, -2.09%, monotonically increases during the day, and the 4pm quote return is the highest, -0.53%. Compared to equity options, the difference between returns based on mid-day quote,1pm, -1.44%, and 4pm quote is even more striking, 96 bps. The smallest difference between intra-day quotes returns and the closing, 48 bps, is observed for the 3pm mid-quote. Given that SPX options are more liquid than equity options, the pattern we observe cannot be attributed to illiquidity. In contrast, it appears even stronger with higher liquidity.

Similar to the equity options, the highest imbalances shocks occur in the morning, between 9:30am and 10am, and the lowest imbalances are observed in the last trading hour. For example, on negative imbalances trading day-hours, the first imbalance, *1h-OIM(t)*, is -41.1%, and the last imbalance for the day is -13.96%. Starting 1pm imbalances stabilize and become less volatile for the rest of the day. Similar patterns are observed for SPX calls in the second sub-period, 2010-2017.

Panel C presents results for index put options for the first sub-period, 2004 to 2010 which includes the crisis, and Panel D for the second, after the crisis sub-period, 2011-2017.

Focusing on the second sub-period, while the return using 4pm mid-quote is negative, -0.48%, the return using 1pm mid-quote is even more so, -1.14%. The difference of 65 bps is economically big. This again highlights the return patterns and superior informativeness of intraday quotes compared to 4pm quote.

4. What can explain these patterns in returns?

Carrying inventories imposes significant costs on OMMs. Jameson and Wilhelm (1992), Green and Figlewski (1999), and Battalio and Schultz (2011) argue that inventory costs and risks are much more serious for option market makers than for liquidity providers in stock markets, due to hedging needs, model risk, and uncertain holding periods. In option markets, market makers also incur hedging and rebalancing costs when they are unable to quickly resell illiquid series (Leland 1985; George and Longstaff 1993; de Fontnouvelle, Fishe, and Harris 2003; Engle and Neri 2010). Overall, holding options inventories is more expensive compared to the stocks. Therefore, optimal inventory theories (Amihud and Mendelson 1980; Stoll 1978; Ho and Stoll 1981, 1983), and especially an idea of going home flat, should be even more applicable in the options market.

If there is a positive buying pressure, OMMs will be accumulating negative inventory positions. To decrease net buying order flows they need to increase mid-point quoted prices. Across both equity and index options, on positive cumulative order imbalance day-hours, we observe increasing through the day return patterns. This is consistent with buying pressure pushing option prices up during the day and OMMs selling at higher prices every next hour as positive net order flows persist (Ho and Stoll (1981)).

On the negative order imbalances days, which is the majority of days for equity options and SPX calls, OMMs are net buyers. Therefore, their optimal inventory level (Amihud and Mendelson 1980) is net long. Unlike positive net-demand pressures, for negative imbalance-hours for the cross-section of options we first observe very low returns in the early trading hours, when net selling is the highest. However, instead of continuing to decrease, returns rebound and start increasing towards the end of a day. This is not consistent with price pressures theory (Ho and

Stoll (1981)), as one would expect the returns to decrease monotonically through the day.[10] Note, however, that the portfolio composition from one hour to another can change, as we rebalance hourly, and these are not cumulative intra-day returns, from the open to close, which we describe in the next section, but rather day to day returns using different quotes of the day. Yet, increasing returns on negative net order flow day-hours towards the end of day is puzzling. While price pressures alone cannot help explaining these patterns, OMMs inventory risk bearing capacity and persistence of negative net order flows can help.

Our main hypothesis here is as follows. OMMs optimal inventory level (Amihud and Mendelson (1980)) is net long, and it has limited risk bearing capacity. Going into overnight or week-end periods with excessive long position is costly and risky. If overnight inventory hedging is not available, first sub-sample, 2004-2010, then OMMs need to bring the inventory levels to the risk bearing capacity by the end of day. Managing end of day inventories and their rebalancing depends on the persistence of net-order flows. If negative net order flows are persistent from day to day, after absorbing negative net demands in the morning, OMMs need to sell the excess of inventory by the end of trading day at prices at least as high as they purchased, as covering long positions at higher prices might not be possible the next day. If positive net order flows are most likely to revert the next day, then covering net short position in the next day open is more optimal rather than on the same day close. These dynamics of net order flows can explain increasing returns on positive imbalance days, and rebounds in returns in the last trading hour on negative imbalance days. In sub-section, 4.1, we document the dynamics of order imbalances from one day to another. In sub-section 4.2 we look at intra-day cumulative returns conditioned on order imbalances. In sub-section 4.3 we confirm our priors with a natural experiment: an Introduction of SPX night trading which allows for inventory risk hedging in the night.

[10] In Section 5 we indeed confirm this intra-day return pattern for equity calls and puts, for the second sub-sample, 2011-2017, but not for the first sub-sample, 2004-2010.

4.1 Day-to-day, hour-by-hour Persistence of Order Imbalances.

In Table 5 we explore the persistence of order imbalances which may impact OMMs inventory management strategies. For each one hour interval during the trading day t, we sort contracts by the previous day t-1 cumulative order imbalances, *COIM(t-1)*, for the same one hour time interval in quintile portfolios, and then compute delta-hedged returns for each of the portfolios using end-of-time interval bid-ask mid-quotes. For each portfolio and time we also report average number of trades, order imbalances by hour, *1h-OIM(t)*, average number of contracts traded per hour and their average dollar volume on day t.

Panel A reports the results for equity calls for the first sub-period. Consider 10 am returns. Portfolio returns on day t, sorted on imbalances between 9:30am and 10am on day t-1, first decrease and then increase with imbalances. The lowest quintile has negative, -55.44% imbalances on day t-1, which also spills over into the next day with lower but still negative net order flows of -5.82%. The highest quintile observes high positive imbalances 51.26% on day t-1, which reverts into negative the next day, -1.64%. Thus, while negative imbalances persist, large positive imbalances revert into modest negative imbalances the next day. Delta hedged returns somewhat resemble the price pressures. The return on the lowest quintile is by 23 bps significantly lower compared to the return on the highest quintile. The relations between order imbalances and returns is not monotonic for returns computed using earlier in a day quotes. This is in sharp contrast to the returns computed using 4pm quotes. Here, returns monotonically increase with the previous day order imbalances, ranging from -0.30% for the lowest quintile to 0.14% for the highest quintile, with the statistically significant difference of 43 bps. These monotonic relations can only be established with the quotes after 2pm when imbalances become relatively stable after more volatile early hours during the day.

Looking at average number of contracts traded, their dollar trading volume, and number of trades, the extreme imbalance portfolios also have lower trading activity. There is one pattern in imbalances which cannot be unnoticed. Larger negative imbalances on day t-1 continue to remain moderately negative next day, while large positive imbalances on day t-1 change the sign and switch to moderately negative. This holds for all time intervals in Panel A. If OMMs are net sellers on day t-1 and are moving mid-quotes upward to reverse buying pressure (Table 3, Panel A), they seem to be able to succeed at least the next day. This should allow them to cover their short

positions at the lower prices. Negative returns for OMMs short positions on day t-1, fifth quintile portfolio, indicate positive profits on day t. This holds for all quotes except 4pm quote where the return on the high imbalances' portfolio is positive, suggesting potential losses to OMMs previous day short position. Therefore, providing liquidity at the closing quotes cannot be profitable.

On the contrary, the negative imbalances persist, and the returns associated with high negative imbalance day-hours at t-1 remain moderately negative the next day. If OMMs trade only at fixed times during the day by providing liquidity to negative order imbalances and then try to unwind the position the next day, they would be losing money. OMMs however trade at all times during the day, and negative returns are increasing (becoming less negative) for the lowest quintile portfolios from -1.27% for 10am quotes to -0.30% for 4pm quotes. Therefore, the only profitable strategy to unwind a positive inventory taken early in a day is to gradually sell at higher prices through the second half of the day.

Panel B presents similar statistics for equity calls for the second period, 2011-2017. As the market becomes more liquid, and outside of financial crisis, we would expect lower persistence in net order flows and higher similarity across low and high imbalances sorted portfolio returns. In contrast, for 10 am quote, the difference between returns of high and low quintiles is even larger, 60 bps, compared to the first sub-sample, Panel A. Only for 10am quote, positive imbalances on day t-1 remain mildly positive for the next day. However, it is not true for the rest of the day, where positive imbalances change the sign across all time intervals. The rest of the results is qualitatively similar to the first sub-period.

Panels C and D of Table 5 report similar statistics for equity put options. Here too, the patterns we document are qualitatively similar to those of calls for the first sub-period. For the second sub-period extreme positive put imbalances, fifth quintile, becomes persistent as the highest positive imbalances remain mildly positive the next trading day. This however only holds for the most illiquid contracts, as the second highest positive imbalance quintile, forth quintile, mean-reverts to mildly negative the next trading day.

The analysis reported in Table 5, which is done on firm/class level, is less relevant for SPX options since they all have the same underlying, and contracts which experience high negative net order flows can be offset or hedged by contracts experiencing positive net order flows. Nevertheless, we are interested to see whether for the same underling, we still can obtain the results similar to equity

options. Table 6 reports the results. In panel A we present the statistics for index call options for the first sub-period. Similar to equity call options, Table 5, Panel A, high negative index call imbalances on day t-1 remain mildly negative on day t, and positive imbalances on day t-1 most of the time change the sign the next day and become mildly negative. This is quite remarkable since these are calls on the same underlying, and for the cross-section of calls with positive imbalances OMMs could easily take offsetting positions in calls with negative imbalances at relatively small differences in deltas. The tabulated results however suggest the limits inventory bearing capacities and demand pressures even on the cross-section of relatively homogeneous contracts. Similar patterns, although less pronounced, are still observed in the second sub-period for calls, Panel B. Here, extreme negative imbalances on day t-1 remain negative the next day but very small in absolute values. In contrast, positive imbalances remain positive for the majority of time intervals the next day, but their values are very close to zero.

For puts, in the first subperiod, Panel C, the patterns in imbalances for majority of cases resemble those of equity put options, Table 5, Panel C. As index puts are known to have high buying pressure, the returns on high imbalance portfolios are significantly higher then those with negative net order flows. The buying pressures on day t-1 revert to moderately negative imbalances the next day most of the time for the first sub-period. This pattern also persists in the second sub-period, Panel D, with two exceptions. First, positive net demand pressures are not high enough to cause the difference between low and high quintile portfolios. Second, as the majority of trading days are positive imbalances days (Table 2, Panel D), extreme negative imbalances on day t-1 become moderately positive the next day.

To summarize, this section establishes the following stylized facts. Negative order imbalances are persistent, and high negative shocks on one day are most likely remain moderately negative on the following day. Positive order imbalances are less persistent. They change to moderately negative in majority of periods we analyze on the following day. This holds strongly across both sub-periods for equity options. We even observe similar patterns in most cases for SPX options where inventory management costs are mush lower, and positive and negative demand pressures can be partially offset on OMMs portfolio position level. Yet, even for SPX options, we observe substantial differences in returns between intra-day quotes versus closing quote. This leads us to conclude that net order flows dynamics, and OMMs optimal inventory level management and

quoting strategies in response to the net order flows could explain the differences in returns we report earlier between closing mid-quotes and mid-quotes during any other trading hour during the day.

A hypothetical prediction for the optimal inventory management on negative imbalance days is to start unwinding positive position taken earlier in a day towards the end of the day, as the negative imbalance persist. For positive imbalances days, it is to increase midpoint during the day and sell at higher prices, since there is always an opportunity to cover short position by repurchasing at lower prices at the open or any time during the next trading day. In the next section, to confirm whether these strategies can indeed explain different quote of a day returns, we estimate delta hedged option returns between close-to-open (overnight) return, and day (Open-to-Close) returns. Unlike all previous analysis which relies on cross-section of options contracts sorted by hour of a day, in the next section we track time series of each contract through a night and trading day.

4.2 Close-to-Open Overnight and Open-to-Close Intra-day Returns.

The analysis in this section is similar to Muravyev and Ni (MN) (2019). We do not follow the authors directly, as we only adopt their methodology for our hypotheses tests. Similar to the authors, here we estimate close-to-open overnight delta hedged return, and use 9:40am quote as an opening quote. We also estimate a set of intraday delta-hedged returns: open-to-10am, open-to-11am, open-to-12pm, open-to-1pm, open-to-2pm, open-to-3pm, open-to-close/4pm delta hedged returns. These returns will allow us to trace mid-quote fluctuations during the day under different net order flow pressures. Our definition of delta-hedged returns is the same as in MN(2019), however, the magnitudes of estimates that we obtain might be different. Unlike the authors, before averaging on a portfolio level, we first estimate value-weighted rather than equally weighted average returns across all contracts on a firm level using dollar open interest form the previous day as the weight. We also use only equity options of S&P500 constituents, while the authors use all stocks. We keep the same filters as before. Similar to the authors, for each option contract and for each quote we now compute Black-Scholes-Merton (BSM) model deltas, and in this section we no longer use OptionMetrics deltas.

Table 7 reports the results for calls and puts separately for both sub-periods. In the first sub-period, we confirm the results of MN (2019) that the nigh returns are negative, and intra-day returns are positive. For calls, Panel A, the overnight, close-to-open, return is -0.27%, and open-to-close returns is 0.25%. The overnight return uses 9:40 am mid-quote and previous day closing, 4pm, mid-quote, while 10am return, 0.08%, is the return between 9:40am and 10am. The opening mid-quote is much lower compared to the previous day close, and jumps up substantially within next 20 min. It then almost monotonically increases during the trading day, reaching 0.16% by 3pm, and 0.25% by 4pm. Similarly, for puts, Panel C, the night return is -0.52%, and the day return is 0.35%. The 10am return is 0.08%, and it monotonically increases through the day. MN (2019) explain negative night and positive day returns by stock volatility differential pricing, as it is higher during the day and lower during the night.

On the negative imbalances firm-days the difference between night and day returns is even higher. Here, unlike previous sections where we sort by hour, we sort firm-day imbalances by the sign of end-of-day cumulative imbalances. If aggregated imbalances, weighted by previous day dollar open interest, on a firm level for a given day are negative, for that day we place firm level option return estimates into negative imbalances portfolio, and we do similarly for positive imbalances portfolio. In Panel A, call overnight returns are -0.22%, and then jump to 0.02% from 9:40am to 10am. The returns increase towards noon, then drop to almost zero and close at 0.04%. Similarly for puts, the overnight return is -0.5%, then it reaches -0.02% by 10am, it decreases in the afternoon to -0.08% and reverts back at the closing to 0.04%. As the sample is very large, majority of returns are significant.

Overall, for both, calls and puts, on negative imbalance firm-days, we observe negative overnight returns, suggesting that the opening price is always lower compared to the previous closing mid-quote. The returns then rebound and increase in the early trading hours, then, given selling pressures, decrease in the afternoon, and rebound back in the last trading hour. This intraday return pattern is consistent with OMMs working their books through the day and aggressively balancing the books in the last trading hour of the day. In Table 3 we showed that the highest negative net order flows shock occurs in the early hours, between opening and 10am. As OMMs are main liquidity providers, they should absorb large positive inventories at lower prices of the day in the opening. As negative order flows pressures decrease during the day (Table 3), OMMs should be

trying to unwind their positive positions by selling at higher prices during the day, as the negative pressures are more likely to persist through the next day (Table 5). Their quotes get especially aggressive in the last hour before the closing, as OMMs are balancing their books towards optimal inventory levels and are pricing overnight risks of their inventories.[11] The overnight risks of OMMs inventories are most likely gamma and less so vega risks, as the price of underlying can change but changes in volatility take longer to realize.

On positive imbalance firm-days we find the results less consistent with those for the whole sample, and negative imbalance portfolios. For calls, the night return is -0.33%, it sharply increases during the day, and the day return is higher and positive, 0.53%, for the first sub-sample. In the second sub-period the difference between night (-0.14%) and day (0.28%) is less striking, but the day returns remains higher than the night return. The contrast between night and day return is even higher for puts, -0.55% (-0.8%) over the night, and 0.79% (0.34%) for the day for the first (second) sub-periods. On average the night returns are negative and higher in absolute values for the whole sample, and for negative imbalance firm-days, which is consistent with findings of MN (2019). However, for positive imbalance firm-days, positive day returns are significantly higher then negative night returns. While inconsistent with different day and nigh volatility pricing story (MN (2019)), this result however is consistent with inventory pressures caused by positive net order flows and OMMs optimal quoting strategies (Ho and Stall (1980)). As before, the opening mid-quotes are low, compared to the previous day closing mid-quote. The highest positive imbalance shock occurs between the opening and 10am (Table 3). As the first positive order imbalance shocks are realized, the options returns jump up substantially by 10am, reaching 0.17% for calls, and 0.22% for puts in the first sub-period, and to 0.3% for calls and puts in the second sub-period. While positive order imbalances continue through the day, OMMs continue selling at higher prices through the day, leading to monotonically increasing intra-day cumulative return pattern. The quotes are the most aggressive at the closing which results in one of the highest returns for the day. Most of these buying pressures reverse the next day (Table 5) which thus allows OMMs to cover their short positions at the next day open. The negative overnight returns on positive imbalance days can thus be considered as OMMs compensation for taking short position over-night risk.

[11] The bid-ask relative quoted spreads are approximately 10% to 13% higher at the closing compared to the rest of the day. It suggests that OMMs increasing activity on the ask side in the end of day widens the spreads.

It is also apparent, that in the second sub-sample, the results for calls look completely different, Panel B, Table 7. Here, unconditionally, the night return is zero, and the day return remains positive, 0.08%. For negative order imbalance firm-days the results look completely different to the rest of Table 7, as the night and day returns flip the signs. The night return is now positive, 0.15%, and the day return is negative, -0.10%. While it is inconsistent with different volatility pricing, it aligns almost perfectly with inventory price pressures. Under negative net order flows through out the end of day, which is our sorting variable, we would expect the day return to decrease monotonically, as OMMs should adjust their quotes to reverse price pressures. The positive night return would be a compensation to OMMs for holding overnight long position. It suggests that in the second sub-period OMMs become less aggressive in balancing their books in the last trading hour, and are able to continue purchasing at lower prices till the end of trading day. What enables them to do this? We defer this discussion to the next section where we consider an introduction of SPX options night trading as a hedge to overnight inventories.

For SPX options, Table 8, for both periods, we observe qualitatively similar results to those for equity options for the first sub-sample.

What are the applications of these findings? First, the main conclusion is that the closing end-of-day prices are not entirely representative of mid-quotes and option returns during the day, and are biased upwards. A simple uniform correction for an upward bias in option prices (Bloom and Stambaugh (1993)) as in the stock market, is not applicable. For options, conditional on net order flows, the biases can vary a lot. For example, the daily returns for negative imbalance portfolios are not nearly as high as daily returns for positive imbalance firm-day portfolios. For calls, the difference between negative and positive imbalance portfolio daily returns (from 9:40 am to 4pm) is 49 bps (=0.53%-0.04%), Panel A, Table 7, and it is 84 bps (=0.79%-(-0.04%)) for puts, Panel C, Table 7. In the end of positive imbalance trading day OMMs increase mid-quotes more aggressively. The difference between 3pm and 4pm intra-day returns for negative imbalance portfolios are 5 bps and 3 bps for calls and puts respectively. The differences for positive imbalance portfolios for the same hours are 12 bps and 13 bps for calls and puts respectively.

Second, while our results are consistent with inventory price pressures we cannot exclude other explanations, like different day and night volatility pricing (MN (2019)), or market wide mispricing due to incorrect treatment of stock variance during times of market closures, JS (2018).

Overnight inventory risk, and the premiums demanded by OMMs at the closing prices should only remain till this risk is not hedgeable during the night. An exogenous shock which would allow overnight hedging should eliminate differential pricing at the closing for negative imbalance firm-days, as OMMs should no longer require risk premium for holding excessive long positions, or they can afford taking more excessive long positions. Luckily, during our sample, we observe such an exogenous event.

4.3 Introduction of SPX options overnight trading.

On March 9 2015 CBOE extended traded hours for SPX options from 2:00am to 8:15am Central time(CT).[12] This provides ideal exogenous event in our sample to test overnight inventory risk explanation of our results. We therefore further split the second period, 2011 to 2017, in two sub-periods, 2011 to 2014, and 2015 to 2017. The last subperiod is a sub-sample where SPX options are traded in the night, and in the early morning hours before opening. If the value of over-night inventory changes between closing and 3:am (ET), OMMs can always re-adjust the hedge in the night or early morning with SPX options before equity options start trading. This, in the very last, should expand their inventory risk bearing capacities. Our numerous conversations with option market makers confirm that they use SPX options substantially to hedge their equity option positions. As the hedge becomes available, we expect to see lower inventory risks, and different quoting strategies.

Table 9 reports the analysis similar to Table 7 for two sub-samples of equity Calls, Panels A and B, and equity Puts, panels C and D for 2011-2014 and 2015-2017 sub-periods respectively. Consider first calls. While 2011-2014, Panel A, sample results look similar to those for 2004-2010 (Table 7, Panel A), in Panel B we observe completely different patterns. The day and nigh returns flip the sign for all imbalance days. The night return is now positive, 0.31%, and the day return is negative, -0.06%. As the majority of trading days are negative imbalances, the day return decreases through the day, with the last two hours having the lowest returns. This pattern is even more pronounced for negative order imbalance days. Here, the night return is 0.55%, and the end of day

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

return is -0.20%. Consistent with negative inventory price pressures, returns monotonically decrease during the day. The high and positive overnight return is a compensation to OMMs for taking excessive long position for the night. This is in sharp contrast to the negative imbalance days reported in Panel A. The only difference is that in Panel B sub-sample OMMs can now afford to take excess of long position as they can hedge it with SPX options in the over-night trading hours. The night return of 0.55% cannot be considered as the net profits to OMMs as we do not know how much they spend in extra overnight hedging/trading in SPX options.

Being able to take more of overnight long position results in faster liquidity provisions on positive imbalance days. Unlike for the first sub-sample, where the open to close return is 0.42%, and the night return is -0.28%, the day and night returns for the second sub-period are positive, with a small day return, 0.09%, and a statistically indifferent from zero night return, 0.05%. The highest return during the day is observed in the second sub-period between opening and 10am, 0.42% which is almost similar to the closing return on positive imbalance days in first sub-period. This suggests that the majority of positive imbalances are accommodated by OMMs in the early hours, and the prices converge to the opening prices by the end of trading day. This is an improvement compared to before introduction of SPX night trading, where on positive imbalance days, calls closing returns are substantially higher compared to the opening. We therefore observe significant improvement in overall equity options liquidity provisions after introduction of SPX night trading. The availability of overnight hedging allows OMMs expand their inventory risk bearing capacities and improve liquidity provisions.

Panels C and D compare overnight and day returns before and after introduction of SPX night trading for equity puts. Interestingly, the night returns for puts become even more negative after introduction of SPX night trading, Panel D, and day returns decrease substantially to become negative for all volume days, -0.07%, compared to sub-sample before, 0.20%. On negative and positive imbalance days, day put returns behave similarly to call returns reported in Panel B. Therefore for puts, while day returns change and became on average negative as one would expect under overall negative net order flows price pressures, even more negative night returns suggest that OMMs might be losing money on put inventories. However, given that calls are on average more active market compared to puts (Christoffersen et al (2018)), we expect that these losses should be limited and partially re-covered by inventory management in a more active call market.

Yet, it still remains puzzling the nature of more negative overnight returns in equity puts, given that they disappear in equity calls, and even in SPX options themselves, which we consider next, after introduction of over-night SPX trading.

Table 10 presents results similar to those in Table 9, but for SPX calls, Panels A and B, and puts, Panels C and D, for the periods before, 2011-2014, and after, 2015-2017, introduction of SPX over-night trading. Similar to the previous sub-sample, for 2011-2014 period, SPX calls have a positive day return, 0.25%, and a highly negative night return, -0.61%. This difference shrinks dramatically after introduction of SPX night trading, Panel B, 2015-2017, with the day return of -0.22 (t=2.46), and only marginally significant night return of -0.31 (t=2.1). For puts, for this period, Panel D, the night return is insignificantly different from zero, -0.33% (t=1.69), and the day return is -0.39% (t=3.43). For comparison, the day returns for puts in 2011-2014 sample are 0.48% (t=3.16), and the night return is -0.94% (t=11.96).

For negative order imbalance days both day and night returns for calls and puts in 2015-2017 sample, Panels B and D respectively, are small and statistically indifferent from zero. Interestingly, on positive imbalance days, the returns decrease through the day, with the closing return to be the most negative for calls and puts, -0.29% and -0.58% respectively. SPX options in this period are dominated by net buying pressures, which we discuss in the next table. OMMs are net-sellers and it appears they are decreasing bid-ask midpoints through the day to attract more buying demand from end-users. They do it more aggressively after introduction of SPX night trading. Interestingly, positive order imbalance day returns for SPX calls and puts in 2015-2017, where OMMs are net sellers look qualitatively similar to negative order imbalance firm day returns for S&P500 index constituents calls and puts in 2015-2017, where OMMs are net buyers. Net long equity call positions can be easily hedged by short SPX call positions, and similarly for puts.

Overall, the availability of overnight SPX trading allows for rebalancing hedge positions in the night hours, decreases the risks of taking overnight inventories, expands OMMs risk bearing capacities, and helps explaining different return patterns and day quotes we observe between different sub-periods.

Table 11 presents summary statistics for SPX calls and puts cumulative order imbalances for two consecutive days (COIM(t) and COIM(t-1)), order imbalances by hour of a day (1h-OIM), average number of trades per hour, average number of contracts traded per hour, and average dollar volume

of contracts traded by hour before and after introduction of overnight trading, 2011-2014 vs 2015-2017 sub-periods. We focus the discussion here on statistics we are primarily interested in. In particular, the introduction of overnight trading should decrease dollar day trading volume, as the hedging activities can now shirt to the night. We also expect lower opening, 9:30am to 10am, imbalances, as the overnight trading allows to shift rebalancing hedged positions until 9:15am before the market opens. Overall, we expect volumes and imbalances to decrease during trading daylight hours.

This is indeed confirmed in the data. For calls, Panels A and B, the average last trading hour volume decrease by 23%, from $20541 to $15573. The opening imbalances on negative net order flow days decrease by 51% (from -10.51% to -5.13%), and by 39% for positive net order flow days (from 9.96% to 6.07%). Qualitatively similar statistics are observed for puts, Panels C and D. This confirms that significant portion of trading volume which is most likely related to overnight hedging has migrated into the night trading hours.

As a counterfactual, in the next section we consider week-end returns. SPX overnight trading is only during week-days and does not extend into week-ends.

5. Trading vs. Non-trading periods.

5.1 Week-end Returns

In the recent paper, Jones and Shemesh (2018) find that option returns are significantly lower over nontrading periods, majority of which are week-ends. The authors find that their results are more consistent with differential treatment of stock return variance between trading and non-trading periods by option traders.

In the context of our results, we hypothesize, that end-of-day prices which are outcomes of net order flow price pressures, may contribute to the explanations of week-end effect in option returns as well. More specifically, we expect OMMs to be more aggressive in managing their books by the end of Friday, compared to any other day of the week, as covering their imbalances in the next open is delayed by two days of week-end, and hence higher and longer uncertainty time interval and inventory risks. Therefore, higher end of day mid-quotes documented above should be observed even more so on Fridays. This too will lead to more negative week-end returns documented by Jones and Shemesh (2018). However, if demand pressures are part of the

explanation, the difference in returns should be less pronounced for mid-day quotes, and even less in the early hours when OMMs have to accommodate the highest liquidity demands, and before they start balancing their inventory\ies going into non-trading periods.

To compare week-end 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 we use OptionMetrcis deltas to delta-hedge options returns. Similar to the authors, the week-end return is measured from Friday close to Monday close, where Monday is considered as the end of non-trading week-end period.

Table 12 presents results for equity calls and puts for two sub-periods. Consider Panel A, call returns for 2004-2010. The first two columns compare non-trading period returns versus trading period returns, where non-trading and trading return estimates are pooled together. The delta-hedged returns are first computed on a contract level, then value-weighted return is computed on a class level using previous day dollar open interest as a weight, and then averaged on a portfolio level across all stocks. Similar to Jones and Shemesh (JS) (2018), using 4 pm quote, we find significant negative non-trading period returns, -0.77%, and positive trading period returns, 0.10%. The difference of -0.87% is statistically significant and economically large[13]. Similar to JS (2018) we also obtain the highest negative return on Monday, -0.73%, with all other days of the week having lower in absolute values returns. As in JS (2018), we find that Wednesday and Thursday returns are positive, with Friday returns being the second most negative return of the week. We therefore replicate JS (2018) results in our sample using 4pm quotes.

The results are different if we compute returns using 10 am quotes. Here, both non-trading and trading period returns are negative, -1.72% and -1.41% respectively, and the difference between mean returns of -31 bps is statistically significant. As the sample size is large, most of t-statistics are significant.

For 10 am quote, compared to 4 pm quote, the difference in returns between non-trading vs trading periods decreased by almost a factor of 3 in absolute value (from -87 bps to -31 bps). This sharp fall in the difference between means cannot be attributed to the differential treatment of stock volatility, and is rather consistent with our explanation of net order flows dynamics and OMMs

[13] 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.

inventory management through the trading day. Therefore, while volatility can still be important to explain 31 bps difference, the majority of the return differences in our sample is due to option net order flows price pressures in the morning and OMMs rebalancing their inventories by the end of day. As the trading continues during the day, the return difference monotonically increases in absolute values.

For 10 am quotes, Monday returns are no longer the most negative as for 4 pm quotes. The most negative return is actually observed on the trading day, Wednesday, -1.80%. Qualitatively similar results are also observed in more recent, 2011-2017 period for calls, Panel B. For 4pm quote, the difference between non-trading and trading period returns is -86 bps, and it drops (in absolute value) to -0.23% for 10 am quote. Monday returns are the most negative for the week with 4 pm quote, and Tuesday with 10 am quote.

For puts, Panels C and D, we find qualitatively similar results too, except that the volatility story becomes less important. The difference in returns between non-trading and trading periods is -0.77% and -1.11% for first and second sub-periods for 4pm quotes. For 10 am quotes this difference drops (in absolute values) to -0.14% and -0.18% respectively. Therefore, the majority of return difference for puts is explained by net order flows price pressures.

With 4 pm quotes we find even bigger differences between non-trading and trading periods for SPX option returns in Table 13. It is almost -1% for calls for both sub-periods, Panels A and B, and -1.4% for puts, Panels C and D. However, the volatility explanation only matters for calls in the second sub-periods, Panel B, where for 10 am quotes the difference in means drops to -0.69%. The return difference for calls in the first sub-period, Panel A, and for puts in the first, Panel C, and second, Panel D, sub periods is statistically indistinguishable from zero for 10 am quotes. It suggests that for index options, price pressures caused by net order flows rather than differential treatment of sock volatility is the main explanation behind different non-trading and trading returns using 4pm quotes.

We conclude that net order imbalances and their dynamics can help explain previously puzzling results in the literature on different day and night returns (Muravyev and Ni (2019)), and different non-trading versus trading returns (JS (2018)).

5.2 Equity Options Week-end Returns after Introduction of SPX Night Trading.

In Table 9, Panel B we discuss how day and night returns flip the signs for equity call options after introduction of SPX night trading. The table however analyzes all days, week-days and week-ends, while SPX night trading does not extend over week-ends, and OMMs therefore cannot rebalance their hedges from Friday close to Monday open. As a counterfactual to Table 9 results, we expect the week-end effect, i.e. high negative returns on Monday, to remain. However, since the night returns on week days are positive, and day returns are moderately negative, we expect 24 –hour returns based on 4pm mid-quotes for week-days to become at least less negative or even positive.

Table 14 presents results similar to those in Table 12, but for sub-sample after introduction of SPX night trading, 2015-2017, for equity calls, Panel A, and puts, Panel B. For calls, the trading period return is positive and almost twice in magnitude compared to 2004-2010 sub-period for 4pm mid-quote in Table 12, Panel A. Monday returns remain the most negative and drive the difference between trading and non-trading periods for 4pm mid-quote based returns. The returns for all other week-days, when overnight hedging is available, are both positive and significant or zero on Fridays. While JS (2018) find that the positive returns on Wednesdays and Thursdays in their sample are anomalous, we also find positive returns for Tuesdays, which confirms our hypothetical predictions.

For Puts, Panel B, we observe qualitatively similar results. For 4pm quote-based returns, Mondays have the most negative returns, while the rest of week-day returns are largely insignificant. Only on Fridays we observe significantly negative returns, -0.21%, but they decrease almost by a factor of two in absolute value after introduction of SPX night trading, compared to the first sub-period, -0.51% (Table 12 Panel C). Overall, as the nigh hedging becomes accessible for week-days, and not week-ends, the negative week-end return still remains significant.

5.3 Discussion.

If a researcher uses 10am quote, then all returns, trading or non-trading periods, look quite similar for both calls and puts. The morning quotes reflect the highest activity in the option market and do not capture OMMs quote responses to inventory pressures. They capture the period of the highest liquidity demand by end-users. Mid-day quotes, 12 pm, reflect both OMMs partially adjusting

quotes with respect to demand pressures, and the beginning of slowdown in net demand pressures for a day. Noon mid-quotes therefore capture the middle activity of options market for both demand and supply sides. Using these quotes decreases the differences between trading and non-trading returns, or day and night returns. Returns based on 4pm quotes are biased the most however.

What is the best quote to use to compute option returns? To our knowledge, only one paper in options literature, Coval and Shumway (2001), uses 10am quotes to estimate option returns. The authors write: "For each option, we identify the first bid-ask quote after 9 a.m. Central Standard Time (CST)". They thus use the first mid-quote after 10 am (ET). The rest of literature use 4pm mid-quotes without exceptions. While we do not know an obvious reason of why Coval and Shumway (2001) use 10 am quotes, our analysis shows that these quotes reflect the returns when liquidity demand is the highest and thus are more representative of what end-users actually pay for immediacy.

6. Conclusion

The main message of this paper is that daily, 24- hour, delta-hedged returns based on closing bid-ask midpoints to proxy for an intra-day option prices are not representative of what end-users actually gain. These delta-hedged returns are biased upward and reflect a mark-up or a premium for options market makers overnight inventory holding costs before introduction of SPX night trading.

After introduction of SPX night trading, which allows OMMs to hedge inventory night risks in the night and before the market opens, these returns are still biased upward, and even more so. These holds for both, equity and SPX options. As the majority of trading days are negative order imbalance days, net selling price pressures result in the lowest day returns if one uses 4pm closing mid-quotes as a proxy for options intra-day prices. These are not the prices an average investor pays, as the next day night return is highly positive as the option market opens up. The positive nigh returns compensate OMMs for holding and rebalancing long inventory positions in the night

but does reflect gains or losses for an average investor. As a result, positive night returns outweigh negative day returns, which results in overly high 24-hour returns.

Our results have a few applications. First, introduction of SPX night trading helps significantly to options market makers to extend their liquidity provision services and take larger excess of inventories into after hours. We observe these improvements for both equity and index options. Moreover, the dynamics of net order imbalances in SPX options becomes less volatile, and price pressures in the early opening hours during a day decrease substantially. As liquidity providers are able to extend their services, the end-users should benefit as well.

Second, our results bring a new prospective on what time of a day it is better to trade from end-users' point of view. For example, Muravyev and Pearson (2019) argue that one can time liquidity during a day, and thus pay substantially lower trading costs in the options market. The authors do not say however when it is better to time liquidity. Our results show, providing that on average end-users are writing options, that early day trading hours is the best time to execute trades. If one wants to purchase however, then late afternoon, before market closes is the best time.

Third, our results leave a lot of room for future research. We do not know how existing conclusions in the literature can change once researchers stop using 4pm closing prices to compute option returns, option greeks, implied volatilities, volatility risk premiums, or risk neutral moments. In our analysis, while we confirm different day and night returns of Muravyev and Ni (2019), and different non-trading and trading period returns of Jones and Shemesh (2018), we provide an alternative explanation for these puzzling results. Why we do not eliminate completely explanations proposed in original papers, which rely on different day and night volatility (Muravyev and Ni (2019)), or different non-trading and trading period volatility treatments by end-users (Jones and Shemesh (2018)), we show that the large majority of these effects is driven by OMMs inventory rebalancing and non-trading period inventory holding risks. We leave it for future research to identify what other option-based anomalies can be explained by our results.

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Table 1. Summary Statistics: Equity Options

The table reports daily summary statistics for call, Panel A, and put, Panel B, options of S&P500 components for 2004 to 2010, and 2011 – 2017 subperiods. *OIM* are option net order imbalances computed from intraday transactions where buy or sell trades are signed using tick rule. R^O is delta-hedged option returns.

Panel A. Call options, 2004-2010

	N (firm/day)	OIM	R^O	R^O Std	R^O P1	R^O P50	R^O P99
All	528,191	-0.0481	-0.0006	0.1066	-0.1436	-0.0060	0.2009
OIM<0	294,183	-0.2656	-0.0025	0.0971	-0.1325	-0.0072	0.1795
OIM>0	222,682	0.2393	0.0016	0.0985	-0.1399	-0.0045	0.2049

Panel B. Call options, 2011-2017

	N (firm/day)	OIM	R^O	R^O Std	R^O P1	R^O P50	R^O P99
All	631,040	-0.0176	0.0011	0.2220	-0.1469	-0.0064	0.2081
OIM<0	332,967	-0.2254	0.0009	0.2377	-0.1375	-0.0068	0.1955
OIM>0	293,159	0.2183	0.0013	0.2025	-0.1508	-0.0058	0.2163

Panel C. Put options, 2004-2010

	N (firm/day)	OIM	R^O	R^O Std	R^O P1	R^O P50	R^O P99
All	468,633	-0.0266	-0.0014	0.1222	-0.1275	-0.0053	0.1885
OIM<0	243,700	-0.2582	-0.0050	0.1188	-0.1221	-0.0074	0.1562
OIM>0	211,977	0.2397	0.0026	0.1232	-0.1205	-0.0027	0.2071

Panel D. Put options, 2011-2017

	N (firm/day)	OIM	R^O	R^O Std	R^O P1	R^O P50	R^O P99
All	586,002	-0.0099	-0.0050	0.2375	-0.1517	-0.0077	0.2056
OIM<0	300,856	-0.2131	-0.0064	0.2013	-0.1442	-0.0087	0.1857
OIM>0	278,749	0.2095	-0.0036	0.2718	-0.1538	-0.0066	0.2220

Table 2. Summary Statistics: SPX Options

The table reports daily summary statistics for call, Panel A, and put, Panel B, SPX options for 2004 - 2010, and 2011 – 2017 subperiods. *OIM* are option net order imbalances computed from intraday transactions where buy or sell trades are signed using tick rule. R^O is delta-hedged option returns.

Panel A. SPX Call options, 2004-2010

	N	OIM	R^O	R^O Std	R^O P1	R^O P50	R^O P99
All	1,754	-0.0191	-0.0053	0.0438	-0.1017	-0.0093	0.1529
OIM<0	965	-0.1269	-0.0067	0.0417	-0.0992	-0.0099	0.1443
OIM>0	781	0.1142	-0.0037	0.0464	-0.1250	-0.0091	0.1656

Panel B. SPX Call options, 2011-2017

	N	OIM	R^O	R^O Std	R^O P1	R^O P50	R^O P99
All	1,749	-0.0184	-0.0033	0.0377	-0.0910	-0.0060	0.1229
OIM<0	958	-0.1107	-0.0027	0.0375	-0.0934	-0.0052	0.1229
OIM>0	790	0.0936	-0.0040	0.0379	-0.0910	-0.0072	0.1242

Panel C. SPX Put options, 2004-2010

	N	OIM	R^O	R^O Std	R^O P1	R^O P50	R^O P99
All	1,754	-0.0050	-0.0013	0.0633	-0.0699	-0.0111	0.1896
OIM<0	885	-0.0745	-0.0006	0.0472	-0.0690	-0.0109	0.1896
OIM>0	861	0.0665	-0.0021	0.0765	-0.0735	-0.0117	0.1984

Panel D. SPX Put options, 2011-2017

	N	OIM	R^O	R^O Std	R^O P1	R^O P50	R^O P99
All	1,749	-0.0004	-0.0048	0.0561	-0.0937	-0.0134	0.2442
OIM<0	836	-0.0490	-0.0015	0.0601	-0.0927	-0.0118	0.2478
OIM>0	912	0.0442	-0.0079	0.0520	-0.0943	-0.0151	0.2328

Table 3. Order Imbalances Portfolio Sorts by Hour of a Day: 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 2004 to 2010, and 2011 – 2017 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. *COIM(t-1)* is cumulative options net order imbalance on day *t-1* for a given hour of a day. The last column of each panel reports order imbalances summed by hour on day t (non-cumulative), *1h –OIM. All* reports hourly statistics without conditioning on net order flows. *Negative (Positive) Order Imbalances* report hourly statistics for portfolio sorted on *COIM(t)<0 (COIM(t)>0)* for that hour of a day *t*. *COIM(t)* for 10am is cumulative order imbalances between 9:30am and 10am, *COIM(t-1)* is corresponding order imbalances for the same time interval the day before. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Call Options, 2004-2010

time	R^O	t-stat	COIM(T)	COIM(T-1)	1h -OIM
			All		
10:00:00	-0.0144	-96.81	-0.0355	-0.0358	-0.0355
11:00:00	-0.0108	-73.06	-0.0446	-0.0449	-0.0496
12:00:00	-0.0083	-57.25	-0.0486	-0.0488	-0.0577
13:00:00	-0.0069	-46.50	-0.0495	-0.0497	-0.0566
14:00:00	-0.0054	-35.73	-0.0493	-0.0500	-0.0556
15:00:00	-0.0033	-21.48	-0.0487	-0.0492	-0.0526
16:00:00	-0.0006	-4.28	-0.0479	-0.0479	-0.0494
			Negative Order Imbalances		
10:00:00	-0.0174	-74.36	-0.4314	-0.0421	-0.4314
11:00:00	-0.0124	-68.25	-0.4073	-0.0537	-0.3425
12:00:00	-0.0094	-53.55	-0.3945	-0.0581	-0.2804
13:00:00	-0.0078	-45.05	-0.3860	-0.0601	-0.2437
14:00:00	-0.0062	-35.63	-0.3789	-0.0621	-0.2237
15:00:00	-0.0042	-24.41	-0.3717	-0.0626	-0.2134
16:00:00	-0.0017	-10.48	-0.3640	-0.0623	-0.2071
			Positive Order Imbalances		
10:00:00	-0.0172	-72.52	0.4262	-0.0129	0.4262
11:00:00	-0.0112	-55.17	0.3970	-0.0223	0.3117
12:00:00	-0.0080	-44.25	0.3827	-0.0259	0.2250
13:00:00	-0.0061	-35.09	0.3735	-0.0267	0.1803
14:00:00	-0.0043	-25.10	0.3661	-0.0257	0.1582
15:00:00	-0.0018	-10.80	0.3587	-0.0245	0.1505
16:00:00	0.0011	6.99	0.3499	-0.0226	0.1480

Panel B. Call Options, 2011-2017

time	R^O	t-stat	COIM(T)	COIM(T-1)	1h -OIM
			All		
10:00:00	-0.0129	-52.93	-0.0084	-0.0098	-0.0092
11:00:00	-0.0084	-26.30	-0.0155	-0.0169	-0.0233
12:00:00	-0.0064	-23.37	-0.0169	-0.0182	-0.0261
13:00:00	-0.0048	-19.64	-0.0175	-0.0188	-0.0283
14:00:00	-0.0029	-9.74	-0.0182	-0.0194	-0.0293
15:00:00	-0.0013	-5.46	-0.0176	-0.0187	-0.0244
16:00:00	0.0011	3.72	-0.0176	-0.0184	-0.0251
			Negative Order Imbalances		
10:00:00	-0.0141	-45.51	-0.4184	-0.0241	-0.4158
11:00:00	-0.0090	-28.00	-0.3900	-0.0319	-0.3326
12:00:00	-0.0064	-21.29	-0.3759	-0.0332	-0.2651
13:00:00	-0.0050	-20.87	-0.3669	-0.0337	-0.2297
14:00:00	-0.0030	-10.00	-0.3596	-0.0345	-0.2108
15:00:00	-0.0017	-7.69	-0.3524	-0.0347	-0.1999
16:00:00	0.0006	2.02	-0.3447	-0.0354	-0.1929
			Positive Order Imbalances		
10:00:00	-0.0167	-48.03	0.4189	0.0067	0.4167
11:00:00	-0.0107	-34.48	0.3895	0.0006	0.3158
12:00:00	-0.0081	-40.53	0.3758	-0.0011	0.2391
13:00:00	-0.0057	-25.44	0.3667	-0.0020	0.1969
14:00:00	-0.0037	-13.43	0.3592	-0.0024	0.1746
15:00:00	-0.0017	-7.37	0.3519	-0.0009	0.1694
16:00:00	0.0006	2.47	0.3432	0.0003	0.1610

Panel C. Put Options, 2004-2010

time	R^O	t-stat	COIM(T)	COIM(T-1)	1h -OIM
			All		
10:00:00	-0.0155	-88.72	-0.0222	-0.0213	-0.0219
11:00:00	-0.0115	-56.10	-0.0258	-0.0245	-0.0273
12:00:00	-0.0089	-38.07	-0.0278	-0.0263	-0.0305
13:00:00	-0.0074	-32.71	-0.0284	-0.0271	-0.0291
14:00:00	-0.0058	-25.08	-0.0279	-0.0263	-0.0252
15:00:00	-0.0037	-15.96	-0.0278	-0.0260	-0.0260
16:00:00	-0.0014	-7.54	-0.0266	-0.0248	-0.0216
			Negative Order Imbalances		
10:00:00	-0.0183	-74.51	-0.3966	-0.0326	-0.3919
11:00:00	-0.0128	-42.13	-0.3787	-0.0370	-0.3186
12:00:00	-0.0099	-33.67	-0.3687	-0.0403	-0.2581
13:00:00	-0.0084	-30.39	-0.3620	-0.0418	-0.2242
14:00:00	-0.0068	-24.85	-0.3565	-0.0421	-0.2042
15:00:00	-0.0049	-18.38	-0.3511	-0.0429	-0.1987
16:00:00	-0.0031	-15.31	-0.3451	-0.0432	-0.1897
			Positive Order Imbalances		
10:00:00	-0.0175	-63.81	0.3868	0.0007	0.3838
11:00:00	-0.0114	-47.63	0.3661	-0.0023	0.2983
12:00:00	-0.0083	-38.47	0.3551	-0.0024	0.2269
13:00:00	-0.0063	-30.63	0.3483	-0.0020	0.1916
14:00:00	-0.0044	-21.37	0.3425	-0.0009	0.1740
15:00:00	-0.0019	-8.98	0.3364	0.0003	0.1661
16:00:00	0.0007	3.40	0.3300	0.0026	0.1624

Panel D. Put Options, 2011-2017

time	R^O	t-stat	COIM(T)	COIM(T-1)	1h -OIM
			All		
10:00:00	-0.0193	-58.36	0.0018	-0.0005	0.0014
11:00:00	-0.0152	-48.76	-0.0063	-0.0078	-0.0117
12:00:00	-0.0129	-37.26	-0.0089	-0.0100	-0.0146
13:00:00	-0.0105	-31.99	-0.0098	-0.0111	-0.0151
14:00:00	-0.0087	-27.16	-0.0098	-0.0112	-0.0126
15:00:00	-0.0066	-23.70	-0.0101	-0.0115	-0.0129
16:00:00	-0.0050	-15.03	-0.0100	-0.0111	-0.0114
			Negative Order Imbalances		
10:00:00	-0.0198	-46.63	-0.3758	-0.0179	-0.3727
11:00:00	-0.0144	-44.24	-0.3538	-0.0268	-0.3068
12:00:00	-0.0123	-31.07	-0.3433	-0.0291	-0.2463
13:00:00	-0.0098	-30.18	-0.3364	-0.0297	-0.2135
14:00:00	-0.0075	-28.76	-0.3303	-0.0304	-0.1935
15:00:00	-0.0057	-22.83	-0.3246	-0.0319	-0.1899
16:00:00	-0.0042	-15.78	-0.3179	-0.0322	-0.1779
			Positive Order Imbalances		
10:00:00	-0.0229	-44.87	0.3726	0.0162	0.3705
11:00:00	-0.0164	-43.95	0.3497	0.0132	0.2949
12:00:00	-0.0125	-42.72	0.3379	0.0110	0.2282
13:00:00	-0.0100	-32.17	0.3304	0.0100	0.1925
14:00:00	-0.0083	-24.87	0.3245	0.0102	0.1758
15:00:00	-0.0061	-20.63	0.3182	0.0116	0.1723
16:00:00	-0.0042	-12.20	0.3111	0.0126	0.1617

Table 4. Order Imbalances Portfolio Sorts by Hour of a Day: SPX Options

The table presents average portfolio delta hedged daily returns using different hour of a day mid-quotes for call and put SPX options of for 2004 to 2010, and 2011 – 2017 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. *COIM(t-1)* is cumulative options net order imbalance on day *t-1* for a given hour of a day. The last column of each panel reports order imbalances summed by hour on day t (non-cumulative), *1h –OIM. All* reports hourly statistics without conditioning on net order flows. *Negative (Positive) Order Imbalances* report hourly statistics for portfolio sorted on *COIM(t)<0 (COIM(t)>0)* for that hour of a day *t*. *COIM(t)* for 10am is cumulative order imbalances between 9:30am and 10am, *COIM(t-1)* is corresponding order imbalances for the same time interval the day before. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SPX Call Options, 2004-2010

time	R^O	t-stat	COIM(T)	COIM(T-1)	1h -OIM
			All		
10:00:00	-0.0209	-18.01	-0.0180	-0.0153	-0.0144
11:00:00	-0.0183	-16.55	-0.0288	-0.0296	-0.0182
12:00:00	-0.0159	-14.93	-0.0244	-0.0254	-0.0093
13:00:00	-0.0149	-14.20	-0.0228	-0.0235	-0.0048
14:00:00	-0.0132	-12.20	-0.0223	-0.0231	-0.0090
15:00:00	-0.0101	-10.37	-0.0241	-0.0252	-0.0181
16:00:00	-0.0053	-5.06	-0.0265	-0.0276	-0.0077
			Negative Order Imbalances		
10:00:00	-0.0285	-21.27	-0.4338	-0.0043	-0.4107
11:00:00	-0.0205	-18.75	-0.4151	-0.0317	-0.3195
12:00:00	-0.0170	-16.32	-0.4006	-0.0329	-0.2246
13:00:00	-0.0155	-15.33	-0.3894	-0.0268	-0.1693
14:00:00	-0.0135	-13.36	-0.3835	-0.0279	-0.1617
15:00:00	-0.0103	-10.86	-0.3769	-0.0307	-0.1530
16:00:00	-0.0052	-4.74	-0.3705	-0.0345	-0.1396
			Positive Order Imbalances		
10:00:00	-0.0289	-22.38	0.4282	-0.0129	0.4071
11:00:00	-0.0218	-17.61	0.4005	-0.0288	0.3115
12:00:00	-0.0180	-15.13	0.3845	-0.0188	0.2183
13:00:00	-0.0166	-14.21	0.3764	-0.0206	0.1737
14:00:00	-0.0143	-11.96	0.3713	-0.0168	0.1518
15:00:00	-0.0109	-10.20	0.3631	-0.0185	0.1268
16:00:00	-0.0057	-5.20	0.3551	-0.0208	0.1383

Panel B. SPX Call Options, 2011-2017

time	R^O	t-stat	COIM(T)	COIM(T-1)	1h -OIM
			All		
10:00:00	-0.0146	-20.77	0.0026	0.0000	0.0045
11:00:00	-0.0120	-18.51	-0.0140	-0.0136	-0.0142
12:00:00	-0.0101	-15.09	-0.0118	-0.0129	0.0014
13:00:00	-0.0087	-13.30	-0.0149	-0.0159	-0.0064
14:00:00	-0.0074	-11.95	-0.0176	-0.0194	-0.0049
15:00:00	-0.0058	-8.96	-0.0188	-0.0204	-0.0022
16:00:00	-0.0033	-4.34	-0.0189	-0.0199	-0.0027
			Negative Order Imbalances		
10:00:00	-0.0187	-22.71	-0.4538	-0.0038	-0.4184
11:00:00	-0.0135	-19.04	-0.4365	-0.0174	-0.3326
12:00:00	-0.0108	-14.75	-0.4264	-0.0244	-0.2310
13:00:00	-0.0089	-12.43	-0.4189	-0.0254	-0.1939
14:00:00	-0.0075	-11.41	-0.4102	-0.0297	-0.1507
15:00:00	-0.0058	-8.97	-0.4054	-0.0304	-0.1420
16:00:00	-0.0034	-4.38	-0.3958	-0.0315	-0.1342
			Positive Order Imbalances		
10:00:00	-0.0199	-21.08	0.4583	0.0047	0.4263
11:00:00	-0.0146	-18.96	0.4335	-0.0149	0.3198
12:00:00	-0.0118	-15.94	0.4187	-0.0001	0.2397
13:00:00	-0.0097	-14.11	0.4104	-0.0069	0.1894
14:00:00	-0.0080	-12.20	0.4020	-0.0116	0.1531
15:00:00	-0.0061	-8.89	0.3966	-0.0122	0.1434
16:00:00	-0.0033	-4.14	0.3856	-0.0097	0.1391

Panel C. SPX Put Options, 2004-2010

time	R^O	t-stat	COIM(T)	COIM(T-1)	1h -OIM
			All		
10:00:00	-0.0170	-22.54	-0.0385	-0.0321	-0.0168
11:00:00	-0.0143	-18.03	-0.0342	-0.0325	-0.0102
12:00:00	-0.0121	-14.83	-0.0378	-0.0361	-0.0187
13:00:00	-0.0106	-11.50	-0.0363	-0.0364	-0.0133
14:00:00	-0.0085	-7.09	-0.0358	-0.0366	-0.0039
15:00:00	-0.0045	-2.58	-0.0323	-0.0332	-0.0105
16:00:00	-0.0013	-0.80	-0.0288	-0.0278	0.0052
			Negative Order Imbalances		
10:00:00	-0.0207	-22.45	-0.3814	-0.0270	-0.3121
11:00:00	-0.0155	-17.77	-0.3517	-0.0327	-0.2293
12:00:00	-0.0123	-13.63	-0.3412	-0.0421	-0.1758
13:00:00	-0.0107	-11.05	-0.3316	-0.0452	-0.1278
14:00:00	-0.0083	-6.42	-0.3226	-0.0453	-0.1014
15:00:00	-0.0046	-2.72	-0.3150	-0.0391	-0.0925
16:00:00	-0.0011	-0.69	-0.3065	-0.0321	-0.0739
			Positive Order Imbalances		
10:00:00	-0.0216	-24.51	0.3490	-0.0221	0.3028
11:00:00	-0.0160	-18.26	0.3241	-0.0193	0.2269
12:00:00	-0.0134	-16.04	0.3058	-0.0259	0.1523
13:00:00	-0.0113	-9.83	0.3017	-0.0276	0.1124
14:00:00	-0.0091	-6.76	0.2949	-0.0264	0.1029
15:00:00	-0.0050	-2.74	0.2860	-0.0289	0.0780
16:00:00	-0.0016	-0.94	0.2781	-0.0242	0.0903

Panel D. SPX Put options, 2011-2017

time	R^O	t-stat	COIM(T)	COIM(T-1)	1h -OIM
			All		
10:00:00	-0.0166	-11.23	-0.0053	-0.0043	0.0018
11:00:00	-0.0148	-17.03	-0.0007	-0.0026	0.0094
12:00:00	-0.0129	-15.15	-0.0029	-0.0030	0.0021
13:00:00	-0.0114	-12.57	-0.0043	-0.0045	-0.0049
14:00:00	-0.0099	-10.77	-0.0039	-0.0042	0.0047
15:00:00	-0.0078	-7.19	-0.0048	-0.0058	-0.0005
16:00:00	-0.0048	-3.65	-0.0065	-0.0062	-0.0082
			Negative Order Imbalances		
10:00:00	-0.0187	-11.85	-0.3249	-0.0055	-0.2867
11:00:00	-0.0155	-17.36	-0.2992	-0.0044	-0.1979
12:00:00	-0.0134	-15.90	-0.2871	-0.0061	-0.1414
13:00:00	-0.0116	-13.02	-0.2769	-0.0098	-0.1104
14:00:00	-0.0102	-11.14	-0.2690	-0.0073	-0.0956
15:00:00	-0.0079	-7.33	-0.2630	-0.0092	-0.0847
16:00:00	-0.0051	-3.95	-0.2523	-0.0082	-0.0899
			Positive Order Imbalances days		
10:00:00	-0.0198	-13.86	0.3195	-0.0002	0.2893
11:00:00	-0.0158	-17.25	0.2928	0.0058	0.2068
12:00:00	-0.0132	-14.60	0.2784	0.0020	0.1392
13:00:00	-0.0114	-12.09	0.2682	-0.0003	0.0966
14:00:00	-0.0097	-9.85	0.2595	-0.0025	0.1001
15:00:00	-0.0076	-6.75	0.2520	-0.0035	0.0802
16:00:00	-0.0046	-3.41	0.2397	-0.0048	0.0706

Table 5. Day-to-Day Dynamics of Order Imbalances: 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 2004 to 2010, and 2011 – 2017 subperiods. R^O is a delta-hedged option return on day *t*. *COIM(t-1)* is cumulative options net order imbalance on day *t-1* for a given hour of a day. *1h –OIM* are order imbalances summed by hour of a day *t* (non-cumulative). For each trading hour on day *t* options are sorted in quintile portfolios based on *COIM(t-1)* for that hour on the previous day t-1. R^O are average returns of quintile portfolios on day t. # trades (1h-#contracts) is an average number of trades (number of contracts traded) computed across all series in each portfolio for a given hour of day t. 1h-$$volume is an average portfolio dollar volume for a given hour (non-cumulative) of day t. For 10 am – it is only a 30 min interval, from 9:30am to 10am. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Portfolio Sort on previous day Cumulative Imbalances by hour, Calls, 2004-2010

Time	Portfolio	R^O	t-stat	COIM(T-1)	# trades	1h -OIM	1h -# contracts	1h-$$volume
10:00:00	Low	-0.0127	-33.45	-0.5544	4	-0.0582	54	105.18
10:00:00	2	-0.0167	-55.87	-0.2916	6	-0.0386	67	150.68
10:00:00	3	-0.0143	-39.35	-0.0530	12	-0.0272	90	233.11
10:00:00	4	-0.0144	-46.29	0.2072	7	-0.0173	77	183.39
10:00:00	High	-0.0104	-35.59	0.5126	5	-0.0164	56	116.21
	Low-High	-0.0023	-4.74					
11:00:00	Low	-0.0102	-29.80	-0.5261	4	-0.0808	76	153.10
11:00:00	2	-0.0129	-41.31	-0.2643	5	-0.0550	98	213.50
11:00:00	3	-0.0111	-30.37	-0.0568	8	-0.0396	124	295.55
11:00:00	4	-0.0102	-34.56	0.1578	10	-0.0340	113	257.87
11:00:00	High	-0.0076	-26.36	0.4647	4	-0.0358	81	162.60
	Low-High	-0.0026	-5.68					
12:00:00	Low	-0.0090	-33.63	-0.5123	4	-0.0899	66	127.74
12:00:00	2	-0.0100	-28.59	-0.2533	5	-0.0612	85	179.41
12:00:00	3	-0.0089	-26.78	-0.0586	9	-0.0501	100	235.89
12:00:00	4	-0.0078	-26.50	0.1383	6	-0.0456	95	215.31
12:00:00	High	-0.0053	-17.73	0.4418	4	-0.0424	75	154.85
	Low-High	-0.0037	-9.29					
13:00:00	Low	-0.0079	-29.88	-0.5027	4	-0.0868	61	117.19
13:00:00	2	-0.0087	-26.36	-0.2446	5	-0.0629	73	152.80
13:00:00	3	-0.0071	-19.06	-0.0578	9	-0.0498	87	199.66
13:00:00	4	-0.0062	-21.59	0.1285	7	-0.0454	83	185.37
13:00:00	High	-0.0041	-14.93	0.4282	4	-0.0426	69	139.30
	Low-High	-0.0038	-10.05					
14:00:00	Low	-0.0065	-24.57	-0.4954	4	-0.0890	57	107.98
14:00:00	2	-0.0068	-20.04	-0.2378	5	-0.0654	69	139.27
14:00:00	3	-0.0059	-16.76	-0.0565	9	-0.0489	82	192.25
14:00:00	4	-0.0044	-13.21	0.1218	7	-0.0411	80	179.47
14:00:00	High	-0.0030	-12.01	0.4181	4	-0.0404	66	133.23
	Low-High	-0.0036	-9.85					
15:00:00	Low	-0.0051	-15.69	-0.4879	4	-0.0866	66	121.82
15:00:00	2	-0.0048	-14.15	-0.2302	5	-0.0604	74	152.27
15:00:00	3	-0.0040	-12.66	-0.0543	9	-0.0449	86	198.10
15:00:00	4	-0.0020	-5.77	0.1172	7	-0.0390	82	183.70
15:00:00	High	-0.0009	-3.35	0.4091	4	-0.0382	73	151.15
	Low-High	-0.0042	-10.21					
16:00:00	Low	-0.0030	-11.21	-0.4804	3	-0.0839	63	116.39
16:00:00	2	-0.0020	-5.84	-0.2220	5	-0.0571	80	162.14
16:00:00	3	-0.0006	-1.66	-0.0515	9	-0.0423	96	220.78
16:00:00	4	0.0007	2.26	0.1131	6	-0.0373	94	211.97
16:00:00	High	0.0014	5.51	0.4013	4	-0.0328	73	148.82
	Low-High	-0.0043	-11.98					

Panel B. Portfolio Sort on previous day Cumulative Imbalances by hour, Calls, 2011-2017

Time	Portfolio	R^O	t-stat	COIM(T-1)	# trades	1h -OIM	1h -# contracts	1h-$$volume
10:00:00	Low	-0.0123	-16.80	-0.5037	6	-0.0303	39	80.08
10:00:00	2	-0.0150	-23.74	-0.2408	8	-0.0168	53	127.19
10:00:00	3	-0.0137	-25.65	-0.0142	9	-0.0078	67	201.31
10:00:00	4	-0.0104	-18.25	0.2180	8	0.0026	55	140.90
10:00:00	High	-0.0063	-10.15	0.4918	6	0.0036	39	82.19
	Low-High	-0.0060	-6.26					
11:00:00	Low	-0.0077	-9.86	-0.4644	5	-0.0473	54	109.49
11:00:00	2	-0.0101	-13.02	-0.2073	7	-0.0302	72	159.85
11:00:00	3	-0.0093	-15.70	-0.0217	8	-0.0220	89	237.18
11:00:00	4	-0.0064	-7.44	0.1665	7	-0.0128	77	183.59
11:00:00	High	-0.0055	-12.08	0.4425	5	-0.0042	54	112.84
	Low-High	-0.0022	-2.42					
12:00:00	Low	-0.0065	-7.72	-0.4462	5	-0.0489	50	97.43
12:00:00	2	-0.0074	-10.37	-0.1930	7	-0.0353	61	130.09
12:00:00	3	-0.0071	-11.69	-0.0223	8	-0.0228	70	178.96
12:00:00	4	-0.0059	-15.26	0.1490	7	-0.0171	64	153.76
12:00:00	High	-0.0034	-6.63	0.4213	5	-0.0068	50	106.74
	Low-High	-0.0031	-3.13					
13:00:00	Low	-0.0061	-10.96	-0.4352	5	-0.0492	43	85.62
13:00:00	2	-0.0067	-12.09	-0.1840	7	-0.0351	54	113.85
13:00:00	3	-0.0050	-7.63	-0.0223	8	-0.0276	58	148.52
13:00:00	4	-0.0038	-8.21	0.1392	7	-0.0188	56	129.40
13:00:00	High	-0.0019	-4.21	0.4083	5	-0.0110	44	89.90
	Low-High	-0.0042	-5.82					
14:00:00	Low	-0.0044	-7.29	-0.4264	5	-0.0494	44	85.02
14:00:00	2	-0.0045	-7.02	-0.1775	7	-0.0359	50	107.84
14:00:00	3	-0.0027	-2.57	-0.0226	8	-0.0277	59	151.78
14:00:00	4	-0.0020	-4.19	0.1318	7	-0.0213	55	124.63
14:00:00	High	-0.0008	-1.98	0.3977	5	-0.0141	43	89.72
	Low-High	-0.0036	-5.06					
15:00:00	Low	-0.0033	-5.68	-0.4176	5	-0.0468	45	85.51
15:00:00	2	-0.0031	-6.47	-0.1706	7	-0.0308	53	113.08
15:00:00	3	-0.0017	-3.45	-0.0214	8	-0.0231	58	149.19
15:00:00	4	0.0003	0.41	0.1270	7	-0.0179	56	131.46
15:00:00	High	0.0014	2.61	0.3890	5	-0.0045	46	95.27
	Low-High	-0.0046	-5.96					
16:00:00	Low	0.0003	0.36	-0.4082	5	-0.0490	46	89.75
16:00:00	2	-0.0001	-0.20	-0.1633	7	-0.0340	58	122.63
16:00:00	3	0.0002	0.31	-0.0204	8	-0.0234	68	181.43
16:00:00	4	0.0012	2.71	0.1208	7	-0.0153	64	156.73
16:00:00	High	0.0035	5.36	0.3792	5	-0.0050	49	99.43
	Low-High	-0.0033	-3.42					

Panel C. Portfolio Sort on previous day Cumulative Imbalances by hour, Puts, 2004-2010

Time	Portfolio	R^O	t-stat	COIM(T)	# trades	1h -OIM	1h-#contracts	1h-$$volume
10:00:00	Low	-0.0153	-52.63	-0.5275	4	-0.0542	61	121.34
10:00:00	2	-0.0180	-35.57	-0.2594	6	-0.0256	68	147.29
10:00:00	3	-0.0155	-34.67	-0.0289	7	-0.0150	83	209.87
10:00:00	4	-0.0140	-31.54	0.2148	6	-0.0080	71	163.66
10:00:00	High	-0.0132	-25.29	0.4946	4	-0.0055	61	121.68
	Low-High	-0.0021	-3.55					
11:00:00	Low	-0.0126	-46.88	-0.5007	4	-0.0606	89	169.15
11:00:00	2	-0.0137	-35.22	-0.2313	5	-0.0292	98	206.82
11:00:00	3	-0.0112	-29.77	-0.0288	6	-0.0199	117	286.40
11:00:00	4	-0.0108	-22.80	0.1785	5	-0.0136	102	229.05
11:00:00	High	-0.0096	-21.34	0.4600	4	-0.0111	86	176.89
	Low-High	-0.0030	-5.67					
12:00:00	Low	-0.0108	-36.90	-0.4884	4	-0.0614	82	157.96
12:00:00	2	-0.0108	-33.48	-0.2200	5	-0.0335	89	185.04
12:00:00	3	-0.0091	-21.84	-0.0292	6	-0.0235	97	229.21
12:00:00	4	-0.0077	-17.72	0.1626	5	-0.0187	93	204.75
12:00:00	High	-0.0073	-16.57	0.4435	4	-0.0192	81	163.15
	Low-High	-0.0035	-6.67					
13:00:00	Low	-0.0095	-33.29	-0.4808	4	-0.0634	79	155.12
13:00:00	2	-0.0094	-26.04	-0.2128	5	-0.0347	83	169.84
13:00:00	3	-0.0075	-18.86	-0.0292	6	-0.0232	88	203.65
13:00:00	4	-0.0054	-13.46	0.1538	5	-0.0169	84	178.77
13:00:00	High	-0.0060	-13.94	0.4334	4	-0.0125	77	156.82
	Low-High	-0.0035	-6.67					
14:00:00	Low	-0.0080	-31.58	-0.4739	4	-0.0578	73	141.82
14:00:00	2	-0.0079	-20.92	-0.2057	5	-0.0317	78	158.72
14:00:00	3	-0.0058	-12.65	-0.0275	6	-0.0210	85	198.69
14:00:00	4	-0.0038	-9.53	0.1493	5	-0.0139	81	177.48
14:00:00	High	-0.0047	-10.59	0.4264	4	-0.0065	75	144.95
	Low-High	-0.0033	-6.60					
15:00:00	Low	-0.0060	-27.28	-0.4678	4	-0.0619	75	142.35
15:00:00	2	-0.0056	-15.43	-0.1995	5	-0.0310	83	166.55
15:00:00	3	-0.0037	-7.55	-0.0262	6	-0.0208	86	204.55
15:00:00	4	-0.0018	-4.39	0.1444	5	-0.0137	84	179.36
15:00:00	High	-0.0025	-5.74	0.4190	4	-0.0098	78	155.23
	Low-High	-0.0035	-7.20					
16:00:00	Low	-0.0038	-12.16	-0.4619	3	-0.0561	76	144.83
16:00:00	2	-0.0032	-7.97	-0.1923	5	-0.0277	88	178.54
16:00:00	3	-0.0012	-2.61	-0.0233	6	-0.0176	98	226.03
16:00:00	4	0.0006	1.50	0.1405	5	-0.0089	90	188.77
16:00:00	High	0.0004	0.96	0.4130	4	-0.0019	78	160.17
	Low-High	-0.0042	-8.20					

Panel D. Portfolio Sort on previous day Cumulative Imbalances by hour, Puts, 2011-2017

Time	Portfolio	R^O	t-stat	COIM(T)	# trades	1h -OIM	1h -# contracts	1h-$$volume
10:00:00	Low	-0.0214	-19.60	-0.4672	6	-0.0214	42	76.85
10:00:00	2	-0.0216	-23.30	-0.2098	7	-0.0071	47	101.02
10:00:00	3	-0.0187	-18.24	0.0009	8	0.0018	54	142.81
10:00:00	4	-0.0179	-19.61	0.2118	7	0.0119	46	100.21
10:00:00	High	-0.0160	-16.80	0.4619	6	0.0174	40	79.16
	Low-High	-0.0054	-3.72					
11:00:00	Low	-0.0172	-22.69	-0.4348	5	-0.0454	53	95.59
11:00:00	2	-0.0167	-21.17	-0.1849	6	-0.0207	64	131.86
11:00:00	3	-0.0143	-20.08	-0.0096	7	-0.0107	71	180.67
11:00:00	4	-0.0146	-15.81	0.1679	6	0.0020	63	137.23
11:00:00	High	-0.0126	-22.13	0.4225	5	0.0158	54	101.45
	Low-High	-0.0046	-4.86					
12:00:00	Low	-0.0147	-19.03	-0.4211	5	-0.0461	48	85.51
12:00:00	2	-0.0150	-13.13	-0.1736	6	-0.0234	56	116.14
12:00:00	3	-0.0126	-19.54	-0.0117	7	-0.0131	59	147.41
12:00:00	4	-0.0119	-14.97	0.1513	6	-0.0035	55	114.92
12:00:00	High	-0.0102	-17.82	0.4050	5	0.0120	52	95.63
	Low-High	-0.0045	-4.66					
13:00:00	Low	-0.0132	-13.39	-0.4121	5	-0.0456	45	81.42
13:00:00	2	-0.0108	-20.64	-0.1666	7	-0.0227	47	95.91
13:00:00	3	-0.0109	-11.15	-0.0127	18	-0.0133	51	122.81
13:00:00	4	-0.0092	-14.67	0.1419	7	-0.0053	49	103.99
13:00:00	High	-0.0081	-14.48	0.3939	5	0.0091	44	80.68
	Low-High	-0.0051	-4.50					
14:00:00	Low	-0.0096	-16.00	-0.4040	5	-0.0408	43	76.45
14:00:00	2	-0.0095	-15.01	-0.1602	7	-0.0213	46	94.30
14:00:00	3	-0.0098	-11.06	-0.0127	7	-0.0113	50	121.01
14:00:00	4	-0.0073	-12.40	0.1355	7	-0.0022	47	96.88
14:00:00	High	-0.0076	-9.60	0.3853	5	0.0104	43	75.56
	Low-High	-0.0020	-2.02					
15:00:00	Low	-0.0081	-18.25	-0.3967	5	-0.0462	45	79.47
15:00:00	2	-0.0074	-16.63	-0.1546	6	-0.0224	48	96.99
15:00:00	3	-0.0065	-11.42	-0.0126	7	-0.0115	52	124.61
15:00:00	4	-0.0059	-8.14	0.1295	7	-0.0014	49	103.54
15:00:00	High	-0.0052	-6.45	0.3768	5	0.0156	45	81.14
	Low-High	-0.0028	-3.07					
16:00:00	Low	-0.0067	-10.36	-0.3880	5	-0.0391	47	84.42
16:00:00	2	-0.0053	-9.19	-0.1478	6	-0.0197	52	102.61
16:00:00	3	-0.0046	-8.15	-0.0117	17	-0.0105	56	134.50
16:00:00	4	-0.0047	-5.85	0.1243	6	-0.0022	53	108.14
16:00:00	High	-0.0042	-4.21	0.3679	5	0.0135	47	85.70
	Low-High	-0.0025	-2.09					

Table 6. Day-to-Day Dynamics of Order Imbalances: 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 2004 to 2010, and 2011 – 2017 subperiods. R^O is a delta-hedged option return on day *t*. *COIM(t-1)* is cumulative options net order imbalance on day *t-1* for a given hour of a day. *1h –OIM* are order imbalances summed by hour of a day *t* (non-cumulative). For each trading hour on day *t* options are sorted in quintile portfolios based on *COIM(t-1)* for that hour on the previous day t-1. R^O are average returns of quintile portfolios on day t. # trades (1h-#contracts) is an average number of trades (number of contracts traded) computed across all series in each portfolio for a given hour of day t. 1h-$$volume is an average portfolio dollar volume for a given hour (non-cumulative) of day t. For 10 am – it is only a 30 min interval, from 9:30am to 10am. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Portfolio Sort on previous day Cumulative Imbalances by hour, Calls, 2004-2010

Time	Portfolio	R^O	t-stat	COIM(T-1)	# trades	1h -OIM	1h-#contract	1h-$$volume
10:00:00	Low	-0.0143	-22.45	-0.6002	13	-0.0116	438	17735.69
10:00:00	2	-0.0341	-20.46	-0.2405	13	0.0073	666	17181.75
10:00:00	3	-0.0447	-16.64	-0.0055	15	-0.0092	633	15451.32
10:00:00	4	-0.0313	-15.03	0.2342	13	-0.0087	570	13279.72
10:00:00	High	-0.0142	-15.65	0.5916	11	-0.0304	416	17387.01
	Low-High	-0.0001	-0.10					
11:00:00	Low	-0.0096	-18.31	-0.5931	9	-0.0377	791	39577.22
11:00:00	2	-0.0225	-16.03	-0.2180	13	-0.0146	1252	36849.20
11:00:00	3	-0.0303	-17.57	-0.0094	15	-0.0067	1311	32819.30
11:00:00	4	-0.0246	-15.76	0.2050	14	-0.0026	1019	26408.23
11:00:00	High	-0.0108	-18.45	0.5760	10	-0.0105	774	31908.55
	Low-High	0.0012	1.50					
12:00:00	Low	-0.0081	-17.93	-0.5882	9	-0.0418	721	39632.37
12:00:00	2	-0.0177	-16.15	-0.2092	12	0.0094	936	28523.88
12:00:00	3	-0.0236	-15.30	-0.0087	14	-0.0016	957	24703.87
12:00:00	4	-0.0189	-15.49	0.1914	12	0.0005	915	26424.37
12:00:00	High	-0.0082	-16.64	0.5696	9	-0.0072	692	31680.29
	Low-High	0.0002	0.24					
13:00:00	Low	-0.0073	-16.72	-0.5822	9	-0.0241	620	28816.17
13:00:00	2	-0.0153	-13.44	-0.2019	12	-0.0018	854	25689.48
13:00:00	3	-0.0206	-13.94	-0.0106	14	0.0098	889	26166.75
13:00:00	4	-0.0177	-16.03	0.1841	13	0.0114	782	21865.45
13:00:00	High	-0.0074	-16.30	0.5670	8	-0.0090	492	19670.84
	Low-High	0.0001	0.11					
14:00:00	Low	-0.0059	-14.78	-0.5800	8	-0.0323	467	21592.24
14:00:00	2	-0.0132	-11.77	-0.1964	12	0.0052	824	30017.96
14:00:00	3	-0.0182	-14.03	-0.0112	13	-0.0118	874	26170.62
14:00:00	4	-0.0143	-13.06	0.1775	12	0.0071	732	22147.89
14:00:00	High	-0.0058	-13.74	0.5625	8	-0.0019	507	23358.41
	Low-High	0.0000	-0.04					
15:00:00	Low	-0.0039	-9.98	-0.5735	8	-0.0143	556	27677.87
15:00:00	2	-0.0091	-8.72	-0.1885	13	0.0035	729	22028.46
15:00:00	3	-0.0125	-9.99	-0.0099	15	-0.0158	997	30345.05
15:00:00	4	-0.0104	-8.89	0.1709	12	-0.0126	726	22328.61
15:00:00	High	-0.0038	-9.40	0.5601	8	-0.0466	499	22768.32
	Low-High	0.0000	-0.07					
16:00:00	Low	-0.0013	-2.92	-0.5673	8	-0.0022	560	25977.70
16:00:00	2	-0.0021	-2.00	-0.1842	12	-0.0092	769	25576.58
16:00:00	3	-0.0034	-2.99	-0.0095	13	-0.0136	974	28297.56
16:00:00	4	-0.0030	-3.00	0.1623	13	-0.0050	900	27592.35
16:00:00	High	-0.0003	-0.52	0.5527	8	-0.0077	486	21709.01
	Low-High	-0.0010	-1.46					

Panel B. Portfolio Sort on previous day Cumulative Imbalances by hour, Calls, 2011-2017

Time	Portfolio	R^O	t-stat	COIM(T-1)	# trades	1h -OIM	1h-#contracts	1h-$$volume
10:00:00	Low	-0.0089	-22.18	-0.6043	10	-0.0043	337	14007.38
10:00:00	2	-0.0242	-25.12	-0.2469	12	0.0110	458	11719.85
10:00:00	3	-0.0330	-21.47	0.0006	14	0.0399	535	14832.36
10:00:00	4	-0.0253	-24.54	0.2517	11	-0.0066	445	11179.81
10:00:00	High	-0.0084	-21.47	0.6050	11	0.0049	303	12253.96
	Low-High	-0.0004	-0.77					
11:00:00	Low	-0.0060	-23.15	-0.6017	9	-0.0034	565	24269.76
11:00:00	2	-0.0178	-27.63	-0.2239	13	-0.0170	978	29728.43
11:00:00	3	-0.0221	-27.01	-0.0010	15	-0.0165	1037	31855.39
11:00:00	4	-0.0176	-26.03	0.2225	14	-0.0191	922	27279.30
11:00:00	High	-0.0061	-21.11	0.5970	8	-0.0143	459	19209.66
	Low-High	0.0001	0.23					
12:00:00	Low	-0.0049	-19.05	-0.5967	8	-0.0039	425	19969.03
12:00:00	2	-0.0137	-24.64	-0.2099	15	-0.0052	730	24040.15
12:00:00	3	-0.0177	-23.31	0.0020	12	0.0054	773	24361.76
12:00:00	4	-0.0139	-22.05	0.2068	12	-0.0110	733	23026.60
12:00:00	High	-0.0047	-18.16	0.5934	8	0.0154	416	19425.83
	Low-High	-0.0001	-0.35					
13:00:00	Low	-0.0040	-18.18	-0.5957	9	-0.0226	351	16559.59
13:00:00	2	-0.0116	-23.14	-0.2028	13	-0.0148	609	19771.12
13:00:00	3	-0.0148	-22.19	0.0005	13	0.0023	666	21200.67
13:00:00	4	-0.0109	-19.16	0.2001	12	0.0065	601	18784.21
13:00:00	High	-0.0036	-15.09	0.5883	9	0.0088	357	15893.19
	Low-High	-0.0004	-1.25					
14:00:00	Low	-0.0034	-16.21	-0.5891	8	-0.0313	347	17239.83
14:00:00	2	-0.0096	-18.18	-0.1967	15	-0.0070	534	17433.52
14:00:00	3	-0.0122	-20.88	-0.0007	13	-0.0050	596	18992.13
14:00:00	4	-0.0091	-15.01	0.1916	13	-0.0019	545	18497.49
14:00:00	High	-0.0031	-13.34	0.5821	8	0.0271	302	14298.71
	Low-High	-0.0002	-0.70					
15:00:00	Low	-0.0022	-10.10	-0.5861	8	-0.0150	332	15711.69
15:00:00	2	-0.0076	-14.85	-0.1913	15	-0.0015	539	17897.79
15:00:00	3	-0.0088	-14.03	-0.0003	13	-0.0115	586	20433.65
15:00:00	4	-0.0069	-11.79	0.1867	13	0.0026	553	18282.37
15:00:00	High	-0.0020	-8.93	0.5791	8	0.0137	331	16535.10
	Low-High	-0.0002	-0.50					
16:00:00	Low	-0.0010	-4.21	-0.5796	7	-0.0090	326	16109.93
16:00:00	2	-0.0035	-6.61	-0.1860	12	0.0124	622	21558.52
16:00:00	3	-0.0053	-8.76	0.0001	13	-0.0006	717	23781.30
16:00:00	4	-0.0033	-5.48	0.1804	12	-0.0208	594	19965.03
16:00:00	High	-0.0005	-1.89	0.5700	7	0.0031	323	15888.03
	Low-High	-0.0005	-1.41					

Panel C. Portfolio Sort on previous day Cumulative Imbalances by hour, Puts, 2004-2010

Time	Portfolio	R^O	t-stat	COIM(T-1)	# trades	1h -OIM	1h-#contracts	1h-$$volume
10:00:00	Low	-0.0167	-18.42	-0.5522	14	-0.0198	474	19706.52
10:00:00	2	-0.0235	-20.38	-0.2214	18	-0.0053	644	15757.47
10:00:00	3	-0.0267	-18.47	-0.0044	17	-0.0187	751	16084.31
10:00:00	4	-0.0218	-19.30	0.2192	16	-0.0019	625	15802.99
10:00:00	High	-0.0158	-19.31	0.5191	13	-0.0090	454	16990.95
	Low-High	-0.0009	-0.74					
11:00:00	Low	-0.0137	-19.41	-0.5281	12	-0.0192	875	37422.74
11:00:00	2	-0.0187	-16.64	-0.1888	16	-0.0051	1294	34649.80
11:00:00	3	-0.0195	-18.28	-0.0020	17	-0.0114	1498	38931.31
11:00:00	4	-0.0167	-17.71	0.1899	15	-0.0117	1300	36859.43
11:00:00	High	-0.0108	-15.67	0.5020	12	0.0022	886	38521.69
	Low-High	-0.0029	-2.89					
12:00:00	Low	-0.0110	-18.16	-0.5194	11	-0.0345	695	30907.01
12:00:00	2	-0.0152	-17.76	-0.1755	14	-0.0083	994	29567.87
12:00:00	3	-0.0166	-16.72	0.0010	15	-0.0185	1134	28593.13
12:00:00	4	-0.0119	-14.74	0.1772	15	-0.0048	1006	27688.72
12:00:00	High	-0.0093	-15.54	0.4892	12	-0.0253	725	30049.68
	Low-High	-0.0016	-1.89					
13:00:00	Low	-0.0108	-16.17	-0.5142	11	-0.0182	595	28065.88
13:00:00	2	-0.0133	-14.28	-0.1658	15	-0.0122	929	29800.36
13:00:00	3	-0.0151	-15.18	0.0006	16	-0.0139	990	26427.80
13:00:00	4	-0.0095	-10.61	0.1686	16	-0.0064	950	27770.36
13:00:00	High	-0.0083	-14.76	0.4910	11	-0.0239	537	22535.20
	Low-High	-0.0025	-2.87					
14:00:00	Low	-0.0084	-13.63	-0.5056	12	-0.0206	524	25084.01
14:00:00	2	-0.0110	-12.09	-0.1586	15	0.0005	799	24061.06
14:00:00	3	-0.0123	-13.77	-0.0003	15	-0.0116	1010	29070.71
14:00:00	4	-0.0076	-8.41	0.1623	14	-0.0055	815	24493.83
14:00:00	High	-0.0058	-9.59	0.4878	11	0.0205	496	21573.30
	Low-High	-0.0026	-3.04					
15:00:00	Low	-0.0064	-11.69	-0.4974	11	-0.0296	514	24621.49
15:00:00	2	-0.0079	-9.20	-0.1524	14	-0.0103	799	25125.66
15:00:00	3	-0.0057	-5.33	0.0014	17	0.0015	923	24190.30
15:00:00	4	-0.0038	-3.97	0.1555	14	-0.0101	842	23622.57
15:00:00	High	-0.0037	-5.91	0.4824	10	-0.0022	525	19926.65
	Low-High	-0.0027	-3.31					
16:00:00	Low	-0.0014	-2.73	-0.4870	10	-0.0071	554	25777.52
16:00:00	2	0.0000	0.04	-0.1436	16	0.0059	903	29294.35
16:00:00	3	0.0017	1.50	0.0041	15	0.0142	1007	26132.80
16:00:00	4	0.0021	2.02	0.1504	12	-0.0031	901	26911.84
16:00:00	High	0.0022	2.95	0.4794	9	0.0167	505	23089.21
	Low-High	-0.0036	-3.97					

Panel D. Portfolio Sort on previous day Cumulative Imbalances by hour, Puts, 2011-2017

Time	Portfolio	R^O	t-stat	COIM(T-1)	# trades	1h -OIM	1h-#contracts	1h-$$volume
10:00:00	Low	-0.0183	-26.12	-0.4816	14	0.0029	524	19375.17
10:00:00	2	-0.0248	-25.41	-0.2004	11	0.0112	616	14170.36
10:00:00	3	-0.0210	-19.02	0.0021	14	0.0060	737	16325.23
10:00:00	4	-0.0249	-26.23	0.2011	12	0.0051	601	13494.29
10:00:00	High	-0.0191	-30.86	0.4724	13	-0.0061	538	19324.85
	Low-High	0.0008	0.86					
11:00:00	Low	-0.0140	-29.41	-0.4642	11	0.0003	769	29943.26
11:00:00	2	-0.0203	-29.88	-0.1728	13	0.0081	1079	27692.35
11:00:00	3	-0.0169	-21.02	0.0037	16	0.0114	1171	28923.44
11:00:00	4	-0.0186	-24.50	0.1756	12	0.0095	1009	25446.27
11:00:00	High	-0.0141	-28.02	0.4521	12	0.0285	807	31172.59
	Low-High	0.0001	0.08					
12:00:00	Low	-0.0123	-27.96	-0.4552	11	0.0085	615	24787.58
12:00:00	2	-0.0174	-29.90	-0.1608	12	-0.0012	790	21229.23
12:00:00	3	-0.0147	-20.48	0.0040	14	-0.0013	898	23218.32
12:00:00	4	-0.0161	-23.12	0.1645	11	0.0043	787	20420.99
12:00:00	High	-0.0118	-26.61	0.4457	11	0.0057	663	25862.25
	Low-High	-0.0005	-0.79					
13:00:00	Low	-0.0103	-23.53	-0.4494	11	0.0025	467	19034.14
13:00:00	2	-0.0155	-27.00	-0.1535	12	-0.0098	648	18093.79
13:00:00	3	-0.0125	-17.25	0.0030	14	-0.0023	756	18871.13
13:00:00	4	-0.0143	-23.33	0.1568	11	0.0038	637	17681.46
13:00:00	High	-0.0104	-26.98	0.4371	12	-0.0136	489	19712.37
	Low-High	0.0001	0.23					
14:00:00	Low	-0.0089	-19.35	-0.4439	11	0.0087	437	17575.10
14:00:00	2	-0.0125	-18.73	-0.1475	13	0.0076	611	17792.74
14:00:00	3	-0.0100	-14.69	0.0032	16	0.0055	672	19335.72
14:00:00	4	-0.0129	-24.59	0.1519	12	0.0055	600	16596.61
14:00:00	High	-0.0092	-25.30	0.4300	12	-0.0056	452	18692.95
	Low-High	0.0003	0.45					
15:00:00	Low	-0.0074	-16.17	-0.4383	11	-0.0021	450	18364.46
15:00:00	2	-0.0092	-12.45	-0.1425	14	-0.0064	613	18273.14
15:00:00	3	-0.0079	-10.58	0.0033	13	0.0038	620	17135.01
15:00:00	4	-0.0103	-18.69	0.1458	13	0.0055	614	18352.02
15:00:00	High	-0.0078	-20.94	0.4227	11	-0.0055	424	17061.53
	Low-High	0.0003	0.59					
16:00:00	Low	-0.0042	-8.52	-0.4277	10	-0.0264	457	18743.81
16:00:00	2	-0.0057	-8.01	-0.1373	13	0.0005	656	18703.57
16:00:00	3	-0.0025	-2.88	0.0028	13	0.0037	763	21127.11
16:00:00	4	-0.0055	-8.84	0.1404	12	-0.0062	660	19008.34
16:00:00	High	-0.0047	-11.60	0.4121	10	-0.0120	482	18495.31
	Low-High	0.0004	0.66					

Table 7. Day and Night Returns, Equity Options

The table presents day and night returns for equity call and put options of S&P500 components for 2004 to 2010, and 2011 – 2017 subperiods. R^O is a delta-hedged option return on day *t*. *All* presents results for all positive volume days. Negative (Positive) Order imbalances are identified on a class/firm level after aggregating contract/series level order imbalances using dollar open interest from the previous day, *t-1*, as a weight. If for a day, class level order imbalances are negative (positive), a firm is placed into negative (positive) portfolio for that day *t*. 10 am return is measured from 9:40am to 10am., and 4pm return is from 9:40am to 16:00. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

	Panel A. Calls, 2004-2010				Panel B. Calls, 2011-2017		
		R^O	t-stat	All		R^O	t-stat
	Night	-0.0027	-21.92		Night	0.0002	0.69
DAY	10:00:00	0.0008	19.92	DAY	10:00:00	0.0016	38.32
	11:00:00	0.0014	25.90		11:00:00	0.0016	30.51
	12:00:00	0.0013	23.99		12:00:00	0.0011	18.05
	13:00:00	0.0014	22.02		13:00:00	0.0006	9.21
	14:00:00	0.0015	22.12		14:00:00	0.0008	11.83
	15:00:00	0.0016	22.55		15:00:00	0.0006	8.05
	16:00:00	0.0025	30.20		16:00:00	0.0008	10.65
	Negative Order Imbalances						
	Night	-0.0022	-13.43		Night	0.0015	4.21
DAY	10:00:00	0.0002	3.70	DAY	10:00:00	0.0004	6.49
	11:00:00	0.0005	6.55		11:00:00	0.0005	7.15
	12:00:00	0.0002	2.95		12:00:00	-0.0002	-1.94
	13:00:00	0.0000	0.21		13:00:00	-0.0007	-9.25
	14:00:00	-0.0001	-0.53		14:00:00	-0.0007	-8.28
	15:00:00	-0.0001	-1.07		15:00:00	-0.0011	-11.87
	16:00:00	0.0004	4.22		16:00:00	-0.0010	-9.88
	Positive Order Imbalances						
	Night	-0.0033	-18.42		Night	-0.0014	-3.92
DAY	10:00:00	0.0017	26.57	DAY	10:00:00	0.0030	48.40
	11:00:00	0.0028	36.09		11:00:00	0.0031	39.26
	12:00:00	0.0031	35.89		12:00:00	0.0027	30.25
	13:00:00	0.0034	36.04		13:00:00	0.0023	25.54
	14:00:00	0.0038	37.43		14:00:00	0.0026	27.52
	15:00:00	0.0041	38.40		15:00:00	0.0025	24.84
	16:00:00	0.0053	42.39		16:00:00	0.0028	25.74

	Panel C. Puts, 2004-2010				Panel D. Puts, 2011-2017		
	All	**R^O**	**t-stat**	**All**		**R^O**	**t-stat**
	Night	-0.0052	-33.81		Night	-0.0066	-17.72
DAY	10:00:00	0.0008	21.66	DAY	10:00:00	0.0015	36.40
	11:00:00	0.0019	38.81		11:00:00	0.0012	23.27
	12:00:00	0.0019	34.66		12:00:00	0.0010	16.94
	13:00:00	0.0019	29.42		13:00:00	0.0007	10.91
	14:00:00	0.0020	30.60		14:00:00	0.0003	5.19
	15:00:00	0.0027	35.44		15:00:00	0.0004	5.98
	16:00:00	0.0035	41.53		16:00:00	0.0009	11.05
	Negative Order Imbalances						
	Night	-0.0050	-25.19		Night	-0.0053	-12.93
DAY	10:00:00	-0.0002	-3.46	DAY	10:00:00	0.0006	9.50
	11:00:00	0.0002	2.75		11:00:00	0.0001	1.91
	12:00:00	-0.0003	-3.38		12:00:00	-0.0004	-5.02
	13:00:00	-0.0007	-9.23		13:00:00	-0.0009	-10.38
	14:00:00	-0.0008	-10.00		14:00:00	-0.0014	-15.79
	15:00:00	-0.0007	-7.21		15:00:00	-0.0015	-15.52
	16:00:00	-0.0004	-3.74		16:00:00	-0.0015	-15.14
	Positive Order Imbalances						
	Night	-0.0055	-22.83		Night	-0.0080	-12.53
DAY	10:00:00	0.0022	33.79	DAY	10:00:00	0.0031	48.38
	11:00:00	0.0040	52.55		11:00:00	0.0029	37.43
	12:00:00	0.0046	51.94		12:00:00	0.0029	32.85
	13:00:00	0.0050	47.65		13:00:00	0.0026	28.43
	14:00:00	0.0055	53.16		14:00:00	0.0024	24.72
	15:00:00	0.0066	56.29		15:00:00	0.0026	24.39
	16:00:00	0.0079	61.96		16:00:00	0.0034	30.22

Table 8. Day and Night Returns, SPX Options

The table presents day and night returns for SPX call and put options for 2004 to 2010, and 2011 – 2017 subperiods. R^O is a delta-hedged option return on day *t*. *All* presents results for all positive volume days. Negative (Positive) Order imbalance days are identified after aggregating contract/series level order imbalances using dollar open interest from the previous day, *t-1*, as a weight. 10 am return is measured from 9:40am to 10am., and 4pm return is from 9:40am to 16:00. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

	Panel A. Calls, 2004-2010				Panel B. Calls, 2011-2017		
	All	R^O	t-stat	All		R^O	t-stat
	Night	-0.0051	-11.52		Night	-0.0048	-6.39
DAY	10:00:00	-0.0009	-4.62	DAY	10:00:00	0.0003	1.29
	11:00:00	-0.0010	-2.44		11:00:00	-0.0001	-0.21
	12:00:00	-0.0013	-2.81		12:00:00	-0.0002	-0.29
	13:00:00	-0.0012	-2.32		13:00:00	0.0000	-0.05
	14:00:00	-0.0009	-1.44		14:00:00	0.0007	1.16
	15:00:00	0.0005	0.63		15:00:00	0.0007	1.14
	16:00:00	0.0016	1.94		16:00:00	0.0005	0.60
	Negative Order Imbalances						
	Night	-0.0048	-6.98		Night	-0.0035	-2.72
DAY	10:00:00	-0.0012	-4.30	DAY	10:00:00	0.0006	1.66
	11:00:00	-0.0013	-2.38		11:00:00	0.0005	0.84
	12:00:00	-0.0008	-1.25		12:00:00	0.0008	1.02
	13:00:00	-0.0006	-0.72		13:00:00	-0.0004	-0.52
	14:00:00	-0.0006	-0.63		14:00:00	0.0005	0.61
	15:00:00	0.0015	1.02		15:00:00	0.0017	1.59
	16:00:00	0.0022	1.78		16:00:00	0.0025	2.05
	Positive Order Imbalances						
	Night	-0.0054	-7.96		Night	-0.0064	-8.8
DAY	10:00:00	-0.0004	-1.46	DAY	10:00:00	0.0000	0.10
	11:00:00	-0.0007	-1.08		11:00:00	-0.0007	-1.10
	12:00:00	-0.0019	-2.91		12:00:00	-0.0012	-1.82
	13:00:00	-0.0020	-2.56		13:00:00	0.0004	0.51
	14:00:00	-0.0012	-1.58		14:00:00	0.0009	1.15
	15:00:00	-0.0007	-0.72		15:00:00	-0.0004	-0.47
	16:00:00	0.0008	0.89		16:00:00	-0.0020	-2.13

	Panel C. Puts, 2004-2010				Panel D. Puts, 2011-2017		
		R^O	t-stat	All		R^O	t-stat
	Night	-0.0048	-8.37		Night	-0.0067	-6.77
DAY	10:00:00	-0.0011	-4.05	DAY	10:00:00	0.0007	2.37
	11:00:00	-0.0012	-2.91		11:00:00	0.0001	0.10
	12:00:00	-0.0013	-2.58		12:00:00	0.0002	0.32
	13:00:00	-0.0009	-1.68		13:00:00	0.0006	0.80
	14:00:00	-0.0006	-0.99		14:00:00	0.0009	1.24
	15:00:00	0.0008	0.84		15:00:00	0.0011	1.34
	16:00:00	0.0020	2.15		16:00:00	0.0011	0.97
	Negative Order Imbalances						
	Night	-0.0046	-6.27		Night	-0.0060	-3.54
DAY	10:00:00	-0.0017	-5.13	DAY	10:00:00	0.0016	3.49
	11:00:00	-0.0007	-1.12		11:00:00	0.0020	2.76
	12:00:00	-0.0005	-0.70		12:00:00	0.0032	2.91
	13:00:00	0.0003	0.31		13:00:00	0.0036	3.31
	14:00:00	-0.0002	-0.22		14:00:00	0.0041	3.51
	15:00:00	0.0016	1.01		15:00:00	0.0042	3.22
	16:00:00	0.0039	2.43		16:00:00	0.0035	2.36
	Positive Order Imbalances						
	Night	-0.0051	-6.6		Night	-0.0075	-8.11
DAY	10:00:00	-0.0004	-1.08	DAY	10:00:00	-0.0002	-0.50
	11:00:00	-0.0018	-2.95		11:00:00	-0.0018	-2.50
	12:00:00	-0.0021	-3.78		12:00:00	-0.0025	-3.44
	13:00:00	-0.0022	-3.07		13:00:00	-0.0023	-2.53
	14:00:00	-0.0011	-1.27		14:00:00	-0.0020	-1.85
	15:00:00	-0.0001	-0.14		15:00:00	-0.0017	-1.50
	16:00:00	0.0000	0.00		16:00:00	-0.0011	-0.70

Table 9. Day and Night Returns, Equity Options, before and after introduction of SPX overnight trading

The table presents day and night returns for equity call and put options of S&P500 components for 2011 to 2014, and 2015 – 2017 subperiods, before and after introduction of SPX night trading respectively. R^O is a delta-hedged option return on day *t*. *All* presents results for all positive volume days. Negative (Positive) Order imbalances are identified on a class/firm level after aggregating contract/series level order imbalances using dollar open interest from the previous day, *t-1*, as a weight. If for a day, class level order imbalances are negative (positive), a firm is placed into negative (positive) portfolio for that day *t*. 10 am return is measured from 9:40am to 10am., and 4pm return is from 9:40am to 16:00. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

	Panel A. Calls, 2011-2014				**Panel B. Calls, 2015-2017**		
		R^O	t-stat	**All**		R^O	t-stat
	Night	-0.0020	-14.42		Night	0.0031	5.70
DAY	10:00:00	0.0009	19.86	DAY	10:00:00	0.0026	33.76
	11:00:00	0.0016	26.28		11:00:00	0.0017	17.71
	12:00:00	0.0013	18.79		12:00:00	0.0008	7.47
	13:00:00	0.0009	12.36		13:00:00	0.0001	1.34
	14:00:00	0.0012	16.37		14:00:00	0.0001	1.23
	15:00:00	0.0014	17.88		15:00:00	-0.0007	-5.83
	16:00:00	0.0018	20.09		16:00:00	-0.0006	-4.84
	Negative Order Imbalances						
	Night	-0.0014	-7.33		Night	0.0055	6.87
DAY	10:00:00	-0.0001	-1.55	DAY	10:00:00	0.0011	10.23
	11:00:00	0.0003	3.61		11:00:00	0.0008	6.33
	12:00:00	-0.0001	-0.74		12:00:00	-0.0003	-1.97
	13:00:00	-0.0007	-7.94		13:00:00	-0.0008	-5.36
	14:00:00	-0.0006	-6.00		14:00:00	-0.0009	-5.73
	15:00:00	-0.0005	-5.21		15:00:00	-0.0018	-11.41
	16:00:00	-0.0003	-2.12		16:00:00	-0.0020	-11.78
	Positive Order Imbalances						
	Night	-0.0028	-13.21		Night	0.0005	0.61
DAY	10:00:00	0.0021	31.13	DAY	10:00:00	0.0041	37.70
	11:00:00	0.0032	35.76		11:00:00	0.0030	21.13
	12:00:00	0.0031	31.22		12:00:00	0.0021	13.54
	13:00:00	0.0029	28.20		13:00:00	0.0014	9.34
	14:00:00	0.0035	31.34		14:00:00	0.0015	9.04
	15:00:00	0.0039	32.72		15:00:00	0.0007	3.95
	16:00:00	0.0042	32.53		16:00:00	0.0009	4.95

	Panel C. Puts, 2011-2014				Panel D. Puts, 2015-2017		
		R^O	t-stat	All		R^O	t-stat
	Night	-0.0056	-33.92		Night	-0.0080	-9.49
DAY	10:00:00	0.0015	32.26	DAY	10:00:00	0.0015	20.51
	11:00:00	0.0014	21.79		11:00:00	0.0011	11.74
	12:00:00	0.0014	19.49		12:00:00	0.0005	4.78
	13:00:00	0.0012	16.27		13:00:00	-0.0001	-0.49
	14:00:00	0.0010	12.19		14:00:00	-0.0005	-4.62
	15:00:00	0.0013	14.92		15:00:00	-0.0007	-6.16
	16:00:00	0.0020	20.96		16:00:00	-0.0007	-5.38
				Negative Order Imbalances			
	Night	-0.0050	-21.54		Night	-0.0056	-6.20
DAY	10:00:00	0.0007	10.16	DAY	10:00:00	0.0004	3.64
	11:00:00	0.0000	0.15		11:00:00	0.0003	2.43
	12:00:00	-0.0003	-3.47		12:00:00	-0.0005	-3.65
	13:00:00	-0.0007	-7.01		13:00:00	-0.0011	-7.67
	14:00:00	-0.0012	-10.84		14:00:00	-0.0018	-11.50
	15:00:00	-0.0011	-9.47		15:00:00	-0.0020	-12.44
	16:00:00	-0.0008	-6.43		16:00:00	-0.0025	-14.89
				Positive Order Imbalances			
	Night	-0.0061	-26.44		Night	-0.0106	-7.28
DAY	10:00:00	0.0028	38.41	DAY	10:00:00	0.0034	30.82
	11:00:00	0.0032	35.79		11:00:00	0.0025	18.60
	12:00:00	0.0035	32.76		12:00:00	0.0020	14.17
	13:00:00	0.0035	31.45		13:00:00	0.0014	9.40
	14:00:00	0.0035	28.79		14:00:00	0.0011	6.55
	15:00:00	0.0039	30.61		15:00:00	0.0008	4.46
	16:00:00	0.0050	35.46		16:00:00	0.0013	7.26

Table 10. Day and Night Returns, SPX Options, before and after introduction of SPX overnight trading

The table presents day and night returns for SPX call and put options for 2011 to 2014, and 2015 – 2017 subperiods, before and after introduction of SPX night trading respectively. R^O is a delta-hedged option return on day *t*. *All* presents results for all positive volume days. Negative (Positive) Order imbalance days are identified after aggregating contract/series level order imbalances using dollar open interest from the previous day, *t-1*, as a weight. 10 am return is measured from 9:40am to 10am., and 4pm return is from 9:40am to 16:00. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

	Panel A. Calls, 2011-2014				Panel B. Calls, 2015-2017		
		R^O	t-stat	All		R^O	t-stat
	Night	-0.0061	-10.41		Night	-0.0031	-2.01
DAY	10:00:00	0.0002	0.64	DAY	10:00:00	0.0004	1.22
	11:00:00	0.0008	1.52		11:00:00	-0.0012	-1.90
	12:00:00	0.0009	1.25		12:00:00	-0.0015	-2.13
	13:00:00	0.0004	0.52		13:00:00	-0.0006	-0.68
	14:00:00	0.0011	1.39		14:00:00	0.0001	0.16
	15:00:00	0.0019	2.17		15:00:00	-0.0009	-1.10
	16:00:00	0.0025	2.16		16:00:00	-0.0022	-2.46
	Negative Order Imbalances						
	Night	-0.0053	-5.87		Night	-0.0009	-0.31
DAY	10:00:00	0.0002	0.51	DAY	10:00:00	0.0010	2.14
	11:00:00	0.0012	1.63		11:00:00	-0.0005	-0.60
	12:00:00	0.0019	1.88		12:00:00	-0.0009	-0.89
	13:00:00	0.0006	0.74		13:00:00	-0.0019	-1.47
	14:00:00	0.0017	1.70		14:00:00	-0.0013	-0.97
	15:00:00	0.0039	3.13		15:00:00	-0.0016	-1.10
	16:00:00	0.0053	3.14		16:00:00	-0.0016	-1.25
	Positive Order Imbalances						
	Night	-0.00637	-8.8		Night	-0.0054	-7.31
DAY	10:00:00	0.0001	0.37	DAY	10:00:00	-0.0001	-0.29
	11:00:00	0.0003	0.40		11:00:00	-0.0020	-2.04
	12:00:00	-0.0004	-0.49		12:00:00	-0.0021	-2.14
	13:00:00	0.0001	0.05		13:00:00	0.0008	0.80
	14:00:00	0.0004	0.31		14:00:00	0.0016	1.63
	15:00:00	-0.0007	-0.55		15:00:00	-0.0001	-0.05
	16:00:00	-0.0012	-0.78		16:00:00	-0.0029	-2.82

	Panel C. Puts, 2011-2014				Panel D. Puts, 2015-2017		
		R^O	t-stat	All		R^O	t-stat
	Night	-0.0094	-11.96		Night	-0.0033	-1.69
DAY	10:00:00	0.0009	2.18	DAY	10:00:00	0.0004	1.03
	11:00:00	0.0016	2.35		11:00:00	-0.0020	-2.51
	12:00:00	0.0020	2.24		12:00:00	-0.0022	-2.50
	13:00:00	0.0019	1.79		13:00:00	-0.0011	-1.07
	14:00:00	0.0024	2.33		14:00:00	-0.0010	-1.01
	15:00:00	0.0035	2.97		15:00:00	-0.0020	-2.08
	16:00:00	0.0048	3.16		16:00:00	-0.0039	-3.43
	Negative Order Imbalances						
	Night	-0.0092	-8.70		Night	-0.0006	-0.15
DAY	10:00:00	0.0020	3.33	DAY	10:00:00	0.0010	1.45
	11:00:00	0.0032	3.26		11:00:00	0.0003	0.32
	12:00:00	0.0050	3.55		12:00:00	0.0001	0.10
	13:00:00	0.0049	3.49		13:00:00	0.0014	0.92
	14:00:00	0.0057	3.66		14:00:00	0.0014	0.92
	15:00:00	0.0065	4.16		15:00:00	0.0004	0.20
	16:00:00	0.0063	3.71		16:00:00	-0.0013	-0.63
	Positive Order Imbalances						
	Night	-0.00956	-8.17		Night	-0.0052	-4.06
DAY	10:00:00	-0.0003	-0.51	DAY	10:00:00	-0.0001	-0.13
	11:00:00	-0.0002	-0.22		11:00:00	-0.0037	-3.77
	12:00:00	-0.0014	-1.61		12:00:00	-0.0037	-3.26
	13:00:00	-0.0016	-1.31		13:00:00	-0.0030	-2.31
	14:00:00	-0.0013	-0.89		14:00:00	-0.0026	-1.73
	15:00:00	0.0002	0.10		15:00:00	-0.0038	-2.51
	16:00:00	0.0033	1.40		16:00:00	-0.0058	-3.53

Table 11. SPX trading before and after introduction of overnight trading hours.

The table presents summary statistics for trading activity of SPX call and put options for 2011 to 2014, and 2015 – 2017 subperiods, before and after introduction of SPX night trading respectively. *COIM(t)* is cumulative options net order imbalance on day t for a given hour of a day. *COIM(t-1)* is cumulative options net order imbalance on day *t-1* for a given hour of a day. *1h –OIM* are order imbalances summed by hour of a day *t* (non-cumulative). # trades (1h-#contracts) is an average number of trades (number of contracts traded) computed across all series in each portfolio for a given hour of day t. 1h-$$volume is an average portfolio dollar volume for a given hour (non-cumulative) of day t. For 10 am – it is only a 30 min interval, from 9:30am to 10am. Negative (Positive) order imbalance days are identified by aggregating net order flows for a day t using dollar open interest form the previous day, t-1, as the weight.

Panel A. Calls, 2011-2014

	All Positive Volume Days					
	COIM(T)	COIM(T-1)	1h -OIM	# trades	1h -# contracts	1h- $$volume
10:00:00	-0.0050	-0.0066	-0.0050	10.78	488.51	13440.3
11:00:00	-0.0135	-0.0134	-0.0088	10.79	953.70	27118.3
12:00:00	-0.0125	-0.0128	-0.0059	10.42	763.70	22569.0
13:00:00	-0.0144	-0.0151	-0.0093	11.14	660.00	19122.3
14:00:00	-0.0160	-0.0163	-0.0021	11.54	608.66	18203.9
15:00:00	-0.0166	-0.0172	-0.0031	11.45	604.39	18604.1
16:00:00	-0.0175	-0.0170	-0.0068	10.64	666.78	20541.4
	Negative Order Imbalances days					
10:00:00	-0.1051	-0.0137	-0.1051	10.66	474.28	13203.4
11:00:00	-0.0908	-0.0211	-0.0530	10.97	999.23	28620.5
12:00:00	-0.0841	-0.0194	-0.0404	10.68	787.27	23502.2
13:00:00	-0.0852	-0.0233	-0.0323	11.57	668.59	19198.4
14:00:00	-0.0816	-0.0232	-0.0130	12.21	610.36	18292.5
15:00:00	-0.0815	-0.0227	-0.0200	11.69	617.75	18840.3
16:00:00	-0.0788	-0.0221	-0.0203	10.72	670.60	20662.8
	Positive Order Imbalances days					
10:00:00	0.0996	0.0015	0.0996	10.89	503.34	13687.4
11:00:00	0.0794	-0.0040	0.0441	10.55	899.14	25318.4
12:00:00	0.0782	-0.0046	0.0375	10.07	733.99	21392.4
13:00:00	0.0730	-0.0049	0.0191	10.61	649.42	19028.6
14:00:00	0.0696	-0.0074	0.0122	10.66	606.45	18088.8
15:00:00	0.0698	-0.0100	0.0194	11.13	586.61	18289.9
16:00:00	0.0643	-0.0104	0.0113	10.52	661.69	20379.3

Panel B. Calls, 2015-2017

	All Positive Volume Days					
	COIM(T)	COIM(T-1)	1h -OIM	# trades	1h -# contracts	1h- $$volume
10:00:00	0.0056	0.0058	0.0056	10.41	346.33	12349.5
11:00:00	-0.0004	-0.0011	0.0010	10.29	616.94	22425.6
12:00:00	0.0001	-0.0007	0.0069	9.55	527.74	19431.0
13:00:00	-0.0021	-0.0025	-0.0005	9.45	418.57	15605.3
14:00:00	-0.0022	-0.0039	0.0015	9.70	373.13	14104.1
15:00:00	-0.0032	-0.0046	-0.0027	9.64	386.55	14720.7
16:00:00	-0.0035	-0.0049	-0.0041	9.79	429.12	15753.1
	Negative Order Imbalances days					
10:00:00	-0.0513	-0.0008	-0.0513	10.54	338.98	12280.7
11:00:00	-0.0603	-0.0018	-0.0351	10.11	625.34	23112.8
12:00:00	-0.0605	-0.0023	-0.0204	9.67	522.86	19517.9
13:00:00	-0.0579	-0.0049	-0.0198	9.46	412.74	15722.1
14:00:00	-0.0583	-0.0074	-0.0131	9.65	379.55	14263.9
15:00:00	-0.0568	-0.0092	-0.0196	9.50	391.01	14812.7
16:00:00	-0.0567	-0.0067	-0.0198	9.48	435.88	16625.0
	Positive Order Imbalances days					
10:00:00	0.0607	0.0121	0.0607	10.29	353.22	12414.0
11:00:00	0.0624	-0.0003	0.0389	10.47	608.12	21704.6
12:00:00	0.0591	0.0009	0.0334	9.43	532.49	19346.5
13:00:00	0.0552	-0.0001	0.0193	9.44	424.56	15485.4
14:00:00	0.0550	-0.0005	0.0164	9.76	366.58	13940.9
15:00:00	0.0546	0.0004	0.0158	9.79	381.68	14620.2
16:00:00	0.0523	-0.0031	0.0126	10.11	421.92	14825.9

Panel C. Puts, 2011-2014

	COIM(T)	COIM(T-1)	1h -OIM	# trades	1h -# contracts	1h- $$volume
All Positive Volume Days						
10:00:00	-0.0059	-0.0061	-0.0059	11.55	601.12	14295.3
11:00:00	-0.0045	-0.0039	0.0008	11.60	1134.08	27701.9
12:00:00	-0.0059	-0.0048	-0.0067	10.92	886.61	22206.1
13:00:00	-0.0067	-0.0052	-0.0057	11.77	751.74	18880.8
14:00:00	-0.0054	-0.0037	0.0004	12.32	686.33	17741.6
15:00:00	-0.0062	-0.0054	-0.0034	12.38	672.75	17774.4
16:00:00	-0.0066	-0.0046	-0.0103	11.33	749.41	19373.0
Negative Order Imbalances days						
10:00:00	-0.0838	-0.0098	-0.0838	11.27	581.94	14046.9
11:00:00	-0.0731	-0.0076	-0.0441	12.10	1141.28	28064.2
12:00:00	-0.0676	-0.0043	-0.0393	11.30	888.40	22867.1
13:00:00	-0.0639	-0.0056	-0.0258	12.48	741.65	18926.1
14:00:00	-0.0605	-0.0046	-0.0172	12.95	670.70	17796.5
15:00:00	-0.0614	-0.0078	-0.0190	12.74	654.76	17883.0
16:00:00	-0.0572	-0.0075	-0.0220	11.43	747.64	19744.6
Positive Order Imbalances days						
10:00:00	0.0807	-0.0015	0.0807	11.85	622.45	14571.6
11:00:00	0.0648	-0.0003	0.0463	11.08	1126.79	27335.3
12:00:00	0.0607	-0.0057	0.0285	10.48	884.68	21494.1
13:00:00	0.0597	-0.0050	0.0176	10.94	763.45	18828.2
14:00:00	0.0582	-0.0028	0.0206	11.59	704.31	17678.5
15:00:00	0.0555	-0.0028	0.0142	11.97	692.98	17652.3
16:00:00	0.0505	-0.0015	0.0030	11.21	751.43	18950.0

Panel D. Puts, 2015-2017

	COIM(T)	COIM(T-1)	1h -OIM	# trades	1h -# contracts	1h- $$volume
All Positive Volume Days						
10:00:00	0.0054	0.0069	0.0054	11.21	397.90	12575.7
11:00:00	0.0096	0.0087	0.0118	11.35	665.67	21667.8
12:00:00	0.0109	0.0109	0.0112	10.28	563.75	18627.5
13:00:00	0.0093	0.0096	-0.0010	10.09	443.13	14578.1
14:00:00	0.0090	0.0093	0.0074	10.28	398.83	13449.7
15:00:00	0.0082	0.0089	-0.0001	10.32	404.64	13435.2
16:00:00	0.0062	0.0067	-0.0006	10.56	463.50	14997.8
Negative Order Imbalances days						
10:00:00	-0.0492	0.0031	-0.0492	11.52	384.70	12290.4
11:00:00	-0.0451	0.0107	-0.0237	11.07	670.72	22041.6
12:00:00	-0.0410	0.0156	-0.0105	10.19	547.08	18581.7
13:00:00	-0.0384	0.0101	-0.0200	9.89	456.59	15861.5
14:00:00	-0.0394	0.0108	-0.0074	10.21	424.35	14820.0
15:00:00	-0.0371	0.0082	-0.0126	10.32	425.10	14305.4
16:00:00	-0.0389	0.0056	-0.0175	11.17	482.14	16172.4
Positive Order Imbalances days						
10:00:00	0.0566	0.0103	0.0566	10.93	409.89	12834.9
11:00:00	0.0519	0.0071	0.0392	11.57	661.76	21378.6
12:00:00	0.0469	0.0076	0.0263	10.34	575.32	18659.3
13:00:00	0.0448	0.0092	0.0132	10.23	433.10	13622.3
14:00:00	0.0419	0.0083	0.0175	10.32	381.52	12519.8
15:00:00	0.0420	0.0094	0.0092	10.31	389.39	12786.6
16:00:00	0.0387	0.0075	0.0115	10.12	450.05	14150.6

Table 12. Week-end Effect in Option Returns, Equity Options

The table presents average portfolio delta hedged daily returns using different hour of a day mid-quotes for call and put options of S&P500 components for 2004 to 2010, and 2011 – 2017 subperiods. Nontrading period is defined as week-ends, from Friday close to Monday close. Trading periods are all other week days, Monday though Friday. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Call Options, S&P500 firms, 2004 - 2010

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0172	-0.0141	-0.0031	-0.0166	-0.0146	-0.0180	-0.0114	-0.0132
	-32.26	-72.21	-5.49	-28.22	-31.96	-52.73	-40.04	-37.38
11:00:00	-0.0148	-0.0098	-0.0050	-0.0145	-0.0102	-0.0129	-0.0062	-0.0102
	-26.57	-52.34	-8.55	-23.86	-22.62	-39.43	-21.79	-30.38
12:00:00	-0.0133	-0.0070	-0.0063	-0.0130	-0.0080	-0.0093	-0.0030	-0.0080
	-28.15	-37.79	-12.46	-24.75	-17.49	-30.52	-11.10	-23.94
13:00:00	-0.0119	-0.0055	-0.0065	-0.0117	-0.0070	-0.0065	-0.0004	-0.0086
	-23.16	-28.22	-11.76	-21.07	-15.30	-22.65	-1.30	-23.76
14:00:00	-0.0111	-0.0037	-0.0074	-0.0108	-0.0064	-0.0045	0.0001	-0.0047
	-21.42	-19.32	-13.42	-19.45	-13.69	-14.63	0.47	-14.67
15:00:00	-0.0100	-0.0016	-0.0083	-0.0096	-0.0043	-0.0012	0.0032	-0.0049
	-18.46	-8.31	-14.55	-16.55	-8.39	-3.80	11.01	-15.93
16:00:00	-0.0077	0.0010	-0.0087	-0.0073	-0.0011	0.0023	0.0052	-0.0028
	-15.26	4.77	-15.91	-13.00	-2.02	6.70	16.13	-7.84

Panel B. Call Options, S&P500 firms, 2010 - 2017

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0161	-0.0139	-0.0023	-0.0160	-0.0177	-0.0131	-0.0114	-0.0133
	-35.30	-72.27	-4.53	-35.25	-52.63	-41.53	-28.78	-28.47
11:00:00	-0.0131	-0.0098	-0.0034	-0.0133	-0.0130	-0.0076	-0.0081	-0.0103
	-32.98	-53.48	-7.67	-34.86	-40.89	-25.18	-20.32	-23.70
12:00:00	-0.0117	-0.0066	-0.0051	-0.0123	-0.0097	-0.0038	-0.0048	-0.0082
	-25.57	-35.24	-10.31	-32.91	-26.12	-11.08	-11.77	-20.09
13:00:00	-0.0108	-0.0044	-0.0065	-0.0122	-0.0073	-0.0019	-0.0035	-0.0047
	-15.15	-17.33	-8.56	-29.81	-22.33	-4.59	-8.58	-6.74
14:00:00	-0.0102	-0.0029	-0.0073	-0.0110	-0.0051	-0.0001	-0.0011	-0.0057
	-23.38	-16.59	-15.47	-28.62	-14.66	-0.20	-2.73	-17.65
15:00:00	-0.0097	-0.0008	-0.0089	-0.0108	-0.0034	0.0008	0.0034	-0.0044
	-21.73	-4.42	-18.35	-26.52	-9.95	2.66	9.19	-9.78
16:00:00	-0.0073	0.0013	-0.0086	-0.0093	-0.0011	0.0039	0.0051	-0.0029
	-12.01	6.63	-13.49	-24.43	-3.65	8.42	13.39	-6.40

Panel C. Put Options, SP500 firms, 2004 - 2010

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0181	-0.0166	-0.0014	-0.0180	-0.0182	-0.0185	-0.0136	-0.0172
	-30.37	-67.64	-2.23	-29.99	-33.96	-46.41	-36.40	-29.03
11:00:00	-0.0158	-0.0114	-0.0044	-0.0158	-0.0131	-0.0130	-0.0083	-0.0128
	-27.41	-48.13	-7	-27.47	-24.56	-32.52	-24.18	-23.00
12:00:00	-0.0139	-0.0084	-0.0055	-0.0139	-0.0098	-0.0096	-0.0049	-0.0105
	-24.45	-36.04	-8.95	-24.59	-18.83	-23.66	-15.25	-19.01
13:00:00	-0.0130	-0.0065	-0.0066	-0.0131	-0.0083	-0.0079	-0.0023	-0.0086
	-24.13	-28.31	-11.19	-24.09	-16.99	-20.47	-6.43	-15.84
14:00:00	-0.0111	-0.0044	-0.0068	-0.0112	-0.0065	-0.0057	-0.0005	-0.0068
	-13.34	-15.09	-7.67	-13.35	-13.24	-14.52	-1.41	-13.71
15:00:00	-0.0090	-0.0018	-0.0072	-0.0100	-0.0038	-0.0026	0.0027	-0.0056
	-10.35	-6.04	-7.89	-11.67	-7.41	-6.34	8.29	-11.46
16:00:00	-0.0076	0.0000	-0.0077	-0.0084	-0.0016	0.0003	0.0050	-0.0051
	-11.83	0.1	-11.04	-13.42	-2.90	0.67	13.08	-8.59

Panel D. Put Options, SP500 firms, 2010 - 2017

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0191	-0.0174	-0.0018	-0.0191	-0.0200	-0.0181	-0.0161	-0.0165
	-38.07	-89.72	-3.26	-37.41	-68.55	-50.12	-35.90	-41.17
11:00:00	-0.0172	-0.0125	-0.0047	-0.0173	-0.0149	-0.0114	-0.0115	-0.0134
	-30.48	-63.47	-7.89	-36.31	-52.48	-31.84	-25.87	-27.64
12:00:00	-0.0166	-0.0093	-0.0073	-0.0171	-0.0109	-0.0086	-0.0080	-0.0105
	-36.8	-50.53	-14.92	-37.49	-39.13	-24.21	-17.75	-27.65
13:00:00	-0.0155	-0.0075	-0.0080	-0.0157	-0.0087	-0.0057	-0.0060	-0.0102
	-28.31	-37.1	-13.78	-34.35	-31.40	-13.75	-13.42	-22.03
14:00:00	-0.0146	-0.0053	-0.0093	-0.0150	-0.0060	-0.0041	-0.0035	-0.0085
	-27.47	-25.87	-16.37	-31.92	-21.12	-9.25	-7.64	-20.23
15:00:00	-0.0132	-0.0030	-0.0102	-0.0136	-0.0040	-0.0019	-0.0012	-0.0069
	-24.62	-13.84	-17.59	-28.34	-13.51	-5.06	-2.42	-14.51
16:00:00	-0.0121	-0.0010	-0.0111	-0.0129	-0.0022	0.0004	0.0017	-0.0056
	-20.22	-4.72	-17.51	-26.28	-7.50	0.86	3.26	-13.15

Table 13. Week-end Effect in Option Returns, SPX Options

The table presents average portfolio delta hedged daily returns using different hour of a day mid-quotes for SPX call and put options for 2004 to 2010, and 2011 – 2017 subperiods. Nontrading period is defined as week-ends, from Friday close to Monday close. Trading periods are all other week days, Monday though Friday. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. SPX Call Options, 2004 - 2010

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0172	-0.0183	0.0011	-0.0171	-0.0187	-0.0250	-0.0096	-0.0202
	-14.23	-29.56	0.80	-14.27	-16.48	-19.50	-10.39	-16.63
11:00:00	-0.0200	-0.0139	-0.0061	-0.0198	-0.0150	-0.0197	-0.0065	-0.0146
	-15.48	-25.68	-4.39	-15.58	-15.46	-17.16	-7.94	-13.75
12:00:00	-0.0179	-0.0116	-0.0063	-0.0178	-0.0144	-0.0155	-0.0030	-0.0136
	-15.1	-24.58	-4.95	-15.21	-17.20	-14.28	-3.66	-15.08
13:00:00	-0.0177	-0.0102	-0.0075	-0.0176	-0.0126	-0.0141	-0.0003	-0.0139
	-13.68	-21.32	-5.34	-13.81	-15.73	-13.98	-0.30	-11.88
14:00:00	-0.0154	-0.0087	-0.0067	-0.0153	-0.0117	-0.0117	-0.0013	-0.0103
	-11.8	-18.75	-4.8	-11.91	-13.47	-12.72	-1.35	-10.44
15:00:00	-0.0140	-0.0056	-0.0084	-0.0139	-0.0080	-0.0083	0.0037	-0.0097
	-9.54	-12.32	-5.44	-9.63	-7.76	-10.02	3.65	-10.66
16:00:00	-0.0097	0.0000	-0.0097	-0.0096	-0.0024	-0.0007	0.0074	-0.0042
	-5.22	0.01	-5.01	-5.25	-2.42	-0.62	6.99	-4.15

Panel B. SPX Call Options, 2010 - 2017

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0187	-0.0118	-0.0069	-0.0186	-0.0134	-0.0060	-0.0101	-0.0173
	-21.92	-40.48	-7.70	-22.02	-24.15	-10.12	-14.71	-24.90
11:00:00	-0.0153	-0.0096	-0.0057	-0.0152	-0.0097	-0.0042	-0.0077	-0.0165
	-21.13	-39.07	-7.4	-21.32	-20.38	-8.14	-11.69	-24.51
12:00:00	-0.0161	-0.0072	-0.0089	-0.0160	-0.0052	-0.0025	-0.0062	-0.0142
	-24.32	-31.86	-12.77	-24.49	-11.10	-5.37	-10.14	-21.67
13:00:00	-0.0169	-0.0051	-0.0117	-0.0168	-0.0021	-0.0019	-0.0036	-0.0123
	-24.87	-25.48	-16.57	-25.09	-4.60	-3.87	-5.42	-19.67
14:00:00	-0.0181	-0.0035	-0.0146	-0.0180	0.0003	-0.0009	-0.0014	-0.0111
	-22.81	-18.76	-17.95	-23.02	0.68	-1.79	-2.19	-17.62
15:00:00	-0.0176	-0.0015	-0.0161	-0.0175	0.0020	-0.0011	0.0038	-0.0099
	-20.21	-7.98	-18.1	-20.42	3.54	-2.03	5.51	-17.10
16:00:00	-0.0108	0.0000	-0.0108	-0.0109	0.0034	0.0037	0.0050	-0.0111
	-13.29	0.04	-12.8	-13.46	6.20	5.04	5.93	-15.13

Panel C. SPX Put Options, 2004 - 2010

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0163	-0.0173	0.0010	-0.0159	-0.0206	-0.0222	-0.0096	-0.0174
	-16.69	-34.12	0.92	-16.41	-19.79	-23.50	-12.02	-17.85
11:00:00	-0.0191	-0.0132	-0.0059	-0.0188	-0.0174	-0.0166	-0.0068	-0.0125
	-18.79	-29.61	-5.3	-18.82	-18.46	-17.87	-9.25	-12.72
12:00:00	-0.0189	-0.0103	-0.0086	-0.0186	-0.0149	-0.0137	-0.0027	-0.0100
	-18.07	-24.96	-7.68	-18.09	-18.56	-16.39	-3.54	-12.82
13:00:00	-0.0181	-0.0091	-0.0091	-0.0178	-0.0144	-0.0133	0.0024	-0.0110
	-15.49	-21.69	-7.29	-15.63	-19.27	-17.34	2.23	-9.66
14:00:00	-0.0168	-0.0070	-0.0098	-0.0166	-0.0127	-0.0091	-0.0013	-0.0052
	-11.64	-17.45	-6.53	-11.79	-18.13	-12.21	-1.53	-5.04
15:00:00	-0.0164	-0.0034	-0.0130	-0.0161	-0.0072	-0.0063	0.0057	-0.0055
	-9.22	-7.84	-7.13	-9.34	-7.85	-10.52	5.22	-6.07
16:00:00	-0.0112	0.0025	-0.0138	-0.0110	-0.0031	0.0027	0.0104	0.0002
	-5.77	5	-6.84	-5.79	-3.05	2.53	9.64	0.19

Panel D. SPX Put Options, 2010 - 2017

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0195	-0.0180	-0.0015	-0.0192	-0.0204	-0.0191	-0.0121	-0.0204
	-19.03	-49.70	-1.37	-19.06	-24.15	-22.80	-12.90	-27.30
11:00:00	-0.0171	-0.0150	-0.0021	-0.0170	-0.0173	-0.0136	-0.0113	-0.0178
	-20.91	-50.17	-2.41	-21.19	-27.63	-20.56	-12.40	-27.08
12:00:00	-0.0193	-0.0122	-0.0070	-0.0190	-0.0134	-0.0122	-0.0076	-0.0159
	-26.95	-41.34	-9.07	-26.76	-20.95	-20.37	-7.62	-21.75
13:00:00	-0.0191	-0.0100	-0.0091	-0.0190	-0.0104	-0.0105	-0.0059	-0.0132
	-22.52	-38.9	-10.26	-22.67	-18.54	-18.08	-6.93	-17.48
14:00:00	-0.0179	-0.0082	-0.0097	-0.0177	-0.0074	-0.0115	-0.0011	-0.0127
	-18.4	-33.7	-9.64	-18.55	-12.36	-16.65	-1.11	-17.78
15:00:00	-0.0196	-0.0054	-0.0142	-0.0194	-0.0048	-0.0100	0.0017	-0.0082
	-20.13	-21.22	-14.14	-20.12	-7.45	-13.55	1.54	-11.50
16:00:00	-0.0163	-0.0017	-0.0146	-0.0162	-0.0037	-0.0011	0.0055	-0.0071
	-15.19	-5.3	-13.06	-15.21	-5.88	-1.24	4.29	-8.41

Table 14. Week-end Effect: Equity Option Returns after Introduction of SPX night trading.

The table presents average portfolio delta hedged daily returns using different hour of a day mid-quotes for call and put options of S&P500 components for 2015 – 2017 period. Nontrading period is defined as week-ends, from Friday close to Monday close. Trading periods are all other week days, Monday though Friday. T-statistics are based on Newey-West standard errors adjusted for 22 lags.

Panel A. Call Options, SP500 firms, 2015 - 2017

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0198	-0.0150	-0.0048	-0.0192	-0.0201	-0.0123	-0.0128	-0.0137
	-23.39	-41.65	-5.23	-22.28	-52.35	-21.21	-16.48	-13.41
11:00:00	-0.0177	-0.0103	-0.0074	-0.0178	-0.0125	-0.0080	-0.0091	-0.0099
	-29.06	-29.9	-10.61	-32.76	-31.85	-13.03	-11.49	-10.60
12:00:00	-0.0153	-0.0067	-0.0086	-0.0163	-0.0082	-0.0039	-0.0056	-0.0084
	-19.93	-17.89	-10.04	-28.24	-22.43	-5.20	-6.68	-8.80
13:00:00	-0.0137	-0.0039	-0.0098	-0.0167	-0.0052	-0.0017	-0.0046	-0.0024
	-8.62	-7.27	-5.84	-23.77	-13.92	-1.79	-5.55	-1.49
14:00:00	-0.0129	-0.0024	-0.0105	-0.0147	-0.0032	0.0006	-0.0024	-0.0041
	-17.9	-7.55	-13.28	-29.56	-6.49	0.92	-2.98	-7.31
15:00:00	-0.0125	-0.0003	-0.0123	-0.0145	-0.0017	0.0017	0.0014	-0.0016
	-16.68	-0.72	-14.8	-24.04	-3.63	2.65	1.94	-1.67
16:00:00	-0.0093	0.0019	-0.0111	-0.0133	0.0011	0.0044	0.0038	-0.0007
	-7.41	4.75	-8.49	-26.57	2.96	4.14	5.33	-0.73

Panel B. Put Options, SP500 firms, 2015 - 2017

time	Nontrading	Trading	Difference	Monday	Tuesday	Wednesday	Thursday	Friday
10:00:00	-0.0200	-0.0179	-0.0021	-0.0199	-0.0208	-0.0173	-0.0194	-0.0163
	-25.36	-53.54	-2.48	-25.45	-43.66	-35.63	-23.07	-22.71
11:00:00	-0.0181	-0.0131	-0.0050	-0.0175	-0.0151	-0.0117	-0.0126	-0.0146
	-17.49	-34.29	-4.52	-26.43	-29.41	-16.28	-15.04	-14.40
12:00:00	-0.0180	-0.0092	-0.0088	-0.0187	-0.0100	-0.0081	-0.0096	-0.0097
	-27	-29.06	-11.95	-29.17	-19.97	-15.48	-11.10	-13.97
13:00:00	-0.0177	-0.0070	-0.0107	-0.0171	-0.0074	-0.0051	-0.0073	-0.0091
	-17.73	-18.63	-10.02	-27.29	-14.94	-7.07	-8.47	-9.59
14:00:00	-0.0167	-0.0045	-0.0121	-0.0168	-0.0033	-0.0039	-0.0053	-0.0066
	-17.22	-11.98	-11.7	-24.77	-6.35	-4.57	-6.00	-8.21
15:00:00	-0.0148	-0.0023	-0.0124	-0.0146	-0.0014	-0.0016	-0.0033	-0.0050
	-15.98	-5.72	-12.33	-21.37	-2.59	-2.63	-3.40	-5.08
16:00:00	-0.0141	-0.0001	-0.0139	-0.0151	0.0008	-0.0001	-0.0007	-0.0021
	-13.05	-0.37	-12.17	-22.39	1.46	-0.12	-0.71	-2.55