DEPARTMENT OF FINANCE
UNIVERSITY OF MELBOURNE

FNCE40006

Finance Research Essay

Stock Market Effects Around Index Futures Expiration

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November 2018

Abstract

Expiration effects associated with stock index futures have been well documented in many markets around the world. Prior research has found evidence of higher stock market volume, volatility and price reversals near expiration, potentially caused by index arbitrage or price manipulation. Several studies have also explored ways to mitigate these ill-effects, proposing that the methodology used to determine the settlement price has a large impact on their severity. This study uses stock data from 24 major indexes around the world to (1) verify the existence of expiration effects and (2) identify the determinants of their severity. It finds that all effects are significant, but volume increases are far greater in magnitude than the changes in volatility and price reversals. Additionally, using an arithmetic average settlement over a long period appears to be the most effective at mitigating these effects.

Declaration

This essay is the sole work of the author whose name appears on the title page. It contains no material which the author has previously submitted for assessment at the University of Melbourne or elsewhere. To the best of the author's knowledge, the essay contains no material previously written or published by another person except where reference is made in the text of the essay.

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Signature of Student

Acknowledgements

I would like to thank Associate Professor John Handley for his guidance and supervision in completing this research essay. I would also like to thank Professor Patrick Verwijmeren, Doctor Jonathan Dark, Professor Bruce Grundy and Doctor James Brugler for assisting me in developing my essay topic.

Contents

1 Introduction

Stock index futures are a commonly used tool to speculate and hedge market risk. In 2017, global volume, measured by the number of contracts traded, exceeded 2.3 billion and accounted for 10% of all derivatives.[1] Their history extends back to February 1982 when the first contract, based on the Value Line Index, began trading on the Kansas City Board of Trade. Prior to their introduction, stock indexes were used to measure the performance of a basket of stocks, but investors did not have a cost-effective way of gaining exposure to these.

Like other futures contracts, the buyer of an index future has an obligation to purchase the underlying at a specified price from the seller on expiration day. If the index value at expiration exceeds this price, the seller pays the difference (usually multiplied by some multiplier) to the buyer. Likewise, if the index value is lower than the specified price, the buyer pays the difference instead.[2]

Shortly after their inception however, controversy arose because of seemingly abnormal behaviour in the underlying stock market around expiration days. In particular, volume and volatility appeared to increase and stock prices tended to revert shortly after expiration. At the heart of these effects was thought to be arbitrageurs unwinding their stock positions or speculators attempting to manipulate the settlement price. This prompted researchers to investigate expiration effects in markets all across the globe. Some have then proposed ways to mitigate these effects.

Building on prior research, the purpose of this paper is to verify the existence of expiration day effects and examine the determinants of their severity. In particular, this study focuses on exploring the methodology used to calculate the settlement

[1] Source: *WFE IOMA 2017 derivatives report* (2017).

[2] Settlement in this way is known as cash settlement. The alternative is physical delivery, which is where the seller gives the underlying to the buyer in exchange for cash.

price. Other determinants, such as the length of the settlement period and index weight, are also explored. These questions are addressed using data from the five largest stocks from 24 major indexes over a period extending from 1 January, 2015 to 31 December, 2017.

The motivation of this research essay is as follows:

1. Mitigation of expiration day effects is in the best interest of market participants and exchange regulators around the world. Firstly, unknowing investors may incur additional trading costs if they enter the market at these inopportune times and transact at prices away from equilibrium. Secondly, excessive volatility and the lack of market efficiency[3] may discourage traders and therefore negatively impact liquidity. Identifying the factors that affect the severity may help exchanges improve current regulations.

2. Prior research has yielded mixed results on whether expiration effects occur. However, they have often focused on a single index or market, which has limited the ability for findings to be extended broadly. This paper is the first to consider a large number of indexes in a single study.

[3] Systematic reversion is a sign of inefficiency.

2 Futures Specifications

Index futures vary in the way the settlement price is determined (referred to as the settlement procedure or method), the length of the settlement period, the frequency of the contracts and the day and time they expire.

The five main settlement procedures are listed below. Over time, the popularity of using a closing settlement method has declined, so futures in this category are not considered in this study.[4]

1. Arithmetic average (arithmetic): the settlement price is determined by a simple average of the index values disseminated over a specified period on expiration day.

2. Closing price (closing): the settlement price is determined by the closing index value, which is calculated from the closing prices of the constituent stocks.

3. Intraday auction (intraday): the settlement price is calculated from the intraday auction prices of the stocks. An intraday auction pauses continuous trading for a short period to accumulate orders. At the end of the auction period, all overlapping bids and offers are traded against each other at a single price.

4. Special Opening Quotation (SOQ): the settlement price is calculated from the opening prices of the stocks. If no opening price is recorded for a certain stock, then the price of the first trade is used instead.[5]

5. Volume weighted average price (VWAP): the settlement price is calculated from the VWAP of each stock over a specified period on expiration day.

Futures expiring via closing, intraday or SOQ are necessarily settled at a single price. Those that settle using an average procedure (arithmetic and VWAP) have

[4] Of the more notable indexes, only KOSPI futures (South Korea) still use the closing method.
[5] The opening and closing prices are also usually determined through an auction.

settlement periods that range from 20 minutes to the entire expiration day.[6]

Index futures usually expire at a quarterly or monthly frequency on a fixed day and week of the month (ie. the third Thursday). However, some exceptions to this rule are iBovespa Index futures (Brazil) which expire on the closest Wednesday to the 15th in even-numbered months only and Hang Seng Index futures (Hong Kong) which expire on the second-to-last business day of the month. Certain exchanges also list mini contracts alongside the regular size contracts. These contracts have a multiplier that is only a fraction of the regular but are otherwise identical.

Tables 1 and 2 on the next two pages present the contract specifications of the index futures used in this study.

[6]The settlement period is where the average index value is calculated over.

Table 1: Contract specifications of the index futures used in this study

Country	Underlying index	Settlement	Frequency	Expiration day	Expiration Time
Australia	**S&P/ASX 200**	SOQ	Monthly	Third Thursday	Open
Austria	**ATX**	Intraday	Quarterly	Third Friday	12:00
Belgium	**BEL 20**	Arithmetic	Monthly	Third Friday	16:00
Brazil	**iBovespa**	Arithmetic	Even months	Closest Wednesday to the 15th	Close
Canada	**S&P/TSX 60**	SOQ	Quarterly	Third Friday	Open
China	**CSI 300**	Arithmetic	Monthly	Third Friday	Close
France	**CAC 40**	Arithmetic	Monthly	Third Friday	16:00
Germany	**DAX**	Intraday	Quarterly	Third Friday	13:00
Greece	**FTSE/ATHEX Large Cap**	Intraday	Monthly	Third Friday	13:45
Hong Kong	**Hang Seng**	Arithmetic	Monthly	Second last business day	Close
Hungary	**BUX**	Arithmetic	Monthly	Third Friday	10:00
India	**NIFTY**	VWAP[7]	Monthly	Last Thursday	Close
Italy	**FTSE MIB**	SOQ	Quarterly	Third Friday	Open
Netherlands	**AEX**	Arithmetic	Monthly	Third Friday	16:00
Norway	**OBX**	VWAP	Monthly	Third Thursday	Close
Poland	**WIG 20**	Arithmetic	Quarterly	Third Friday	Close
Russia	**RTS**	Arithmetic	Quarterly	Third Thursday	16:00
South Africa	**FTSE/JSE Top 40**	Intraday	Quarterly	Third Thursday	12:00
Spain	**IBEX 35**	Arithmetic	Monthly	Third Friday	16:45
Sweden	**OMXS 30**	VWAP	Monthly	Third Friday	Close
Switzerland	**SMI**	SOQ	Quarterly	Third Friday	Open
Taiwan	**TAIEX**	Arithmetic	Monthly	Third Wednesday	Close
UK	**FTSE 100**	Intraday	Quarterly	Third Friday	10:15
US	**S&P 500**	SOQ	Quarterly	Third Friday	Open

The contract specifications presented apply over the study period, which is from 1 January, 2015 to 31 December, 2017. 'Settlement' denotes the settlement procedure. 'Frequency' denotes if the contract cycle is monthly or quarterly. 'Expiration Day' denotes the day, in each expiration month that the futures contracts expire. 'Expiration Time' denotes the time of day the settlement price is determined on expiration days. Whenever the frequency is quarterly, it refers to the March, June, September, December cycle.

[7] NIFTY futures are actually listed as using closing. However, the closing prices of the underlying stocks are determined by their VWAP in the last half hour before close. Therefore, it is more appropriate to categorise them as using VWAP.

Table 2: Calculation methodology for average settled futures

Underlying index	**Settlement method**	**Settlement period and calculation method**
BEL 20	Arithmetic	Average of index values between 15:40 - 16:00
iBovespa	Arithmetic	Average of index values published every 30 seconds in the last three hours before close
CSI 300	Arithmetic	Average of index values in the last two hours before close
CAC 40	Arithmetic	Average of index values between 15:40 - 16:00
Hang Seng	Arithmetic	Average of index values over the entire day, taken at five minute intervals
BUX	Arithmetic	Average of index values from 9:20:01 to 10:00:00, ignoring the top and bottom 15 values
NIFTY	VWAP	VWAP over the last 30 minutes before close
AEX	Arithmetic	Average of index values between 15:30 - 16:00, taken at one minute intervals
OBX	VWAP	VWAP taken over the entire expiration day
WIG 20	Arithmetic	Average of index values over the last hour of trading after rejecting the five top and bottom index values
RTS	Arithmetic	Average of index values over 15:00 to 16:00
IBEX 35	Arithmetic	Average of index values between 16:15 and 16:45
OMXS 30	VWAP	VWAP taken over the entire expiration day
TAIEX	Arithmetic	Average of index values over the last 30 minutes before close

This table presents the settlement period and calculation method for average settled futures (arithmetic and VWAP). They apply over the study period, which is from 1 January, 2015 to 31 December, 2017.

3 Theoretical Background

Prior research has proposed that index arbitrage and price manipulation are the root causes of expiration effects. To understand the first, suppose there is an arbitrageur who has a short index futures position and a long position in the underlying basket of stocks (known as long arbitrage). At expiration, the futures position is closed out automatically through cash settlement, leaving the arbitrageur to manually sell the basket. Suppose also, that many traders have set up similar positions and therefore all need to sell stock. This selling pressure may result in higher volume and cause sharp downward price movements, leading also to higher volatility. Additionally, should the temporary price pressure drive prices away from equilibrium, corrective trading may ensue after expiration to reverse these prices. Similarly, these effects would also be prevalent if traders had set up short arbitrage (long futures, short stock) positions instead.[8]

If index futures were physically settled, expiration day effects may not be as potent. Long arbitrageurs could simply deliver the underlying basket to their counter-parties, exiting both their futures and stock positions simultaneously. They would then no longer need to trade in the market, thus eliminating any potential price pressure. However, it has been generally considered impractical to physically deliver index futures, as the underlying they are written over consists of many stocks. Delivery of such a basket and in the correct proportions is almost impossible.

To see how price manipulation causes expiration effects, consider a speculator with a long futures position who benefits from the index finishing at a higher price. Therefore, on expiration day, they have an incentive to manipulate the settlement price upwards by buying the constituent stocks. Again, if many speculators have the same idea, this may cause large upwards price pressure, leading to the same result

[8]The only difference is that there may be upwards price movements instead.

of higher volume, volatility and price reversals. Similarly, effects may also occur if speculators held short futures positions instead. However, one observable difference between arbitrage and price manipulation is the extent to which all stocks in the index are affected. Arbitrage trading should see effects occur evenly in many stocks since trading in a large proportion of the basket is required to adequately track the index. In contrast, price manipulation can be effectively achieved by trading in just the largest stocks.

4 Literature Review

4.1 General findings on expiration day effects

A seminal paper on expiration day effects is Stoll and Whaley's (1987) research on the US market. The contracts they studied, which were on the S&P 100 and S&P 500 indexes, expired on quarterly Fridays and used the closing settlement method.

Stoll and Whaley captured volume effects by measuring the number of shares traded in the last hour on Fridays. They found that this volume was 58% higher than average[9] on quarterly expiration Fridays but almost unchanged (3% lower) on non-expiration Fridays.[10] They also reported higher volatility, measured by the standard deviation of final hour returns, in index stocks but insignificant changes in non-index stocks.[11] This finding of higher volatility being unique to index stocks was strongly supportive of expiration effects.

Stoll and Whaley then examined price reversals, which they defined as:

$$Reversal_t = \begin{cases} r_{t+1}, & \text{if } r_t < 0 \\ -r_{t+1}, & \text{if } r_t > 0 \end{cases}$$

where:

1. r_t is the index return over the last hour on Fridays
2. r_{t+1} is the index return over the first half hour on Mondays

According to this measure, reversals are reflected through a positive value, whilst a negative value indicates a continuation. On expiration days, they reported an

[9] The average per hour volume across the rest of the day.

[10] In addition to quarterly futures expiration days, options expiration occurred monthly on a Friday. Non-expiration Fridays are when neither expire.

[11] The return on non-index stocks was calculated by adjusting the NYSE index returns (which is a broader based index of the US market) to exclude the S&P 500.

average of +0.383%.

Hence, Stoll and Whaley concluded that expiration effects did exist, finding higher volume, volatility and reversals. However, they noted that the magnitude of the reversals was economically insignificant. Typically, a reversal of half the bid-ask spread is expected in the normal course of trading. Over the period they studied, this spread was approximately 0.50%.

Chamberlain, Cheung, and Kwan (1989) however, found mixed evidence in Canada. Volume was unchanged, but returns and volatility were significantly higher. Chamberlain et al also looked for price reversals using a regression approach. They fitted the equation:

$$r_{t+1} = \alpha_0 + (\alpha_1 + \alpha_2 D_t) r_t + \epsilon_t$$

where:

1. r_{t+1} is the index return over the first half hour on Mondays
2. r_t is the index return over the last half hour on Fridays
3. D_t is an indicator variable set equal to 1 on expiration days and 0 otherwise

The coefficient of interest was α_2 which captures the incremental price reversal on expiration Fridays. They found that α_2 was significantly negative, indicating that prices did tend to revert.

A conjecture made to explain their findings was that short arbitrage was more prevalent than long arbitrage over their study period. The unwinding of these positions tends to drive prices up (leading to positive returns) and corrective trading ensues after to create reversals. To verify this, Chamberlain et al identified the times where the spot and futures traded outside of their arbitrage bounds. In support of their hypothesis, nearly all violation occurred when the futures traded too low relative to the spot.

Schlag (1996) investigated DAX futures in Germany, which expired through a SOQ. Individual stock reversals over the first hour after expiration averaged 0.23% whilst the average for an equally-weighted portfolio was 0.18%, both of which were significantly higher than non-expiration days. Interestingly, reversals on the DAX index were slightly negative, though insignificantly. This was explained by stocks with larger weights generally experiencing continuations whilst smaller stocks experienced large reversals

Another expiration effect Schlag reported was the increase in volume at the open. Overnight volume, defined as the trading volume on computerised systems after floor trading closed, was found to be 50% lower before expiration days. This was then followed by a sharp increase in volume at the open. Stocks with the largest weights also experienced significant delays until their opening prices were recorded, indicative of an order imbalance.

Schlag found that some of these effects also occurred in non-DAX stocks. This appeared to cast some doubts on the findings but may also be explained by the lead effect of the DAX, given its importance in the German market.

In Japan, Karolyi (1996) examined volume, volatility and reversals by comparing the effects on expiration day to a randomly sampled non-expiration group.[12] On 'double-witching' days, when both futures and options in Japan expired together, volume rose by about 50%. Across all types of expirations, which included the expiration of Nikkei futures traded in Singapore and the US, volume was about 10%

[12]This method is also known as bootstrapping.

higher. Karolyi also controlled volume for a time trend and day-of-the-week effects over concerns that these may have affected the results. Controlled volume was also found to increase significantly.

Despite the findings on volume, no other expiration day effects were detected. In particular, volatility was unchanged and price reversals did not occur. This led Karolyi to conclude that the expiration day phenomenon in Japan was really "much ado about nothing." Except heightened trading, there were no other signs of market stress.

Illueca and Lafuente (2006) examined expiration day effects associated with IBEX 35 derivatives in Spain. These expired on the third Friday each month and were settled at the arithmetic average taken between 16:15 and 16:45. Like Karolyi, Illueca and Lafuente were concerned that volume tended to trend up over time. They addressed this by dividing the index volume on any given day by its 31-day moving average:

$$Detrended\,volume_t = \frac{Volume_t}{\frac{1}{31}\sum_{k=-15}^{15} Volume_{t+k}}$$

Both daily volume and the volume between 16:00 and 17:30 (known as the last period) were examined.[13] In both cases, a positive and significant increase was found. Illueca and Lafuente also examined realised volatility, which they found to be unchanged when measured over the entire day and only weakly higher in the last period. However, after controlling for volume and lagged volatility, which they suspected may have been correlated with current volatility,[14] significant effects in both periods were found.

[13]The last period is of interest because it encompasses the settlement period.

[14]Andersen, Bollerslev, Diebold, and Ebens (2001) showed that realised volatility is dependent on past realised volatility. Karpoff (1987) reported that realised volatility depends positively on trading volume.

4.2 Expiration day effects in markets with a long settlement period

A major risk index arbitrageurs face is basis or settlement risk, which arises when the average prices obtained for their stocks do not match those used to calculate the settlement index value.[15] This risk is particular large when an average settlement procedure is used. To avoid this, arbitrageurs are encouraged to spread out their trading over the entire settlement period, which means arbitrages become increasingly difficult as the length of this period increases. For these reasons, index futures that use a long average settlement procedure are expected to mitigate the severity of expiration effects by (1) spreading out the effects over the settlement period and (2) deter traders from setting up arbitrage positions altogether.

An example of such contracts are HSI futures traded in Hong Kong. These futures settle at the arithmetic average taken at five-minute intervals over the entire expiration day. Expiration effects from HSI derivatives have been widely documented in past literature.

Bollen and Whaley (1999) were the first researchers to study HSI derivatives following concerns over excess volatility in the stock market. They measured volume effects using the volume growth rate, which they defined as:

$$Volume\ growth\ rate_t = ln\left(\frac{Volume_t}{Volume_{t-1}}\right)$$

This was found to be -1.080% on expiration days, indicating that volume decreased, whilst the non-expiration average was +0.184%. In response to this surprising result, Bollen and Whaley suspected it was due to arbitrage activity only being a recent phenomenon in Hong Kong. Repeating their test for a more recent sub-period, they

[15] Attempting to match the prices is known as 'marking' the settlement price.

found that volume was indeed higher, by a margin of 0.967% to 0.021%. However, this difference was still too small to be statistically insignificant.

Interestingly, Bollen and Whaley found evidence of continuations, not reversals, in the overnight period after expiration. The average was -0.156% across the full sample and -0.335% in the more recent sub-period. Index volatility was also lower, by a margin of 1.78% to 3.59%.

Similarly, Kan (2001) did not find evidence of higher volatility or price reversals. In fact, like Bollen and Whaley, continuations were found on expiration days instead. Kan suggested that the lack of effects may have been due to the absence of computerised trading over the period studied. Arbitrageurs would then take longer to unwind their positions, spreading out the effects and making them harder to detect.

Y. F. Chow, Yung, and Zhang (2002) found that volatility tended to be higher on expiration days. They compared expiration days to the trading day before (T – 1), the day after (T + 1), the fifth day before (T – 5) and the fifth day after (T + 5) by 'pairing' each expiration day to one of the control days (T - 1, T + 1 etc.) in the same month. Using the sum of squared five-minute returns, they found that index volatility was significantly higher than control days T – 5 and T – 1.

Price reversals however, did not seem to exist. This was verified through a binomial test, which examines if the proportion of positive reversals is significantly higher than 50%. Of 114 expiration days, only 49 positive index reversals were observed, representing a proportion of only 43%.

Fung and Yung (2009) noticed increased volume around the five-minute marks that were used to calculate the settlement price. Of the 48 expiration days they studied, 37 had higher per-minute volume around the five-minute marks than the rest of the day.[16] This was significant under both the binomial test and the non-parametric Wilcoxon test.[17] In comparison, volume on non-expiration control days did not seem to concentrate.

Fung and Yung also documented persistent order imbalances[18] around the five-minute marks. On 13 (11) expiration days, a significant positive (negative) imbalance was found. Viewed in conjunction with volume concentration, this was consistent with arbitrageurs or speculators attempting to 'mark' the settlement price.

However, this was not verified by price reversals, which only occurred on 17 of the 48 expiration days. Additionally, the next day's returns were not linked to the direction of the imbalance.[19] Thus, it appeared that despite signs of arbitrage or manipulation, the Hong Kong market handled the expiration day stress well.

Another contract that uses a long settlement procedure are OMX index futures traded in Sweden. These settle at the VWAP taken over the entire expiration day. Alkebäck and Hagelin (2004) found that volume was 9.4% higher on expiration days and 5.9% higher in expiration weeks. This indicated that arbitrage positions were not only unwound on expiration day, but also in the week leading up. Other effects observed were significantly lower returns in a period where short-selling was restricted. Alkebäck and Hagelin suggested that this may have been due to the unwinding of long arbitrage positions, which drives prices down, as short arbitrage was not possible.

[16] The per-minute volume traded from 30 seconds before to 30 seconds after each mark was compared to the per-minute volume traded across other times.

[17] A non-parametric test does not make assumptions about the distribution of the variable.

[18] Order imbalances were measured as the volume traded on the offer minus the volume traded on the bid.

[19] If an order imbalance pushes prices away from equilibrium, it is expected that corrective trading should move prices back. Therefore, returns should be in the opposite direction to the imbalance.

However, higher volatility and reversals were not found. Thus, like Hong Kong, it appeared that using an average settlement procedure over a long period was effective at curbing expiration effects. Despite the perceived advantages however, they noted that the average settlement procedure increased basis risk, potentially complicating the arbitrage and hedging strategies employed by various traders.

4.3 Studies on changes in settlement procedures

In June 1987, US exchanges changed the settlement of S&P 500 and NYSE index derivatives from the closing price to a SOQ. Derivatives on other indexes, such as the Major Market Index (MMI) and S&P 100 continued to expire at the close. Stoll and Whaley (1991) conducted a follow-up study to determine if these changes were effective.

S&P 500 volume in the last half hour on expiration days fell as a result of the change but volume at the open increased by a similar amount. MMI and S&P 100 closing volume however, did not change significantly. Price reversals appeared to follow a similar pattern. Overnight reversals in S&P 500 stocks declined from an average of 0.366% before the change to 0.211% after. However, reversals in the first 30 minutes after the open increased from 0.061% to 0.281%. Thus, it appeared that the regulation change did not mitigate expiration effects but simply shifted them from the close to the open.

Chen and Williams (1994) examined volatility effects after the change. Volatility in the US market was captured in three ways: (1) standard deviations of daily returns on the NYSE and S&P 500 indexes, (2) standard deviation of hourly returns on the Dow Jones Industrial Average (DJIA) and (3) implied volatility of at-the-money options on the S&P 100 index. None of the three methods were able to detect a significant change in volatility. However, Chen and Williams also examined the DJIA volatility in the first hour after open and before close. It was discovered that after the change volatility decreased from 0.9449% to 0.3040% at the close and increased from 0.1512% to 0.3196% at the open. Thus, like Stoll and Whaley (1991), Chen and Williams also observed a shift in timing.

Another market that was subject to a regulation change was Taiwan. Futures on the Taiwan Capitalisation Weighted Stock Index (TAIEX) originally expired through a SOQ but this was changed to an arithmetic average over the first 15-minutes after open. Additionally, futures on the Morgan Stanley Capital International Taiwan (MSCI-TW) index, which had above 97% correlation with the TAIEX, settled using the closing price and were traded alongside TAIEX futures. The closing price of each stock was originally determined by the last value in the continuous trading period, but this was later changed to a five-minute closing auction.

Chung and Hseu (2008) found expiration day effects to be larger around MSCI-TW futures expirations. Higher volatility was found in the last half hour before close. Additionally, after the adoption of the closing auction, prices tended to revert in the overnight period after. Out of 30 expiration days studied, 21 reversals were found, representing a proportion of 70%. Chung and Hseu also found that the average reversal for the largest stock, Taiwan Semiconductor Manufacturing Corporation (1.6240%), was significantly larger than the TAIEX index (0.5136%), which was consistent with price manipulation. On the other hand, no expiration effects were found around TAIEX futures expiration.

4.4 Summary table of previous literature

Table 3 below summarises the findings from each paper.

Table 3: Summary of previous literature

		Volume	Volatility	Price reversal
General studies on expiration effects				
Stoll and Whaley (1987)		Y	Y	Y
Chamberlain, Cheung and Kwan (1989)		N	Y	Y
Schlag (1996)		Y	N	Y
Karolyi (1996)		Y	N	N
Illueca and Lafuente (2006)		Y	Y	-
Expiration-day effects in markets with a long settlement period				
Bollen and Whaley (1999)		N	N	N
Kan (2001)		-	N	N
Chow, Yung and Zhang (2003)		N	Y	N
Fung and Yung (2009)		Y	-	N
Alkebäck and Hagelin (2004)		Y	N	N
Studies on changes in settlement procedures				
Stoll and Whaley (1991)		Y	-	Y
Chen and Williams (1994)		Y	Y	-
Chung and Hseu (2008)	MSCI-TW	-	Y	Y
	TAIEX	-	N	N

Effects are categorised into volume effects, volatility effects and price reversals. 'Y' indicates that this effect was found, 'N' indicates that it was not found and '-' indicates that it was not examined in the paper.

5 Data

The stock data used in this study includes daily open, close, high, low prices, volume and intraday prices (at five-minute intervals) for each of the top five stocks from 24 major indexes.[20] The sample period begins on 1 January, 2015 and ends on 31 December, 2017. The chosen stocks represent the five largest by market capitalisation on 1 July, 2016, the middle date of the sample period. The same stocks were then used for the entire period and are therefore, not necessarily the five largest on every given date. Since only large stocks are used, thin trading is generally not a issue. Stocks that did have low liquidity were removed from the sample.

Throughout the study, continuous returns are used. These were calculated according to the equation:

$$r_t = ln\left(\frac{p_t}{p_{t-1}}\right)$$

Returns were not adjusted for dividends. However, as there were very few dividend days in the sample, this omission should not severely affect the results.[21]

Some data issues were:

1. ELMU from the BUX index (Hungary) did not trade frequently and was consequently removed from the data set.

2. SAB from the FTSE/JSE Top 40 (South Africa) was acquired and privatised in October, 2016. Data before its privatisation was still used in the analysis. Following its privatisation, this stock was not replaced with another.

3. The Athens Stock Exchange was closed between 27 June, 2015 and 3 August, 2015. Thus, no data was available for FTSE/ATHEX Large Cap index (Greece)

[20] This data was obtained from Thomson Reuters DataScope Select.

[21] A simple robustness check was performed to verify this. Details can be found in the appendix.

stocks over this period.

4. Intraday data was not available for:

    (a) SMI index (Switzerland) stocks on dates before March, 2016.

    (b) BUX index (Hungary) stocks before November, 2015.

    (c) NOKIA from the OMXS30 index (Sweden) before August, 2015.

    (d) ENGIE from the BFX index (Belgium) before July, 2015.

Index weights, which were used to identify the top stocks and as a control variable in the analysis (discussed further in the Methodology and hypotheses section), could not be obtained directly. Instead, these were manually calculated according to the equation:[22]

$$weight_{i,t} = \frac{p_{i,t} \times q_{i,t}}{\sum_{i=1}^{n} p_{i,t} \times q_{i,t}}$$

where:

1. $p_{i,t}$ is the price of stock i on day t

2. $q_{i,t}$ is the number of shares outstanding of stock i on day t

Due to the amount of data required to obtain weights at a daily frequency, they were instead calculated semi-annually on the first trading days after 1 January and 1 July each year. These weights were then carried forward until the next calculation day, effectively rebalancing the index every six months.[23]

[22]This approach is only accurate for capitalisation-weighted indexes which all indexes studied are.

[23]Aside from the low frequency, a drawback of this method is that it fails to take into account cap factors, which is a limit on the maximum weight a stock can have. However, these are rarely exceeded.

Futures data used includes the contract specifications [24] and open interest.[25] The futures were selected to cover a range of settlement methods, which is the main variable of interest. Overall, 11 use an arithmetic average, 5 use an intraday auction, 5 use a SOQ and 3 use a VWAP. Days without any open interest in the front month futures contract were filtered out from the sample. This did not occur often and only for some of the more illiquid contracts.

Tables 4 and 5 on the next two pages present summary statistics on the indexes and stocks used in the analysis. Only a select number of stocks are presented in table 5. For a full list, please see the appendix.

[24] Contract specifications can be obtained the from exchange websites. For example, see *ASX Index Futures contract specifications* (2010) for the specfications of the S&P/ ASX 200 index futures.

[25] Obtained from Thomson Reuters DataScope Select.

Table 4: Summary statistics of stock indexes used in this study

Index	***Capitalisation*** **Total capitalisation (USD, bil)**	**Average capitalisation (USD, bil)**	**Capitalisation of the top 5 stocks as percentage of the entire index (%)**	***Volume*** **Daily dollar volume (USD, mil)**	**Daily dollar volume as a percentage of total capitalisation (%)**	***Performance*** **Return (% p.a.)**	***Risk*** **Volatility (% p.a.)**
S&P/ASX 200	1106	5.7	29.1	3332	0.30	3.64	13.93
ATX	60	3.2	56.1	126	0.21	16.32	18.63
BEL 20	421	21.0	77.3	852	0.20	6.32	15.93
iBovespa	499	8.9	39.3	1780	0.36	15.47	23.19
S&P/TSX 60	1110	19.1	28.7	2554	0.23	3.63	12.11
CSI 300	3234	10.9	20.7	31830	0.98	3.50	26.98
CAC 40	1230	33.3	38.2	3870	0.31	7.31	18.76
DAX	1045	34.8	39.5	3996	0.38	9.29	19.19
FTSE/ATHEX Large Cap	34	1.4	54.4	72	0.21	77.93	144.13
Hang Seng	1674	33.5	47.7	3729	0.22	8.13	17.51
BUX	19	1.3	96.4	33	0.18	29.36	16.09
NIFTY	841	16.8	29.7	1333	0.16	8.15	13.87
FTSE MIB	401	10.3	44.8	2691	0.67	4.40	24.41
AEX	451	23.7	71.1	1331	0.30	8.36	17.25
OBX	118	4.9	60.6	417	0.35	11.51	17.95
WIG 20	75	3.8	51.3	162	0.22	2.14	17.23
RTS	430	10.2	51.0	500	0.12	13.93	27.79
FTSE/JSE Top 40	614	15.0	55.0	1076	0.18	6.20	16.25
IBEX 35	539	16.3	53.3	1837	0.34	-0.99	20.87
OMXS 30	532	17.7	43.8	1393	0.26	2.49	17.87
SMI	1057	52.9	70.2	3255	0.31	1.61	16.21
TAIEX	791	0.9	30.3	2552	0.32	4.73	12.89
FTSE 100	2420	24.7	23.9	6188	0.26	5.34	14.78
S&P 500	18910	38.3	10.5	35175	0.19	8.68	12.36

All dollar figures are presented in USD using the exchange rate on 1 July, 2016, the middle of the sample period. 'Total Capitalisation', 'Average capitalisation' and 'Capitalisation of the top 5 stocks as percentage of the entire index' were calculated on 1 July, 2016. 'Daily dollar volume' is the average daily dollar volume over the entire sample period (1 January, 2015 to 31 December, 2017). 'Daily dollar volume as a percentage of total capitalisation' was obtained by dividing 'Daily dollar volume' by 'Total capitalisation.' 'Return' was calculated by taking the average daily (continuous) returns and multiplying it by 252 (assumed number of trading days per year). 'Volatility' was calculated by multiplying the standard deviation of daily returns by $\sqrt{252}$.

Table 5: Summary statistics of selected stocks used in this study

Index	Full name	Exchange	Ticker	*Capitalisation* Market capitalisation (USD, bil)	Index weight (%)	*Volume* Daily dollar volume (USD, mil)	Daily dollar volume as a percentage of total capitalisation (%)	*Performance* Return (% p.a.)	*Risk* Volatility (% p.a.)
S&P/ASX 200	AUSTRALIA NEW ZEALAND BANKING ORD	ASX	ANZ	52.4	4.74	140	0.27	-3.80	21.64
S&P/ASX 200	COMMONWEALTH BANK OF AUSTRALIA ORD	ASX	CBA	94.9	8.58	187	0.20	-2.16	19.35
S&P/ASX 200	NATIONAL AUSTRALIA BANK ORD	ASX	NAB	50.1	4.53	123	0.25	-4.21	20.88
S&P/ASX 200	TELSTRA CORPORATION ORD	ASX	TLS	51.1	4.62	106	0.21	-16.45	19.72
S&P/ASX 200	WESTPAC BANKING CORPORATION ORD	ASX	WBC	73.2	6.62	145	0.20	-1.97	21.39
DAX	BASF N ORD	GER	BAS	71.0	6.80	241	0.34	9.08	22.91
DAX	BAYER N ORD	GER	BAYN	83.5	7.99	277	0.33	-2.74	25.36
DAX	DEUTSCHE TELEKOM N ORD	GER	DTE	79.4	7.60	182	0.23	3.80	24.09
DAX	SAP ORD	GER	SAP	92.2	8.82	213	0.23	15.61	19.72
DAX	SIEMENS N ORD	GER	SIE	87.1	8.34	262	0.30	7.07	22.79
Hang Seng	HSBC HOLDINGS ORD	HKG	0005	120.9	7.22	205	0.17	2.63	20.32
Hang Seng	TENCENT ORD	HKG	0700	213.6	12.76	522	0.24	43.56	26.90
Hang Seng	CCB ORD H	HKG	0939	158.7	9.48	233	0.15	3.48	23.56
Hang Seng	CHINA MOBILE ORD	HKG	0941	234.0	13.98	185	0.08	-4.85	22.53
Hang Seng	AIA ORD	HKG	1299	72.0	4.30	155	0.22	14.16	24.03
FTSE 100	BRITISH AMERICAN TOBACCO ORD	LSE	BATS	120.6	4.99	192	0.16	12.38	20.43
FTSE 100	BP ORD	LSE	BP	111.0	4.59	196	0.18	8.01	26.17
FTSE 100	HSBC HOLDINGS ORD	LSE	HSBA	123.5	5.10	221	0.18	7.47	22.16
FTSE 100	ROYAL DUTCH SHELL CL A ORD	LSE	RDSA	119.1	4.92	171	0.14	4.45	25.79
FTSE 100	ROYAL DUTCH SHELL CL B ORD	LSE	RDSB	104.1	4.30	166	0.16	3.82	26.78
S&P 500	APPLE ORD	NSM	AAPL	525.2	2.78	1114	0.21	14.52	22.99
S&P 500	AMAZON COM ORD	NSM	AMZN	342.4	1.81	753	0.22	44.30	28.17
S&P 500	JOHNSON & JOHNSON ORD	NYS	JNJ	333.6	1.76	268	0.08	9.65	14.17
S&P 500	MICROSOFT ORD	NSM	MSFT	402.1	2.13	506	0.13	20.08	22.76
S&P 500	EXXON MOBIL ORD	NYS	XOM	389.1	2.06	332	0.09	-3.47	18.73

All dollar figures are presented in USD using the exchange rate on 1 July, 2016, the middle of the sample period. 'Market capitalisation' and 'Index weight' were calculated on 1 July, 2016. 'Daily dollar volume' is the average daily dollar volume over the entire sample period (1 January, 2015 to 31 December, 2017). 'Daily dollar volume as a percentage of total capitalisation' was obtained by dividing 'Daily dollar volume' by 'Market capitalisation'. 'Return' was calculated by taking the average daily (continuous) returns and multiplying it by 252 (assumed number of trading days per year). 'Volatility' was calculated by multiplying the standard deviation of daily returns by $\sqrt{252}$. Only statistics for a few of the stocks are presented in this table. For a full list, please see the appendix.

6 Methodology and hypotheses

This study examines expiration day effects by comparing volume, volatility and price effects (reversals and shocks) in the top five stocks of each index on expiration days to a sample of non-expiration control days. For most indexes, the control sample consists of all trading days that share the same day of the week as expiration (where expiration falls on a certain day of the week). The single exception, as mentioned before, is Hang Seng index futures which expire on the second-to-last business day. The control sample for stocks in this index are the trading days exactly 7, 14 and 21 calendar days before each expiration. Setting the control sample in this way eliminates any potential day-of-the-week effects.

Initially, only daily data was used to investigate these effects. Analysis using intraday data was later added over concerns that volatility and price effects may not be adequately captured using daily data. Therefore, the measures are also separated into daily and intraday.[26]

[26] All coding was done using R.

6.1 Abnormal effect measures obtained from daily data

6.1.1 Measuring volume effects

Volume effects are measured by (1) daily traded volume[27] and (2) the volume growth rate, as used by Bollen and Whaley (1999). These are defined as:

$$traded\, volume_{i,t} = number\; of\; shares\; of\; stock\; i\; traded\; on\; day\; t \tag{1}$$

$$volume\; growth\; rate_{i,t} = ln\left(\frac{traded\, volume_{i,t}}{traded\, volume_{i,t-1}}\right) \tag{2}$$

6.1.2 Measuring volatility effects

Volatility is captured using (1) Parkinson's (1980) high low estimator and (2) absolute close-to-close returns. These are defined as:

$$high\; low_{i,t} = \sqrt{\frac{\left(ln\, p_{i,t}^{high} - ln\, p_{i,t}^{low}\right)^2}{4\, ln(2)}} \tag{3}$$

where:

1. $p_{i,t}^{high}$ is the highest price of stock i on day t
2. $p_{i,t}^{low}$ is the lowest price of stock i on day t

$$absolute\; return_{i,t} = |p_{i,t}^{close} - p_{i,t-1}^{close}| \tag{4}$$

where:

1. $p_{i,t}^{close}$ is the closing price for stock i on day t.

The high low estimator captures within-day volatility only whilst absolute returns also capture overnight volatility. Absolute returns however, only provide a rough

[27] From here on, volume refers to the category of effects whereas traded volume refers to the actual measure.

proxy as a highly volatile trading day would not be reflected if prices revert back to their previous day's close. The high low estimator on the other hand, is highly efficient and robust to micro-structure noise.[28] Thus, it is used as the primary measure of volatility whilst absolute returns are used to verify any findings.

6.1.3 Measuring price effects

To measure price effects, (1) Stoll and Whaley's (1987) reversal and (2) Vipul's (2005) price shock are adopted. Price reversals are expected to occur in the period immediately after expiration. Thus, different definitions are adopted depending on the expiration time of the futures contract.

1. For futures that expire at the **open** (ie. through a SOQ), reversals are defined as:

$$price\,reversal_{i,t} = \begin{cases} r^{oc}_{i,t}, & \text{if } r^{co}_{i,t} < 0 \\ -r^{oc}_{i,t}, & \text{if } r^{co}_{i,t} > 0 \end{cases} \tag{5}$$

   where:

   (a) $r^{co}_{i,t}$ is the return from the close on day t - 1 to the open on day t (overnight return)

   (b) $r^{oc}_{i,t}$ is the return from open to close on day t (within-day return)

   According to this definition, a positive reversal is observed when the return in the period before expiration (overnight in this case) has a different sign to the period after (within-day). On the other hand, a negative reversal, or continuation, occurs when the returns share the same sign. In both cases, the magnitude is captured by the size of the return in the latter period.

[28] A paper by Alizadeh, Brandt, and Diebold (2002) establishes this result for range-based estimators.

2. For futures that expire at **other times**, reversals are defined as:

$$price\,reversal_{i,t} = \begin{cases} r^{co}_{i,t+1}, & \text{if } r^{oc}_{i,t} < 0 \\ -r^{co}_{i,t+1}, & \text{if } r^{oc}_{i,t} > 0 \end{cases} \tag{6}$$

As before, a positive reversal is observed when the signs of the returns in the period before (within-day in this case) and after (overnight) are different.[29]

Price shocks were introduced by Vipul to overcome a shortcoming of Stoll and Whaley's reversal. Reversals consider the magnitude returns in the period after expiration but ignore the magnitude in the period before. This leads to a loss of information and potentially a failure to capture price effects. For example, consider a +0.1% return in the period before and a +5% return in the period after. The large difference in returns is strongly indicative of price effects but the price reversal would be negative, indicating a continuation. On the other hand, a smaller change from +0.1% in the period before to -0.1% in the period after would be recognised as a reversal. Price shocks, defined as the absolute difference in returns between the two periods, captures the price effects that reversals cannot.

1. For futures that expire at the **open**, price shocks are defined as:

$$price\,shock_{i,t} = |r^{oc}_{i,t} - r^{co}_{i,t}| \tag{7}$$

2. For futures that expire at **other times**, price shocks are defined as:

$$price\,shock_{i,t} = |r^{co}_{i,t+1} - r^{oc}_{i,t}| \tag{8}$$

[29] This definition is strictly accurate only for futures that expire at the close. However, this is applied to all futures that don't expire at the open because daily data cannot be used to obtain returns over other intervals.

6.2 Abnormal effect measures obtained from intraday data

The measures obtained from daily data may not adequately capture volatility and price effects since these may only increase in a short period around expiration. Additionally, price effects for futures that expire in the middle of the day (any time that is not open or close) cannot be accurately measured using daily data. In 6.1.3, the definitions for price effects for these futures uses the within-day period as the period before and the overnight period as the period after. However, this would not be appropriate if the expiration time was say, 12:30, and the market closed at 16:00. A more accurate approach would be to use 11:30 – 12:30 as the period before and 12:30 – 13:30 as the period after. Returns over these periods can only be measured using intraday price data.

6.2.1 Measuring volatility effects

Volatility is measured using realised volatility over a short period around expiration. Therefore, this definition differs depending on the expiration time.

1. For futures that expire at the **open**, this period extends from market close on the previous day to 1 hour after open. With five-minute price data, there are 13 return calculations possible: one in the overnight period and 12 over the first hour. Thus, realised volatility for these stocks is defined as:

$$realised\,volatility_{i,t} = \sqrt{\left(r^{co}_{i,t}\right)^2 + \sum_{j=1}^{12} r^2_{j,t}} \tag{9}$$

   where:

   (a) $r^{co}_{i,t}$ is return from close on day t - 1 to the open on day t

   (b) $r_{j,t}$ is the return over the jth five-minute interval in the first hour of trading on day t

2. For futures that expire at the **close**, this period extends from one hour before

close to open on the next day. Again, 13 return calculations are possible over this period: 12 in the last hour and one in the overnight period. Thus, realised volatility for these stocks is defined as:

$$realised\,volatility_{i,t} = \sqrt{\sum_{j=1}^{12} r_{j,t}^2 + \left(r_{i,t+1}^{co}\right)^2} \tag{10}$$

where:

(a) $r_{j,t}$ is the return over the jth five-minute interval in the last hour of trading on day t

(b) $r_{i,t+1}^{co}$ is return from close on day t to open on day t+1

3. For futures that expire in the **middle of the day**, this period extends from one hour before expiration time to one hour after. In total, 24 return calculations are possible over this two-hour period. Thus, realised volatility for these stocks is defined as:

$$realised\,volatility_{i,t} = \sqrt{\sum_{j=1}^{24} r_{j,t}^2} \tag{11}$$

where:

(a) $r_{j,t}$ is the return over the jth five-minute interval in the period from one hour before expiration time to one hour after

6.2.2 Measuring price effects

Price reversals and shocks are defined similarly to those using daily data but are now calculated over a smaller interval around expiration time.

1. For futures that expire at the **open**:

$$price\,reversal_{i,t} = \begin{cases} r_{i,t}^{o,o+1}, & \text{if } r_{i,t}^{co} < 0 \\ -r_{i,t}^{o,o+1}, & \text{if } r_{i,t}^{co} > 0 \end{cases} \tag{12}$$

$$price\ shock_{i,t} = |r_{i,t}^{o,o+1} - r_{i,t}^{co}| \tag{13}$$

where:

(a) $r_{i,t}^{co}$ is the return from close on day t - 1 to open on day t

(b) $r_{i,t}^{o,o+1}$ is the return over the first hour of trading on day t

This definition implies that the period before expiration is taken as the overnight period (prior to expiration) and the period after is taken as the first hour after open.

2. For futures expiring at the **close**:

$$price\ reversal_{i,t} = \begin{cases} r_{i,t+1}^{co}, & \text{if } r_{i,t}^{c-1,c} < 0 \\ -r_{i,t+1}^{co}, & \text{if } r_{i,t}^{c-1,c} > 0 \end{cases} \tag{14}$$

$$price\ shock_{i,t} = |r_{i,t+1}^{co} - r_{i,t}^{c-1,c}| \tag{15}$$

where:

(a) $r_{i,t}^{c-1,c}$ is the return over the final hour of trading on day t

(b) $r_{i,t+1}^{co}$ is the return from close on day t to open on day t + 1

This means that the period before expiration is taken as the last hour before close and the period after is taken as the overnight period (following expiration).

3. For futures that expire in the **middle of the day**:

$$price\ reversal_{i,t} = \begin{cases} r_{i,t}^{e,e+1}, & \text{if } r_{i,t}^{e-1,e} < 0 \\ -r_{i,t}^{e,e+1}, & \text{if } r_{i,t}^{e-1,e} > 0 \end{cases} \tag{16}$$

$$price\ shock_{i,t} = |r_{i,t}^{e,e+1} - r_{i,t}^{e-1,e}| \tag{17}$$

where:

(a) $r_{i,t}^{e-1,e}$ is the return over the last hour of trading before expiration time on day t

(b) $r_{i,t}^{e,e+1}$ is the return over the first hour of trading after expiration time on day t

This means that the period before expiration is taken as the last hour before expiration time and the period after is taken as the first hour after expiration time. Using daily data however, these futures had the same reversal and shock definition as futures expiring at the close.

6.3 Standardisation

The mean and standard deviation of effect measures varies across stocks so standardisation is necessary in order to combine their findings. This standardisation is performed using a Z-score approach. For each stock, the mean and standard deviation of each effect measure is computed over the stock's control days. Each day's (both expiration and control days) measure is then standardised by subtracting this mean and dividing by this standard deviation. Therefore, the standardised measure is defined as:

$$Y_{i,t}^{standardised} = \frac{Y_{i,t} - \bar{Y}_i^c}{sd\left(Y_i^c\right)} \tag{18}$$

where:

1. $Y_{i,t}$ is the effect measure for stock i on day t.

2. $\bar{Y}_i^c$ is the sample mean of all $Y_{i,t}$ that fall on control days

3. $sd\left(Y_i^c\right)$ is the standard deviation of all $Y_{i,t}$ that fall on control days.

6.4 Regression analysis and hypothesis

Using the standardised measures as response variables three regression models are formulated to:

1. verify that effect measures are different on expiration days compared to control days
2. examine if the settlement procedure affects the severity of these effects
3. examine if the length of the settlement period or index weight affects the severity

In all fitted equations and hypothesis tests, Newey-West standard errors are used to account for potential heteroskedasticity and autocorrelation.[30]

6.4.1 Equation 1

The first equation explores if effect measures on expiration days are different to those on control days. The model formulated is:

$$Y_{i,t} = \alpha_0 + \alpha_1 D_{i,t} + \epsilon_{i,t} \tag{19}$$

where:

1. $D_{i,t}$ equals 1 if day t is an expiration day for stock i and 0 otherwise.[31]
2. $\epsilon_{i,t}$ is the random error term.

The coefficients have the following interpretations:

[30] Standard errors may be heteroskedastic because they may vary between stocks and over time. They may be auto-correlated because stocks that belong to the same index are likely to move together.

[31] To be precise, this should read "if day t is an expiration day for the futures on the index that stock i belongs to." Whenever a stock's expiration day, settlement procedure etc. is mentioned, it refers to the expiration day, settlement procedure etc. for the futures on the index that stock belongs to.

1. α_0 measures the average effect on control days.

2. α_1 measures the additional effect of expiration days (in number of control day standard deviations).

Thus, to determine if effect measures are different on expiration days, the hypothesis tested is:

$$H_0 : \alpha_1 = 0$$

$$H_1 : \alpha_1 \neq 0$$

6.4.2 Equation 2

The second equation examines if the settlement procedure affects the severity of expiration effects. The model formulated is:

$$\begin{aligned} Y_{i,t} =& \alpha_0 + \alpha_1 D_{i,t} + \beta_1 Intraday_i + \beta_2 SOQ_i + \beta_3 VWAP_i + \\ & \gamma_1 Intraday_i \times D_{i,t} + \gamma_2 SOQ_i \times D_{i,t} + \gamma_3 VWAP_i \times D_{i,t} + \epsilon_{i,t} \end{aligned} \tag{20}$$

where:

1. $D_{i,t}$ and $\epsilon_{i,t}$ are the same as in equation 1.

2. $Intraday_i$, SOQ_i and $VWAP_i$ are equal to 1 if stock i uses an intraday, SOQ or VWAP settlement procedure respectively and are 0 otherwise. A variable for arithmetic is not included because it is used as the base cateogry.

3. $Intraday_i \times D_{i,t}$,$SOQ_i \times D_{i,t}$ and $VWAP_i \times D_{i,t}$ are interaction terms between those settlement methods and expiration day. This means that the variable equals 1 only if both are true.[32]

[32]For example, $Intraday_i \times D_{i,t}$ is only equal to 1 when stock i uses an intraday settlement and day t is an expiration day for that stock.

The coefficients have the following interpretations:

1. α_0 measures the average effect on non-expiration days for the base category (arithmetic).

2. α_1 measures the additional effect of expiration days for the base category.

3. β_1, β_2 and β_3 measure the additional effect of intraday, SOQ and VWAP relative to the base category.

4. γ_1, γ_2 and γ_3 measure the additional effect of intraday, SOQ and VWAP relative to the base category on expiration days.

Therefore, the difference between abnormal effects on expiration and non-expiration days for the arithmetic settlement procedure can be expressed as:

$$(\alpha_0 + \alpha_1) - \alpha_0 = \alpha_1$$

Hence, to examine if expiration effects exist for arithmetic, the hypothesis tested is:

$$H_0 : \alpha_1 = 0$$

$$H_1 : \alpha_1 \neq 0$$

The difference for other settlement procedures can be expressed as:

$$(\alpha_0 + \alpha_1 + \beta_j + \gamma_j) - (\alpha_0 + \beta_j) = \alpha_1 + \gamma_j, \quad \text{where j = 1, 2, 3}$$

Hence, to examine if expiration effects exist for these procedures, the hypotheses tested are:

$$H_0 : \alpha_1 + \gamma_j = 0$$

$$H_1 : \alpha_1 + \gamma_j \neq 0$$

6.4.3 Equation 3

The third equation also examines if the settlement procedure affects the severity but controls for the length of the settlement period and index weight. However, the significances of these variables are also examined to explore whether they also affect the severity of effects. The model formulated is:

$$
\begin{aligned}
Y_{i,t} =& \alpha_0 + \alpha_1 D_{i,t} + \beta_1 Intraday_i + \beta_2 SOQ_i + \beta_3 VWAP_i + \\
& \gamma_1 Intraday_i \times D_{i,t} + \gamma_2 SOQ_i \times D_{i,t} + \gamma_3 VWAP_i \times D_{i,t} + \\
& \delta_1 (SettPeriod > 1Hr)_i + \delta_2 (SettPeriod = Whole\ Day)_i + \\
& \tau_1 (SettPeriod > 1Hr)_i \times D_{i,t} + \tau_2 (SettPeriod = Whole\ Day)_i \times D_{i,t} + \\
& \rho_1 weight_{i,t} + \rho_2 weight_{i,t} \times D_{i,t} + \epsilon_{i,t}
\end{aligned}
\tag{21}
$$

where:

1. $D_{i,t}$, $Intraday_t$, SOQ_i, $VWAP_i$, $Intraday_i \times D_{i,t}$,$SOQ_i \times D_{i,t}$, $VWAP_i \times D_{i,t}$ and $\epsilon_{i,t}$ have the same definition as in equation 2.

2. $(SettPeriod > 1Hr)_i$ and $(SettPeriod = WholeDay)_i$ are equal to 1 if the length of the settlement period for stock i is longer than one hour but less than the whole day (referred to as medium) or the whole day (long) respectively and are 0 otherwise. This only applies if the futures contract uses an average settlement procedure (arithmetic or VWAP). The base category (not included as an indicator variable) is set as less than one hour (short).[33]

3. $(SettPeriod > 1Hr)_i \times D_{i,t}$ and $(SettPeriod = Whole\ Day)_i \times D_{i,t}$ are the interaction terms between settlement period and expiration day.

4. $weight_{i,t}$ denotes the decimal weight of stock i in its respective index on day t.

[33] Average settlement over a short period is the most comparable to settlement using a single price. Thus, setting the base category to short allows the most comparability between the coefficients of average and single price procedures.

5. $weight_{i,t} \times D_{i,t}$ is the interaction term between weight and expiration day. It is equal to 0 when t is a non-expiration day and is equal to $weight_{i,t}$ when t is an expiration day.

The coefficients are interpreted as follows:

1. α_0 measures the average effect on non-expiration days for the base categories (arithmetic, short settlement period).
2. α_1 measures the additional effect of expiration days for the base categories.
3. β_1, β_2 and β_3 measure the additional effect of intraday, SOQ and VWAP settlement methods relative to arithmetic.
4. γ_1, γ_2 and γ_3 measure the additional effect of intraday, SOQ and VWAP settlement methods relative to arithmetic on expiration days.
5. δ_1 and δ_2 measure the additional effect of using medium and long settlement periods relative to a short period.
6. τ_1 and τ_2 measure the additional effect of using medium and long settlement periods relative to a short period on expiration days.
7. ρ_1 measures the additional effect of a unit increase in index weight.[34]
8. ρ_2 measures the additional effect of a unit increase in index weight on expiration day.

Given these interpretations, the hypotheses to test if the settlement method affects the severity remains the same as in equation 2. However, it is important to note that the effect estimates on arithmetic and VWAP now apply to a short settlement period where as in equation 2, they applied across all period lengths.

[34] Since weights are expressed in decimals, one unit is equal to 100%.

The difference between the effect of settlement period on expiration and control days can be expressed as:

$$(\delta_j + \tau_j) - \delta_j = \tau_j \quad \text{where j} = 1,\ 2$$

Hence, to determine if the settlement period affects expiration effects, the hypotheses tested are:

$$H_0 : \tau_j = 0$$

$$H_1 : \tau_j \neq 0$$

Similarly, to examine if index weight affects the severity, the hypothesis tested is:

$$H_0 : \rho_2 = 0$$

$$H_1 : \rho_2 \neq 0$$

6.4.4 Summary of hypothesis tests

Table 6 below summaries the hypotheses tested. The 'Short description' column denotes how each hypothesis is referred to in the Results and discussion section.

Table 6: Summary table of hypothesis tests

Test	**Short description**	**Null**	**Alternative**
Equation 1			
Effects are different on expiration day compared to control days	Expiration	$\alpha_1 = 0$	$\alpha_1 \neq 0$
Equation 2			
Effects are different for arithmetic on expiration day	Arithmetic	$\alpha_1 = 0$	$\alpha_1 \neq 0$
Effects are different for intraday on expiration day	Intraday	$\alpha_1 + \gamma_1 = 0$	$\alpha_1 + \gamma_1 \neq 0$
Effects are different for SOQ on expiration day	SOQ	$\alpha_1 + \gamma_2 = 0$	$\alpha_1 + \gamma_2 \neq 0$
Effects are different for VWAP on expiration day	VWAP	$\alpha_1 + \gamma_3 = 0$	$\alpha_1 + \gamma_3 \neq 0$
Equation 3			
Effects are different for arithmetic on expiration day	Arithmetic	$\alpha_1 = 0$	$\alpha_1 \neq 0$
Effects are different for intraday on expiration day	Intraday	$\alpha_1 + \gamma_1 = 0$	$\alpha_1 + \gamma_1 \neq 0$
Effects are different for SOQ on expiration day	SOQ	$\alpha_1 + \gamma_2 = 0$	$\alpha_1 + \gamma_2 \neq 0$
Effects are different for VWAP on expiration day	VWAP	$\alpha_1 + \gamma_3 = 0$	$\alpha_1 + \gamma_3 \neq 0$
Effects are different if a medium settlement period is used	Medium	$\tau_1 = 0$	$\tau_1 \neq 0$
Effects are different if a long settlement period is used	Long	$\tau_2 = 0$	$\tau_2 \neq 0$
Effects are affected by the weighting of the stock on expiration day	Weight	$\rho_2 = 0$	$\rho_2 \neq 0$

'Test' is a long description of what factor is being tested. 'Short description' denotes how the test is referred to in the Results and discussion section. The 'Null' and 'Alternative' denote the null and alternative hypotheses of the test.

6.5 Statistical test

To test each of the hypotheses, a Wald test is used.[35] Each null hypothesis is essentially a restriction on the model parameters that can be expressed in the form:

$$H_0 : R\beta = r$$

$$H_1 : R\beta \neq r$$

where:

1. R is $(q \times K)$ matrix, with q equal to the number of restrictions and K equal to the number of coefficients
2. β is a $(K \times 1)$ vector of coefficients
3. r is a $(K \times 1)$ vector

For example, in equation 1, the null hypothesis $\alpha = 0$ can be expressed in the form:

$$H_0 : \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} \alpha_0 \\ \alpha_1 \end{bmatrix} = 0$$

with q = 1 and K = 2. The statistic (also referred to as the χ^2 statistic) for this test is:

$$(R\hat{\beta} - r)'(R\hat{V}R')^{-1}(R\hat{\beta} - r) \sim asymp.\ \chi^2_q$$

where:

1. $\hat{\beta}$ is the estimated vector of coefficients
2. $\hat{V}$ is the estimated variance-covariance matrix of the parameters
3. χ^2_q is a chi-squared random variable with q degrees of freedom.

[35] See Agresti (2002, p. 11)

In all tests, only one model restriction is used so q is always equal to 1. If the p-value is lower than 0.05, the coefficient (or sum of coefficients) is deemed significant. If the p-value is only lower than 0.10, the coefficient is deemed weakly significant.

7 Results and discussion

For brevity, only results from the statistical tests are presented in this section. Estimated coefficients from the regression equations and graphical representations of the effects measures can be found in the appendix.

7.1 Results from daily measures

7.1.1 Table of results

Table 7 on the next page presents the results of the statistical tests on measures obtained from daily data. In equation 1, only expiration day is used as an explanatory variable. In equation 2, the settlement method is then added. Finally, in equation 3, the length of the settlement period and index weight are added.

Table 7: Results of the statistical test on measures obtained from daily data

Null hypothesis	**Test**	***Effect measures*** **volume**	**Volume growth rate**	**High low**	**Absolute return**	**Price reversal**	**Price shock**
Equation 1							
$\alpha_1 = 0$	Expiration	1.169***	0.867***	0.064***	0.027	0.011	0.082***
	(χ^2 statistic)	(258.04)	(532.91)	(8.99)	(1.51)	(0.14)	(10.04)
Equation 2							
$\alpha_1 = 0$	Arithmetic	0.625***	0.561***	0.011	-0.069***	-0.026	0.036
	(χ^2 statistic)	(131.15)	(164.62)	(0.18)	(7.32)	(0.49)	(1.36)
$\alpha_1 + \gamma_1 = 0$	Intraday	2.338***	1.496***	0.223***	0.165***	0.084*	0.137***
	(χ^2 statistic)	(86.41)	(112.80)	(14.83)	(12.49)	(3.40)	(10.05)
$\alpha_1 + \gamma_2 = 0$	SOQ	2.503***	1.604***	0.006	0.106	-0.005	0.148***
	(χ^2 statistic)	(65.61)	(110.73)	(0.02)	(2.37)	(0.01)	(7.57)
$\alpha_1 + \gamma_3 = 0$	VWAP	0.783***	0.679***	0.137**	0.131*	0.072	0.116
	(χ^2 statistic)	(17.31)	(82.69)	(4.70)	(3.78)	(0.41)	(1.75)
Equation 3							
$\alpha_1 = 0$	Arithmetic	0.812***	0.773***	0.084*	-0.061	-0.045	0.124**
	(χ^2 statistic)	(64.21)	(156.93)	(3.15)	(2.14)	(0.40)	(5.25)
$\alpha_1 + \gamma_1 = 0$	Intraday	2.325***	1.530***	0.262***	0.177***	0.069	0.182***
	(χ^2 statistic)	(84.36)	(139.22)	(16.67)	(11.18)	(1.41)	(12.04)
$\alpha_1 + \gamma_2 = 0$	SOQ	2.494***	1.627***	0.032	0.114	-0.014	0.179***
	(χ^2 statistic)	(63.42)	(137.26)	(0.47)	(2.40)	(0.06)	(9.27)
$\alpha_1 + \gamma_3 = 0$	VWAP	1.390***	1.062***	0.218**	0.105	0.203	0.261
	(χ^2 statistic)	(22.18)	(141.84)	(4.35)	(1.49)	(0.91)	(2.56)
$\tau_1 = 0$	Medium	-0.519***	-0.646***	-0.136**	-0.012	0.171*	-0.130
	(χ^2 statistic)	(13.40)	(45.43)	(4.62)	(0.03)	(2.72)	(1.96)
$\tau_2 = 0$	Long	-0.930***	-0.524***	-0.065	0.057	-0.217	-0.150
	(χ^2 statistic)	(20.80)	(39.12)	(0.61)	(0.50)	(2.17)	(1.61)
$\rho_2 = 0$	Weight	0.144	-0.353	-0.403	-0.121	0.146	-0.473
	(χ^2 statistic)	(0.05)	(0.73)	(2.32)	(0.23)	(0.14)	(2.23)

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

The 'Null hypothesis' and 'Test' columns denote which coefficient (or sum of coefficients) is being examined. 'Effect measures' denote which measure is being used as the response variable. Estimates of the coefficients (or sum of coefficients) tested in each null hypothesis and for each effect measure are presented with its χ^2 statistic (in brackets) underneath. In equation 1, only expiration day is used as an explanatory variable. In equation 2, the settlement method is then added. In equation 3, the length of the settlement period and index weight are then added. *, ** and *** indicates that the coefficient (or sum of coefficients) is significant at 0.1, 0.05 and 0.01 levels respectively. In all cases, the χ^2 statistic follows a χ^2 distribution with 1 degree of freedom under the null.

7.1.2 Volume effects

Equation 1 (table 7) shows that both traded volume and the volume growth rate are significantly higher on expiration days, increasing by 1.169 and 0.867 standard deviations respectively. To provide some economic significance to these numbers, consider CBA from the S&P/ ASX 200 (Australia), which has a mean traded volume of 2.96 million and a standard deviation of 1.16 million shares over its control days. An increase of 1.169 standard deviations is equivalent to 1.35 million shares, which is approximately 45.7%.[36]

Equation 2 shows that volume effects occur regardless of the settlement method used as both traded volume and the volume growth rate are significantly higher for all. However, a clear divide can be seen between the procedures that use an average settlement versus a single price. Expiration day increases of 2.338 and 2.503 are observed for intraday and SOQ (single price), substantially higher than the 0.625 and 0.783 observed for arithmetic and VWAP (average price). A statistical test on the largest difference, which is between SOQ and arithmetic, verifies that this disparity is significant at a 1% level.[37] Furthermore, the differences are also present when the volume growth rate is used as the response variable instead. Increases of 1.496 and 1.604 are found for intraday and SOQ, compared to 0.561 and 0.679 for arithmetic and VWAP.

Equation 3 largely verifies the findings on settlement method. Once again, all are found to increase significantly on expiration day, but a clear distinction can be

[36] CBA volume actually increases by 32.3%. These numbers are only used to demonstrate what a 1.169 standard deviation would look like when applied to a typical stock.

[37] The difference between SOQ and arithmetic can be expressed as:

$$(\alpha_1 + \gamma_2) - \alpha_1 = \gamma_2$$

Therefore, a test on the difference is equivalent to testing the linear restriction $\gamma_2 = 0$. The χ^2 statistic, which follows one degree of freedom, is 35.79. Tests similar to this are used throughout the discussion of the results.

seen between those that use a single price versus an average price. A statistical test on the difference between SOQ (2.494) and arithmetic (0.812) is significant at a 1% level.[38] However, the increases for arithmetic and VWAP are now applied to a short settlement period only whereas in equation 2, they applied across all period lengths. Thus, it is interesting to note that using an average procedure, even over a short period, results in lower volume effects than a single price procedure. Increasing the settlement period to medium or long further reduces effects. Significant decreases of -0.519 and -0.930 are found for traded volume whilst decreases of -0.646 and -0.524 are found for the volume growth rate. These last two findings follow Alkebäck and Hagelin's (2004) conclusion that an average procedure over a long period mitigates effects, perhaps due to the spreading out effect or the reduction of arbitrage trading altogether. Finally, index weight does not have a clear effect.

7.1.3 Volatility effects

Equation 1 presents mixed evidence on volatility effects, where a significant increase is found according to the high low but not according to absolute returns. These inconsistent findings may be due to the different way volatility is captured by each measure. At best, absolute returns can only be used as a rough proxy, given its failure to capture volatility if prices revert. However, even the increase according to the high low is substantially smaller than volume effects (in terms of control day standard deviations). The increase of 0.064 is less than one-tenth of the increase in traded volume. Using CBA to provide an economic interpretation, the change is equivalent to an increase from 0.819% to 0.845%.[39]

Equation 2 indicates that volatility effects exist only for intraday and VWAP. According to the high low, significant increases of 0.223 and 0.137 are observed for

[38]The χ^2 statistic for this test is 29.38.

[39]This is measured in terms of daily within-day volatility. It is equivalent to an increase from 13.00% to 13.41% annually (assuming 252 trading days in a year).

these two methods respectively. Similar results are found when absolute returns are used as the response variable instead, though for VWAP this increase is only weakly significant. Interestingly, according to absolute returns, volatility decreases for arithmetic. However, this is only weakly significant and not supported by the high low estimator. Finally, volatility appears to be unchanged when using SOQ.

Adding control variables in equation 3 does not substantially change the findings on either intraday or VWAP, which increase significantly by 0.262 and 0.218 according to the high low. However, when absolute returns are used instead, the increase for VWAP is then no longer significant. Significantly higher volatility for VWAP is surprising, though this may be due to small sample size issues, as only three of the indexes use this method. There is now also some evidence of volatility effects for arithmetic, which increases by 0.084 according to the high low and is weakly significant. Once again, using SOQ does not result in any volatility effects according to either measure. This finding of higher volatility for intraday but not SOQ indicates that a single price does not necessarily result in greater effects, but it also depends on expiration time. There is some evidence that increasing the settlement period leads to lower effects. According to the high low, increasing to medium and long lowers effects by -0.136 and -0.065 respectively, though only the first is statistically significant. However, this is not supported by absolute returns, where both are insignificant. Finally, index weight has an negative but insignificant impact on both the high low and absolute returns. This final point is explored further using intraday data.

7.1.4 Price effects

In equation 1, price shocks increase by 0.082 (significant at the 1% level) but reversals appear to be unchanged. Using CBA as a reference stock, this is equivalent to an increase from 0.935% on control days to 1.003% on expiration days.

In equation 2, shocks are significantly higher for intraday and SOQ, which increase by 0.137 and 0.148 respectively. This again highlights the distinction between using an average and single price settlement where the latter appears to be associated with larger expiration effects. Reversals on the other hand, are only significant for intraday. The increase of 0.084 however, is only weakly significant. No other settlement procedure experiences a significant change in price reversals.

Once control variables are added, none of the settlement procedures show a significant change in reversals. Moreover, equation 3 shows that the only factor that is significant is the medium length settlement period, which increases reversals by 0.171. However, this does not necessarily imply that increasing the settlement period increases reversals as the coefficient on long is insignificant and negative. Price shocks on the other hand, are significantly higher for arithmetic (0.124), intraday (0.182) and SOQ (0.179). Interestingly, the estimate on VWAP is larger in magnitude (0.261) than the others but is insignificant. This may again be due to small sample issues. Coefficients on medium and long are both negative, but insignificant. Finally, index weight does not have a clear effect.

Overall, price shocks are detected for arithmetic, intraday and SOQ. Price reversals however, appear to be almost non-existent. This is potentially due to the information loss associated with reversals, as raised by Vipul (2005). Other factors are insignificant but this may be attributed to the low data frequency failing to adequately capture these effects. Measures obtained from intraday data are discussed next to shed more light on these findings.

7.2 Results from intraday measures

As discussed in the methodology section, volatility and price effects may only occur in a short period around expiration time, which can only be captured using intraday data. This following section presents the results of this analysis.

7.2.1 Table of results

Table 8 on the next page presents the results of the statistical tests on measures obtained from intraday data. As before, in equation 1, only expiration day is used as an explanatory variable. In equation 2, the settlement method is then added. Finally, in equation 3, the length of the settlement period and index weight are added.

Table 8: Results of the statistical test on measures obtained from intraday data

Null hypothesis	**Test**	***Effect measures*** **Realised volatility**	**Price reversal**	**Price Shock**
Equation 1				
$\alpha_1 = 0$	Expiration	0.190***	0.052*	0.148***
	(χ^2 statistic)	(28.26)	(3.19)	(21.64)
Equation 2				
$\alpha_1 = 0$	Arithmetic	0.034	0.065**	0.043
	(χ^2 statistic)	(1.60)	(4.64)	(2.19)
$\alpha_1 + \gamma_1 = 0$	Intraday	0.529***	0.104	0.338***
	(χ^2 statistic)	(35.69)	(2.64)	(25.75)
$\alpha_1 + \gamma_2 = 0$	SOQ	0.254***	0.110**	0.234***
	(χ^2 statistic)	(8.20)	(4.81)	(12.70)
$\alpha_1 + \gamma_3 = 0$	VWAP	0.327**	-0.069	0.238*
	(χ^2 statistic)	(5.21)	(0.36)	(3.30)
Equation 3				
$\alpha_1 = 0$	Arithmetic	0.181***	0.091	0.172***
	(χ^2 statistic)	(6.70)	(2.15)	(7.43)
$\alpha_1 + \gamma_1 = 0$	Intraday	0.609***	0.109	0.420***
	(χ^2 statistic)	(47.89)	(2.21)	(32.70)
$\alpha_1 + \gamma_2 = 0$	SOQ	0.309***	0.113**	0.289***
	(χ^2 statistic)	(9.90)	(4.02)	(17.00)
$\alpha_1 + \gamma_3 = 0$	VWAP	0.666**	-0.096	0.508**
	(χ^2 statistic)	(6.13)	(0.20)	(4.39)
$\tau_1 = 0$	Medium	-0.086	-0.156	-0.052
	(χ^2 statistic)	(0.90)	(2.40)	(0.31)
$\tau_2 = 0$	Long	-0.394**	0.048	-0.289*
	(χ^2 statistic)	(4.65)	(0.11)	(3.02)
$\rho_2 = 0$	Weight	-0.842**	-0.041	-0.851***
	(χ^2 statistic)	(4.10)	(0.01)	(6.71)

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

The 'Null hypothesis' and 'Test' columns denote which coefficient (or sum of coefficients) is being examined. 'Effect measures' denote which measure is being used as the response variable. Estimates of the coefficients (or sum of coefficients) tested in each null hypothesis and for each effect measure are presented with its χ^2 statistic (in brackets) underneath. In equation 1, only expiration day is used as an explanatory variable. In equation 2, the settlement method is then added. In equation 3, the length of the settlement period and index weight are then added. *, ** and *** indicates that the coefficient (or sum of coefficients) is significant at 0.1, 0.05 and 0.01 levels respectively. In all cases, the χ^2 statistic follows a χ^2 distribution with 1 degree of freedom under the null.

7.2.2 Volatility effects

Across all settlement methods, realised volatility is significantly higher on expiration days. Equation 1 (table 8) shows that volatility is 0.190 control day standard deviations higher, equivalent to an increase from 0.837% to 0.924% in CBA.[40] In terms of standard deviations, this magnitude is substantially higher than the increase captured by daily measures (for example, high low increases by 0.064). This indicates that effects are more severe around expiration time, potentially because traders concentrate their efforts over this period.

In equation 2, volatility effects are detected for intraday, SOQ and VWAP which increase by 0.529, 0.254 and 0.327 respectively. Arithmetic however, does not experience a significant change. Additionally, the difference between intraday and SOQ is significant at a 5% level.[41] This again indicates that when using a single price settlement, expiration time may affect the severity of effects.

In equation 3, volatility effects are now associated with all settlement methods. The magnitudes, in increasing order, are 0.181 (arithmetic), 0.309 (SOQ), 0.609 (intraday) and 0.666 (VWAP). A statistical test on the difference between arithmetic and the other methods shows that it is significantly lower than intraday and VWAP (at 1% and 5% significance levels respectively) but not SOQ.[42] Furthermore, the difference between intraday and SOQ is significant at a 5% level, supporting the conjecture made in equation 2.[43] Other findings include settlement period having the expected result of mitigating volatility effects. Increasing the period to medium decreases effects by -0.086 and increasing to long decreases effects by -0.394, though

[40]For CBA, the period realised volatility is calculated over is from close on the day before to one hour after open.

[41]The null hypothesis of this test can be expressed as: $H_0 : \gamma_1 - \gamma_2 = 0$. The χ^2 statistic, with one degree of freedom, is 4.79.

[42]χ^2 statistics for these three tests are: 18.51 (intraday), 4.68 (VWAP) and 1.66 (SOQ).

[43]The χ^2 statistic is 5.93.

only the latter is statistically significant. Finally, having a larger index weight also results in smaller effects, which may be due to higher market depth offsetting the concentrated efforts from price manipulation. This contradicts the findings of Chung and Hseu (2008) in Taiwan, where effects were found to be more severe in the largest TAIEX stock.

7.2.3 Price effects

In equation 1, both reversals and shocks are detected, measuring 0.052 (only weakly significant) and 0.148 standard deviations higher on expiration days. Using CBA, this is equivalent to an increase in reversals from 0.124% to 0.157% and increase in shocks from 0.784% to 0.889%. Like realised volatility, these increases are substantially higher than those captured using daily measures (0.011 standard deviations for reversals and 0.082 for shocks), suggesting that price effects may also be concentrated around expiration time.

In equation 2, reversals are significantly higher for arithmetic (0.065) and SOQ (0.110) whilst shocks are higher for intraday (0.338), SOQ (0.234) and VWAP (0.238 but weakly significant). Thus, there is some evidence of price effects for all settlement methods.

Once control variables are added, only SOQ continues to show a significant coefficient in the reversal equation, which increases by 0.113. Price shocks on the other hand, are found to be higher for all methods. In order of increasing magnitude, the changes are 0.172 (arithmetic), SOQ (0.289), intraday (0.420) and VWAP (0.508). A test on the difference between arithmetic and the other methods shows that it is significantly lower than intraday and VWAP (at 1% and 10% levels respectively) but not SOQ. [44] Additionally, decreases are also associated with

[44] χ^2 statistics for these three tests are: 9.91 (intraday), 2.73 (VWAP) and 2.17 (SOQ).

medium and long, which measure -0.052 and -0.289 respectively. However, only the latter is significant and only weakly. Finally, having a larger index weight appears to decrease shocks. Overall, these findings largely follow those on realised volatility.

8 Conclusion

This study verifies the existence of expiration effects and analyses the determinants of their severity. Using data from 24 major indexes around the world, volume, volatility and price effects on expiration and non-expiration control days are measured and then compared through a regression analysis. A summary of the findings is now presented.

8.1 Summary of findings

Overall, evidence of all three categories of effects are found. Volume increases however, are substantially more severe than the others. As evidence of this, traded volume increases by 1.169 standard deviations on expiration day. In comparison, the largest increase in a non-volume effect measure is 0.190 in realised volatility. Volatility and price effects also appear to be more concentrated in a short period around expiration time as opposed to occurring evenly throughout the day. This may be due to arbitrageurs and manipulators concentrating their efforts in a period where it matters most.

All three effects also occur regardless of the settlement procedure used. However, using an arithmetic average procedure generally results in smaller effects. Statistical tests on the differences show that realised volatility and price shock increases for arithmetic are significantly lower than intraday and VWAP. Similarly for volume, using an average settlement results in smaller effects than using a single price. A possible reason for this is that an average procedure encourages arbitrageurs and manipulators to spread out their trading over the settlement period instead of transacting at a single point in time.

Analysis on the settlement period shows that using a longer period generally results in smaller effects. This is not surprising given a longer period means that trading is further spread out. Volatility and price effects are also smaller in stocks with larger index weights, possibly due to greater market depth.

Considering all evidence, it can be concluded that using an arithmetic procedure over a long settlement period is the most effective at curbing expiration effects. This finding is not surprising considering that these procedures are specifically designed to reduce abnormal market movements. Turnbull and Wakeman (1991) write: "Average options, by their design, ... provide a way to ameliorate any possible price distortions that might arise because of a lack of depth in the market of the underlying asset." Should mitigation of expiration effects be the only consideration, arithmetic definitely achieves the best result. However, as Alkebäck and Hagelin (2004) note, this does have the drawback of complicating arbitrage and hedging strategies. Correctly balancing these considerations is crucial in determining the optimal settlement design.

8.2 Economic significance

Economically, average expiration effects across all stocks are not large. Only volume is substantially higher, but these effects are not disruptive to the underlying market. However, the difference between using one settlement procedure instead of another may be quite substantial. For example, the difference in high low volatility between using an intraday and an arithmetic procedure with a long settlement period is 0.243 standard deviations. [45] Applying this number to CBA, this is equivalent to a difference of 0.097% in daily volatility or 1.54% annually. For reference, CBA has a daily volatility of 0.819% and an annual volatility of 13.00% across its control days. Thus, this difference represents a sizeable amount.

[45] From equation 3 in table 8, increase for intraday is 0.262 and the increase for an arithmetic with a long settlement procedure is $0.084 - 0.065 = 0.019$. Taking the difference between them yields 0.243.

8.3 Limitations and areas for further research

The biggest limitation of this research is the small sample of VWAP settled futures used. As an average procedure, VWAP should in theory, be just as effective at reducing expiration effects as arithmetic. However, evidence of this is not found, possibly due to an insufficient sample size. Currently, the number of exchanges using this method is still limited. As more exchanges adopt this however, future research with a greater representation of these futures may enrich the discussion.

Secondly, the statistical test used is in this analysis is parametric and assumes that effect measures are normally distributed. Past researchers have used non-parametric tests such as the Wilcoxon signed rank test, since financial data is often skewed or leptokurtic. Using these tests will improve the robustness of the findings.

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Appendices

A Full summary of stocks used in the analysis

Index	Full name	Exchange	Ticker	*Capitalisation* Market Capitalisation (USD, bil)	Index weight (%)	*Volume* Daily dollar volume (USD, mil)	Daily dollar volume as a percentage of total capitalisation (%)	*Performance* Return (% p.a.)	*Risk* Volatility (% p.a.)
S&P/ASX 200	AUSTRALIA NEW ZEALAND BANKING ORD	ASX	ANZ	52.4	4.74	140	0.27	-3.80	21.64
S&P/ASX 200	COMMONWEALTH BANK OF AUSTRALIA ORD	ASX	CBA	94.9	8.58	187	0.20	-2.16	19.35
S&P/ASX 200	NATIONAL AUSTRALIA BANK ORD	ASX	NAB	50.1	4.53	123	0.25	-4.21	20.88
S&P/ASX 200	TELSTRA CORPORATION ORD	ASX	TLS	51.1	4.62	106	0.21	-16.45	19.72
S&P/ASX 200	WESTPAC BANKING CORPORATION ORD	ASX	WBC	73.2	6.62	145	0.20	-1.97	21.39
ATX	ANDRITZ ORD	VIE	ANDR	5.0	8.32	9	0.17	0.78	24.87
ATX	ERSTE GROUP BANK ORD	VIE	EBS	9.5	15.88	24	0.26	20.05	31.27
ATX	OMV ORD	VIE	OMV	9.2	15.35	16	0.18	29.26	29.36
ATX	TELEKOM AUSTRIA ORD	VIE	TKA	3.9	6.50	2	0.04	12.16	20.59
ATX	VOESTALPINE ORD	VIE	VOE	6.1	10.09	14	0.23	13.85	30.95
BEL 20	AB INBEV ORD	BRU	ABI	211.8	50.34	191	0.09	0.17	22.37
BEL 20	ENGIE ORD	PAR	ENGI	39.1	9.30	93	0.24	-4.50	23.73
BEL 20	ING GROEP GDR	AEX	INGA	39.5	9.40	260	0.66	13.28	35.13
BEL 20	KBC GROEP ORD	BRU	KBC	20.3	4.81	56	0.28	13.54	28.93
BEL 20	UCB ORD	BRU	UCB	14.6	3.46	25	0.17	0.92	27.84
iBovespa	AMBEV ORD	SAO	ABEV3	93.3	18.70	73	0.08	9.64	19.90
iBovespa	BANCO BRADESCO ORD	SAO	BBDC3	23.4	4.68	13	0.06	-2.18	34.77
iBovespa	CIELO ORD	SAO	CIEL3	23.7	4.75	51	0.21	-17.75	35.53
iBovespa	ITAU UNIBANCO HOLDING PRF	SAO	ITUB4	28.1	5.62	138	0.49	7.79	32.85
iBovespa	PETROBRAS ORD	SAO	PETR3	27.7	5.55	49	0.18	21.36	53.56
S&P/TSX 60	BANK NOVA SCOTIA ORD	TOR	BNS	59.0	5.31	114	0.19	7.12	15.71
S&P/TSX 60	CANADIAN NATIONAL RAILWAY ORD	TOR	CNR	45.9	4.13	85	0.19	8.55	18.33
S&P/TSX 60	ROYAL BANK OF CANADA ORD	TOR	RY	88.0	7.92	166	0.19	8.03	14.79
S&P/TSX 60	SUNCOR ENERGY ORD	TOR	SU	46.2	4.16	91	0.20	7.06	25.14
S&P/TSX 60	TORONTO DOMINION ORD	TOR	TD	79.6	7.17	149	0.19	9.61	14.32

Index	Full name	Exchange	Ticker	*Capitalisation* Market Capitalisation (USD, bil)	Index weight (%)	*Volume* Daily dollar volume (USD, mil)	Daily dollar volume as a percentage of total capitalisation (%)	*Performance* Return (% p.a.)	*Risk* Volatility (% p.a.)
CSI 300	CHINA PETROLEUM ORD A	SHH	600028	67.5	2.09	226	0.33	-5.23	30.34
CSI 300	AGRI BANK OF CN ORD A	SHH	601288	142.3	4.40	214	0.15	-0.53	25.46
CSI 300	ICBC ORD A	SHH	601398	181.1	5.60	194	0.11	6.97	25.82
CSI 300	PETROCHINA ORD A	SHH	601857	175.7	5.43	146	0.08	-13.20	30.74
CSI 300	BANK OF CHINA ORD A	SHH	601988	102.0	3.15	296	0.29	-3.68	29.67
CAC 40	BNP PARIBAS ORD	PAR	BNP	55.4	4.50	252	0.45	7.54	30.88
CAC 40	LVMH MOET HENNESSY LOUIS VUITTON SE	PAR	MC	77.0	6.26	155	0.20	20.55	25.33
CAC 40	L'OREAL ORD	PAR	OR	108.1	8.79	120	0.11	9.71	21.02
CAC 40	SANOFI ORD	PAR	SAN	107.5	8.74	250	0.23	-1.59	22.91
CAC 40	TOTAL ORD	PAR	FP	122.0	9.91	317	0.26	2.60	24.74
DAX	BASF N ORD	GER	BAS	71.0	6.80	241	0.34	9.08	22.91
DAX	BAYER N ORD	GER	BAYN	83.5	7.99	277	0.33	-2.74	25.36
DAX	DEUTSCHE TELEKOM N ORD	GER	DTE	79.4	7.60	182	0.23	3.80	24.09
DAX	SAP ORD	GER	SAP	92.2	8.82	213	0.23	15.61	19.72
DAX	SIEMENS N ORD	GER	SIE	87.1	8.34	262	0.30	7.07	22.79
FTSE/ATHEX Large Cap	ALPHA BANK R ORD	ATH	ALPHA	2.7	7.74	15	0.56	46.61	241.28
FTSE/ATHEX Large Cap	COCA COLA HBC ORD	ATH	EEE	7.4	21.54	1	0.01	20.15	30.32
FTSE/ATHEX Large Cap	NAT BANK OF GREECE R ORD	ATH	ETE	1.9	5.64	11	0.59	-53.38	180.27
FTSE/ATHEX Large Cap	GREEK ORGANITION OF FOOTBALL R ORD	ATH	OPAP	2.2	6.35	6	0.27	4.25	44.13
FTSE/ATHEX Large Cap	HELLENIC TELECOM ORG R ORD	ATH	HTO	4.5	13.13	7	0.16	7.18	42.22
Hang Seng	HSBC HOLDINGS ORD	HKG	0005	120.9	7.22	205	0.17	2.63	20.32
Hang Seng	TENCENT ORD	HKG	0700	213.6	12.76	522	0.24	43.56	26.90
Hang Seng	CCB ORD H	HKG	0939	158.7	9.48	233	0.15	3.48	23.56
Hang Seng	CHINA MOBILE ORD	HKG	0941	234.0	13.98	185	0.08	-4.85	22.53
Hang Seng	AIA ORD	HKG	1299	72.0	4.30	155	0.22	14.16	24.03
BUX	GEDEON RICHTER ORD	BUD	RICHTER	3.7	19.73	7	0.18	21.94	22.33
BUX	MOL HUNGARIAN OIL AND GAS ORD	BUD	MOL	6.1	32.41	7	0.11	-44.21	122.57
BUX	MAGYAR TELECOM ORD	BUD	MTELEKOM	1.6	8.55	2	0.10	10.24	15.20
BUX	OTP BANK ORD	BUD	OTP	6.2	33.00	16	0.27	35.02	24.84

Index	Full name	Exchange	Ticker	*Capitalisation* Market Capitalisation (USD, bil)	Index weight (%)	*Volume* Daily dollar volume (USD, mil)	Daily dollar volume as a percentage of total capitalisation (%)	*Performance* Return (% p.a.)	*Risk* Volatility (% p.a.)
NIFTY	HDFC BANK ORD	NSI	HDFCBANK	44.3	5.27	31	0.07	22.85	15.94
NIFTY	INFOSYS ORD	NSI	INFY	39.9	4.74	63	0.16	-21.59	46.98
NIFTY	ITC ORD	NSI	ITC	45.3	5.39	41	0.09	-11.24	34.24
NIFTY	RELIANCE INDUSTRIES ORD	NSI	RELIANCE	47.0	5.58	64	0.14	1.24	47.61
NIFTY	TATA CONSULTANCY SERVICES ORD	NSI	TCS	73.3	8.72	42	0.06	2.00	21.27
FTSE MIB	ENEL ORD	MIL	ENEL	45.1	11.23	185	0.41	10.91	25.89
FTSE MIB	ENI ORD	MIL	ENI	60.0	14.95	281	0.47	-1.83	27.33
FTSE MIB	INTESA SANPAOLO ORD	MIL	ISP	29.7	7.39	358	1.21	4.03	38.48
FTSE MIB	LUXOTTICA GROUP ORD	MIL	LUX	24.0	5.99	43	0.18	3.98	26.81
FTSE MIB	SNAM ORD	MIL	SRG	21.1	5.26	61	0.29	0.00	24.82
AEX	ASML HOLDING ORD	AEX	ASML	42.5	9.43	139	0.33	15.94	26.62
AEX	HEINEKEN ORD	AEX	HEIA	53.7	11.91	64	0.12	13.38	19.14
AEX	KONINKLIJKE PHILIPS ORD	AEX	PHIA	23.8	5.27	102	0.43	8.69	22.03
AEX	ROYAL DUTCH SHELL CL A ORD	AEX	RDSA	119.9	26.60	252	0.21	0.05	25.94
AEX	UNILEVER DRC	AEX	UNA	80.5	17.86	208	0.26	12.31	22.56
OBX	DNB ORD	OSL	DNB	19.6	16.62	40	0.21	10.44	25.98
OBX	GJENSIDIGE FORSIKRING ORD	OSL	GJF	8.5	7.19	8	0.09	7.86	20.86
OBX	ORKLA ORD	OSL	ORK	9.1	7.73	15	0.17	17.68	18.89
OBX	TELENOR ORD	OSL	TEL	25.5	21.62	35	0.14	4.81	23.82
OBX	YARA INTERNATIONAL ORD	OSL	YAR	8.7	7.40	29	0.33	3.61	26.73
WIG 20	BANK ZACHODNI ORD	WSE	BZW	6.5	8.60	5	0.08	2.24	31.87
WIG 20	BANK PEKAO ORD	WSE	PEO	8.9	11.87	20	0.23	-10.64	25.52
WIG 20	POLSKIE GORNICTWO NAFTOWE I GAZ. ORD	WSE	PGN	8.4	11.14	6	0.08	11.85	31.92
WIG 20	POLSKI KONCERN NAFTOWY ORLEN ORD	WSE	PKN	7.4	9.89	21	0.28	26.06	30.70
WIG 20	PKO BANK POLSKI ORD	WSE	PKO	7.3	9.78	19	0.26	7.18	28.81
RTS	GAZPROM ORD	MCX	GAZP	51.9	12.08	66	0.13	-0.87	22.63
RTS	LUKOIL ORD	MCX	LKOH	36.1	8.39	37	0.10	12.44	25.56
RTS	NOVATEK ORD	MCX	NVTK	30.6	7.13	9	0.03	13.23	25.38
RTS	ROSNEFT ORD	MCX	ROSN	55.2	12.84	21	0.04	13.09	26.68
RTS	SBERBANK ORD	MCX	SBER	45.3	10.53	137	0.30	46.11	29.98

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FTSE/JSE Top 40	BHP BILLITON ORD	JNB	BIL	26.2	4.27	37	0.14	0.33	37.47
FTSE/JSE Top 40	BRITISH AMERICAN TOBACCO ORD	JNB	BTI	120.3	19.59	38	0.03	9.38	20.80
FTSE/JSE Top 40	RICHEMONT GDR	JNB	CFR	30.7	5.00	34	0.11	2.18	25.08
FTSE/JSE Top 40	NASPERS N ORD	JNB	NPN	66.8	10.88	183	0.27	27.27	31.38
FTSE/JSE Top 40	SABMILLER ORD	JNB	SAB	93.6	15.24	71	0.08	15.99	26.21
IBEX 35	BANCO BILBAO VIZCAYA ARGENTARIA ORD	MCE	BBVA	36.9	6.86	197	0.53	-3.53	31.19
IBEX 35	IBERDROLA ORD	MCE	IBE	42.1	7.82	117	0.28	4.67	20.00
IBEX 35	INDITEX ORD	MCE	ITX	104.1	19.32	108	0.10	6.53	22.98
IBEX 35	BANCO SANTANDER ORD	MCE	SAN	56.3	10.44	304	0.54	-8.14	35.03
IBEX 35	TELEFONICA ORD	MCE	TEF	48.0	8.91	191	0.40	-12.42	27.80
OMXS 30	ABB LTD N ORD	STO	ABB	46.1	8.66	34	0.07	9.41	18.92
OMXS 30	ASTRAZENECA ORD	STO	AZN	76.5	14.36	31	0.04	0.77	25.25
OMXS 30	HENNES & MAURITZ B ORD	STO	HM B	43.6	8.19	109	0.25	-21.89	25.11
OMXS 30	NORDEA BANK ORD	STO	NDA SEK	34.1	6.40	93	0.27	2.87	24.71
OMXS 30	NOKIA ORD	STO	NOKIA SEK	33.0	6.20	9	0.03	-10.32	32.38
SMI	ABB LTD N ORD	VTX	ABBN	46.1	4.36	144	0.31	21.53	15.23
SMI	NESTLE N ORD	VTX	NESN	243.2	23.00	476	0.20	10.81	13.38
SMI	NOVARTIS N ORD	VTX	NOVN	217.2	20.54	406	0.19	5.88	15.68
SMI	ROCHE HOLDING PAR	VTX	ROG	185.3	17.52	418	0.23	1.51	15.95
SMI	UBS GROUP N ORD	VTX	UBSG	50.9	4.82	206	0.41	23.77	22.49
TAIEX	FORMOSA PLASTICS ORD	TAI	1301	15.4	1.94	15	0.10	10.01	19.39
TAIEX	HON HAI IND ORD	TAI	2317	40.0	5.06	104	0.26	2.41	22.80
TAIEX	TWN SEMICONT MAN ORD	TAI	2330	130.7	16.53	172	0.13	16.13	21.82
TAIEX	CHUNGHWA TELECOM ORD	TAI	2412	28.0	3.54	30	0.11	3.95	11.17
TAIEX	FORMOSA PETRO ORD	TAI	6505	25.9	3.27	10	0.04	17.91	25.11
FTSE 100	BRITISH AMERICAN TOBACCO ORD	LSE	BATS	120.6	4.99	192	0.16	12.38	20.43
FTSE 100	BP ORD	LSE	BP	111.0	4.59	196	0.18	8.01	26.17
FTSE 100	HSBC HOLDINGS ORD	LSE	HSBA	123.5	5.10	221	0.18	7.47	22.16
FTSE 100	ROYAL DUTCH SHELL CL A ORD	LSE	RDSA	119.1	4.92	171	0.14	4.45	25.79
FTSE 100	ROYAL DUTCH SHELL CL B ORD	LSE	RDSB	104.1	4.30	166	0.16	3.82	26.78

Index	Full name	Exchange	Ticker	***Capitalisation*** Market Capitalisation (USD, bil)	Index weight (%)	***Volume*** Daily dollar volume (USD, mil)	Daily dollar volume as a percentage of total capitalisation (%)	***Performance*** Return (% p.a.)	***Risk*** Volatility (% p.a.)
S&P 500	APPLE ORD	NSM	AAPL	525.2	2.78	1114	0.21	14.52	22.99
S&P 500	AMAZON COM ORD	NSM	AMZN	342.4	1.81	753	0.22	44.30	28.17
S&P 500	JOHNSON & JOHNSON ORD	NYS	JNJ	333.6	1.76	268	0.08	9.65	14.17
S&P 500	MICROSOFT ORD	NSM	MSFT	402.1	2.13	506	0.13	20.08	22.76
S&P 500	EXXON MOBIL ORD	NYS	XOM	389.1	2.06	332	0.09	-3.47	18.73

All dollar figures are presented in USD using the exchange rate on 1 July, 2016, the middle of the sample period. 'Market capitalisation' and 'Index weight' were calculated on 1 July, 2016. 'Daily dollar volume' is the average daily dollar volume over the entire sample period (1 January, 2015 to 31 December, 2017). 'Daily dollar volume as a percentage of total capitalisation' was obtained by dividing 'Daily dollar volume' by 'Market capitalisation'. 'Return' was calculated by taking the average daily (continuous) return and multiplying it by 252 (assumed number of trading days per year). 'Volatility' was calculated by multiplying the standard deviation of daily returns by $\sqrt{252}$. Only statistics for a few of the stocks are presetented in this table.

B Estimated coefficients from regressions on measures obtained from daily data

Explanatory variable	***Effect measures*** volume	Volume growth rate	High low	Absolute return	Price reversal	Price shock
Equation 1						
Constant	0.000	0.000	0.000	0.000	0.000	0.000
(standard error)	(0.015)	(0.007)	(0.017)	(0.012)	(0.008)	(0.010)
$D_{i,t}$	1.169***	0.867***	0.064***	0.027	0.011	0.082***
(standard error)	(0.073)	(0.038)	(0.021)	(0.022)	(0.030)	(0.026)
Equation 2						
Constant	0.000	0.000	0.000	0.000	0.000	0.000
(standard error)	(0.025)	(0.010)	(0.025)	(0.018)	(0.012)	(0.016)
$D_{i,t}$	0.625***	0.561***	0.011	-0.069***	-0.026	0.036
(standard error)	(0.055)	(0.044)	(0.027)	(0.026)	(0.037)	(0.031)
$Intraday_i$	0.000	0.000	0.000	0.000	0.000	0.000
(standard error)	(0.040)	(0.017)	(0.047)	(0.034)	(0.021)	(0.027)
SOQ_i	0.000	0.000	0.000	0.000	0.000	0.000
(standard error)	(0.039)	(0.018)	(0.044)	(0.032)	(0.021)	(0.028)
$VWAP_i$	0.000	0.000	0.000	0.000	0.000	0.000
(standard error)	(0.047)	(0.02)0	(0.044)	(0.035)	(0.026)	(0.029)
$Intraday_i \times D_{i,t}$	1.713***	0.935***	0.211***	0.234***	0.109*	0.100*
(standard error)	(0.258)	(0.148)	(0.064)	(0.053)	(0.058)	(0.053)
$SOQ_i \times D_{i,t}$	1.878***	1.043***	-0.006	0.175**	0.021	0.112*
(standard error)	(0.314)	(0.159)	(0.050)	(0.074)	(0.063)	(0.062)
$VWAP_i \times D_{i,t}$	0.158	0.118	0.126*	0.200***	0.097	0.080
(standard error)	(0.196)	(0.087)	(0.069)	(0.072)	(0.119)	(0.093)

Explanatory variable	***Effect measures*** volume	Volume growth rate	High low	Absolute return	Price reversal	Price shock
Equation 3						
Constant	0.021	0.003	0.017	0.012	-0.006	0.003
(standard error)	(0.036)	(0.017)	(0.040)	(0.030)	(0.019)	(0.026)
$D_{i,t}$	0.812***	0.773***	0.084*	-0.061	-0.045	0.124**
(standard error)	(0.101)	(0.062)	(0.047)	(0.042)	(0.071)	(0.054)
$Intraday_i$	-0.003	-0.001	-0.003	-0.002	0.001	0.000
(standard error)	(0.041)	(0.019)	(0.048)	(0.035)	(0.022)	(0.028)
SOQ_i	-0.008	-0.001	-0.006	-0.005	0.002	-0.001
(standard error)	(0.040)	(0.020)	(0.046)	(0.034)	(0.022)	(0.030)
$VWAP_i$	-0.004	-0.001	-0.004	-0.003	0.001	-0.001
(standard error)	(0.052)	(0.026)	(0.057)	(0.041)	(0.033)	(0.041)
$(SettPeriod > 1Hr)_i$	-0.009	-0.002	-0.008	-0.005	0.003	-0.001
(standard error)	(0.081)	(0.024)	(0.068)	(0.049)	(0.032)	(0.041)
$(SettPeriod = WholeDay)_i$	0.003	0.001	0.003	0.002	-0.001	0.000
(standard error)	(0.051)	(0.025)	(0.059)	(0.045)	(0.033)	(0.045)
$weight_{i,t}$	-0.194	-0.033	-0.165	-0.115	0.058	-0.025
(standard error)	(0.225)	(0.119)	(0.291)	(0.217)	(0.129)	(0.193)
$Intraday_i \times D_{i,t}$	1.513***	0.757***	0.179***	0.238***	0.114*	0.057
(standard error)	(0.257)	(0.134)	(0.066)	(0.055)	(0.066)	(0.057)
$SOQ_i \times D_{i,t}$	1.681***	0.855***	-0.052	0.175**	0.031	0.055
(standard error)	(0.310)	(0.145)	(0.054)	(0.074)	(0.074)	(0.068)
$VWAP_i \times D_{i,t}$	0.577**	0.289***	0.135	0.166**	0.248	0.136
(standard error)	(0.250)	(0.083)	(0.094)	(0.081)	(0.179)	(0.139)
$(SettPeriod > 1Hr)_i \times D_{i,t}$	-0.519***	-0.646***	-0.136**	-0.012	0.171*	-0.130
(standard error)	(0.142)	(0.096)	(0.063)	(0.071)	(0.104)	(0.093)
$(SettPeriod = WholeDay)_i \times D_{i,t}$	-0.930***	-0.524***	-0.065	0.057	-0.217	-0.150
(standard error)	(0.204)	(0.084)	(0.083)	(0.081)	(0.147)	(0.118)
$weight_{i,t} \times D_{i,t}$	0.144	-0.353	-0.403	-0.121	0.146	-0.473
(standard error)	(0.650)	(0.413)	(0.265)	(0.254)	(0.391)	(0.317)

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

The 'Explanatory variable' column denotes which coefficient is being estimated. 'Effect measures' denote which measure is being used as the response variable. Estimates of the coefficients for on each explanatory variable for each effect measure are presented with its standard deviation (in brackets) underneath. In equation 1, only expiration day is used as an explanatory variable. In equation 2, the settlement method is then added. In equation 3, the length of the settlement period and index weight are then added. *, ** and *** indicates that the coefficient (or sum of coefficients) is significant at 0.1, 0.05 and 0.01 levels respectively.

C Estimated coefficients from regressions on measures obtained from intraday data

Explanatory variable	*Effect measures* Realised volatility	Price reversal	Price shock
Equation 1			
Constant	0.000	0.000	0.000
(standard error)	(0.015)	(0.008)	(0.010)
$D_{i,t}$	0.190***	0.052*	0.148***
(standard error)	(0.036)	(0.029)	(0.032)
Equation 2			
Constant	0.000	0.000	0.000
(standard error)	(0.024)	(0.012)	(0.016)
$D_{i,t}$	0.034	0.065**	0.043
(standard error)	(0.027)	(0.030)	(0.029)
$Intraday_i$	0.000	0.000	0.000
(standard error)	(0.045)	(0.021)	(0.028)
SOQ_i	0.000	0.000	0.000
(standard error)	(0.039)	(0.021)	(0.028)
$VWAP_i$	0.000	0.000	0.000
(standard error)	(0.038)	(0.027)	(0.030)
$Intraday_i \times D_{i,t}$	0.494***	0.039	0.295***
(standard error)	(0.093)	(0.071)	(0.073)
$SOQ_i \times D_{i,t}$	0.220**	0.046	0.191***
(standard error)	(0.093)	(0.059)	(0.072)
$VWAP_i \times D_{i,t}$	0.293**	-0.134	0.194
(standard error)	(0.146)	(0.118)	(0.134)

Explanatory variable	***Effect measures*** **Realised volatility**	**Price reversal**	**Price shock**
Equation 3			
Constant	0.015	0.008	0.013
(standard error)	(0.040)	(0.021)	(0.025)
$D_{i,t}$	0.181***	0.091	0.172***
(standard error)	(0.070)	(0.062)	(0.063)
$Intraday_i$	-0.002	-0.001	-0.002
(standard error)	(0.049)	(0.022)	(0.030)
SOQ_i	-0.006	-0.003	-0.005
(standard error)	(0.043)	(0.023)	(0.030)
$VWAP_i$	-0.003	-0.002	-0.003
(standard error)	(0.049)	(0.034)	(0.040)
$(SettPeriod > 1Hr)_i$	-0.006	-0.004	-0.006
(standard error)	(0.052)	(0.031)	(0.039)
$(SettPeriod = WholeDay)_i$	0.002	0.001	0.002
(standard error)	(0.058)	(0.033)	(0.047)
$weight_{i,t}$	-0.137	-0.075	-0.119
(standard error)	(0.282)	(0.147)	(0.169)
$Intraday_i \times D_{i,t}$	0.429***	0.017	0.247***
(standard error)	(0.100)	(0.075)	(0.079)
$SOQ_i \times D_{i,t}$	0.128	0.022	0.117
(standard error)	(0.099)	(0.067)	(0.079)
$VWAP_i \times D_{i,t}$	0.485**	-0.188	0.336*
(standard error)	(0.224)	(0.180)	(0.203)
$(SettPeriod > 1Hr)_i \times D_{i,t}$	-0.086	-0.156	-0.052
(standard error)	(0.091)	(0.101)	(0.093)
$(SettPeriod = WholeDay)_i \times D_{i,t}$	-0.394**	0.048	-0.289*
(standard error)	(0.183)	(0.146)	(0.167)
$weight_{i,t} \times D_{i,t}$	-0.842**	-0.041	-0.851***
(standard error)	(0.416)	(0.382)	(0.329)

$^*p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

The 'Explanatory variable' column denotes which coefficient is being estimated. 'Effect measures' denote which measure is being used as the response variable. Estimates of the coefficients for on each explanatory variable for each effect measure are presented with its standard deviation (in brackets) underneath. In equation 1, only expiration day is used as an explanatory variable. In equation 2, the settlement method is then added. In equation 3, the length of the settlement period and index weight are then added. *, ** and *** indicates that the coefficient (or sum of coefficients) is significant at 0.1, 0.05 and 0.01 levels respectively.

D Distribution of effect measures obtained from daily data on expiration and control days

Figure 1: Distribution across all futures

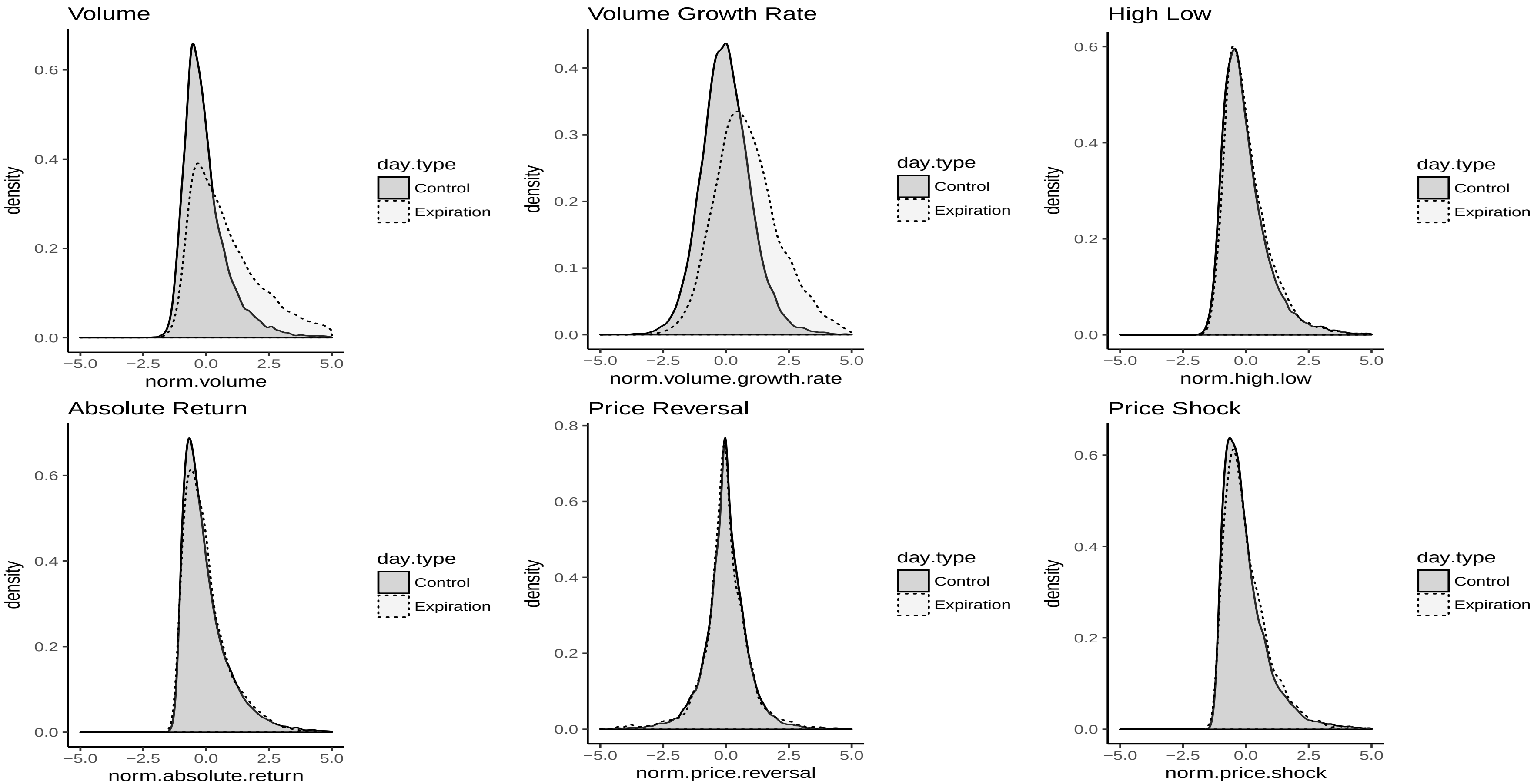


Figure 2: Distribution across arithmetic settled futures

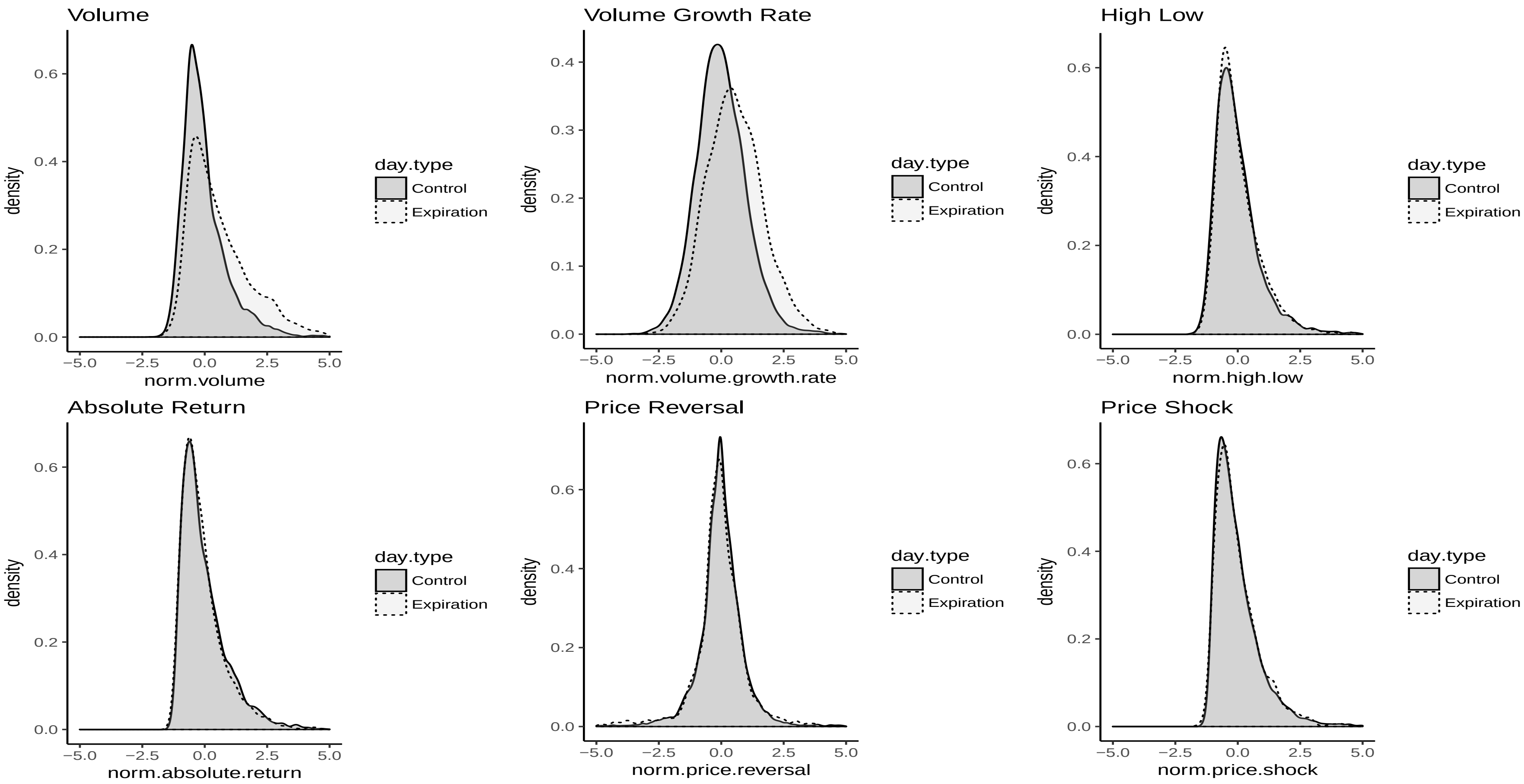


Figure 3: Distribution across intraday settled futures

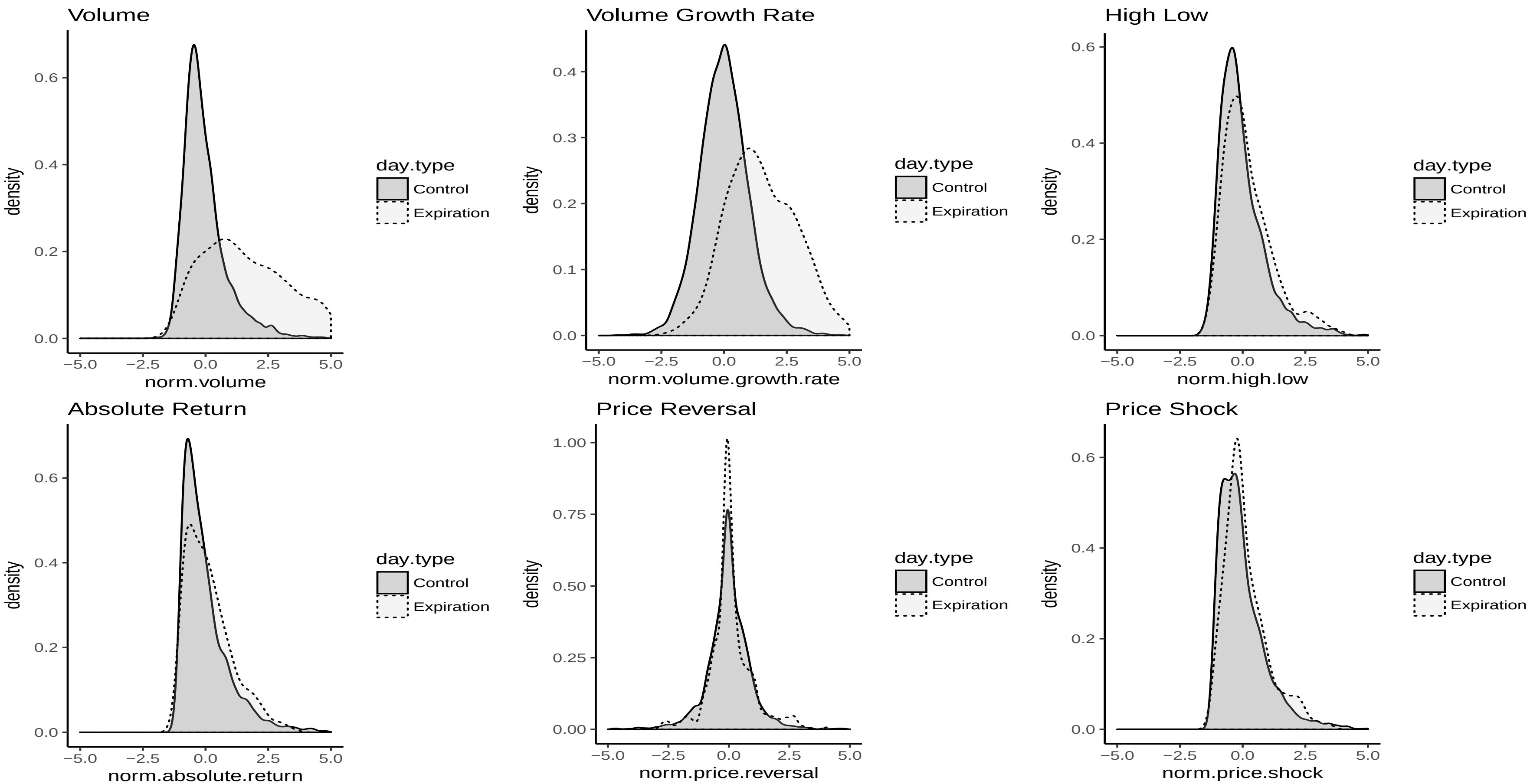


Figure 4: Distribution across SOQ settled futures

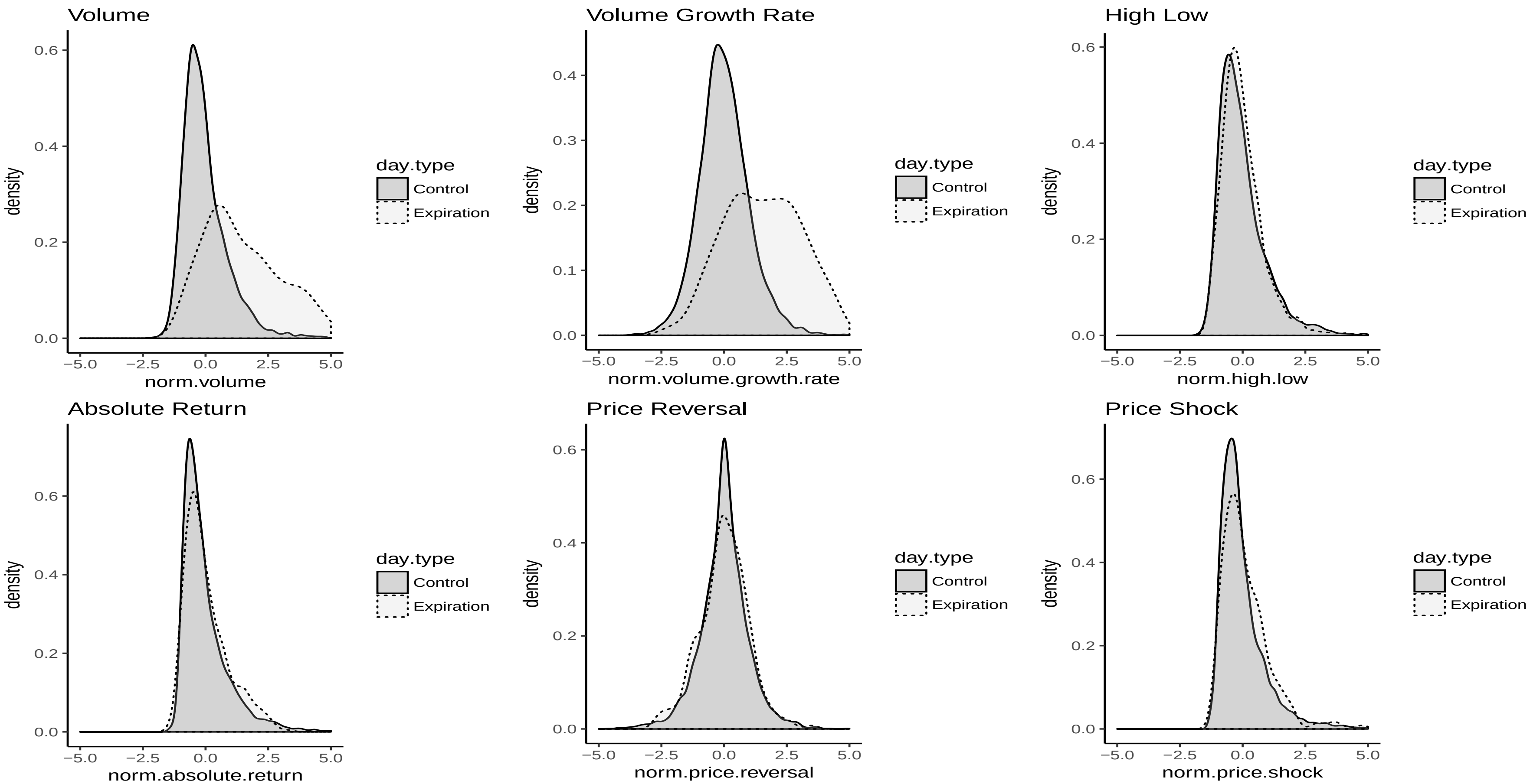
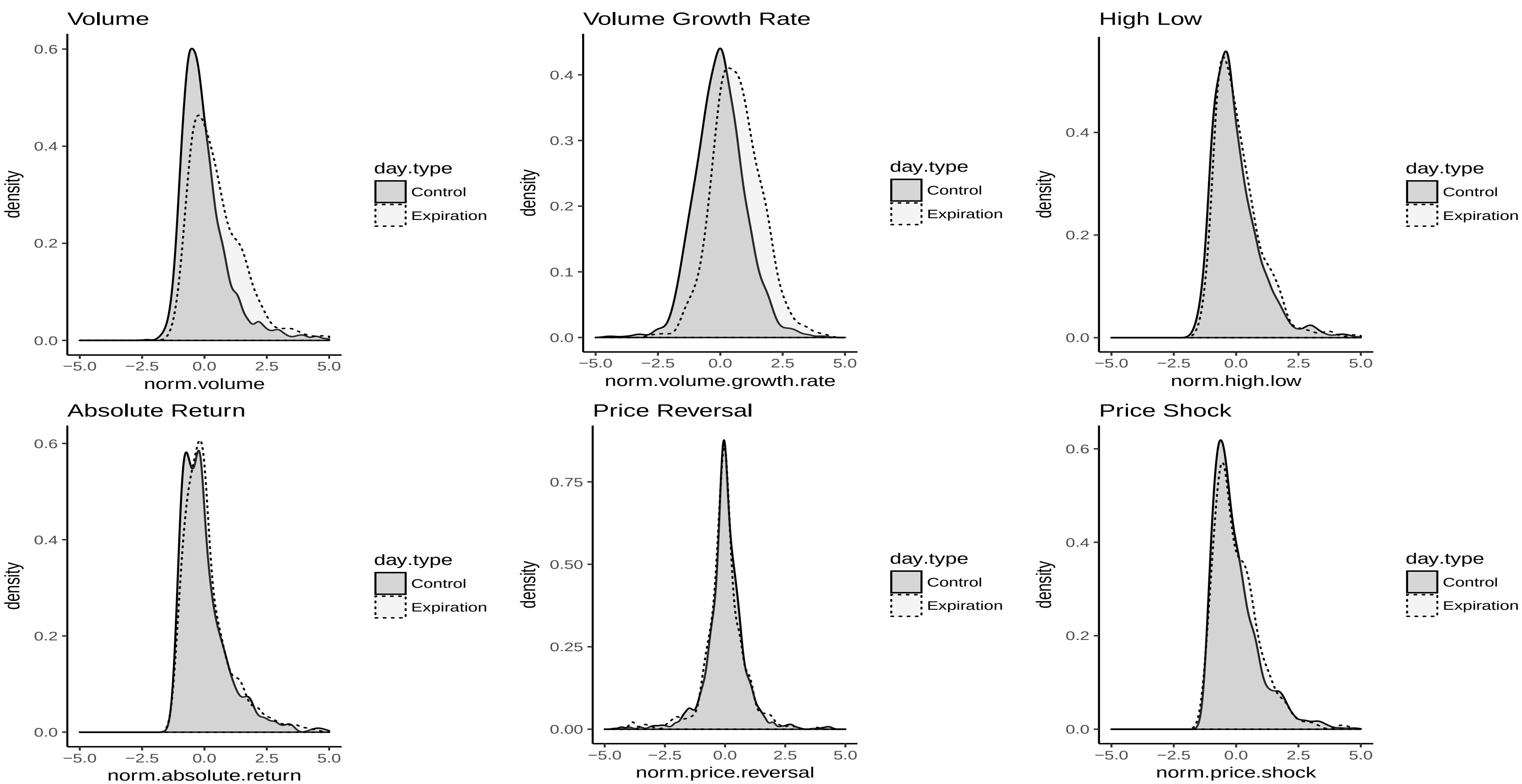


Figure 5: Distribution across VWAP settled futures



E Distribution of effect measures obtained from intraday data on expiration and control days

Figure 6: Distribution across all futures

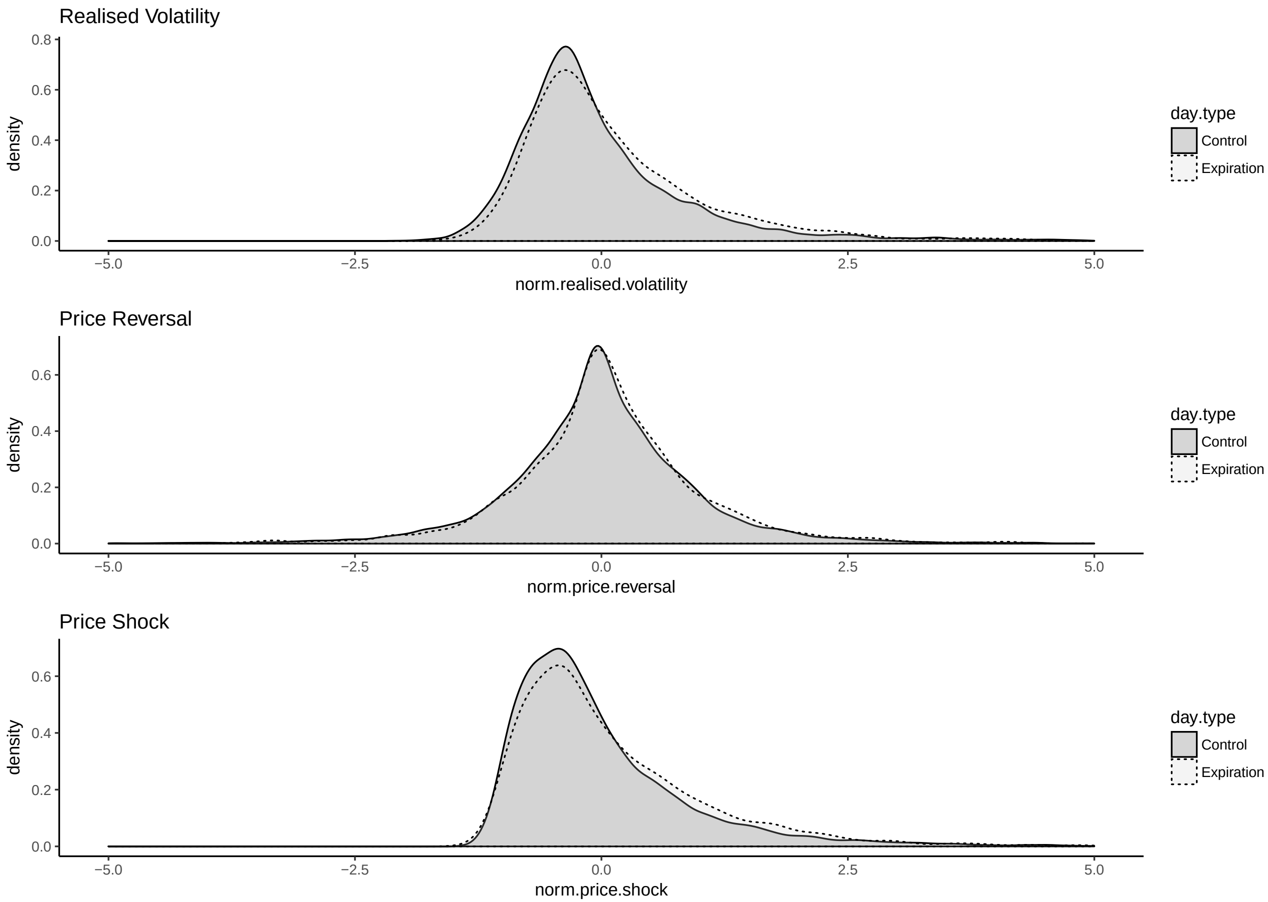


Figure 7: Distribution across arithmetic settled futures

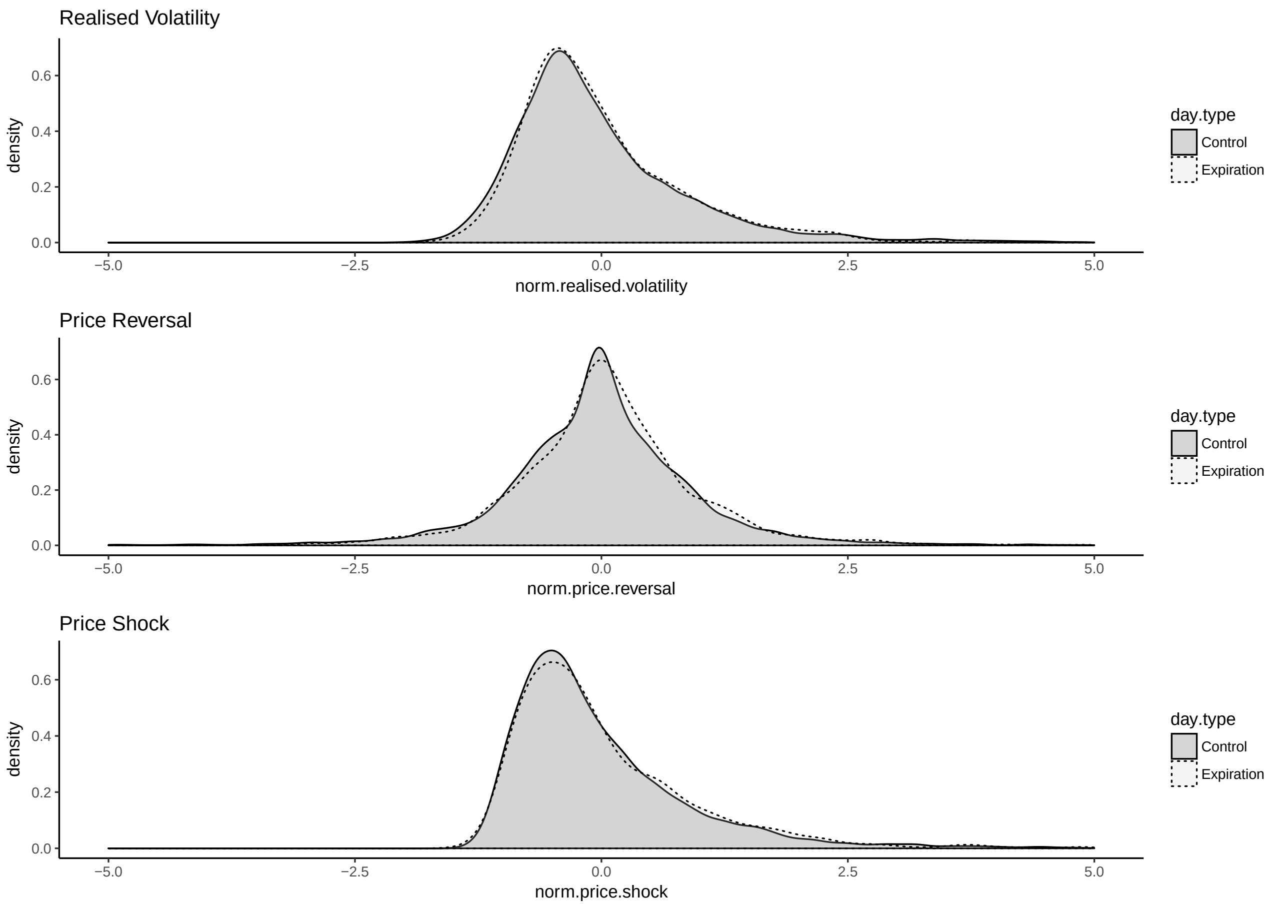


Figure 8: Distribution across intraday settled futures

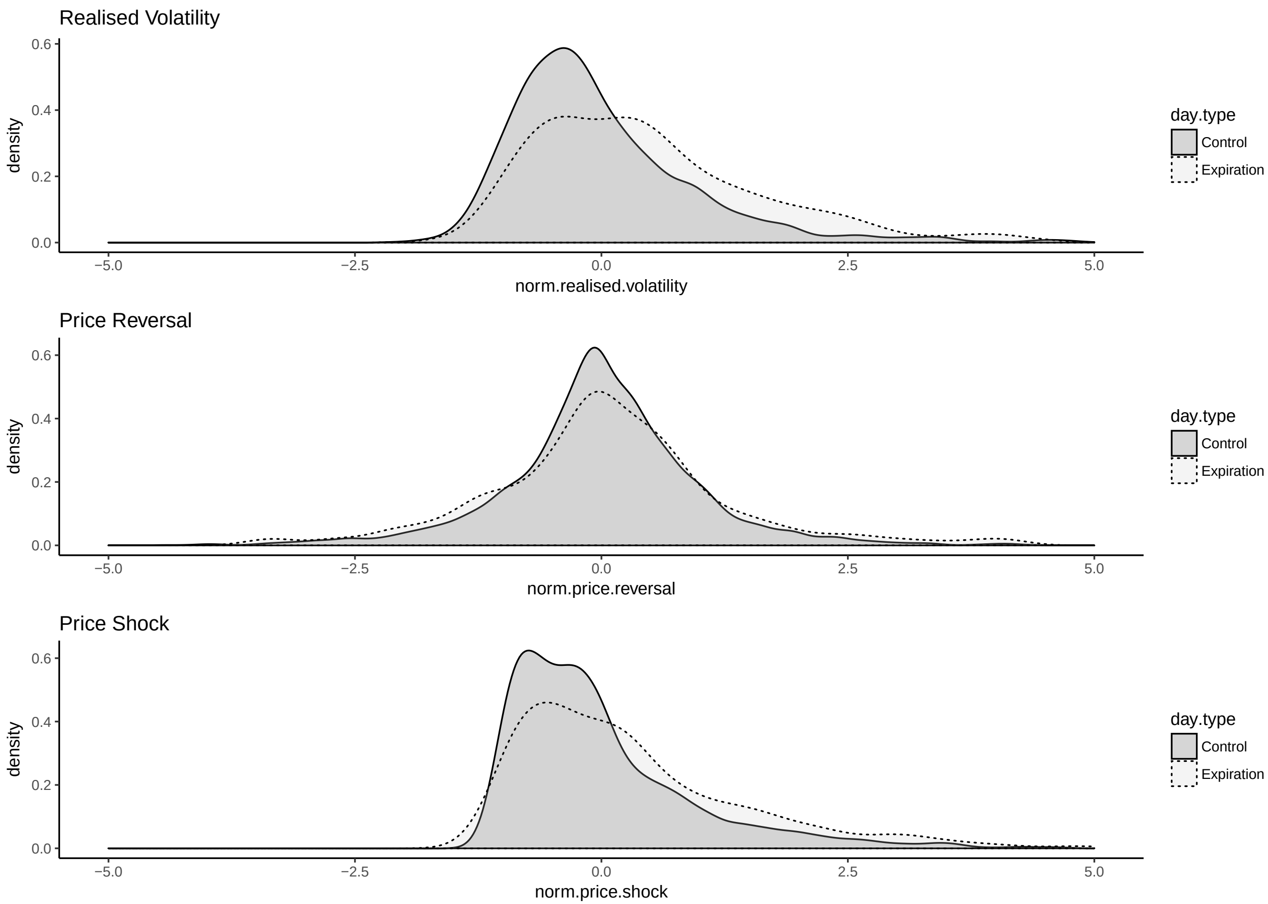


Figure 9: Distribution across SOQ settled futures

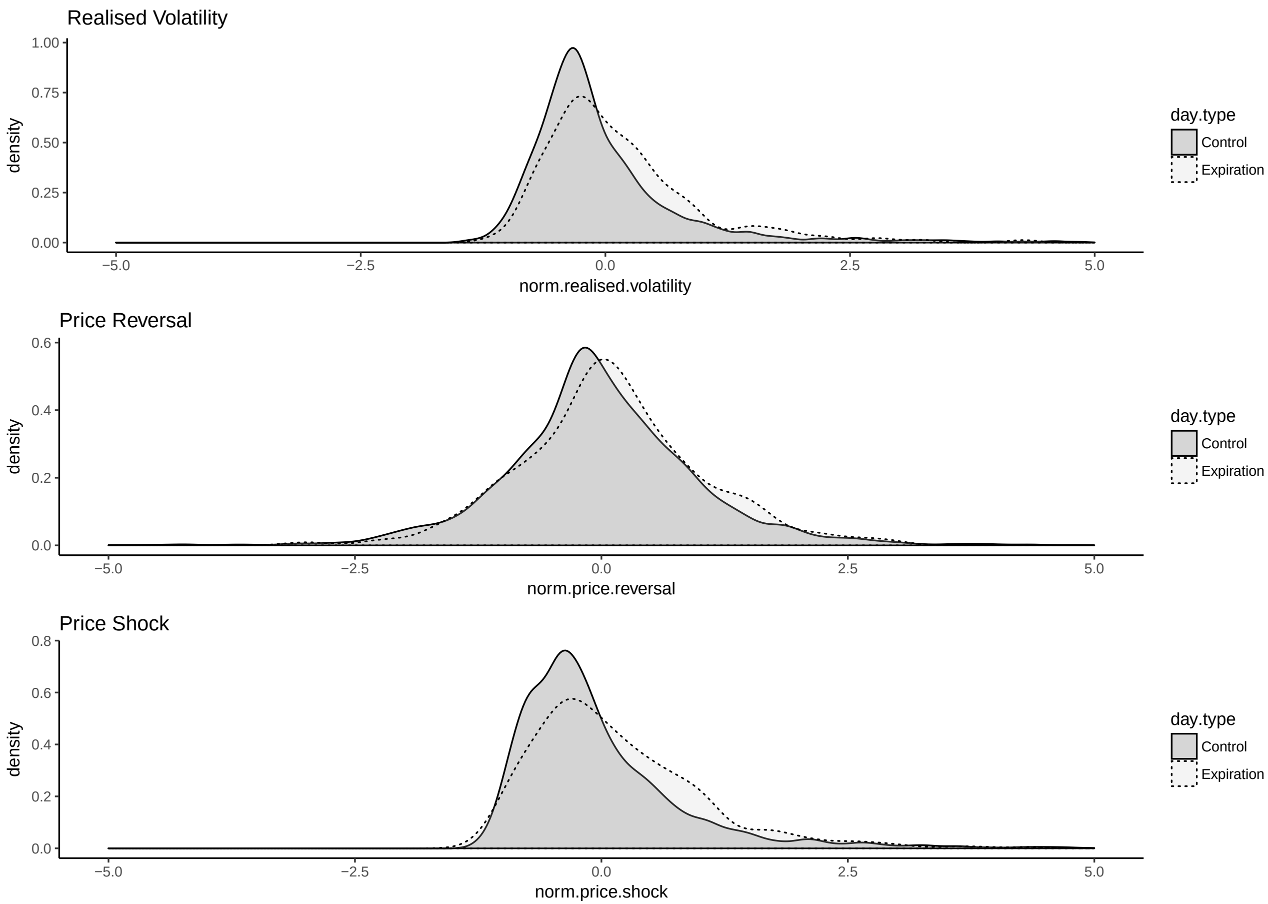
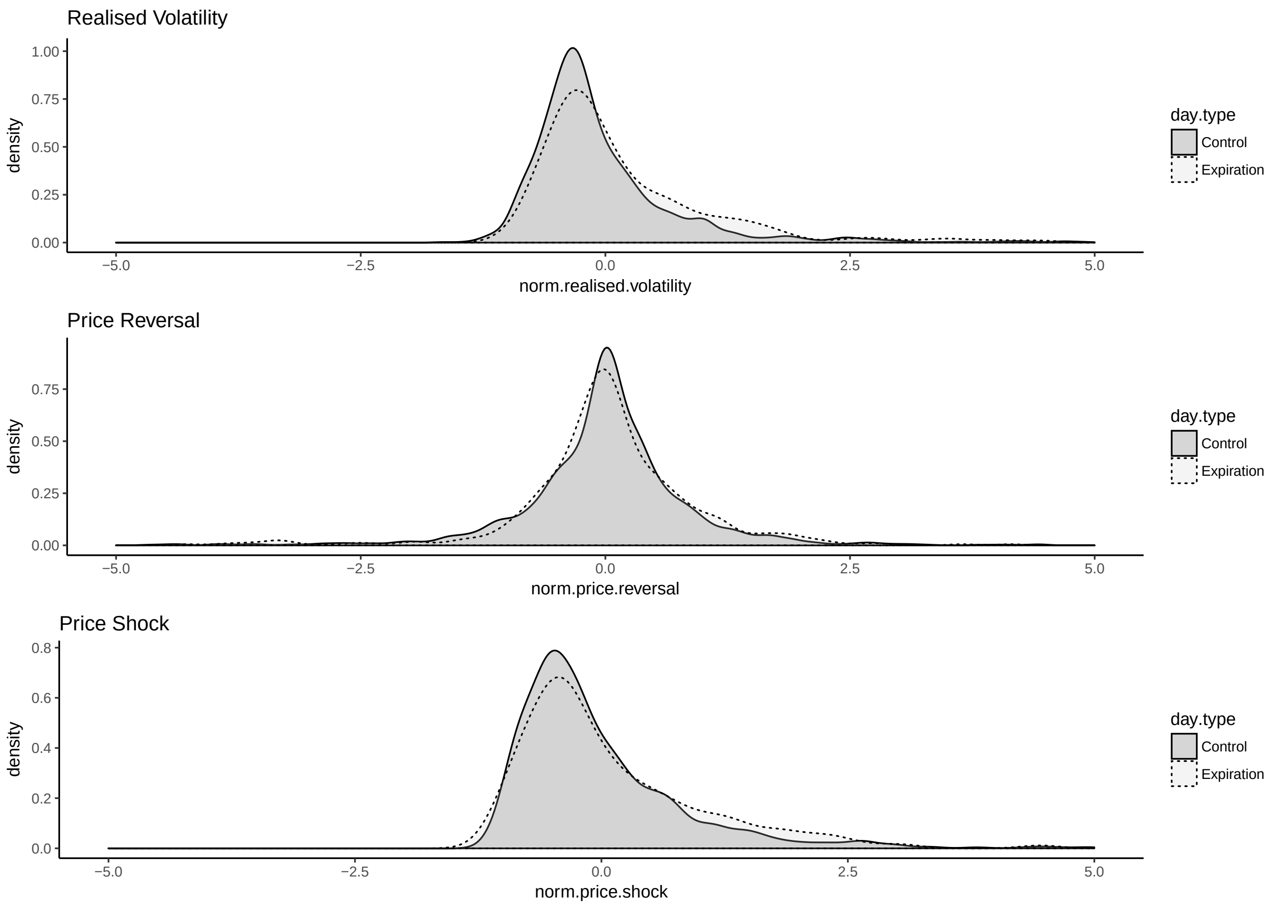


Figure 10: Distribution across VWAP settled futures



F Robustness check on dividend adjustment

Since prices were not adjusted for dividends, a simple robustness check was performed to see if this would affect results. To do this, the mean and standard deviation of the high low volatility measure (other measures could also be used) was computed for all stocks, firstly across all control days and then with the ex-dividend dates removed. The means and standard deviations between these two samples were then compared.

Overall, 75 of the 119 stocks recorded no difference. This was because for these stocks, no ex-dividend dates fell on control days. Of the remaining 44 stocks that did record a difference, the differences were generally small. This implies that not adjusting for dividends should not severely affect the results. The table on the next page presents the results of this test. Only stocks that had a non-zero difference are reported.

Robustness check on dividend adjustment

Stock	*Ex dividend dates included* Mean high low volatility (%)	Standard deviation of high low volatility (%)	*Ex dividend dates excluded* Mean high low volatility (%)	Standard deviation of high low volatility (%)	Difference in mean (%)	Difference in standard deviations (%)
0005.HK	0.7516	0.4168	0.7574	0.4182	-0.006	-0.001
0939.HK	1.1176	0.5333	1.1134	0.5364	0.004	-0.003
1301.TW	0.9493	0.4620	0.9523	0.4650	-0.003	-0.003
600028.SS	1.4388	1.2070	1.4340	1.2116	0.005	-0.005
601288.SS	1.0472	0.9428	1.0080	0.8534	0.039	0.089
601398.SS	1.1320	0.9272	1.1322	0.9315	0.000	-0.004
601988.SS	1.2488	1.2355	1.2146	1.1901	0.034	0.045
6505.TW	1.2540	0.6064	1.2331	0.5667	0.021	0.040
AAPL.OQ	0.9065	0.5348	0.9105	0.5348	-0.004	0.000
ABEV3.SA	1.2094	0.4913	1.2027	0.4870	0.007	0.004
ABI.BR	1.1610	0.5586	1.1530	0.5547	0.008	0.004
ANDR.VI	1.1943	0.6282	1.1952	0.6305	-0.001	-0.002
ASML.AS	1.1708	0.6899	1.1795	0.6928	-0.009	-0.003
BBDC3.SA	1.8128	0.6571	1.8005	0.6565	0.012	0.001
BBVA.MC	1.5477	0.9001	1.5513	0.9034	-0.004	-0.003
BNS.TO	0.7177	0.3014	0.7130	0.2995	0.005	0.002
CIEL3.SA	1.7546	0.6199	1.7598	0.6194	-0.005	0.000
CNR.TO	0.8814	0.3114	0.8831	0.3136	-0.002	-0.002
DTEGn.DE	1.1161	0.5791	1.1129	0.5801	0.003	-0.001
HDBK.NS	0.8919	0.3690	0.8938	0.3701	-0.002	-0.001
IBE.MC	0.9931	0.8291	0.9894	0.8361	0.004	-0.007
INFY.NS	1.3295	0.8140	1.3210	0.8160	0.009	-0.002
INGA.AS	1.4787	1.0299	1.4827	1.0472	-0.004	-0.017
ITUB4.SA	1.6288	0.6174	1.6325	0.6139	-0.004	0.004
JNJ.N	0.6325	0.2870	0.6302	0.2822	0.002	0.005
LKOH.MM	1.4214	0.7353	1.4268	0.7350	-0.005	0.000
NAB.AX	0.9025	0.4689	0.9117	0.4713	-0.009	-0.002
NVTK.MM	1.5504	0.6901	1.5536	0.6914	-0.003	-0.001
OMVV.VI	1.5331	0.7904	1.5314	0.7932	0.002	-0.003
OPAr.AT	1.7521	1.0370	1.7519	1.0421	0.000	-0.005
OREP.PA	1.1318	0.6709	1.1312	0.6706	0.001	0.000
ORK.OL	0.9149	0.4462	0.9176	0.4473	-0.003	-0.001
OTEr.AT	1.6855	1.0163	1.6942	1.0173	-0.009	-0.001
OTPB.BU	1.0050	0.5535	1.0113	0.5597	-0.006	-0.006
RELI.NS	1.3020	0.5868	1.3055	0.5895	-0.004	-0.003
RY.TO	0.7084	0.3583	0.7031	0.3417	0.005	0.017
SAPG.DE	0.9663	0.4795	0.9637	0.4803	0.003	-0.001
SBER.MM	1.6168	0.9231	1.6145	0.9259	0.002	-0.003
TCS.NS	1.1719	0.5652	1.1719	0.5677	0.000	-0.003
TD.TO	0.6683	0.3819	0.6687	0.3838	0.000	-0.002
TEL.OL	1.0977	0.5372	1.0958	0.5407	0.002	-0.004
UCB.BR	1.2911	0.7431	1.2875	0.7488	0.004	-0.006
WBC.AX	0.9174	0.4335	0.9216	0.4329	-0.004	0.001
XOM.N	0.8028	0.4153	0.8050	0.4174	-0.002	-0.002

Each stock is referred to in the 'Stock' column by its Reuters Instrument Code (RIC). The next two columns present the means and standard deviations of the high low volatility measure when ex-dividend dates are included in the sample. Columns 4 and 5 present the means and standard deviations when ex-dividend dates are removed. Columns 6 and 7 present the differences between the means and standard deviations.