# Settlement Procedures and Stock Market Efficiency

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**ABSTRACT**

This study examines why most derivatives markets settling on the day following expiration choose the opening rather than the closing price as the final settlement price (FSP), whereas most markets that settle on the expiration day select an average price rather than a single price as the FSP. Four exogenous changes in the TAIFEX settlement procedures provide an experimental basis to study the settlement procedures' impact on the underlying assets. We observe the highest market efficiency when FSP is determined by a single rather than an average price and hypothesize that manipulation prevention occurs at the expense of market quality.

**Keywords:** Expiration-day effects, liquidity, market efficiency, price discovery, intraday seasonality, spillover effect, market depth

JEL: G13, G14, G15

## 1. Introduction

In finance literature, stock market volume, price, and volatility have been shown to be affected by the expiration of index futures and options contracts. These expiration-day effects are generally viewed as a combined result of the cash settlement feature of index derivatives contracts and the unwinding of index arbitrage positions in the underlying stock market. This unwinding is often concentrated at a time immediately prior to the contract expiration, creating excess volume and noticeable price pressure on the constituent index stocks. [1] The magnitude of the price effects on the settlement or expiration day depends in part on how the stock market handles order imbalances that may arise when arbitrage positions are unwound. Because expiration-day phenomena are especially obvious at the triple witching hour, they are referred to as triple witching hour effects. [2] The settlement procedure affects the approach arbitrageurs adopt to unwind index-derivative arbitrage positions and causes arbitrage-related trading activities to be concentrated around the close/opening of the expiration/settlement day.

Around the world, most markets undergo anomalous trading activity on expiration day. In an attempt to alleviate spot expiration-day effects, settlement procedures for the Taiwan Stock Exchange Capitalization Weighted Stock Index (TAIEX) futures and options have been altered four times over the past decade. The exogenous changes in settlement procedures provide us with an excellent experimental ground to study the impact of different settlement procedures on various trading activities, market liquidity, price efficiency, and price discovery. To this end, this study explores expiration-day effects in the underlying stock market caused by the evolution of settlement mechanisms. Herbst and Maberly (1990) and Whaley and Stoll (1991) find that the change of settlement from market close to market

[1] A price effect exists if the serial correlation between the expiration day return and the subsequent day return is negative although it is normally positive. If the stock market moves late in the day but not all stocks trade at the close, a positive serial correlation can result.

[2] The term "triple witching hour" is used to refer to a time at which stock options, index options, and index futures expire simultaneously.

open does not reduce the impact of index derivatives expiration on spot market volatility. Although the two studies suggest that expiration-day trading may split between the opening and the close, the inference is limited to only the Special Open Quotation settlement procedure. The four changes within the past decade make this market a paragon for testing the effectiveness of changes in settlement procedures and a more comprehensive understanding of settlement mechanisms, e.g., whether a tradeoff exists between market manipulation prevention and market efficiency (and other market quality factors).

To obtain a clean measurement of the expiration-day effect, we decompose the effect into four components: opening/closing effect (intraday seasonality effect), spillover effect, settlement regime, and the effect resulting from the settlement procedure. This decomposition has the benefit of allowing us to trace the source of the expiration-day effects resulting from the type of settlement procedure rather than the mixed effects one observes in expiration-day literature. Thus, this study examines whether market liquidity, market efficiency, and price discovery are driven by the nature of the settlement procedure by purging the intraday seasonality and spillover effect. Our research addresses the following three questions: (1) Do settlement procedures reduce, enhance, or split expiration-day effects between the close and next opening and should settlement be at the opening or at the close? (2) What type of settlement procedure results in higher liquidity, a more efficient price, and better price discovery? And (3) is there a tradeoff between manipulation prevention and liquidity, market efficiency, and price discovery?

The results of this research suggest that volume, price effect, liquidity, and order imbalances in the underlying stock market attributable to the expiration of index futures and options are not trivial. The index value fluctuates markedly during the opening interval on settlement day. On more than one-third of the settlement days, the stock index fluctuates more than one hundred index points, and the mean index fluctuation is 99.78 index points (1.57% of index value). None of the settlement days, in contrast, fluctuates more than 100 index points during the closing interval. Such evidence supports a hypothesis that index derivatives should settle at the close to avoid volatile index fluctuation and market manipulation. We find procedures settled by a single price undergo greater fluctuations than those settled by an average price. There is a striking case of fluctuating 290.91 index points (nearly 4% index value) within a 15-minute interval in the market with a 7% daily fluctuation limit.

In this study, we find that changes in settlement procedures result in a more efficient price on settlement day than on regular days, depending on the specific type of settlement procedure. The period settled by a single price over a longer time interval (referred to as the special opening quotation) produces the most efficient opening price on settlement day, whereas the period settled by an arithmetic method results in a more efficient closing price. Our results consistently support the hypothesis that market efficiency is higher at the opening of a trading day than at the close and indicate that FSP determined by a single price reduces market efficiency the least, leading to the argument that manipulation prevention using average prices comes at the expense of market efficiency. We examine whether short liquidity at the expiration of index derivatives is associated with the nature of the settlement procedure and find that liquidity is shorter when FSP is calculated using an average price. The results imply that manipulation prevention using an average price instead of a single price for settlement exacerbates liquidity. Finally, we investigate price discovery during different intervals of a trading day (pre-opening, opening, closing, and mid-day) and during different settlement procedure regimes. Because FSP determined by a price at a given time point is manipulated more easily than a price determined by a longer period of time, we find the price discovery of the former is lower. Although FSP determined by an average price relative to a single price could potentially reduce price manipulation, this average-price type of settlement procedure avoids price discovery exaggeration on settlement day. In summary, manipulation-proofing settlement procedures aggravate market quality represented by market efficiency, liquidity, and price discovery. The central findings of this study have implications for settlement procedures around the world and beyond the Taiwan equity market.

The remainder of this paper is organized as follows. In Section 2, we review the literature. In Section 3, we report our data and discuss the evolution of settlement mechanisms in Taiwan. In Section 4, we report and interpret volatility, trading volume, and other trading activities at the opening and the close of settlement day, expiration day, and regular days, and then classify by settlement procedure. Additionally, a model is employed to examine the effect of changes in the settlement procedure on market trading activities, including liquidity. In Section 5, we determine how the nature of the settlement procedure can affect market efficiency and price discovery at different times of the day. Finally, we summarize the conclusions of the study in Section 6.

## 2. Literature Review

Literature focusing on the existence of expiration-day effects gives significant attention to comparisons of the settlement mechanisms. These studies include, for example, Feinstein and Goetzmann (1988), Herbst and Maberly (1990), Stoll and Whaley (1990b, 1991, 1997), Chung and Hseu (2008), and Hsieh and Ma (2009). Stoll and Whaley (1991) claim that after adopting a new settlement procedure, which moved the settling of the S&P 500 and NYSE index futures and options contracts from the close to the opening of the third Friday, anomalies decreased moderately, and the anomalistic difference between the S&P 500 index stocks and non-index stocks became trivial.

The earliest settlement rules in Taiwan involved only a single price at the opening. Derivatives traded in the US market settling at a single price include the S&P 100 index options, which are settled at the closing, and the S&P 500 index futures, which are settled at the opening price. To calculate the final settlement price (FSP), the Taiwan Stock Exchange substitutes the previous day's closing price for the current price if transactions involving the component stocks are not recorded immediately at the opening. Chow, Yung and Zhang (2003) suggest that determining the FSP using an average price over a longer time interval rather than by a single price at a single point in time better mitigates expiration-day effects and prevents the market from price manipulation. Alkeback and Hagelin (2004) support Chow, Yung and Zhang (2003) using Swedish market data. The FSP of the Swedish OMX index futures are set to the average of the volume-weighted index values on the last trading day.

Financial markets adopting volume-weighted price to determine the FSP generally settle at the close. Taiwan adopted the volume-weighted price of each component stock for determining FSP between 2001 and 2008, but Taiwan was unique in settling at the opening. However, the opening settlement mechanism may reflect the fact that expiration-day trading is split between the opening and the close. Herbst and Maberly (1990) first described that a change in settlement procedure moving settlement from the close of trading to the opening moves high volatility from only the last hour of the last trading day to the first hour of the next day. The authors thus conclude that the change in settlement procedure is ineffective. Stoll (1988) also claims that modifications of expiration-day procedures cannot eliminate the price effect stemming from the imbalances in a large number of stocks. Similarly, Stoll and Whaley (1991) find that quarterly trading activity and price volatility were smaller at the close than at the opening after moving settlement from the close to the opening in June 1987. They also find that trading volume and price reversals increased significantly at the opening, and the price effect at the opening was somewhat smaller than it had been at the close prior to June 1987[3].

[3] Prior to June 1987, all index futures and options contracts expired at the close of trading on the third Friday of the contract month. Since June 1987, the S&P 100, MMI, and Value Line futures and options have continued to expire and settle at the close of trading, but the S&P 500 and NYSE index contracts settle at the opening of the third Friday and expire on the Thursday preceding the third Friday for quarterly expirations. Monthly expirations for the S&P 500 and NYSE index contracts are still settled at the close of trading on the third

The settlement of index derivatives in the Taiwan market causes the underlying stock market to incur abnormal returns, return volatility, volume, and price reversals. Lin and Ku (2008) document that Taiwan spot indices (e.g., TAIEX, Taiwan 50 and Taiwan mid-cap 100) generate a significant increase in trading volume and return volatility during the last 30 minutes of a trading day when MSCI TW futures contracts expire. They also find that the Taiwan stock market index takes approximately 30 minutes to react to information resulting from the expiration of MSCI TW futures, but it takes longer to react to the expiration of TAIEX futures. Such a finding suggests that a settlement period longer than 30 minutes may be necessary to ease the expiration-day anomalies. These outcomes confirm that settlement of TAIEX futures using an average price calculated by a longer time interval would mitigate expiration-day effects better than settlement of MSCI TW futures depending on a single closing price.

## 3. Market Data and Settlement Mechanisms

### 3.1 Data

The data used in this study come from two sources: (1) the TAIEX provided by the Taiwan Stock Exchange (TWSE) and (2) TAIEX futures from the beginning of their compilation on July 21, 1998, provided by the Taiwan Futures Exchange (TAIFEX). The TAIEX covers all stocks (except preferred stocks, full-delivery stocks, and newly listed stocks) that have been listed in the exchange for at least one month. The equity and futures exchanges in Taiwan are open electronic limit order book (OELOB) markets. This type of market dispenses with officially designated market makers[4] for all stocks traded on the TWSE, as well as futures contracts traded on the TAIFEX, and it allows people to directly

Friday of the contract month.

[4] Market makers play a vital role in dealing with small-cap, illiquid stocks, but computerized order matching is the best way to deal with higher volume markets.

trade against one another.

During the regular trading sessions from 9:00 a.m. to 1:30 p.m.[5], buy and sell orders can interact to determine the executed price, subject to applicable automated matching rules. Orders can be entered half an hour before the trading session starts at 9:00 a.m. At the end of the session, orders are accumulated over the last five minutes (from 1:25 p.m. to 1:30 p.m.), before the closing call auction. The futures are executed similarly, except that their trading opens 15 minutes earlier and closes 15 minutes later than for stocks. The opening price for the two markets is the price at which the maximum number of bids and asks can be matched. Order and trade information are disseminated to the public on a real-time basis. All brokers are directly connected to the electronic trading system.

To maintain a stable market, the daily price fluctuation limits of both stocks and futures are set at 7% of the closing price of the preceding business day. However, the range for both markets is occasionally adjusted based on market performance. The order limit for stocks is 500 units, with a standard unit being 1000 shares. The order limit for futures is 100 contracts (contract value equals NT$200 times TAIEX index points). The futures are not on a quarterly expiration cycle; instead, the two closest monthly contracts (spot month, next calendar month) plus the three next quarterly contracts, for a total of five, are traded at a time. To examine the equity market's liquidity and volatility, we employ trading data with a one minute interval from July 21, 1998 to November 28, 2014. There were 1,911,842 intraday trades[6] and 4,112 daily trades during the sample period.

### 3.2 World-wide settlement procedures

Final settlement procedures around the world are diverse. Table 1 summarizes the

[5] Each trading day begins with the opening of the TWSE at 9:00 a.m. For the sample period before January 2, 2001, it ended at 12:00 p.m., but after that it ended at 1:30 p.m. Before February 20, 1999, the TAIEX index value was reported every five minutes; since then it has been reported every minute and currently every 15 seconds. In contrast, futures prices are reported as soon as a new transaction occurs.

[6] TWSE reports the index value every 15 seconds, changed from per minute since January 2, 2011 and every five minutes before February 20, 1999.

world-wide settlement procedures for two settlement times: Type A, settlement day is the day after expiration day; and Type B, settlement day is the same as expiration day. Most nations that choose Type A; such as the US, Japan, and Australia, select the opening price rather than the closing price as the final settlement price (FSP). Only a few countries, such as Korea, Brazil and Singapore, settle at the closing price because this settlement procedure tends to result in large orders, order imbalances, and price manipulation. Most nations that choose Type B, such as Singapore, India, Turkey, Brazil, South Africa, Sweden, Poland, Russia, Spain, and Hong Kong, select an average price rather than a single price as the FSP. The Euro countries are inclined to settle index derivatives at an average price. TAIEX derivatives have used these two settlement options since their launch. Few financial markets adopt the volume-/value-weighted average price as the FSP. In all, settlement procedures all over the world are split into two groups: one focuses on market efficiency; the other focuses on manipulation prevention. All the financial markets settling at the opening incline to settle by SOQ (special opening quotation), whereas those taking the arithmetic average price as FSP are apt to settle at the close. The markets implementing SOQ attempt to focus on market efficiency; those adopting the average price tend to focus on manipulation prevention. The evidence signals a trade-off between market efficiency and manipulation prevention.

**3.3 The evolution of settlement procedures in Taiwan**

In financial derivatives markets, settlement price is determined by one of the following: the closing price, the opening price, or the average price. Currently, expiring TAIEX futures and options contracts are settled at the close of trading on the third Wednesday of the contract month, whereas they were previously settled at the opening of the third Thursday. Whether to use the opening or closing price in contract settlement depends on the desire that the buying and selling interests be representative of the market’s true condition and not be unduly influenced by the expiration itself. The decision for using opening or closing prices has two elements: one is market depth, and the other is market integrity. If settlement of contracts is at the close, the sale of stocks as part of large index arbitrage unwinding can put pressure on stock price because there is insufficient time to locate the other side of the trade. Comparing the average with a single price, the average price is used on the ground that it is more difficult to influence an average price than a single price; hence, it is more manipulation proof. From the perspective of hedgers and arbitrageurs, however, an average price is less desirable than a single price because it introduces basis risk.

TAIFEX detects a high index-value fluctuation in the stock market when index derivatives are settled and considers changes in settlement procedures necessary. Over the past decade, the TAIEX futures and options have gone through four changes in settlement procedures, which are briefly described in the following.

*3.3.1 Settlement procedure 905/901*

The TAIEX futures and options contracts were first settled on the published index value at 9:05 on the third Thursday, the next opening of the last trading day, referred to as 905. In the second quarter of 1999, the settlement procedure was amended to settle on the index value at 9:01 on the third Thursday due to the increase of display frequency from every five minutes to every one minute. This settlement procedure is referred to as 901. Settling index derivatives at a single price observed at a given point in time, however, can potentially cause acute demand shock in the spot market and tend to create a large order imbalance because of the unwinding operations of index arbitrageurs. TAIFEX observed some stocks did not open when the market was settled by 905 or 901. The opening rate for component stocks of TAIEX on settlement day reached 75.35% (91.86%, 94.77%, 96.56%) one minute (five minutes, fifteen minutes, thirty minutes) after the market opens and 99.60% for the whole day. Nonetheless, speculators may concentrate on only the subset of stocks that they believe have the greatest impact on the index. To enhance execution efficiency, arbitrageurs can construct a replicate portfolio that includes a subset of stocks, perhaps the largest in the index portfolio.

*3.3.2 Settlement procedure SOQ*

Because a longer settlement time interval may be better for mitigating expiration-day effects and reducing price manipulation, a settlement procedure called Special Opening Quotation (SOQ), which calculates FSP within a 15-minute settlement period replaced 905/901 in May 1999. Relative to 905/901, which settles contracts at a single time point, SOQ settles at a single price with a longer settlement period (15 minutes). In this case, FSP is calculated using the normal index calculation procedure, except that the value of the respective component is the actual opening price of each of the component equities. Because real-time trade data at the tick level are publicly available for all index stocks, the FSP resulting from this settlement procedure can be known a priori, which means the final settlement price can be manipulated.

*3.3.3 Settlement procedure VWA*

To further reduce the chances of manipulating FSP, the Taiwan Futures Exchange (TAIFEX) introduced a new settlement procedure at the end of 2001. With this procedure, referred to as VWA (volume-weighted average price), FSP is computed using the standard index calculation procedure with the volume-weighted price of each component stock. The volume-weighted price of each component stock is calculated by all trades during the opening 15 minutes to obtain an average price. There is no artificial adjustment after calculation of the FSP. VWA, like other average-price settlement mechanisms, engenders a basis risk because proceeds from the liquidation activities of an index arbitrageur cannot replicate the settlement price exactly. Although arbitrageurs can minimize this risk by spreading out liquidation trades over multiple expiration periods, this method has the undesirable side effect of creating temporary order imbalances, thereby increasing volatility in the spot market. Although the VWA settlement procedure discourages speculators and favors hedgers, hedgers in the Taiwan market make up only a small percentage of the trader pool.

*3.3.4 Settlement procedure 26IA*

Prior to December 2008, stock index futures and options contracts expired at the close of trading on the third Wednesday of the contract month and were settled at the opening of the next trading day. Since then, trading ends and the settlement occurs on the same day, the third Wednesday of the contract month, hence moving the FSP from opening to closing. The settlement period has been extended from 15 to 30 minutes because extending the settlement period for calculating FSP may reduce the possibility of manipulation and increase the capability to react to information resulting from the expiration of TAIEX derivatives. Settling at the close can lower over-night risk and enforce the efficiency of fund usage because margins can be unlocked upon the expiration of contracts. After adoption of the 5-minute closing call procedure in the underlying stock market on July 1, 2002, the disclosed frequency of index value reduced to 26 times within the 30 minutes settlement period (25 times on a minute basis plus the last 5 minutes). The calculation of FSP simply uses the arithmetic average of the underlying 26 cash index values (26IA henceforth); [7] hence, the FSP is more transparent and can be computed easily.

## 3.4 Summary

The four changes in the TAIFEX settlement procedures are summarized in Table 2.

[7] In January 2011, TWSE changed the frequency of displaying TAIEX trading information from every minute to every 15 seconds, denoted by 15SEC; thus, the index value displays 101 times during the last 30 minutes. This settlement procedure determines the FSP as a simple arithmetic average of the underlying 101 cash index values. Because this period changes only the frequency of information display, we do not consider it a settlement procedure change.

In essence, through these four exogenous procedure changes, we can study the pros and cons of a single time-point-price vs. a longer-period-price FSP; opening-price vs. closing-price FSP; single-price vs. average-price FSP, and non-weighted average-price vs. volume-weighted average-price FSP. Using a single country's data to study the changes minimizes institutional and investor clientele differences, which occur in cross-country comparisons.

In the last column of Table 2, we provide preliminary statistics that show the average TAIEX volatility over the four settlement regimes. We report those fluctuating over one hundred index points during the settlement period of each regime. The mean index point fluctuations is approximately 77.21 index points (1.13% index value) in 905/901, 99.78 index points (1.57% index value) in SOQ, 70.00 index points (1.12% index value) in VWA, and 59.93 index points (0.88% index value) in 26IA on settlement day. We find the single-price type of settlement procedures, 905/901 and SOQ, have more volatile fluctuations than do the average-price type of settlement procedures, VWA and 26 IA. Not shown in the table, the most serious fluctuation occurred in the SOQ regime, with a fluctuation of 290.91 index points (approximately 4% index value). For a market limited to a 7% fluctuation per day, the evidence is strikingly significant.

## 4. Preliminary Results of Expiration-Day Effects

### 4.1 Data and variables

In this section, we explore the expiration-day effects on volatility, price reversal, and more importantly, stock market liquidity. We use three liquidity proxies to examine the liquidity effects. We conjecture that there might be a particularly high demand for liquidity on settlement-/expiration-day and these demands occur simultaneously for a large number of stocks rather than for a single stock. If the underlying market for these index stocks is deep and suppliers of liquidity are quick to respond to selling or buying pressure, the liquidity effect of large arbitrage unwinding will be small. However, if large orders are received late in the day and traders who take the other side are difficult to locate, liquidity effects are possible.

The first measure of liquidity is market depth, defined as the ability of a market to absorb large quantities of trading without having a large effect on price. Bessembinder and Seguin (1992) document that expiration-day effects have implications on market depth. Kyle (1985) suggests that market depth is the order flow required to move prices by one unit. To align with our data, Kyle's formula is modified as

$$Depth = \frac{\sum DVol_{\min}}{\sum |\Delta Index|}, \tag{1}$$

where market depth denotes the dollar order flow required to move prices by one unit.

The second measure is illiquidity, adapted from Amihud (2002). Illiquidity is formally defined as the average ratio of daily absolute return to dollar trading volume during a given interval:

$$ILiq_{di} = \frac{\frac{1}{D_d}\sum_{i=1}^{D_d} |R_{di}|}{VOLD_{di}}, \tag{2}$$

where $R_{di}$ is the TAIEX return during interval $i$ of day $d$, $VOLD_{di}$ is the corresponding dollar volume during interval $i$, and $D_d$ is the number of intervals on day $d$. This measure is the average per-interval association between per unit volume and price change; as such, it combines the expiration effect (high trading volume) and price effect. This ratio was devised originally as a measure of the daily price impact of order flow. Harris and Raviv (1993) interpret *ILiq* as a measure of the investors' consensus belief about new information[8].

The third liquidity proxy is the number of shares traded per minute *Qmin*. The rationale of this proxy is described by equation (1) in Stoll (2000).

In addition to liquidity proxies, we also examine the expiration effect on volatility

[8] When investors agree about the implication of news, stock prices change with no trading, whereas disagreement increases trading.

(*Std*), measured by the standard deviation of stock index returns; on order imbalance (|OIB|) measured by bid orders minus ask orders on a one-minute basis; and on the reversal of stock price (*REV*). The price reversal formulas used in this study are similar in spirit to those in Stoll and Whaley (1991), that is, the price reversal $REV_i$ is positive (zero) when the sign of the return after expiration is the opposite of (same as) the sign of the return before expiration. Price reversals for settlement at Thursday opening are calculated based on the TAIEX returns from Wednesday close to Thursday opening and from Thursday opening to 15 minutes after opening. For settlements at Wednesday close, price reversals are calculated based on the TAIEX returns during the last 30 minutes on expiration Wednesday and on returns from the close of expiration Wednesday to the opening of the following Thursday. Price reversal thus measures price informativeness. Price reversal is not likely if the closing price reflects all public information. Price reversal often follows price manipulations.

Our sample contains 9 expirations for 905/901, 29 for SOQ, 85 for VWA, and 25 for 26IA. The data used in this study are on a one-minute basis. We divide all trading days into three categories (settlement days, expiration days, and regular days), and each trading day is divided into three time intervals (opening, closing, and the rest of a trading day) for all tests. Regular days are defined as non-expiration days and non-settlement days. Settlement day, expiration day, and regular days are labeled as *s, e*, and *g, respectively*, whereas the opening, the closing, and the rest of a trading day are labeled as *o, c,* and *d, respectively*. To calculate a final settlement price, an opening and a closing interval is determined using prices in a 15-minute interval before 26IA and 30-minute interval afterward. For example, *go* and *gc* (*eo* and *ec*, *so* and *sc*) denote the first and last 15 minutes of trading on regular days (expiration day, settlement day) prior to the adoption of 26IA and the first and last 30 minutes of trading after the adoption of 26IA.

### 4.2 Market opening and closing effects

Because the expiration effect can be confounded by both the open-close effect and the settlement effect, in Panel A of Table 3, we provide preliminary statistics of the expiration-day effects by taking into account both the time dimension and the settlement-procedure dimension. In this subsection, we first examine the market open-close effect, and the settlement effect is discussed in the next subsection. The table shows the expiration-day effects from the prospect of the volatility of stock index returns (*Std*), the number of shares traded per minute (*Qmin*), the reversal of stock index price (*REV*), the illiquidity of the stock index (*ILiq*), market depth (*Depth*), and absolute order imbalance (|*OIB*|) during trading intervals *so, go, ec* and *gc*. Trading is found to be anomalous rather than normal only for the volatility and liquidity measures, which does not completely conform to expiration-day literature.

Nevertheless, we observe that volatility is consistently higher at market opening than at market close across the entire sample period (e.g., $\mathrm{Std}^{so} = 0.0138 > \mathrm{Std}^{ec} = 0.0006$). Such evidence confirms the findings of Amihud and Mendelson (1987), Stoll and Whaley (1990c), and Stoll (2000) that volatility is normally higher at the opening than at the close. The liquidity measures, represented by *Qmin* and *ILiq,* are higher, *and Depth* is lower during the opening interval of settlement day (*so*) than during the same interval of regular days (*go*). Our results also indicate that price reversals are higher at the open/close on settlement/expiration day than on regular days (e.g., $REV^{ec}$ vs. $REV^{gc}$), with stronger results found at the close rather than at the opening. Moreover, the share volume of the underlying stock market during the opening (closing) interval on settlement (expiration) day is 1.07 (1.06) times the normal volume during the same interval on regular days, but the difference between settlement (expiration) day and regular days reduces (increases) after moving settlement from the opening to the close, indicating that the settlement of index derivatives contracts creates excess trading volume on constituent index stocks. The higher trading volume at the opening contradicts Hsieh and Ma (2009)[9], who report that settling at the closing price is associated with a larger volume than settling at the opening price or average price.

Furthermore, most activities are consistently higher at the opening than at the close on any trading day, regardless of the settlement procedure. Although this preliminary evidence suggests that volume, price effects, liquidity, and order imbalance attributable to the expiration of index derivatives are not trivial, there is an appreciable difference only in volatility and liquidity measures between settlement day/expiration day and regular days with a stronger effect at the opening than at the close. Unlike the expiration-day effect, evidence (so-ec) highlights that there is a strong time interval effect (opening vs. close), and the argument for/against settling contracts at the close instead of at the opening should consider such effect.

### 4.3 Settlement procedure effects

To compare the effects of different settlement procedures, we examine the same trading activities as in Section 4.2. Generally, the effects of the settlement-procedure dimension are less obvious than those of the time-interval dimension and are therefore suppressed from Panel A. In Figures 1-A to 1-E, rolling window charts show abrupt patterns observed in the data. The patterns in the graphs are consistent with an expiration-day-effect hypothesis, except the price-reversal graph, and reaffirm the findings in Panel A.[10] To investigate whether there is excess/short liquidity in the underlying stock market at the expiration of TAIEX derivatives, we examine the frequency, duration and conditional probability of short liquidity during the opening interval on settlement day (*so*) and during the closing interval on expiration day (*ec*).

[9] Using a ratio defined as the trading volume within a certain period divided by the trading volume on the entire expiration day, Hsieh and Ma (2009) find the trading volume on expiration days to be concentrated in the last five minutes.

[10] There is a break in the post-26IA regime, which results from no trades on January 22, 2009 due to the Chinese New Year holiday.

To examine whether short liquidity is associated with settlement procedure and trading period, we introduce the following model from Berenson, Levine and Goldstein (1983) to calculate the conditional probability of short liquidity:

$$\ln m_{ijk} = \mu + \mu_{A(i)} + \mu_{B(j)} + \mu_{C(k)} + \mu_{AB(ij)} + \mu_{AC(ik)} + \mu_{BC(jk)} + \mu_{ABC(ijk)}, \quad (3)$$

where $\ln m_{ijk}$ represents the natural logarithm of the expected frequency in category *ijk*; $\mu_{A(i)}$ represents the settlement-procedure period, with $i$ = 905/901, SOQ, VWA, or 26IA; $\mu_{B(j)}$ represents the trading period within the trading day, with $j$ = opening, closing, or the rest of the day; $\mu_{C(k)}$ represents the level of liquidity, with $k$ = excessive or short; $\mu_{AB(ij)}$ is the interaction between $\mu_{A(i)}$ and $\mu_{B(j)}$; $\mu_{AC(ik)}$ is the interaction between $\mu_{A(i)}$ and $\mu_{C(k)}$; and $\mu_{BC(jk)}$ is the interaction between $\mu_{B(j)}$ and $\mu_{C(k)}$. Because short liquidity is more important to expiration-day effects than excess liquidity, Panel B of Table 3 reports only conditional probabilities for the short-liquidity periods during the opening and the closing intervals of a trading day. If a conditional probability is not equal to 0.5, we can conclude that short liquidity is related to the settlement procedure and the trading period. The farther the conditional probability departs from 0.5, the greater its association with the settlement procedure and trading period. The results indicate that short liquidity is associated with the settlement procedure and trading period. Panel B reveals that liquidity is shorter during the opening interval on settlement day than during the closing interval on expiration day.

Panel C shows there are generally more periods with short liquidity during the opening interval on settlement day than during the closing interval on expiration day. The frequency of short (excess) liquidity is defined as the number of minutes during which liquidity is lower (higher) than normal divided by the total number of minutes in the interval. The duration of short liquidity is defined as the difference in minutes between two adjoining periods of short liquidity. If the settlement of index futures and options contracts causes a short-liquidity syndrome, the amount of time that liquidity is short is longer and the duration between two adjoining short liquidity periods is shorter in *so* than in *ec*. The results confirm a larger percentage and longer time period of short liquidity in *so* than in *ec*.

Maniar, Bhatt, and Maniyar (2009) claim that the average-price settlement mechanisms engender a basis risk and result in a temporary short liquidity. Our results show only weak evidence of larger short liquidity for regimes that calculate FSP using average price.[11] Specifically, *Qmin* generally indicates that short liquidity declines after the settlement procedures changed to average-price FSP. Although the other two short liquidity measures, *Depth* and *Iliq*, do not show such a pattern, the worse liquidity in *ec* after the settlement procedure changed from VWA (settles at the opening) to 26IA (settles at the close) provides some evidence that the settlement of index futures and options contracts contributes to a short liquidity. This result indicates that manipulation prevention occurs at the expense of market liquidity.

### 4.4 Sources of expiration-day effects

Whereas Sections 4.2 and 4.3 provide preliminary statistics, in this section, we use a regression model to further examine the expiration effects. As indicated in the previous discussions, expiration effects can be muddied by the time interval effect and settlement procedure effect; therefore, our regression model specifically takes into account intraday seasonality, trading spill, and trading splits between opening and closing. The argument about whether derivative contracts should be settled at the opening or the close is equivalent to the argument about whether the expiration day should be the same as the settlement day. The latter argument is important if expiration-day trading splits between opening and close. Therefore, to examine the expiration-day effect that also considers the hypothesis proposed

[11] Index option was introduced on December 24, 2001, and VWA was conducted on November 22, 2001. There might be a confounding effect during this period.

by Herst and Maberly (1990) and Stoll and Whaley (1991) that a change in the settlement procedure moves only the expiration trading at the close of the last trading day to the opening at the next day, we construct the regression model in Equation (4). Equation (4) decomposes the sources of expiration-day effects into the settlement procedure effect, intraday seasonality effect, and spillover effect.

$$Dep^{so} = \alpha_0^{so} + \alpha_1 Dep^{go} + \alpha_2 Dep^{ec} + \sum_{i=1}^{3} \alpha_{i+2} Sr_i + \sum_{i=1}^{3} \alpha_{i+5} Dep^{ec} * Sr_i + \varepsilon^{so}, \qquad (4)$$

In Equation (4), $Dep^{so}$ is the dependent variable during time interval $so$ (i.e., opening on settlement day). $Dep$ represents the trading activities, including volatility $Std$ (using ABDL's return volatility $Sigmasq$ proposed by Andersen, Bollerslev, Diebold and Labys (2001) yields a similar result); liquidity, denoted by three proxies $Q_{\min}, Depth, ILiq$ ; and price reversal $Rev$. The independent variables include the same trading activity during the opening interval on regular days $Dep^{go}$ , the same trading activity during the closing interval on expiration day $Dep^{ec}$ , dummy variables $Sr_1$ , $Sr_2$ and $Sr_3$ , and three interaction terms, $Dep^{ec} * Sr_1$, $Dep^{ec} * Sr_2$, and $Dep^{ec} * Sr_3$. $Sr_i$ ($i$ = 1, 2, 3) denotes a dummy variable that takes a value of one when TAIEX futures and options are settled by 905/901, SOQ, or VWA and zero otherwise; 26IA is the reference group because 905/901, SOQ and VWA all settle at the opening, whereas 26IA settles at the closing. Hence, $Dep^{go}$ serves as a proxy for the lagged term of the dependent variable within the contract month to control for the persistent time-varying opening components of the trading activity and contract-wise effects. In Equation (4), therefore, the link between the independent variable $Std^{go}$ and the dependent variable $Std^{so}$ measures the intraday seasonality effect on settlement day, whereas the link between the independent variable $Std^{ec}$ and the dependent variable $Std^{so}$ measures the spillover effect from the closing interval on expiration day to the opening on settlement day, which addresses the argument in Stoll and Whaley (1991) that expiration-day trading may split between the market's opening and close. The dummy variables $Sr_i$ ($i$ = 1, 2, 3) are adopted to control for the effect of changes in settlement procedures. The interaction terms thus examine whether the argument of Stoll and Whaley (1991) is settlement procedure-dependent. $Sr_i$ and the intercept together measure the settlement effect.

Table 4 presents the results of a paired time-series regression for volatility (*Std*), share volume per minute (Qmin), and price reversal (Rev) at the opening on settlement day. The coefficient of $Dep^{go}$ measures the intraday seasonality effect. $Std^{so}$ is positive and significant at the 1% level, and $Qmin^{so}$ is also positive and statistically significant at the 1% level, suggesting a strong intraday seasonality effect. Although not shown in Table 4, the three liquidity measures discussed in Section 4.1 also confirm the intraday seasonality effect on settlement day. There is some evidence of the spillover effect, as measured by the coefficient of $Dep^{ec}$. The coefficients of $Dep^{ec}$ in the *Std*, *Qmin,* and *REV* equations are all significant at the 1% level.

Of the settlement procedures, 26IA has the strongest spillover effect[12] because the coefficients of $Dep^{ec}*Sr_i$ ($i$ =1, 2, 3) are significantly negative in all three models. 905/901 is different from the other three procedures because the coefficients of $Dep^{ec}* Sr_1$ are significant in all three models. The more significant the coefficients of $Dep^{ec}*Sr_i$, the more procedure-dependent the spillover effect is. Taking the volatility model as an example, the closing volatility $Std^{ec}$ is found to provide significant explanatory power (at the 1% significance level) to the opening volatility on settlement day $Std^{so}$ under the 905/901 settlement procedure. The statistical significance of the interaction terms $REV^{ec}*Sr_1$ and $REV^{ec}*Sr_2$ (at 5% level) and $REV^{ec}*Sr_3$ (at 1% level) indicates that the expiration-day price reversal splitting between the opening and the close on settlement day is associated with the nature of the settlement procedure. Overall, the more significant the coefficients of the interaction terms $Dep^{ec}*Sr_i$ ($i$ =1, 2, 3), the greater the difference between the effect due to opening settlement and closing settlement and also the more effective the changes in the settlement

[12] The spillover effect of 26IA is intercept +0*(-0.761 ) +0*(-0.290)+0*(-0.352) = intercept; the spillover effect of 905/901 is intercept + 1*(-0.761)+0*(-0.290)+0* (-0.352) = Intercept -0.761.

procedure to mitigate expiration-day effects. Therefore, Stoll and Whaley's (1991) hypothesis does not hold. A robustness check using pooled time-series regressions yields similar conclusions.

Because missing factors may affect volatility, share volume, and price reversal, in Panel B of Table 4, we repeat the test using a seemingly unrelated regression (SUR) approach. We regress these three variables on a set of independent variables in a system of equations assuming the variance-covariance matrix contains cross-correlations, which is deemed more efficient. The independent variables are exactly the same as in each individual equation in Panel A. The purpose of running SUR is that the residuals in the volume equation may be correlated with those in the volatility equation, which is likely because residuals measure the effect of omitted variables and such variables may affect both the volume and the volatility. Karolyi (1996) shows that although expiration days exhibit higher-than-average trading volume, the intraday return volatility in the last hours of trading on expiration days and the first hours of trading following expirations of Japanese stock index futures and options contracts are only marginally greater than on other days. The results of Panel B show similar results as in Panel A.

## 5. The quality of the stock market

In this section, we turn our attention to examining the expiration impact of TAIEX futures and options contracts on market efficiency and price discovery in the spot market. Whether the type of settlement procedure affects such impact is also investigated.

### 5.1 Market efficiency

Different exchanges have different mechanisms to determine opening price. The opening mechanism of an exchange is important because it is used to determine prices when uncertainty about fundamental values is particularly high after an extended non-trading period. Because derivatives in the Taiwan market tended to be settled mostly using the opening price until December 2008, the efficiency of the opening price is nontrivial. The primary focus in this section is to explore whether a specific type of settlement procedure affects the price efficiency and whether it is more efficient for index futures and options contracts to settle at the opening than at the close. Beginning at 9:00 a.m., the TWSE operates an opening call auction for each listed stock. At 8:30 a.m., investors can submit market or limit orders electronically. To test the extent to which security prices reflect noise or information, Biais, Hillion, and Spatt (1999) propose a regression framework that they refer to as "unbiasedness regressions." Close-to-close return is regressed on close-to-open return, with the model

$$Ret_{cc} = \alpha + \beta * Ret_{co} + \varepsilon \ . \tag{5}$$

To measure the effect of settlement type on market efficiency, we modify the model as

$$Ret_{cc} = \alpha + \beta_1 Ret_{jk} + \sum_{i=1}^{3} \beta_{i+1} Sr_i + \sum_{i=1}^{3} \beta_{i+4} Sr_i * Ret_{jk} + \varepsilon_{jk} \tag{6}$$

The dependent variable $Ret_{cc}$ is the TAIEX return from close to close. The independent variable $Ret_{jk}$ is the TAIEX return of each intraday trading time period, e.g., $Ret_{co}$ refers to the TAIEX return from close to open. As in the previous section, the three dummy variables $Sr_1$ , $Sr_2$ , and $Sr_3$ denote the settlement regimes to capture the changes in the settlement procedures of 905/901, SOQ, and VWA, with SOQ being the reference group.

The slope coefficient $\beta_1$ in the regression is commonly interpreted as a signal-to-noise ratio[13]. If index returns are serially uncorrelated and measured without error, the slope

[13] Regressing $ret_{cc}$ on $ret_{co}$ using ordinary least squares produces slope coefficient b, and $p\lim b = \beta(\frac{\sigma^2_{RET_{co}}}{\sigma^2_{RET_{co}} + \sigma^2_u})$ . The term in parentheses is the signal-to-noise ratio, where $\sigma^2_{RET_{co}}$ is the

coefficient in the unbiasedness regression would equal one. In Table 5, Panel A reports the market efficiency of the pre-opening period (from the previous close to the opening), Panel B shows the opening period (from 9:00 to 9:15 or 9:00 to 9:30), Panel C presents the closing period (the last 15 or 30 minutes before closing), and Panel D is the mid-day trading period (daytime, excluding the opening and closing intervals) for the settlement day, expiration day, and regular days. The pre-opening period provides traders with an important time lag to evaluate overnight information and incorporate the information into stock prices more quickly upon the commencement of trading.

We first compare the efficiency of settlement day, expiration day, and regular days. Panel A shows that pre-opening prices are generally more efficient on settlement day than on expiration day and are likewise more efficient on regular days than on expiration day because the market efficiency of the pre-opening prices, as indicated by the sum of the coefficients of $Ret_{co}$ and $Ret_{co}*Sr_i$, is greater on settlement day than on regular days and is also greater on settlement day than on expiration day. This result supports the hypothesis that settlement of index derivatives improves market efficiency in the spot market.

In Panel B, where opening efficiency is examined, a different pattern is observed, i.e., the opening prices are not less efficient on expiration day than on regular days and are not always higher on settlement day than on expiration day. The results are inconsistent with the findings in Barclay, Hendershott, and Jones (2008) that opening prices on witching day are less efficient than normal opening prices. Therefore, our findings are settlement procedure-dependent. In Panel C, the pattern differs from that in Panel A. Closing prices are more efficient on expiration day than on regular days among all regimes, and they are also higher on regular days than on settlement day, continuing to support the conclusion that maturation

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information obtained from the close to the open and $\sigma_u^2$ is the noise in the opening price. Although the signal and noise components cannot be measured separately with this technique, the extent to which b is less than one allows us to infer the signal-to-noise ratio. Noise in market prices can be related to microstructure effects (e.g., bid-ask spreads) or temporary pricing errors.

of index futures and options increases the efficiency of the underlying stock market. In Panel D, where mid-day trading efficiency is examined, the mid-day efficiency on settlement day is higher than on regular days and expiration day, although it is somewhat lower on expiration day, regardless of whether opening- or closing-price settlement is used. The results generally support the notion that market efficiency in the stock market is affected by the expiration and settlement of index futures and options contracts.

We next focus on the impact of the settlement procedure on the price efficiency in different time periods of a trading day. To this end, we examine interaction terms $Ret*Sr_1$, $Ret*Sr_2$, and $Ret*Sr_3$ that indicate which settlement procedure contributes the greatest market efficiency. In Panel A, the settlement procedures are generally not associated with pre-opening efficiency on settlement day. The coefficients of the interaction terms are statistically insignificant for settlement procedures 905/901 and 26IA, except VWA with a 9% significance level. The result suggests market efficiency is indifferent between SOQ and the other settlement regimes, but it is weakly lower in the VWA regime, whose FSP is calculated by an average price. The literature suggests that FSP calculated by an average method prevents market manipulation. Because a volume-weighted FSP prevents manipulation better than an arithmetic-average FSP, this outcome lends support to the argument that the greater the manipulation prevention, the less efficient the prices.

Panel B shows that on settlement day, the opening price has the highest efficiency when SOQ is operative but becomes less efficient when 905/901, 26IA, and VWA are used. The opening efficiency in the 905/901 regime, denoted by the coefficient of $Ret_{o1}*Sr_1$, decreases by 18 basis points (significant at the 5% level) relative to SOQ because a single price at a single point in time was used to compute FSP on settlement day. This result is consistent with Chow, Yung and Zhang (2003), who find that determining the FSP using an average price over a longer time interval rather than by a single price at a single point in time better mitigates the expiration-day effects and prevents the market from price manipulation.

Likewise, the opening efficiency decreases significantly in the 26IA (VWA) regime, as denoted by the coefficient of $Ret_{o1}*Sr_3$ $(Ret_{o1}*Sr_2)$. The decrease of 27 (44) basis points is significant at the 1% level relative to SOQ due to the use of a volume-weighted arithmetic-average FSP. This result supports the argument that the greater the manipulation prevention, the less efficient the prices.

In Panel C, the closing efficiency is statistically significant at the 1% level on expiration day in all settlement regimes, which indicates that settling by SOQ produces no higher closing efficiency than the other settlement procedures. In Panel D, the coefficient of interaction term associated with mid-day efficiency on settlement day, $Ret_{12}*Sr_1$, is insignificant, but $Ret_{12}*Sr_2$ and $Ret_{12}*Sr_3$ are statistically significant at the 5% level. We can conclude that 905/901 presents no better or worse mid-day price efficiency than SOQ, but 26IA and VWA produce less efficiency than SOQ. The evidence indicates that the 15 minute sample period for 905/901 is sufficient for the market to react to the information resulting from the expiration of TAIEX futures and options to recover the efficiency level of SOQ, but it takes more than 15 minutes for VWA and even more than 30 minutes for 26IA to react to the information.

The above conclusion might incur a confounding effect resulting from non-settlement Thursdays and non-expiration Wednesdays being included as regular days. To remove this weekday effect, we re-run the test only on non-settlement Thursdays and non-expiration Wednesdays, and we observe a similar pattern as described above. Moreover, for a parallel comparison among all settlement procedures, we employ a 15-minute sample period for the 26IA regime and find a reduction of closing efficiency by 22 bases. This finding suggests that lengthening the settlement period to 30 minutes is necessary to avoid efficiency deterioration. To ensure the robustness of the above inference, we further investigate whether the changes are really exogenous and whether the changes could result from altered market conditions. To this end, we examine whether a clear time trend exists but find no such pattern for each intraday trading time period on settlement and expiration days.

Instead of comparing all settlement procedures together, in Panel E we compare the price efficiency for a single-time-point price (905/901) vs. a single-longer-period price (SOQ), single price (SOQ) vs. average price (VWA), and opening price (VWA) vs. closing price (26IA). Dummy d1 takes the value of one for settlement procedure SOQ and zero for settlement procedure 905/901; dummy d2 takes the value of one for settlement procedure VWA and zero for settlement procedure SOQ; dummy d3 takes the value of one for settlement procedure 26IA and zero for settlement procedure VWA; and d4 takes the value of one for 15SEC and zero for settlement procedure 26IA to compare two adjoined settlement procedures. 15SEC denotes stock index displays from per minute to per 15 seconds. The coefficient of $Ret_{o1}$*d1 shows that the price efficiency in the SOQ regime is 103% higher than in the 905/901 regime, i.e., a single-longer-period settlement procedure produces better opening price efficiency than a single-time-point settlement procedure. The coefficient of $Ret_{o1}$*d2 suggests that the price efficiency in the VWA regime is 57% lower than in the SOQ regime, i.e., an average price settlement procedure that can prevent price manipulation reduces the opening price efficiency compared with a single settlement procedure. The coefficient of $Ret_{o1}$*d3 indicates that the price efficiency in the 26IA regime is 61% larger than in the VWA regime, i.e., a closing price settlement procedure results in a higher price efficiency than an opening price settlement procedure. In Panel F, the results show that the price efficiency in the pre-opening and opening-close periods improves after the disclosure frequency of index value increases from per minute to per 15 seconds.

### 5.2 Price discovery

Price discovery describes a process through which new information is incorporated into prices. To examine new information reflected in the pre-opening and opening prices, the information arrival in each time period is measured by determining the fraction of the 24-

hour (close-to-close) index return that is discovered in each period. To quantify the amount of price discovery in each period, the weighted price contribution (WPC) modified by Barclay and Hendershott (2008) is used to measure the fraction of the close-to-close return that occurs in each period with the same fraction of a 24-hour day, as in Session 5.1.

The WPC is defined as:

$$WPC_i = \sum_{t=1}^{T} \left( \frac{|ret_t|}{\sum_{t=1}^{T} |ret_t|} \right) \times \left( \frac{ret_{i,t}}{ret_t} \right), \tag{7}$$

where $ret_{i,t}$ is the log return during trading period $i$ on day $t$, and $ret_t$ is the total close-to-close return on day $t$ (from the close on day $t-1$ to the close on day $t$). The first term of the WPC is the weighted factor for each day. The second term is the relative contribution of the return for period $i$ on day $t$. The WPC normalizes the price discovery per period such that the WPCs sum to one. The weights in the WPC reduce the heteroscedasticity in the observations and avoid the difficulties associated with zero price changes.[14] As in the price efficiency analysis, the WPC is calculated for each period to create a panel dataset that forms the basis for our analysis.

Table 6 provides the average WPC (proxy for price discovery) during different intervals of a day (pre-opening, opening, closing, and mid-day trading) and during different settlement regimes. A few observations are worth noting. First, when TAIEX futures and options are settled at market opening (regimes 905/901, SOQ, and VWA), the price discovery during the pre-opening period is generally better on settlement day than on expiration day/regular days. However, the pre-opening price discovery on settlement day decreases dramatically from 54.8% in the 905/901 regime to 28.2% in the 26IA regime because 26IA settles at close. Pre-opening price discovery on regular days, on the other hand, does not show such a pattern. On regular days, price discovery improves over time, i.e., it increases

[14] Previous studies use price changes rather than returns, e.g., Barclay and Warner (1993), Cao, Ghysels, and Hatheway (2000), and Huang (2000). Barclay and Hendershott (2008) use returns to make the results comparable across stocks and to facilitate the calculation of standard errors.

from 28% in the 905/901 regime to 43.7% in the 26IA regime. Second, the mid-day trading period is the dominant period of price discovery, irrespective of settlement, expiration, or regular days, except on single-price settlement dominated by the pre-opening period. Third, price discovery during the opening period on settlement day is relatively low and noisy compared with the same period on expiration day/regular days for all settlement regimes, except 26IA. Although a greater opening price discovery of 7.2% on settlement day is observed in the SOQ regime due to SOQ's tendency to encourage arbitraging, the greatest opening price discovery of 20.4% is found in the 26IA regime, during which the settlement of index derivatives contracts is not only moved from the opening to the close but the time period to calculate settlement price is also doubled. This evidence lends support to the hypothesis that opening settlement reduces price discovery in the opening period. Fourth, the closing price discovery in the 26IA regime is 12.8% on expiration day, the same day as settlement day, relative to the price discovery of 7.5% on regular days and 12.7% on settlement day. This evidence suggests that closing settlement improves price discovery. However, the results in Table 6 do not present obvious evidence that opening price discovery is higher than closing price discovery on regular days.

Although the FSP determined by a single-time-point price, as in the 905/901 regime, moves price discovery from the opening to the pre-opening on settlement day, it is more likely to be manipulated than a single-longer-period price, as in the SOQ regime. The fact that price discovery in the 905/901 regime moves from the opening to the pre-opening on settlement day might result from the fact that it is easier to manipulate the FSP when it is determined at a single time point. Still, we find that single-price types of settlement procedures can avoid the price discovery deterioration that follows attempts to reduce price manipulation. Hence, the settlement procedures are changed to volume-weighted or arithmetic-average price settlement procedures, which cannot avoid price discovery deterioration. Thus, manipulation prevention appears to decrease price discovery.[15] To meet the need of high frequency traders, the Taiwan stock exchange shortened the display time of the index value from per minute to per 15 second on January 17, 2011. Therefore, we tested whether price discovery improves after the shortening of the displaying time of stock index values. The results of 15SEC in Table 6 support the prediction that price discovery at the opening and at the close both improve; price discovery improves from 0.128 to 0.226 at the close of expiration day and from 0.09 to 0.23 at the opening of regular days.

## 6. Conclusions

Expiration-day literature has evolved from the existence of the expiration-day effect to exploring the effectiveness of changes in settlement procedure. Our study complements this body of literature by focusing on the impact of changes in settlement procedure on overall market quality. In the literature, the magnitudes of expiration-day effects are shown to depend on whether there are index arbitrage opportunities; whether index futures and options are settled by cash; how well the stock market procedures accommodate the unwinding of arbitrage positions in the underlying stock market; and whether prices are purposely manipulated. Taking advantage of the four TAIFEX exogenous changes in the settlement procedures, this study first summarizes the settlement procedures implemented in global financial markets and then provides empirical evidence of the impact of different settlement procedures on price effects, volume, order imbalance, and liquidity in the Taiwan stock index market. In contrast to the expiration-day literature, this study finds that the trading effect is anomalous only for volatility and liquidity. The impact on volume is most significant when

[15] Likewise, we include only non-settlement Thursdays and non-expiration Wednesdays to preclude weekday effects and observe that price discovery is slightly higher at the opening than at the close. Similarly, we employ a 15-minute sample period for the 26IA regime for a parallel comparison among all settlement procedures. We find the opening (closing) price discovery in the 26IA regime decreases to 0.004 (0.062) on settlement day and -0.018 (-0.119) on expiration day, indicating that an increase in settlement period to 30 minutes is necessary.

the volume-weighted average is used to calculate the final settlement price, whereas price reversal is increased when settlement occurs at the close instead of at the opening.

A few pieces of evidence highlight that it may be better to settle contracts at the close than at the opening. Volume, volatility, illiquidity, and order imbalance are consistently higher at the opening than at the close on any trading day, regardless of which settlement procedure is used. We observe that the index value fluctuates markedly during the opening interval on settlement day, but none of the settlement days fluctuate more than 100 index points during the closing interval. Moreover, short liquidity is greater at the opening on settlement day than at the close on expiration day. Our results support the hypothesis that efficiency is higher at the opening of a trading day than at the close but do not support the notion that price discovery in the opening period is higher than in the closing period, regardless of settlement, expiration or regular days.

Furthermore, this study documents that the sources of expiration-day effects include the type of settlement procedure, intraday seasonality, settlement regime, and spillover effect. Although the spillover effect is proved to have a stronger impact on the expiration-day effect than the type of settlement procedure, the closing settlement procedure tends to enforce expiration-day trading split between market's open and close more than other settlement procedures. The literature suggests that using an average price to determine FSP better mitigates expiration-day effects and prevents the market from price manipulation. We find settling at a single price discovers the price more efficiently than the average price and conclude that manipulation prevention comes at the expense of market efficiency. This conclusion is evidenced by the fact that market is the least efficient in the VWA and 26IA regimes because in these regimes, index derivative contracts are settled by an average price instead of a single price. We further explore short/excess liquidity at the expiration of index derivatives, and the results suggest that settlement contributes to short liquidity and that liquidity is the shortest during the opening intervals on settlement and expiration days, particularly if these intervals fall in the SOQ regime. The evidence also reveals that the average-price settlement results in a shorter liquidity, suggesting that manipulation prevention deteriorates market liquidity. In terms of price discovery, settlement procedures that determine FSP by a single price rather than an average price facilitate better price discovery during the pre-opening period of the settlement day, although the mid-day period dominates price discovery irrespective of settlement, expiration, or regular days. This result highlights the notion that preventing manipulation hampers the price discovery process. Overall, manipulation prevention comes at the expense of liquidity, market efficiency, and price discovery.

# Appendix

## A.1 Settlement mechanisms for S&P 500 derivatives

To mitigate concerns about occasional abnormal stock price movements at the triple witching hour, the Chicago Mercantile Exchange, the New York Stock Exchange, and the New York Futures Exchange moved the settling of the S&P 500 and NYSE index futures and option contracts from the close of trading to the opening in June 1987. In 1985 and 1986, the US SEC and others proposed various solutions for limiting expiration-day price effects. These include (1) reducing futures position limits near the expiration day, (2) using the expiration-day average price as the settlement price, and (3) shifting the expiration day for various contracts to a different day. In June 1986, the SEC suggested that stock market procedures should be modified to more readily accommodate trade imbalances on expiration days. In addition, the SEC suggested that stock market procedures be modified to more readily accommodate trade imbalances on expiration days. The suggested modifications include (1) the disclosure of market-on-close orders prior to the close, (2) a halt to trading before the close to give the market time to respond to order imbalances, and (3) the use of the opening price as the settlement price.

The S&P 500 futures settle by a special opening quotation (SOQ) at the Friday open, where the special opening quotation is based on the index value computed from the opening price of each stock in the cash index. The SOQ was first used with the June expiration of the S&P 500 futures in 1987; since then, it has not changed. Prior to the SOQ, the last trading day was also the day it settled. For example, the last trading day would have been the third Friday of the contract month when it settled at the closing value. When the SOQ was instituted, the last trading day became the Thursday, prior to the third Friday for the big S&P 500 futures contract. For E-mini S&P 500 futures, the last trading day is the third Friday of the contract month; however, trading stops at 8:30 a.m. before the underlying stocks open.

### A.2 International evidence for expiration-day effects

Researchers in world financial markets have extensively explored expiration-day trading patterns characterized by abnormal volume, volatility, and price reversals for intraday frequency in the cash market. Edward (1988) finds that the introduction of futures has no long-term impact on the underlying spot market, which becomes more volatile when index futures on the S&P 500 and Value Line expire. Exploring S&P 500 index stocks, Hancock (1993) finds that the return volatility significantly increases or decreases at the triple witching hours and confirms the existence of expiration-day effects on the S&P 500. Examining the TSE 300, Chamberlain, Cheung and Kwan (1989) observe higher volatility, greater trading volume, and a pattern of price reversals during the last half hour of expiration days. Karolyi (1996) notes that although expiration days are associated with higher-than-average trading volume, the intraday return volatility in the last hours of trading on expiration days and the first hours of trading following the expirations of Japanese stock index futures and options contracts are only marginally greater on expiration days than on other days.

In the German market, Schlag (1996) finds a significant increase in trading volume on quarterly futures expiration days, stable volatility, and higher price reversals when a futures contract expires at opening with a 10-minute settlement period. However, we find no clear reversal pattern when an option expires at the close. Examining daily price and volume surrounding the expirations of Hang Seng Index (HSI) derivative contracts traded on the Hong Kong Futures Exchange, Bollen and Whaley (1999) find no evidence of increased stock market volatility when trading volume is higher than normal. Chow, Yung and Zhang (2003) uncover a possible negative price effect and some volatility of returns on the HSI, but they find no evidence of abnormal trading volume on HSI derivatives on expiration days or abnormal price reversals after expiration. Alkeback and Hagelin (2004) report that the trading volume in the Swedish cash market from 1988 to 1998 was significantly higher on expiration days than on other days, but they find no evidence of price distortions. Using the volatility measure proposed by Andersen, Bollerslev, Diebold and Labys (2001), Illueca1 and LaFuente (2006) find a significant increase in spot trading activity and a significant jump in spot volatility at expiration of the Ibex 35 stock index futures traded in the Spanish market. Fung and Yung (2009) report that both trading volume and the total number of trades of Hong Kong index stocks on the expiration day is higher than normal and increases close to the five-minute time mark[16]. Fung and Yung (2009) find no price reversals and price compression patterns. They find a significant order imbalance pattern on some expiration days but no association between order imbalance and the next day return. Hsieh (2009) reports high volatility and strong price reversals for individual component stocks of the Taiwan Stock Exchange's Capitalization Weighted Stock Index (TAIEX), with large- and small-cap stocks being affected more than medium-size stocks.

[16] In Hong Kong, index futures and index options are settled against an arithmetic average of the underlying cash index taken every five minutes on the expiration day.

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**Table 1 Summary for Settlement Methods of World-wide Index Futures**

FSP denotes the final settlement price, and SOQ denotes the special opening quotation. Type A (B) denotes the group of settlement day following (same as) the last trading day.

| FSP Calculated by | Nation | Exchange | Index Futures Contracts | Settlement Period | Type |
|---|---|---|---|---|---|
| *Opening price* | USA | CBOT | Dow Jones industrial average | SOQ | A |
| | | | Mini Dow Jones average | SOQ | A |
| | | CME | S&P 500 | SOQ | A |
| | | | Nasdaq 100 | SOQ | A |
| | | | E-Mini S&P 500 | SOQ | A |
| | | | E-Mini Nasdaq 100 | SOQ | A |
| | | | E-Mini Russell 2000 | SOQ | A |
| | | KCBT | Value Line | SOQ | A |
| | Japan | OSE | Nikkei 225 | SOQ | A |
| | | | Mini Nikkei 225 | SOQ | A |
| | | TSE | TOPIX | SOQ | A |
| | Australia | SFE | SPI 200 | SOQ | B |
| | Singapore | SGX | Nikkei 225 | SOQ | A |
| *Closing price* | Singapore | SGX | MSCI Taiwan | | B |
| | Brazil | BM&F | Ibovespa | | B |
| | | | Mini Ibovespa | | B |
| | Korea | KRX | KOSPI 200 | | B |
| *Arithmetic average price* | France | NYSE Liffe -Paris | CAC 40 | 15:40~16:00 | B |
| | Belgium | NYSE Liffe -Brussels | BEL 20 | 15:40~16:00 | B |
| | Holland | NYSE Liffe -Amsterdam | AEX | 15:30~16:00 | B |
| | UK | NYSE Liffe -London | FTSE 100 | 10:10~10:30 | B |
| | German | Eurex -Germany | Dow Jones Euro STOXX 50 | 11:50~12:00 | B |
| | South Africa | SAFEX | FTSE/JSE TOP 40 | 12:01~13:40 | B |
| | Poland | WSE | WIG 20 | 1 hour before closing | B |
| | Russia | RTS | RTS | 1 hour before closing | B |
| | Turkey | TURKDEX | ISE National-30 | 15 min before closing | B |
| | Spain | MEFF | IBEX-35 | 16:15~16:45 | B |
| | HK | HKEX | Hang Seng | All day | B |
| | Singapore | SGX | STI | 1 hour before closing | B |
| | Taiwan | TAIFEX | TAIEX | 30 min before closing | B |
| *Volume / Value-weighted price* | India | NSE | S&P CNX Nifty | 30 min before closing | B |
| | India | SEM | SENSEX | 30 min before closing | B |
| | Taiwan | TAIFEX | TAIEX | 9:00~9:15 | A |
| | Singapore | SGX | CNX Nifty | 30 min before closing | B |
| | Sweden | OM | OMX 30 | All day | B |

**Table 2 TAIEX Intraday Trading Behavior**

This table reports the settlement procedure changes experienced at TAIFEX. 905/901 (SOQ, VWA, 26IA) denotes a settlement procedure whose final settlement price is determined by the 9:05 or 9:01 index value (by special open quotation, volume-weighted average prices of index stocks during the first 15 minutes of trading, arithmetic average of the last 30 minutes of index values). Before (After) December 2008, Taiwan index (TAIEX) futures contracts expired at the close of the third Wednesday of the contract month but settled at the opening of the next trading day (at the close on the same day). The column Mean (Max-Min) reports the mean difference between the maximum and minimum index values greater than 100 index points, and % represents the difference scaled by the index value within a sample period 15 or 30 minutes.

| ***Summary of TAIFEX Settlement Procedure Changes*** | | | |
|---|---|---|---|
| Settlement Procedure | Settle at Open/Close price | Settlement Price | Mean (Max-Min) |
| 905/901 | Next open after expiration | Index value at 905/901 | 77.21<br>1.13% |
| SOQ | Next open after expiration | Opening price within 15 minutes | 99.78<br>1.57% |
| VWA | Next open after expiration | Volume weighted 15 minutes average | 70.00<br>1.12% |
| 26IA | Close at expiration | 30 minutes average | 59.93<br>0.88% |

**Table 3 TAIEX Intraday Trading Behavior**

This table presents the TAIEX intraday trading behavior when TAIEX derivatives expire. *So* and *go* denote the first 15 (30) minutes of trading on settlement day and regular days, whereas ec and gc denote the last 15 (30) minutes of trading on expiration day and regular days before (after) adopting settlement procedure *26IA*. Panel A reports the mean values of the Taiwan stock index return volatility during the first 15 (30) minutes on settlement day denoted by $Std^{so}$, the first 15 (30) minutes on regular days $Std^{go}$, the last 15 (30) minutes on expiration day $Std^{ec}$, and the last 15 (30) minutes on regular days $Std^{gc}$ before (after) *26IA*. *Qmin* represents the share volume, *REV* is the price reversal, *ILiq* is illiquidity, *Depth* is market depth, and *|OIB|* is the absolute order imbalance. Dmean denotes the mean difference between the opening on settlement day *so* and regular days *go* or between the close on expiration day *ec* and regular days *gc*. Mean (so-ec) denotes the mean difference between settlement opening *so* and expiration close *ec*. P-values are in parentheses. Panel B reports the conditional probability of short liquidity during the opening interval on settlement day (*so*) and during the closing interval on expiration day (*ec*). The conditional probability is defined as P ( *C* = Short | SP = *I,* Period = *J* ), where I denotes a settlement procedure, *905/901, SOQ, VWA, or 26IA,* and J denotes the opening or closing trading interval and is computed from the model: $\ln m_{ijk} = \mu + \mu_{A(i)} + \mu_{B(j)} + \mu_{C(k)} + \mu_{AB(ij)} + \mu_{AC(ik)} + \mu_{BC(jk)} + \mu_{ABC(ijk)}$. The measures to proxy for liquidity are: *Depth* market depth, *ILiq* illiquidity, and *Qmin* represents the share volume. Panel C reports the duration of short liquidity defined as the time difference between one case of short liquidity and the next during the opening and closing intervals for respective settlement regime, *905/901, SOQ, VWA, and 26IA*.

***Panel A: Opening and Closing Trading Activity***

| | $Std^{so}$ | $Std^{go}$ | $Std^{ec}$ | $Std^{gc}$ | $Qmin^{so}$ | $Qmin^{go}$ | $Qmin^{ec}$ | $Qmin^{gc}$ | $REV^{so}$ | $REV^{go}$ | $REV^{ec}$ | $REV^{gc}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 0.0138 | 0.0020 | 0.0006 | 0.0006 | 29964 | 27969 | 21167 | 19911 | 0.0032 | 0.0020 | 0.0073 | 0.0034 |
| Dmean | 0.0101 | (<0.001) | 2.4E-05 | (0.55) | 3313 | (0.18) | 2134 | (0.07) | 1.9E-04 | (0.35) | -1E-04 | (0.25) |
| Mean (so-ec) | | | 0.0113 | (<0.001) | | | 9261 | (<0.001) | | | -0.0014 | (0.002) |

| | $\lvert OIB^{so}\rvert$ | $\lvert OIB^{go}\rvert$ | $\lvert OIB^{ec}\rvert$ | $\lvert OIB^{gc}\rvert$ | $ILiq^{so}$ | $ILiq^{go}$ ( $10^{-4}$) | $ILiq^{ec}$ | $ILiq^{gc}$ | $Depth^{so}$ | $Depth^{go}$ | $Depth^{ec}$ | $Depth^{gc}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 2369 | 2940 | 1298 | 2012 | 0.082 | 0.020 | 0.009 | 0.010 | 61 | 168 | 300 | 289 |
| Dmean | -501 | (0.09) | -635 | (0.18) | 6E-06 | (<0.001) | -1E-07 | (0.23) | -91 | (<0.001) | 12 | (0.47) |
| Mean (so-ec) | | | -1183 | (<0.001) | | | 7E-06 | (<0.001) | | | -211 | (<0.001) |

***Panel B: Conditional probability of short liquidity***

| Period | Depth | Iliq | Qmin |
|---|---|---|---|
| so | 0.96 | 0.94 | 0.52 |
| ec | 0.55 | 0.53 | 0.54 |

***Panel C: Duration of short liquidity (min)***

| SP | Period | Depth | Iliq | Qmin |
|---|---|---|---|---|
| 905/901 | so | 1.50 | 1.52 | 1.69 |
| | ec | 13.21 | 5.77 | 2.27 |
| SOQ | so | 1.00 | 1.01 | 1.31 |
| | ec | 3.07 | 2.37 | 2.22 |
| VWA | so | 1.00 | 1.02 | 1.40 |
| | ec | 4.88 | 3.29 | 2.41 |
| 26IA | so | 1.00 | 1.04 | 1.41 |
| | ec | 3.79 | 3.15 | **2.69** |

***Figure 1-A***

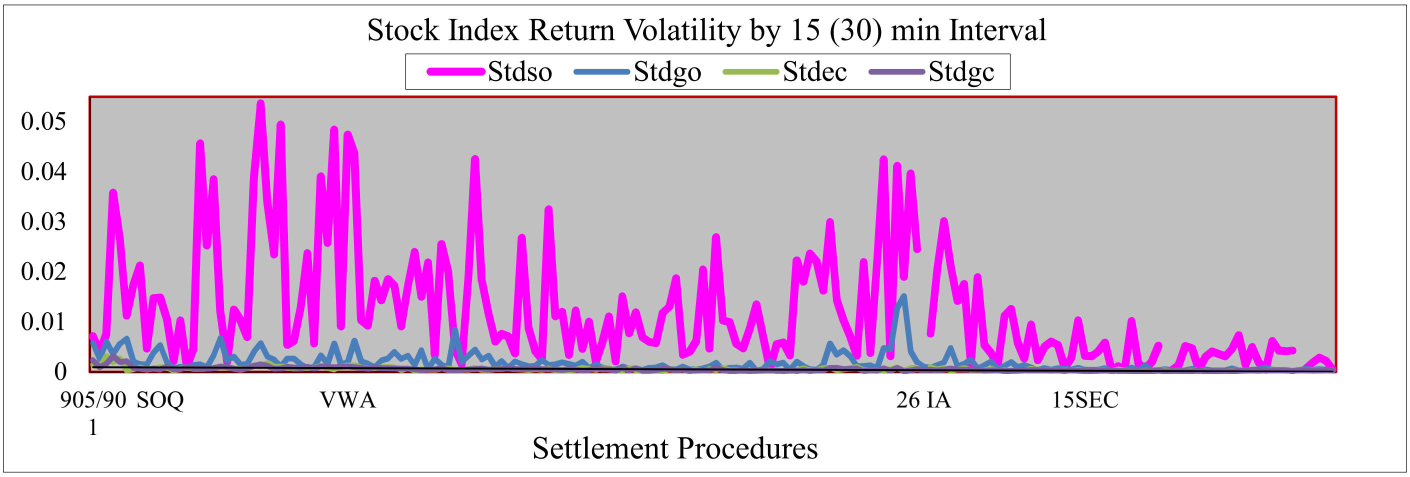


***Figure 1-B***

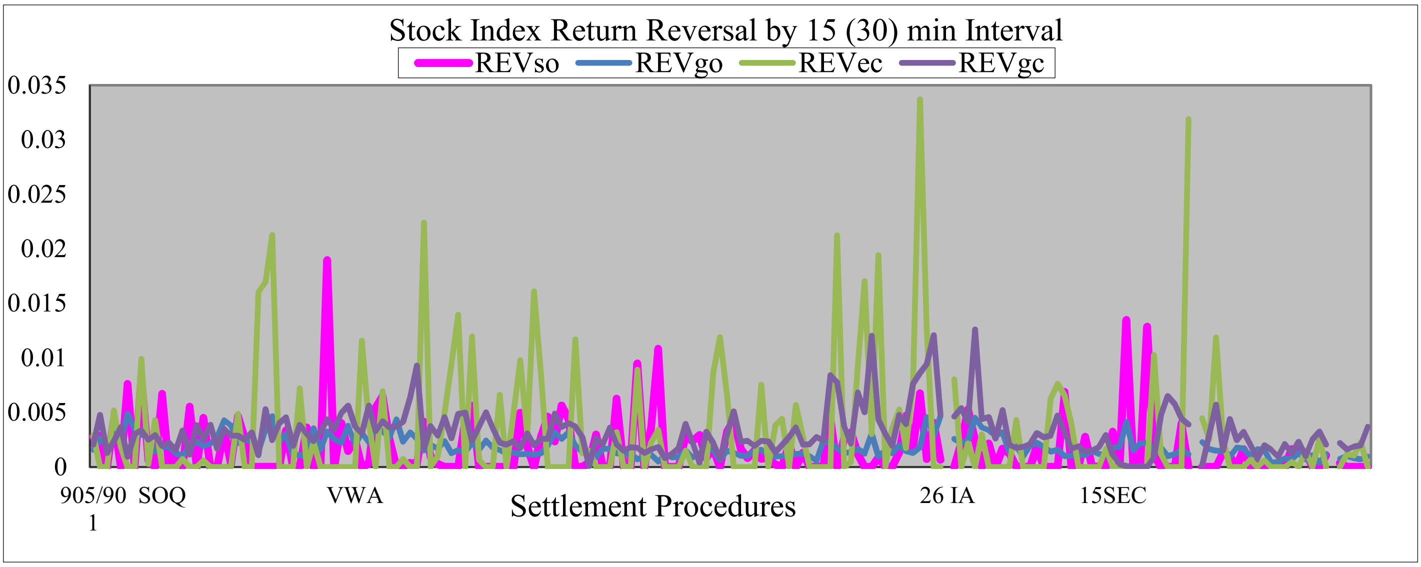


***Figure 1-C***

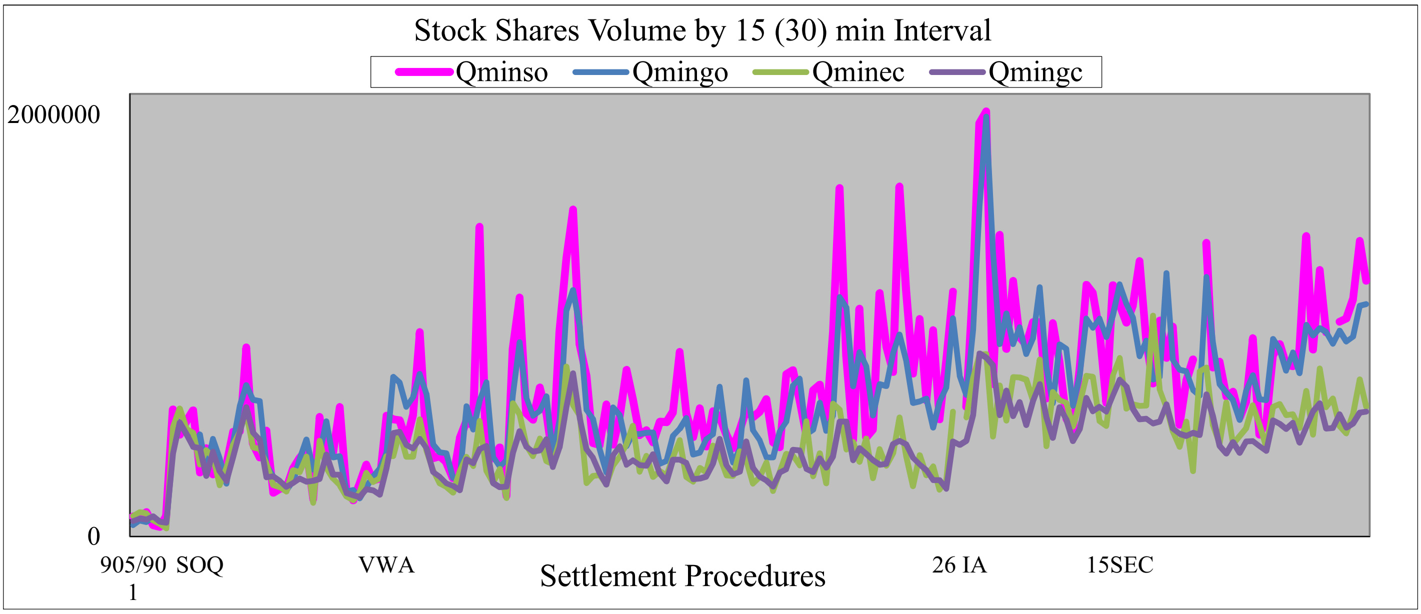

*Figure 1-D*

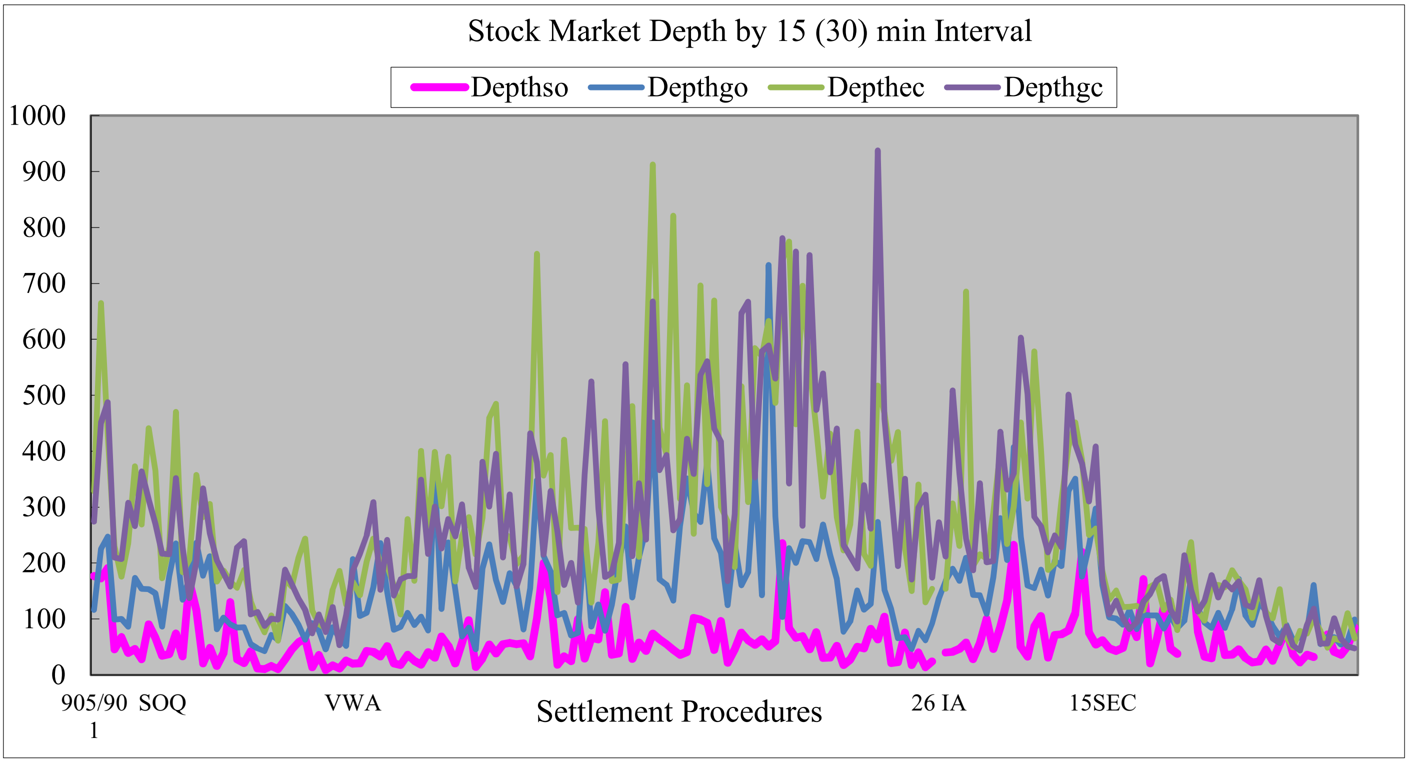


*Figure 1-E*

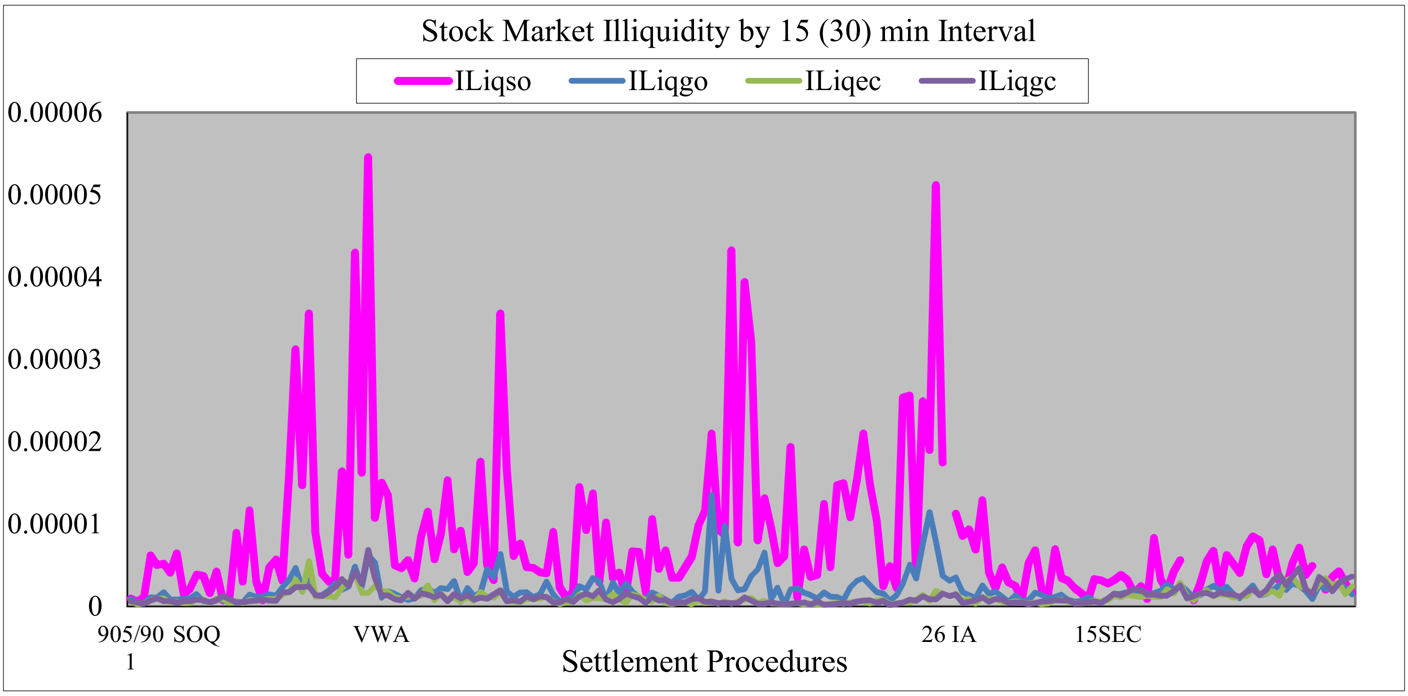

**Table 4 Sources of Expiration-day Effect**

Model $Dep^{so} = \alpha_0^{so} + \alpha_1 Dep^{go} + \alpha_2 Dep^{ec} + \sum_{i=1}^{3} \alpha_{i+2} Sr_i + \sum_{i=1}^{3} \alpha_{i+5} Dep^{ec} * Sr_i + \varepsilon^{so}$ is adopted to explore the sources of the expiration-day effect. Independent variables $Dep^{go}$ and $Dep^{ec}$ represent the same variable as the dependent variable during different time intervals and are controlled by the settlement procedure dummies $Sr_1$, $Sr_2$, and $Sr_3$ to examine the intraday seasonality and spillover effects of the stock index volatility at the opening on settlement day when TAIEX futures and options expire. Dummy $Sr_i$ ($i$ = 1, 2, 3) takes the value of one for settlement procedures *905/901, SOQ,* and *VWA* and zero otherwise, with *26IA* as a reference group. The link between variable $Dep^{go}$ and the dependent variable is a proxy for the intraday seasonality on settlement day, whereas the link between variable $Dep^{ec}$ and dependent variable is a proxy for spillover effect on settlement day. *So*, *go*, and *eo* denote the first 15 (30) minutes of trading on settlement, regular, and expiration days, *respectively*, and *sc*, *gc*, and *ec* denote the last 15 (30) minutes of trading on settlement, regular, and expiration days before (after) adopting *26IA*. Panel A uses the standard deviation of return *Std*, trading volume per minute, *Qmin* and price reversal *REV* to investigate this relationship. Panel B repeats the test using a seemingly unrelated regression (*SUR*) approach. The purpose of running *SUR* is that the residual in one equation may be correlated with that in the other. We regress the three variables in a system of equations assuming the variance-covariance matrix contains cross-correlations, which is deemed more efficient.

| Independent Variables | Dependent Variable | | | | | |
|---|---|---|---|---|---|---|
| ***Panel A*** | $Std^{so}$ | p-value | $Qmin^{so}$ | p-value | $REV^{so}$ | p-value |
| $Dep^{go}$ *(Intraday Seasonality)* | 0.224 | (0.00) | 0.256 | (0.00) | 0.096 | (0.38) |
| $Dep^{ec}$ *(Spillover Effect)* | 0.918 | (0.00) | 0.880 | (0.00) | 0.993 | (0.00) |
| $Sr_1$ | 0.868 | (0.08) | 0.857 | (0.01) | 0.002 | (0.02) |
| $Sr_2$ | 0.503 | (0.29) | 0.741 | (0.02) | 0.003 | (0.00) |
| $Sr_3$ | 0.639 | (0.01) | 0.766 | (0.00) | 0.002 | (0.00) |
| $Dep^{ec}*Sr_1$ | -0.761 | (0.00) | -0.188 | (0.00) | -0.001 | (0.05) |
| $Dep^{ec}*Sr_2$ | -0.290 | (0.23) | -0.268 | (0.01) | -0.003 | (0.00) |
| $Dep^{ec}*Sr_3$ | -0.352 | (0.07) | -0.187 | (0.06) | -0.005 | (0.00) |
| $R^2$ / *DW* | 0.403 | (1.99) | 0.853 | (2.02) | 0.626 | (2.02) |

| ***Panel B: Seemingly Unrelated Regression*** | | | | | | |
|---|---|---|---|---|---|---|
| $Dep^{go}$ *(Intraday Seasonality)* | 0.209 | (0.00) | 0.268 | (0.00) | 0.097 | (0.40) |
| $Dep^{ec}$ *(Spillover Effect)* | 0.925 | (0.00) | 0.866 | (0.00) | 0.994 | (0.00) |
| $Sr_1$ | 0.790 | (0.10) | 0.864 | (0.00) | 0.002 | (0.03) |
| $Sr_2$ | 0.622 | (0.19) | 0.801 | (0.01) | 0.003 | (0.00) |
| $Sr_3$ | 0.623 | (0.01) | 0.743 | (0.00) | 0.002 | (0.00) |
| $Dep^{ec}*Sr_1$ | -0.739 | (0.00) | -0.190 | (0.00) | -0.001 | (0.04) |
| $Dep^{ec}*Sr_2$ | -0.334 | (0.16) | -0.291 | (0.00) | -0.003 | (0.00) |
| $Dep^{ec}*Sr_3$ | 0.338 | (0.08) | -0.178 | (0.06) | -0.005 | (0.00) |
| $R^2$ / *DW* | 0.376 | (2.08) | 0.859 | (2.17) | 0.599 | (2.01) |

**Table 5 Efficiency in the Cash Index Market by Time Period**

This table examines the efficiency of the pre-open (opening, closing, mid-day trading) prices of the Taiwan stock index market affected by different settlement procedures on settlement, expiration and regular days when TAIEX derivatives expire. Mid-day trading is defined as the trading day, excluding the opening and closing intervals. $Ret_{cc} = \alpha + \beta_1 Ret_{jk} + \sum_{i=1}^{3} \beta_{i+1} Sr_i + \sum_{i=1}^{3} \beta_{i+4} Sr_i * Ret_{jk} + \varepsilon_{jk}$. Dummy $Sr_i$ ($i$ = 1, 2, 3) takes the value of one for settlement procedures *905/901, SOQ,* and *VWA* and zero otherwise, with *SOQ* as a reference group. The dependent variable $Ret_{cc}$ is the TAIEX return from close to close. The independent variable $Ret_{jk}$ is the TAIEX return of each intraday trading time period, e.g., $Ret_{co}$ refers to the TAIEX return from close to open. Regressing the close-to-close index return $Ret_{cc}$ on close-to-open index return $Ret_{co}$ (opening to 9:15 or 9:30 return $Ret_{o1}$, the last 15 or 30 minutes before closing return $Ret_{2c}$, opening to close return $Ret_{oc}$) using Yule-Walker GLS method produces a slope coefficient b. Dummy *d1* (*d2*, *d3*, *d4*) takes the value of one for settlement procedure *SOQ* (*VWA, 26IA*, *15SEC*) and zero for settlement procedure *905/901* (*SOQ*, *VWA*, *26IA*) to compare two adjoined settlement procedures. Market efficiency is indicated as the sum of the coefficients of $Ret_{co}$ and $Ret_{co}*Sr_i$. P-values are in parentheses.

| Independent Variable | Settlement day | | Expiration day | | Regular days | |
|---|---|---|---|---|---|---|
| | Dependent Variable: $Ret_{CC}$ (close-to-close return) | | | | | |
| ***Panel A:** Pre-open efficiency (Close to opening)* | | | | | | |
| Intercept | 0.11 | (0.39) | -0.05 | (0.74) | -0.01 | (0.78) |
| $Ret_{CO}$ | 0.79 | (0.00) | 0.40 | (0.00) | 0.57 | (0.00) |
| $Sr_1$ | -0.38 | (0.26) | 0.00 | (0.99) | -0.06 | (0.35) |
| $Sr_2$ | 0.02 | (0.90) | -0.05 | (0.77) | 0.00 | (0.91) |
| $Sr_3$ | -0.27 | (0.07) | 0.18 | (0.28) | 0.03 | (0.46) |
| $Ret_{CO}*Sr_1$ | 0.10 | (0.20) | 0.11 | (0.19) | 0.02 | (0.24) |
| $Ret_{CO}*Sr_2$ | -0.15 | (0.09) | 0.17 | (0.15) | 0.00 | (0.96) |
| $Ret_{CO}*Sr_3$ | -0.01 | (0.82) | 0.04 | (0.62) | 0.02 | (0.24) |
| $R^2$/DW | 0.50 | (2.02) | 0.34 | (2.02) | 0.34 | (2.01) |
| ***Panel B:** Opening efficiency (Opening to 9:15 or 9:30)* | | | | | | |
| Intercept | -0.35 | (0.04) | -0.21 | (0.21) | -0.11 | (0.01) |
| $Ret_{o1}$ | 0.56 | (0.00) | 0.43 | (0.00) | 0.41 | (0.00) |
| $Sr_1$ | 0.90 | (0.01) | 0.41 | (0.25) | 0.06 | (0.47) |
| $Sr_2$ | 0.44 | (0.03) | 0.19 | (0.32) | 0.12 | (0.02) |
| $Sr_3$ | 0.25 | (0.22) | 0.28 | (0.14) | 0.15 | (0.00) |
| $Ret_{o1}*Sr_1$ | -0.18 | (0.02) | -0.16 | (0.05) | -0.06 | (0.00) |
| $Ret_{o1}*Sr_2$ | -0.44 | (0.00) | 0.03 | (0.73) | -0.07 | (0.00) |
| $Ret_{o1}*Sr_3$ | -0.27 | (0.01) | -0.09 | (0.38) | -0.03 | (0.14) |
| $R^2$/DW | 0.14 | (2.00) | 0.17 | (2.02) | 0.12 | (2.00) |
| ***Panel C:** Closing efficiency (the last 15 or 30 minutes before closing)* | | | | | | |
| Intercept | -0.21 | (0.29) | -0.10 | (0.49) | -0.04 | (0.36) |
| $Ret_{2c}$ | 0.11 | (0.40) | 0.43 | (0.00) | 0.27 | (0.00) |
| $Sr_1$ | 0.85 | (0.04) | 0.25 | (0.42) | 0.00 | (1.00) |
| $Sr_2$ | 0.26 | (0.25) | 0.06 | (0.74) | 0.04 | (0.45) |
| $Sr_3$ | 0.15 | (0.53) | 0.18 | (0.31) | 0.06 | (0.21) |
| $Ret_{2c}*Sr_1$ | 0.06 | (0.43) | 0.05 | (0.48) | -0.03 | (0.09) |
| $Ret_{2c}*Sr_2$ | 0.20 | (0.06) | -0.03 | (0.71) | 0.07 | (0.00) |
| $Ret_{2c}*Sr_3$ | 0.03 | (0.77) | -0.03 | (0.72) | 0.01 | (0.70) |
| $R^2$/DW | 0.11 | (1.95) | 0.19 | (2.05) | 0.10 | (2.00) |

| Independent Variable | Settlement day | | Expiration day | | Regular days | |
|---|---|---|---|---|---|---|
| ***Panel D:*** *Mid-day trading efficiency (daytime excluding opening and closing intervals)* | | | | | | |
| Intercept | -0.13 | (0.41) | -0.22 | (0.07) | -0.03 | (0.33) |
| $Ret_{12}$ | 0.86 | (0.00) | 0.60 | (0.00) | 0.66 | (0.00) |
| Sr1 | 0.48 | (0.15) | 0.49 | (0.04) | 0.09 | (0.16) |
| Sr2 | 0.12 | (0.51) | 0.24 | (0.08) | 0.03 | (0.46) |
| Sr3 | 0.16 | (0.42) | 0.24 | (0.09) | 0.04 | (0.30) |
| $Ret_{12}$*Sr1 | 0.03 | (0.62) | 0.09 | (0.14) | 0.04 | (0.00) |
| $Ret_{12}$*Sr2 | -0.22 | (0.04) | 0.08 | (0.40) | 0.01 | (0.78) |
| $Ret_{12}$*Sr3 | -0.14 | (0.05) | 0.02 | (0.79) | 0.01 | (0.71) |
| $R^2$/DW | 0.46 | (2.01) | 0.50 | (2.04) | 0.47 | (2.01) |
| ***Panel E:*** | | | | | | |
| $Ret_{o1}$ | -0.29 | (0.52) | -0.22 | (0.59) | 0.16 | (0.05) |
| d1 | -0.92 | (0.04) | -0.41 | (0.39) | -0.06 | (0.55) |
| $Ret_{o1}$*d1 | 1.03 | **(0.08)** | 0.74 | (0.15) | 0.31 | (0.00) |
| $R^2$/DW | 0.33 | (2.08) | 0.18 | (2.07) | 0.17 | (2.00) |
| $Ret_{o1}$ | 0.56 | (0.00) | 0.43 | (0.00) | 0.41 | (0.00) |
| d2 | 0.44 | (0.06) | 0.19 | (0.38) | 0.12 | (0.03) |
| $Ret_{o1}$*d2 | -0.57 | **(0.00)** | 0.05 | (0.73) | -0.10 | (0.00) |
| $R^2$/DW | 0.14 | (1.93) | 0.17 | (1.99) | 0.11 | (2.00) |
| $Ret_{o1}$ / $Ret_{2c}$ | -0.22 | (0.04) | 0.51 | (0.00) | 0.28 | (0.00) |
| d3 | -0.02 | (0.90) | 0.11 | (0.41) | 0.01 | (0.69) |
| Ret*d3 | 0.61 | **(0.00)** | -0.11 | (0.47) | 0.00 | (0.99) |
| $R^2$/DW | 0.05 | (1.86) | 0.19 | (2.00) | -0.07 | (2.00) |
| ***Panel F:*** | | | | | | |
| $Ret_{co}$ | 0.49 | (0.00) | 0.27 | (0.02) | 0.55 | (0.00) |
| d4 | 0.01 | (0.96) | -0.25 | (0.10) | -0.02 | (0.56) |
| $Ret_{co}$*d4 | 0.21 | **(0.02)** | 0.30 | **(0.00)** | 0.08 | **(0.00)** |
| $R^2$/DW | 0.44 | (1.94) | 0.44 | (1.95) | 0.38 | (1.98) |
| $Ret_{oc}$ | 0.54 | (0.00) | 0.31 | (0.01) | 0.72 | (0.00) |
| d4 | -0.11 | (0.24) | -0.04 | (0.69) | -0.11 | (0.00) |
| $Ret_{oc}$*d4 | 0.20 | **(0.01)** | 0.36 | **(0.00)** | 0.07 | **(0.00)** |
| $R^2$/DW | 0.72 | (1.90) | 0.65 | (1.96) | 0.58 | (2.00) |

**Table 6 Price Discovery in the Cash Index Market by Time Period and Settlement Procedure**

The price discovery represented by the weighted price contribution $WPC_i = \sum_{t=1}^{T}\left(\frac{|ret_t|}{\sum_{t=1}^{T}|ret_t|}\right)\times\left(\frac{ret_{i,t}}{ret_t}\right)$ for the close to close into the close to opening (pre-opening), open to 9:15 or 9:30 (opening), 9:15 to 11:45 or 13:15 (mid-day trading), 11 (15- or 30-min before close) for TAIEX from July 1998 to November 2014. The mid-day trading period is defined a opening and closing intervals. When TAIEX derivatives expire, the weighted price contribution (*WPC*) is calculatec expiration day, and regular days, and also for the settlement procedures *905/901, SOQ, VWA*, *26IA* and *15SEC*. The results computed only for non-expiration Wednesdays and non-settlement Thursdays, whereas the numbers in square brac the results calculated for 30- (15-)minute sample periods. *15SEC* represents the frequency at which the index value of reported, from per minute to per 15 seconds.

| Category | Settlement Procedure | N | Pre-opening<br>Close-opening | Opening<br>Opening-9:15 or 9:30 | 15 (30)-min before closing<br>11:45-12:00 or 13:15-13:30 |
|---|---|---|---|---|---|
| | 905/901 | 9 | 0.548 | -0.082[0.134] | 0.155 [0.254] |
| Settlement | SOQ | 29 | 0.461 | 0.072 [0.062] | 0.040 [0.078] |
| Day | VWA | 85 | 0.397 | -0.047 [0.052] | 0.082 [0.132] |
| | 26IA | 25 | 0.282 | 0.204 (0.004) | 0.127 (0.062) |
| | 15SEC | 47 | 0.308 | 0.236 | 0.025 |
| | 905/901 | 9 | 0.300 | 0.056 [0.060] | 0.031 [0.195] |
| Expiration | SOQ | 29 | 0.155 | 0.074 [0.136] | 0.147 [0.294] |
| Day | VWA | 85 | 0.414 | 0.068 [0.059] | 0.081 [0.088] |
| | 26IA | 25 | 0.379 | 0.083(-0.018) | 0.128(-0.119) |
| | 15SEC | 47 | 0.284 | 0.131 | 0.226 |
| | 905/901 | 196 (**64**) | 0.280 | 0.043 [0.129] | 0.061 [0.145] |
| | | | **0.327** | **0.022 [0.009]** | **0.025 [0.066]** |
| Regular | SOQ | 543(**169**) | 0.229 | 0.141 [0.203] | 0.087 [0.154] |
| | | | **0.288** | **0.117 [0.171]** | **0.097 [0.171]** |
| Days | VWA | 1508(**491**) | 0.388 | 0.069 [0.088] | 0.076 [0.105] |
| | | | **0.385** | **0.070 [0.078]** | **0.069 [0.110]** |
| | 26IA | 465(**149**) | 0.437 | 0.093 (0.046) | 0.075 (0.039) |
| | | | **0.460** | **0.090 (0.050)** | **0.074 (0.044)** |
| | 15SEC | 820 | 0.349 | 0.230 | 0.114 |