Warrants and Their Underlying Stocks: Microstructure Evidence from an Emerging Market

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Working Paper: Please Do Not Quote without Permission

JEL Classifications: G10; G82

Keywords: Warrants, spreads, depths, intraday pattern, Thailand

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The authors wish to thank Kee H. Chung, Quentin C. Chu, Chandrasekhar Krishnamurti, and seminar participants at the 16th Australasian Finance and Banking conference in Sydney, University of Waikato, and Nanyang Technological University for their valuable suggestions. Nuttawat Visaltanachoti gratefully acknowledges the financial support provided by the International Research Development Grant (IRDG). Any errors are the responsibility of the authors.

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Abstract

The Stock Exchange of Thailand (SET) provides an ideal platform for comparing the trading characteristics of warrants and their underlying stocks since both types of securities trade in the same market venue under identical trading rules. Hence, any impact of the trading protocol on the intraday variation of spread, depth, and order flow and on an informed trader's decision to trade in warrants or stocks is naturally controlled. We find that the patterns of warrants and their underlying stocks are downward-sloping for spreads, U-shaped for flow toxicity, volatility, depth concentration, and trading volume, and upward-sloping for depth and market order flow ratio. This implies that trading under identical market structures leads to similar trading characteristics. We further document that flow toxicity is negatively related to spread and positively related to depth, market order flow ratio, trade size, trading value and volatility.

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INTRODUCTION

Numerous studies (Admati and Pfleiderer 1988; Brock and Kleidon 1992; Foster and Viswanathan 1990; Jain and Joh 1988; McInish and Wood 1992; Wood et al. 1985) examine the intraday pattern of quote- and trade-related variables on the stock market, but little research examines the intraday pattern of warrants in a limit order market. While the intraday behavior of derivative securities has been thoroughly examined on the Chicago Board Options Exchange (CBOE), where there are competing market makers, little research investigates the intraday behavior of such securities traded in a pure order-driven market. The intraday patterns of spread and volume do not only exist in quoted markets such as the New York Stock Exchange (NYSE) or the National Association of Securities Dealers Automated Quotations (NASDAQ) but have also been documented on the Tokyo Stock Exchange (TSE) and the Hong Kong Stock Exchange (HKSE), which operate without market makers (Lehman and Modest 1994; Ahn and Cheung 1999).

Because options and stocks provide different advantages to traders and, given the presence of asymmetric information among traders, one would expect that options and stocks would exhibit different trading patters (e.g., Black 1975). It was hypothesized that, if the market structure influences intraday patterns (Chan, Chung, and Johnson 1995), both warrants and stocks should exhibit a similar intraday pattern of spreads and volume after controlling for these influences. Therefore, in this study, the intraday patterns of bid-ask spreads and order flows of warrants and their underlying stocks are compared.

The study discussed in this article uses the limit order book on the Stock Exchange of Thailand (SET) to uncover how the SET's underlying market architecture affects the intraday

patterns of derivative securities. The SET provides a good platform for comparing the trading characteristics of warrants and their underlying stocks because both these securities are traded in the same market venue and have identical trading rules. Therefore, the impact of the trading protocol on intraday variation and an informed trader's decision to buy warrants or stocks is controlled. By controlling for the impact of market structure, this present study sheds light on the competition among limit order traders and strategic order submissions in both warrants and stocks trading. The findings of this study should be of interest to regulators, traders, and international portfolio managers.

The remainder of the paper is organized as follows. The next section reviews the pertinent literature and develops the hypotheses. This is followed by a description of the market architecture of the SET, the sample data, and research methodology. The fourth section presents the empirical results of the intraday patterns, the adverse selection component, the relationship between spread and depths, liquidity immediacy, and the market order submission. The final section summarizes and concludes.

LITERATURE REVIEW AND HYPOTHESES

Many studies show that trading mechanisms affect the intraday pattern of trade and quote variables. Amihud and Mendelson (1980) find that the distribution of open-to-open returns has greater dispersion, higher mode, and fatter tails than the distribution of close-to-close returns. They argue that the low variation of close-to-close returns results from market makers trying to stabilize prices and alleviate their cumulative inventory imbalance. They conclude that open-to-open returns capture opening trade price behavior in a call market, but market makers' influence on price is best examined using close-to-close returns. Chan, Christie, and Schultz (1995) and Chan, Chung, and Johnson (1995) argue that differences between the market power of NYSE

specialists and NASDAQ and CBOE dealers cause intraday variations in bid-ask spreads. They find that bid-ask spreads for NYSE stocks follow a U-shaped pattern, while spreads of NASDAQ stocks and CBOE options traded near market close are narrower.

Besides the trading mechanisms, intraday patterns are also associated with the behavior of informed traders, especially when and what they trade. Black (1975) argues that options trading should provide two advantages: financial leverage and volatility trading. Several studies (e.g., Anthony 1988; Manaster and Rendleman 1982; Stephan and Whaley 1990; Vijh 1990) investigate the interrelationship between option and stock markets, but they are unable to pinpoint where informed traders initiate their trades. Chan et al. (2002) suggest that informed traders hesitate to initiate trade in options markets due to lower liquidity in these markets.

Easley et al. (1998) show that informed traders use depths and the availability of leverage to decide how and where to trade, i.e., they may pool and trade in both option and stock markets or separate their trades in one market. Brock and Kleidon (1992) suggest that the non-trading period during market closure causes the price to deviate from equilibrium. Therefore, the degree of asymmetric information is largest at the opening. Moreover, since asymmetric information is resolved through trading, liquidity traders may trade more around the closing period than in other periods. For example, index-tracking funds rebalance their portfolio right before market closures to minimize the tracking error.

The market closure impact implied by Brock and Kleidon (1992) is not limited to the stock market. Other markets, such as the options market, should exhibit a similar U-shaped pattern as the stock market. However, because the values of derivative securities are determined solely by the movement of their underlying assets, the intraday patterns of trade- and quote-related variables for options and stocks should not be different, no matter where informed traders initiate their trades. As a result, the following hypothesis is expected to hold.

Hypothesis 1: Warrants and stocks should have similar intraday patterns of trade- and quote-related variables.

A number of studies document both intraday and interday U-shaped patterns of trading volume. Admati and Pfleiderer (1988) and Foster and Viswanathan (1990), for example, find that trading volume patterns result from the strategic behavior of liquidity traders and informed traders. Traders adjust their transactions to avoid times when trading costs are high. Informed traders only trade when they can profit from their information, while market makers, who have access to all order flow information, set prices to reflect the asset value. If traders' performance with market return is measured, trading is just a zero-sum game. This means that informed traders will trade and profit from liquidity traders. Therefore, for the price to be informative, the presence of the liquidity trader is necessary. Foster and Viswanathan (1990) argue that the private information of informed traders becomes less valuable over time because portions of private information are revealed to the public through public announcements. Liquidity traders, therefore, have an incentive to postpone their trades during a period when informed traders remain in the market.

Conversely, neither the game theory model of Admati and Pfleiderer (1988) nor the model of Foster and Viswanathan (1990) implies the higher spread and volume at market opening and closing. Brock and Kleidon (1992) point out that passive portfolio managers choose to trade at the end of the trading day because a market index is calculated using closing prices and the performance of these funds is measured by how closely they track an index. Moreover, Brock and Kleidon's model predicts that liquidity risk is higher when holding securities that are not allowed to trade. In addition, investors may opt to trade at the market open in order to adjust their portfolio imbalances during the non-trading interval and trade again at the market close to

adjust their portfolio for optimal overnight holding. This results in higher trading activity at the beginning and end of a trading interval. The arguments of Admati and Pfleiderer (1988), Foster and Viswanathan (1993), and Brock and Kleidon (1992) led to the following hypothesis:

Hypothesis 2: Trading volume is high at market opening and closing.

Observing high volatility during trading periods does not reveal the source of volatility. On one hand, high volatility during trading periods may stem from temporary price changes due to liquidity trading. On the other hand, new information, which arrives frequently during business hours, can cause high volatility during trading periods. French and Roll (1986) compare price volatility during a special event, when the New York Stock Exchange closed for 2 days and other business entities stayed opened, to price volatility over a normal weekday period. It was assumed that if information is the only source of volatility the variance over a 2-day exchange holiday would double the normal weekday variance. Their results show that the variance of a 2-day exchange holiday was only 14% higher than the variance of a normal period. This result shows that trading is also an important source of volatility.

Harvey and Huang (1991) show that the pattern of volatility variation may reflect information flow. They find that U.S. macroeconomic announcements on Thursday and Friday affect the U.S. foreign exchange market, and volatility is higher for all currencies during the first hour of Friday trading. In addition, a contagion effect causes an increase or decrease of volatility in one market as a result of activity in another market. King and Wadhwani (1990) propose a model where traders in one market infer information from another market, resulting in market integration. They predict a volatility drop when an associated market closes. Their results show that the volatility on the London market declined when the U.S. stock markets were shut down

on Wednesdays during the second half of 1968. Chan et al. (1996) find that European stocks listed on the U.S. stock market have high volatility during the early morning compared to American stocks with similar daily volume and volatility.

Past studies have shown that volatility is determined by trading activity and information flow. Moreover, liquidity traders cluster their trades and attract informed traders around the opening and closing periods. Therefore, the intraday pattern of volatility should be similar to that of volume. This led to the following hypothesis:

Hypothesis 3: Volatility is high at the opening and closing of trading sessions.

Previous literature view the bid-ask spread as a measure of trading costs or compensation to market makers for order processing costs, inventory costs, and asymmetric information costs. Garman (1976) and Ho and Stoll (1981) show that market makers face an inventory imbalance due to the uncertainty of buy and sell order arrivals. Therefore, the inventory imbalance is most severe at the close of the market. To mitigate the inventory imbalance problem, dealers use bid-ask spreads to manage their inventory by increasing bid or lowering ask quotes to attract buy and sell orders from others. Madhavan (1992) points out that the asymmetric information problem is alleviated over the trading day because trading is a process that incorporates both private and public information into price. As a result, the asymmetric information component in the bid-ask spread declines and makes the total bid-ask spread fall throughout the trading day.

Although McInish and Wood (1992) find a U-shape pattern of spreads for stocks listed on the NYSE, the intraday patterns of spreads found on other exchanges are different. Chan, Chung and Johnson (1995) compare the intraday pattern of spreads for actively traded CBOE options and their NYSE-traded underlying stocks and find that the bid-ask spread pattern of options is

different from the pattern of the underlying stocks. While both options and stocks have a wide spread at the open, at the close, the spreads of options are narrow, while the spreads of stocks are wide again. They explain that the difference in spread variation arises from differences in the market architecture used by the two markets. On CBOE, market makers compete with each other, whereas market making on the NYSE is monopolistic. In addition, Chan, Christie and Schultz (1995) and Affleck-Graves et al. (1994) find that the bid-ask spread for NASDAQ stocks declines throughout the day. Based on these arguments, the following hypotheses should hold.

Hypothesis 4: The bid-ask spread is high at the opening and declines throughout the day.

Hypothesis 5: Flow toxicity is high at the market opening.

Copeland and Galai (1983) point out that bid and ask quotes placed by market makers is a straddle option, where the difference of straddle prices forms the bid-ask spread. Lee et al. (1993) find that during an earning announcement period specialists quote a wide spread with a small depth to counter their asymmetric information risk. In a pure limit order market, liquidity providers receive the spread as compensation for their inventory costs and adverse selection cost. Therefore, the availability of depth should be negatively associated with the presence of informed traders. In addition, because the degree of asymmetric information declines over the course of trading, the depth in a limit order book should increase throughout the trading day. This led to the following hypotheses.

Hypothesis 6: Depth is low at the market opening and increases throughout the day.

Hypothesis 7: There is an inverse relationship between bid-ask spread and depth.

Brock and Kleidon (1992) argue that fund managers who replicate an index movement are likely to submit market orders to execute their trades around the market close because the index level is generally computed using closing prices. Moreover, day traders use market orders to close their positions around the closing period. Therefore, if the market order ratio is defined as the number of market orders divided by the number of limit orders submitted near the best quotes, that is at or above the best three quotes level on the limit order book, the following hypothesis should hold.

Hypothesis 8: Market order ratio is low at the opening and increases throughout the day.

Easley, Lopez and O'Hara (2012) argue that order flow is toxic if liquidity provider offers liquidity at a loss. They suggest a procedure to measure a flow toxicity based on the volume synchronized probability of informed trading (VPIN). The VPIN is useful in measuring the high-frequency dynamic of asymmetric information which is associated with variables such as spread, depth, volatility and order submission strategy. While the bid-ask spread compensates limit order traders for providing liquidity immediacy, it is a cost for market order traders. Biais et al. (1995), Chung et al. (1999), and Bae et al. (2003) find that when the bid-ask spread is narrow and the order size is small market orders are used more than limit orders. In other words, market orders are used when the cost of doing so is low, and limit orders are used when the cost is high. In addition, among limit order traders, the competition to provide liquidity is higher when the compensation (i.e., spread) is high. As flow toxicity consumes liquidity, informed traders quickly submit their orders when liquidity is sufficiently available to minimize the price impact. These arguments led to the following hypotheses.

Hypothesis 9: Flow toxicity is positively associated with liquidity measured by spread, depth, market order flow ratio.

Hypothesis 10: Flow toxicity is positively associated with volatility as price is moved by trading of informed traders.

MARKET ARCHITECTURE AND SAMPLE DATA

The SET operates under an automated limit order trading system. Trading on the exchange occurs daily from Monday to Friday in two trading sessions from 10:00am to 12:30pm and 2:30pm to 4:30pm. The trading system uses a call market mechanism to determine the closing price of the day and the opening price of the securities in each trading session and the. Traders can place several order types – limit, at-the-open, at-the-close, immediate-or-cancel, fill-or-kill, and conditionally published orders.[1] Since the trading system of the SET does not allow market orders to be submitted, traders demanding immediacy have to submit limit orders that immediately trade against an opposite limit order standing at the best quote. In this context, such orders are deemed to be market orders.

We use the trade and order book data provided by Thomson Reuters Tick History database from January 1996 to June 2012 for all warrants and underlying stocks. The trade file contains the trade time, record type (trade or quote), trade price, trading volume (in number of hundred shares), best bid and ask prices, and best bid and ask sizes (in number of hundred shares). The order book file contains bid and ask prices and sizes up to the best three quotes on each side of the book.

[1] Conditionally published orders allow a trader to reveal some portion of his or her order size and hide the remaining order from the public.

Figure 1 shows that from 1996 to 2012 trading in warrants is quite active, especially after during the second half of 1997 when the July trading volume is even higher than that of the underlying stocks. During the study period there are 270 warrants trade on the SET. These warrants represent an average monthly trading value more than half of the volume traded by their underlying stocks.[2]

Many previous studies (Mcinish and Wood (1992), Chan, Christie, and Schultz (1995), and Chan, Chung, and Johnson (1995)) utilize a 30-minute interval in their intraday analysis. However, the popularity of algorithmic trading in recent years suggest that a higher frequency interval is more appropriate. We use a 1-minute interval and only select actively traded securities to tradeoff between non-synchronous trading problems and stale trading problems.[3] A recent study by Ding and Charoenwong (2003) shows that the bid-ask spread of thinly-traded futures contracts computed from days without trades are less informative than those computed from days with trades. In light of this finding, the following sample selection criteria are used. Each warrant and its underlying stock must have at least 40 trading days that both securities trade with each having more than 20 trades a day. Securities with very low prices are constrained by minimum tick size and, consequently, have very large relative spreads. In order to reduce the impact of the minimum tick size on the relative spread, warrants and stocks trading below five baht are excluded. Ninty-one pairs of warrants and stocks meet these criteria with each having an average of 261 trading days. These 91 warrants and stocks represent more than 80% of the trading value and the market capitalization of the original sample. Although there are only 91 pairs of warrants and stocks in the final sample, they account for almost the entire original sample based on their market value and trading activity. Most of these warrants are long-term call options, whose

[2] The high warrant trading volume is not surprising since there are several turbulent events in the data sample including the 1997 which was the year that the Asian Financial Crisis began, the 1998 the Russian bond crisis, the 2001 the dot-com bubble burst, the 2007-2012 US subprime mortgage meltdown and the European debt crisis. The stock market was especially volatile in 1997 and warrants are the ideal vehicle for capitalizing on the volatility.

[3] Ideally, the intraday interval should be as short as possible to capture the details of the patterns.

maturity range from one to five years. Given the long maturities, it is not surprising that most warrants are issued deep out-of-the-money. The average prices of the warrants and underlying stocks vary from 5.34 to 222.27 baht and from 13.16 to 291.21 baht, respectively.

The bid-ask spread is defined as the difference between the best bid and best ask prices divided by the midpoint of the quotes. The market depth is the number of warrant units or stock shares posted at the best bid and ask quotes. The next 2-level depth or thickness of the book is the aggregation of the orders currently residing in the next 2-level of the limit order book. In addition, volatility, trading volume, and market order ratio are computed, where volatility is the average value of absolute returns, trading volume is measured in baht within an interval, and market order ratio is the number of market orders that arrive in the interval divided by all orders submitted at or better than the third bid ask prices in the book that arrive in the same interval. The prices of warrants and stocks in the sample range from 10 to 50 baht with a minimum tick size of 0.5% to 2.5%.[4] The warrants have an average spread of 1.24%, which is higher than the stocks' spread of 0.66%. The higher percentage spreads of warrants than stocks reflect the higher risk of warrants. The cross-sectional average market depths are 27,592 warrant baht and 106,524 stock baht.

Table I show the cross-section statistics of the limit order book and trade in the morning and afternoon sessions of warrants and stocks, respectively. The parametric paired t-test is used to find the difference between variables in the morning and afternoon sessions. For the limit order book, the spread is the difference between the best ask and best bid price divided by the average of the bid and ask price. The spreads of warrants (stocks) are 1.64% (0.77%) in the morning and 1.18% (0.54%) in the afternoon. Higher spreads in the morning reflects the high level of information asymmetry given the overnight information that is yet incorporated into

[4] The SET imposes various minimum tick sizes for warrants and stocks over the price range. A stock with a trading price of 5 baht has a minimum price change of 2%, while a stock price of 20 baht has a minimum price change of 1%.

prices. This is consistent with studies that document lower information content earlier in the trading day (e.g., Biais et al. 1995). In the unreported results, we find the average spread of 19 active pairs of warrants and stocks during the Thai Baht devaluation and financial crisis year of 1997 is 2.92% (1.86%) in the morning and 2.41% (1.5%) in the afternoon. The reduction of minimum tick size in December 1997 combined with the growth in trading volume over time results in the fall in spread over time.

Market depth, a sum of the shares standing at the best bid and the best ask of the limit order book, is lower in the morning than in the afternoon. The morning market depth of warrants is 2.6486 million baht and it rises slightly to 2.6984 million baht in the afternoon. The market depths of stocks are 9.923 million baht in the morning and 12.6443 million baht in the afternoon. We also compute the next 2-level depth which is the less aggressive orders standing in the book. Specifically, it is the sum of orders at the next two quotes on the bid and ask side. On the SET, the bid and ask up to 5-level on each side of the book are visible to the trader. The next total depth of warrants and stocks are, on average, significantly higher in the afternoon than in the morning. A comparison of the order book in the morning and in the afternoon shows that the characteristics of an order book may follow a time-varying pattern.

We examine the aggressiveness of limit order submission using the depth concentration which is the proportion of market depth and the sum of market depth and the next 2-level depth. The morning depth concentration of warrants is slightly higher than in the afternoon by 0.86% while the afternoon depth concentration of stocks is higher than in the morning by 1.07%. It indicates that the warrants traders use more aggressive limit order in the morning while stock traders submit more aggressive limit order in the afternoon. Warrants and stocks have a higher market order flows relative to limit order arrivals at the three best quotes arrivals in the afternoon

than in the morning. A comparison of the order flow in the morning and in the afternoon suggests the possibility of an intraday variation of orders.

The number of warrant trades is higher than stock trades, and trades occur more frequently in the morning than in the afternoon. Warrants (stocks) have 270 (231) trades in the morning and 206 (195) trades in the afternoon. Trade size, measured in baht, is higher for stocks than warrants. In the morning session, warrant (stock) trade size is 47,000 baht (103,200 baht) whereas, in the afternoon session, it is 50,700 baht (133,400 baht). Trading value of warrants is higher in the morning than in the afternoon while the opposite holds for the stock trading value.

Both warrants and stocks have a higher return volatility in the morning than in the afternoon. This pattern is similar to those found in previous studies on the options (e.g.,) and stock (e.g., McInish and Wood 1992) markets. The higher volatility in the morning session reflects the higher degree of uncertainty arising from the price discovery process at the market opening.

Stocks show a higher level of toxic order flow than warrants. Both warrants and stocks have a higher VPIN in the morning than in the afternoon. This result combined with the finding that liquidity measured by spread and depth is lower in the morning than in the afternoon suggests that informed investors time the trades in accordance to the availability of liquidity.

EMPIRICAL EVIDENCE

Intraday Variation of Spreads, Depth, Market Order, Volume, Volatility, and VPIN

Pattern of Spreads

We regress the spreads, depths, liquidity immediacy, volume, volatility, and market order ratio of the warrants and their underlying stocks against dummy variables to capture the intraday variation, while controlling for the day-of-the-week effect:

$$Y_t = \hat{\alpha} + \sum_{h=1}^{9} \hat{\beta}_h dtime_{h,t} + \sum_{k=1}^{5} \hat{\gamma}_k dweek_{k,t} + \hat{\varepsilon}_t \text{ subject to } \sum_{h=1}^{9} \beta_h = 0, \sum_{k=1}^{5} \gamma_k = 0 \quad (1)$$

where Y_t represents the 1-minute interval of bid-ask spread, market depth, next 2-level depth, depth concentration, market order flow, number of trade, trade size, trade volume, volatility, and VPIN, *dtime* are dummy variables that capture the 30-minute intraday variation and *dweek* are dummy variables that control for the day-of-the-week effect.

To facilitate the interpretation of the dummy coefficients, the intercept and all dummy variables, with a constraint that the sum of dummy coefficients in the same group is zero, are included. This constraint prevents perfect multicollinearity. This scheme of dummy variables is used in several recent studies of intraday pattern (see, for example, Ahn and Cheung 1999; Lehman and Modest 1994). The regression is performed for 91 individual warrants and stocks. The intercept of the regression (α) represents the cross-sectional average value of the variable of interest. Note that the number of observations for each stock is not equal because nonactive trading days are truncated. We estimate parameters in the regression by using the Generalized Method of Moment (GMM) with the Newey and West (1987) correction for an unknown form of serial correlation and heteroskedasticity.

From the regression in Equation (1), the cross-sectional average bid-ask spread of warrants is 1.24%, which is 0.72% wider than the stocks spread. This result indicates a higher execution cost in warrant trading compared to stock trading. The spread of actively traded stocks on SET, 0.66%, is higher than the 0.6% of average stock spreads on the NYSE. However, it was lower than the 1.15% of average stock spreads on the Tokyo Stock Exchange (TSE) and the 1.73% of average stock spreads on the Hong Kong Stock Exchange (HKSE).[5] The intraday variation of relative spreads of warrants and stocks is shown in Tables II and III. The bid-ask

[5]The average NYSE spread is from the 1994 *NYSE Fact Book*; the average TSE spread is from January 1991 to April 1993 (see Lehman and Modest 1994). The average HKSE spread is from October 1996 to March 1994 (see Ahn and Cheung 1999).

spread is highest 10:00 a.m. to 10:30 a.m. Warrant and stock spreads in this period are 0.48% and 0.21% higher than the average spread in other periods. The dummy coefficients of most intervals in the morning are significantly positive. For warrants, the time interval coefficients starting from the last 30-minute before the morning session break to the end of trading day are significantly negative. For stocks, the dummy coefficients are significantly negative for an interval before the morning session break and two 30-minute intervals before the end of the trading day. Nevertheless, the magnitude of the dummy interval coefficient monotonically declines to the lowest value of -0.35% for warrants and -0.17% for stocks during the last 30 minutes of the trading day. Therefore, the spreads of both warrants and stocks have a similar downward pattern over trading time, with spreads highest right after market opening and lowest before market closing.[6]

This result confirms the effect of market structure on the intraday pattern documented in Chan et al. (1995). The options traded on CBOE, which is a competitive dealer market, have narrower spreads at closing compared to their underlying stocks traded on the monopoly specialist NYSE. In contrast, warrants and their underlying stocks listed on SET are traded under the same market structure and regulations, and both exhibit the same intraday reverse J-shape pattern. The results of this study suggest that the pattern of stock spreads is similar to the bid-ask spread pattern on the NYSE, TSE, and HKSE (see Ahn and Cheung 1999; Lehman and Modest 1994; McInish and Wood 1992). Market close also appears to affect the day of the week pattern. As shown in Tables II and III, the spreads of warrants and stocks are highest on Tuesdays (Mondays), and they are 0.19% and 0.94% higher than other days of the week. Figure 2 plots the intraday spread of warrants and stocks using 1-minute interval. The graph shows downward

[6] This study also examines intraday variation of absolute spread and it indicates that the downward pattern is being driven by the spread not by the quote mid-point. Results are available upon request.

trend in spread over the time of the day and it shows the high spread after the market open in the morning and in the afternoon.

Pattern of Depths

While spread is the most popular proxy for the price of liquidity, depths of a limit order book measure the size of liquidity. Lee et al. (1993) show that providers of liquidity use both depths and spreads to manage the risk of asymmetric information. Four variables are used in this study to constitute depths: market depth, displayed depth, total depth, and the ratio of the market depth to total depth or liquidity immediacy. A comparison of liquidity immediacy across different periods is used to reveal the change of market depth relative to total depth.

Table II and Table III show that the cross-sectional active trading day weighted market depths of warrants and stocks are 2,759,200 baht and 10,652,400 baht, respectively. Active stocks are likely to have thick depths and more active trading days, so stocks have higher cross-sectional day weighted market depths than the cross-sectional average market depth. The active trading day weighted next 2-level depths of warrants and stocks are 11,120,500 baht and 31,136,800 baht, respectively. Both types of depth are low at opening and continually increase to highest at closing. Compared to spread, the intraday pattern of market depth is a reverse image of the intraday spread pattern. As shown on Figure 3, market depth is lowest at opening and monotonically increases to highest at closing.

While both market depths and the next-2 level depths increase over the course of the trading day, the depth concentration of warrants and stocks follows the U-shape pattern with the cross-sectional average of 23.25% and 23.85%, respectively. The depth concentration ratio can be viewed as a proxy for the degree of the limit order trader's willingness to supply liquidity. The depth concentrations are less than one-third so it suggests either that a limit order trader on

average demand more compensation for providing liquidity than the spread or there is a high degree of front-running activity among limit order traders. The U-shape pattern of depth concentration shown on Figure 4 suggests an active competition among limit order traders during the market open and close. When compared to the NYSE, the results in this study concur with Lee et al.'s (1993) assertion that the liquidity supplied by limit order traders in a limit order book of warrants and stocks is reflected in both spreads and depths.

Pattern of Market Order, Volume, and Volatility

The average values of the market order ratio across all time intervals are 23.20% for warrants and 20.82% for stocks. As shown in Table II and Table III, the market order ratio is lowest during the first 30-minute interval and increases to its highest level during the last 30-minute interval. There is also a lunch-break effect for market order submissions. Right before lunch, the market order ration rises significantly. After lunch, the market order ratio drops during the first 30-minute interval and then increases. During the afternoon session, the pattern of market order ratio rises steadily and increases significantly in several minutes before the close. This pattern is likely to reflect the activity of day-trade investor who does not want to hold the position overnight. In general, warrants and stocks show the upward pattern of the market order ratio. An increase in market order submissions is consistent with the increase of market depths and the decrease of spreads. This shows that market order traders consume the liquidity supplied by limit order traders.

The intraday pattern of spreads, depths, and market order submissions supports the hypothesis that investors strategically submit more (less) market orders when the spread, which is the cost of submission, is low (high) and when market depths are high (low) (see Bae et al. 2003; Biais et al. 1995). Keim and Madhavan (1995) show that the institutional trader who is a

liquidity trader, such as index fund managers, tends to use market orders. This observation is consistent with the results of this study, which show a large increase in market orders during closing. A comparison of the market order ratio between warrants and stocks is shown in Figure 5, which illustrates the similarity in their intraday patterns.

As shown in Table II and III, the coefficients of number of trades, trade size, trading value, and volatility are statistically positive at the first and last trading intervals. There is evidence of the U-shaped pattern in number of trades, trade size and trading value confirming the same pattern found in many other markets, including U.S. markets, which have specialists and dealers to provide liquidity of the last resort, and pure limit order markets, such as those or the TSE, the Paris Bourse, and the HKSE. Figure 6 shows that the intraday variation of warrants and stocks trading value on SET follows the U-shaped pattern. Consistent with previous studies, volatility of both warrants and stocks also exhibits the U-shape pattern. The highest level of volatility occurs at the first trading interval of the day, and it falls before increasing again during the closing interval. The impact of trade discontinuity due to the two-hour lunch break does not appear in the intraday volatility pattern. Figure 7 presents the intraday pattern of volatility.

Flow Toxicity

According to Madhavan (1992), asymmetric information is resolved through trading, and this explains the downward intraday pattern of spreads and the upward intraday pattern of market depth. In order to test if asymmetric information falls over the course of trading, this study measure the high frequency dynamic of flow toxicity using the procedure suggested by Easley, Lopez and O'Hara (2012). They use volume synchronized probability of informed trading or VPIN to measure the flow toxicity. The VPIN has an advantage over the other measures when measuring asymmetric information at a high frequency interval as it does not require an

intermediate numerical estimation of unobservable parameters. As shown in Table II and III, the cross-sectional mean of the VPIN varies from 19.9% to 33.7% for warrants and from 24.9% to 40.3% for stocks. The VPIN are usually highest after the market has been open for 30 minutes and falls over time but it is high again in the last 30 minutes before the market close. Figure 8 shows the U-shape pattern of the VPIN of warrants and stocks.

The findings in the present study show that the adverse selection cost declines over time. Madhavan (1992) notes that the adverse selection problem is resolved by trading. This implies that on SET the adverse selection component at the open is higher than during trading intervals throughout the day, and it is lowest at the close. Other models report the higher adverse selection component at the close. This might be a result of strategic order submissions by informed traders. Handa and Schwartz (1996) and Harris and Hasbrouck (1996) show that limit orders placed at the best or better than the prevailing quotes yield superior returns to limit orders placed behind the book and market order. As a result, to maximize the value of their information, informed traders may use a marketable limit order,[7] but if no execution occurs before market close, they may switch to a market order for immediate execution. Therefore, liquidity providers before the close will demand a compensation for a higher asymmetric information cost. However, as noted in Ahn et al. (2002), all of the models assume that the information is immediately impounded to price after each trade. If the trading pattern is endogenously determined and lagged trades and quotes have an impact on current trade and quote, the vector autoregressive model of Hasbrouck (1988) may be more appropriate.

[7] A marketable limit order is a limit order placed at the best quote.

Association of Flow Toxicity, Limit Order Book and Trades

The results of the present study show that spread declines over the trading day, while market depth, next 2-level depth, and market order ratio increase. This study also examines the correlation between flow toxicity, spreads and other variables, including depths, depth concentration, market order ratio, trade size, trading value, and volatility, when the intraday pattern is and is not controlled. Table IV and V show that without a control of intraday intervals, the flow toxicity is negatively associated with spread for both warrants and stocks. The correlations of VPIN and spread are -0.20 for warrants and -0.19 for stocks. However, VPIN is positively positive related to depths for both warrants (0.27) and stocks (0.27). This suggests that the presence of informed trader occurs concurrently with the availability of liquidity.

There is almost no correlation between flow toxicity and depth concentration but there is a strong positive correlation with the market order ratio and trade size. This evidence indicates that informed traders do not only observe liquidity but they also design their order strategy to minimize trading costs and maximize the benefits from their information advantages by using market order with large trade size.

Flow toxicity is positively associated with volatility. Consistent with the price discovery process, trading of informed trader incorporates information into prices causing price to move toward fundamental value and increases volatility.

However, the correlation of VPIN and the other variables may arise from a strong relationship in a certain period of the day, especially during the opening and closing periods. In order to confirm whether such relationships occur during a specific period of a trading day, this study examines correlation at each trading interval. As shown in Table IV and V, the association of VPIN and other variables across the trading day and across weekdays is not sharply different

from relationships that have not been controlled for time variations. This shows that the intraday effect has little impact on the relationship of flow toxicity and other variables.

CONCLUSIONS

The results of this study show that market structure has a significant effect on the intraday pattern of spread, depth, market order ratio, volatility, and volume. The results show that warrants and stocks have wider spreads at the open, and these spreads become gradually narrower until they reach their lowest level at the close. These findings support the idea that market structure influences intraday patterns.

The intraday pattern of trade and quote variables for both warrants and stocks traded on SET are compared in this study. Although five warrants are in the top 20 for trading volume during 1997, which indicates a relatively high liquidity of warrants compared to stocks, generally, the intraday spreads, depths, depth concentration, market order ratio, trading value, volatility, and flow toxicity of warrants and stocks have a similar pattern. Percentage spreads are the highest at the opening, monotonically decrease during the day, and are lowest at the closing. Moreover, warrant spreads are higher than stock spreads for the whole period. The market depths, the next 2-level depths, and market order ratio are lowest in the opening interval and increase to their highest level at closing. The depth concentration, trading value, volatility and flow toxicity have the U-shape pattern. The volatility of warrants is higher than stocks, but the flow toxicity of stocks is higher than warrants.

This study also shows the negative association of flow toxicity and spreads. Depths, market order ratio, trade size, trading value and volatility all have positive association with flow toxicity. These relationships occur in all time intervals, so they do not occur because of a strong relationship in a specific interval. The inverse relationship between VPIN and spread supports

the notion that informed traders consider liquidity when managing their submission strategy. The positive correlation of flow toxicity and market order ratio implies a strategic market order submission by informed trader. The positive association of flow toxicity and volatility is an evidence of permanent price movement as a result of informed trading.

APPENDIX: VPIN Measurement

Easley, Lopez and O'Hara (2012) suggest a procedure to measure flow toxicity based on volume synchronized probability of informed trading.

$$VPIN \approx \frac{\sum_{\tau=1}^{n} |v_{\tau}^{B} - v_{\tau}^{S}|}{nV}$$

Following Easley, Lopez and O'Hara (2012), we use n=50 bucket so V is 1/50 of the average daily volume. We classify each trade based on Lee and Ready algorithm. A trade is buy initiated if price is above the midpoint and vice versa.

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TABLE I
Descriptive Statistics of Limit Order Book and Trade of Warrants and Stocks

	Morning			*Afternoon*				
	Mean	*Median*	*S.D.*	*Mean*	*Median*	*S.D.*	*Mean of Diff*	*t-stats*
Panel A: Warrants								
Spread	1.64%	1.58%	0.80%	1.18%	1.19%	0.91%	0.46%	5.38
At the Market Depth	26,486	5,033	104,070	26,984	5,691	100,011	-498	-0.93
Next 2-Level Depth	125,344	15,963	471,769	128,722	20,228	479,409	-3,378	-2.24
Depth Concentration	24.44%	23.68%	3.91%	23.59%	23.02%	2.29%	0.86%	2.49
Market Order Flow	24.04%	24.61%	2.23%	26.25%	26.76%	2.83%	-2.20%	-10.88
Number of Trades	0.63	0.48	0.47	0.60	0.43	0.44	0.03	4.38
Trade Size	470	157	1423	507	175	1563	-37	-2.43
Trading Value	2,259	384	10,990	2,079	364	9,920	180	1.58
Volatility	0.123%	0.118%	0.063%	0.099%	0.100%	0.033%	0.025%	4.33
VPIN	0.217	0.194	0.096	0.232	0.209	0.093	-0.015	-11.59
Panel B: Stocks								
Spread	0.77%	0.79%	1.75%	0.54%	0.73%	2.27%	0.23%	1.50
At the Market Depth	99,230	27,733	341,995	126,443	36,372	442,432	-27,213	-2.27
Next 2-Level Depth	316,350	84,154	1,122,322	374,153	94,263	1,370,436	-57,803	-1.95
Depth Concentration	23.38%	22.50%	2.60%	24.45%	24.02%	2.26%	-1.07%	-5.81
Market Order Flow	21.05%	21.13%	2.28%	23.96%	23.55%	2.88%	-2.91%	-14.82
Number of Trades	0.79	0.64	0.58	0.81	0.62	0.58	-0.02	-1.89
Trade Size	1032	595	2430	1,334	757	3,391	-302	-2.59
Trading Value	4,433	1,321	14,012	5,273	1,756	18,886	- 840	-1.39
Volatility	0.073%	0.070%	0.023%	0.071%	0.068%	0.031%	0.002%	0.74
VPIN	0.262	0.251	0.124	0.289	0.275	0.129	-0.027	-14.75

Note. This table presents the cross-sectional statistics of limit order book and trade in the morning and afternoon sessions. Spread is the best ask minus the best bid prices divided by the midpoint of the bid and ask prices. At the market depth is the sum of shares in hundred thousand bath at the best quotes in the limit order book. Next 2-Level depth is the sum of shares in hundred thousand baht at the next two quotes in the limit order book. Depth concentration is the ratio between at the market depth and next 2-level depth. Market order flow is the proportion of a number of market orders to a number of limit orders submitted at or better than the 3rd level in the limit order book. Volatility is the absolute percentage price change. VPIN is the volume synchronized probability of informed trading computed as per Easley, Lopez and O'Hara (2012).

TABLE II
Intraday Patterns of Warrants

	Spread	*At the market depth*	*Next 2-level depth*	*Depth concentration*	*Market order flow*	*Number of trades*	*Trade Size*	*Trading Value*	*Volatility*	*VPIN*
Constant	1.238***	27.592***	111.205***	23.247***	23.202***	0.709***	0.475***	1.668***	0.103***	0.318***
10:00–10:30	0.477***	-2.770***	-17.813***	2.069***	-1.936***	0.455***	0.147***	1.218***	0.093***	-0.009***
10:30–11:00	0.335***	-0.788***	-3.860***	0.379***	-1.053***	0.102***	0.036***	0.186***	0.020***	-0.048***
11:00–11:30	0.125***	-0.227	1.788**	-0.288***	-0.568***	-0.077***	-0.045***	-0.191***	-0.009***	-0.086***
11:30–12:00	0.020*	0.313	3.552***	-0.682***	-0.372***	-0.166***	-0.089***	-0.412***	-0.027***	-0.107***
12:00–12:30	-0.023**	0.163	4.421***	-0.937***	0.597***	-0.228***	-0.123***	-0.587***	-0.038***	-0.119***
14:30–15:00	-0.183***	0.115	5.433***	-0.660***	0.015	-0.107***	-0.042***	-0.265***	-0.016***	-0.094***
15:00–15:30	-0.166***	0.443*	5.253***	-0.503***	0.089	-0.117***	-0.044***	-0.274***	-0.021***	-0.088***
15:30–16:00	-0.241***	0.613***	3.487***	-0.407***	0.528***	-0.087***	-0.012***	-0.174***	-0.020***	-0.077***
16:00–16:30	-0.345***	2.136***	-2.263***	1.027***	2.700***	0.226***	0.171***	0.499***	0.019***	0.019***
Monday	0.001	-2.894***	-6.559***	0.103***	0.040	-0.050***	-0.019***	-0.112***	-0.006**	-0.008***
Tuesday	0.191***	-1.563***	-2.483***	0.131***	0.093	-0.027***	-0.024***	-0.126***	-0.007***	-0.009***
Wednesday	-0.155***	1.484***	0.060***	0.083***	0.096*	0.019***	0.009***	0.046***	0.010***	0.002***
Thursday	-0.199***	1.497***	6.343***	-0.146***	-0.071	0.029***	0.013***	0.005	0.004	0.004***
Friday	0.163***	1.476***	2.638***	-0.171***	-0.159***	0.030***	0.021***	0.187***	-0.001	0.004***

Note. The intraday patterns of interested variables are estimated as follows:

$$Y_t^{1-\min} = \alpha + \sum_{h=1}^{9} \beta_h dtime_{h,t} + \sum_{k=1}^{5} \gamma_k dweek_{k,t} + \varepsilon_t \text{, subject to } \sum_{h=1}^{9} \beta_h = 0,\ \sum_{k=1}^{5} \gamma_k = 0$$

where $Y^{1\text{-}min}{}_t$ denotes the variables of interest measured at 1-minute interval consisting of spread, at-the-market depth, next 2-level depth, depth concentration, market order ratio, number of trades, trade size, trading volume, volatility, and VPIN. For each warrant, these variables are regressed against a set of dummies and controlled variables. This table reports the cross-sectional averages of the coefficients. The statistical significance is based on the signed tests on the estimated coefficients, where ***, **, and * indicate a 99%, 95% and 90% significance level, respectively.

TABLE III
Intraday Patterns of Stocks

	Spread	*At the market depth*	*Next 2-level depth*	*Depth concentration*	*Market order ratio*	*Number of trades*	*Trade Size*	*Trading Value*	*Volatility*	*VPIN*
Constant	0.657***	106.524***	311.368***	23.848***	20.818***	0.858***	1.185***	4.078***	0.072***	0.382***
10:00–10:30	0.208***	-33.896***	-84.945***	0.025	-2.497***	0.429***	0.127***	1.593***	0.054***	-0.026***
10:30–11:00	0.110***	-17.734***	-34.650***	-0.985***	-1.648***	0.076***	-0.073***	-0.122	0.006***	-0.066***
11:00–11:30	0.088***	-7.431***	-9.092***	-0.984***	-1.106***	-0.107***	-0.135***	-0.212*	-0.011***	-0.100***
11:30–12:00	-0.020	-1.009	4.987***	-0.806***	-0.636***	-0.200***	-0.255***	-0.902***	-0.019***	-0.123***
12:00–12:30	-0.114***	2.796***	16.766***	-0.663***	0.719***	-0.262***	-0.301***	-1.376***	-0.022***	-0.133***
14:30–15:00	-0.016	7.602***	30.634***	-0.136***	0.079*	-0.085***	0.016	-0.124	-0.009***	-0.098***
15:00–15:30	-0.007	12.387***	34.616***	0.191***	0.144***	-0.099***	-0.016	-0.382***	-0.009***	-0.091***
15:30–16:00	-0.169***	18.155***	32.745***	0.902***	0.845***	-0.069***	0.068***	-0.272***	-0.010***	-0.076***
16:00–16:30	-0.079***	19.131***	8.939***	2.455***	4.101***	0.316***	0.568***	1.795***	0.021***	0.021***
Monday	0.935***	-16.335***	-29.276***	0.277***	0.127***	-0.029***	-0.052***	0.016	-0.004***	-0.008***
Tuesday	0.303***	-2.413***	1.161	0.096***	-0.068**	-0.028***	-0.046***	-0.370***	-0.003***	-0.010***
Wednesday	-0.659***	-0.118	-1.087	0.212***	-0.028	0.012***	0.005	-0.093	0.004***	-0.002***
Thursday	-0.389***	13.820***	16.768***	-0.265***	0.057**	0.020***	0.066***	0.240***	0.000	0.000***
Friday	-0.190***	5.046***	12.434***	-0.320***	-0.089***	0.024***	0.028***	0.207***	0.001	0.002***

Note. The intraday patterns of interested variables are estimated as follows:

$$Y_t^{1-\min} = \alpha + \sum_{h=1}^{9} \beta_h dtime_{h,t} + \sum_{k=1}^{5} \gamma_k dweek_{k,t} + \varepsilon_t \text{, subject to } \sum_{h=1}^{9} \beta_h = 0, \ \sum_{k=1}^{5} \gamma_k = 0$$

where $Y^{1\text{-}min}{}_t$ denotes the variables of interest measured at 1-minute interval consisting of spread, at-the-market depth, next 2-level depth, depth concentration, market order ratio, number of trades, trade size, trading value, volatility, and VPIN. For each stock, these variables are regressed against a set of dummies and controlled variables. This table reports the cross-sectional averages of the coefficients. The statistical significance is based on the signed tests on the estimated coefficients, where ***, **, and * indicate a 99%, 95% and 90% significance level, respectively.

TABLE IV
Spearman Correlation of Flow Toxicity, Limit Order Book and Trades of Warrants

	Spread	*At the market depth*	*Next 2-level depth*	*Depth concentration*	*Market order ratio*	*Trade Size*	*Trading Value*	*Volatility*
Constant	-0.2046***	0.2712***	0.3453***	-0.0136***	0.8555***	0.9293***	0.9165***	0.1999***
10:00–10:30	-0.1908***	0.2381***	0.2886***	0.0013	0.8870***	0.9571***	0.9499***	0.1718***
10:30–11:00	-0.1681***	0.2160***	0.2571***	0.0094***	0.9032***	0.9714***	0.9668***	0.1712***
11:00–11:30	-0.1480***	0.1985***	0.2340***	0.0091***	0.9132***	0.9773***	0.9738***	0.1690***
11:30–12:00	-0.1406***	0.1907***	0.2252***	0.0117***	0.9206***	0.9819***	0.9793***	0.1573***
12:00–12:30	-0.1452***	0.1931***	0.2360***	0.0156***	0.9060***	0.9734***	0.9692***	0.1784***
14:30–15:00	-0.1477***	0.1936***	0.2348***	0.0049***	0.9017***	0.9730***	0.9688***	0.1603***
15:00–15:30	-0.1414***	0.2003***	0.2410***	0.0182***	0.8991***	0.9696***	0.9650***	0.1540***
15:30–16:00	-0.1248***	0.2183***	0.2613***	0.0383***	0.8366***	0.9335***	0.9227***	0.1229***
16:00–16:30	-0.1526***	0.2127***	0.2617***	0.0206***	0.8930***	0.9683***	0.9632***	0.1685***
Monday	-0.1550***	0.2082***	0.2550***	0.0159***	0.8920***	0.9678***	0.9626***	0.1751***
Tuesday	-0.1517***	0.2116***	0.2546***	0.0146***	0.8897***	0.9639***	0.9579***	0.1743***
Wednesday	-0.1594***	0.2099***	0.2487***	0.0188***	0.8902***	0.9634***	0.9575***	0.1753***
Thursday	-0.1566***	0.2185***	0.2546***	0.0160***	0.8915***	0.9632***	0.9573***	0.1718***
Friday	-0.2046***	0.2712***	0.3453***	-0.0136***	0.8555***	0.9293***	0.9165***	0.1999***

The statistical significance is based on the signed tests on the estimated coefficients, where ***, **, and * indicate a 99%, 95% and 90% significance level, respectively.

TABLE V
Spearman Correlation of Flow Toxicity, Limit Order Book and Trades of Stocks

	Spread	*At the market depth*	*Next 2-level depth*	*Depth concentration*	*Market order ratio*	*Trade Size*	*Trading Value*	*Volatility*
Constant	-0.1860***	0.2699***	0.2861***	-0.0199***	0.8412***	0.9095***	0.8952***	0.1675***
10:00–10:30	-0.1679***	0.2576***	0.2589***	0.0194***	0.8843***	0.9436***	0.9355***	0.1438***
10:30–11:00	-0.1500***	0.2419***	0.2472***	0.0168***	0.9079***	0.9605***	0.9552***	0.1328***
11:00–11:30	-0.1315***	0.2237***	0.2333***	0.0122***	0.9180***	0.9687***	0.9647***	0.1308***
11:30–12:00	-0.1317***	0.2213***	0.2327***	0.0109***	0.9241***	0.9738***	0.9705***	0.1240***
12:00–12:30	-0.1382***	0.2274***	0.2390***	0.0086***	0.9051***	0.9599***	0.9546***	0.1374***
14:30–15:00	-0.1367***	0.2313***	0.2451***	0.0092***	0.9014***	0.9585***	0.9532***	0.1238***
15:00–15:30	-0.1300***	0.2394***	0.2537***	0.0144***	0.8920***	0.9534***	0.9475***	0.1181***
15:30–16:00	-0.1210***	0.2476***	0.2565***	0.0288***	0.8111***	0.9029***	0.8896***	0.1009***
16:00–16:30	-0.1421***	0.2410***	0.2497***	0.0096***	0.8913***	0.9529***	0.9464***	0.1382***
Monday	-0.1401***	0.2300***	0.2385***	0.0156***	0.8928***	0.9537***	0.9474***	0.1391***
Tuesday	-0.1384***	0.2366***	0.2449***	0.0181***	0.8884***	0.9502***	0.9433***	0.1381***
Wednesday	-0.1452***	0.2313***	0.2384***	0.0166***	0.8867***	0.9490***	0.9420***	0.1394***
Thursday	-0.1471***	0.2415***	0.2469***	0.0207***	0.8857***	0.9483***	0.9411***	0.1402***
Friday	-0.1860***	0.2699***	0.2861***	-0.0199***	0.8412***	0.9095***	0.8952***	0.1675***

The statistical significance is based on the signed tests on the estimated coefficients, where ***, **, and * indicate a 99%, 95% and 90% significance level, respectively.

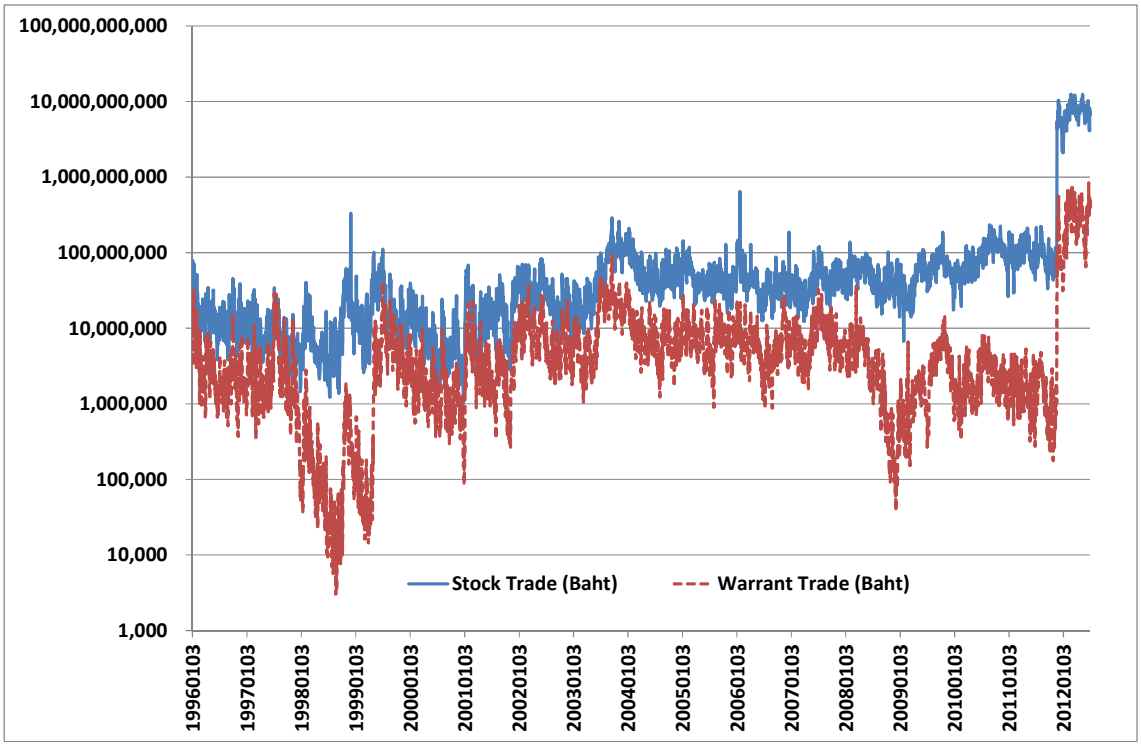

Figure 1
Daily Trading Volume of Warrants and Stocks

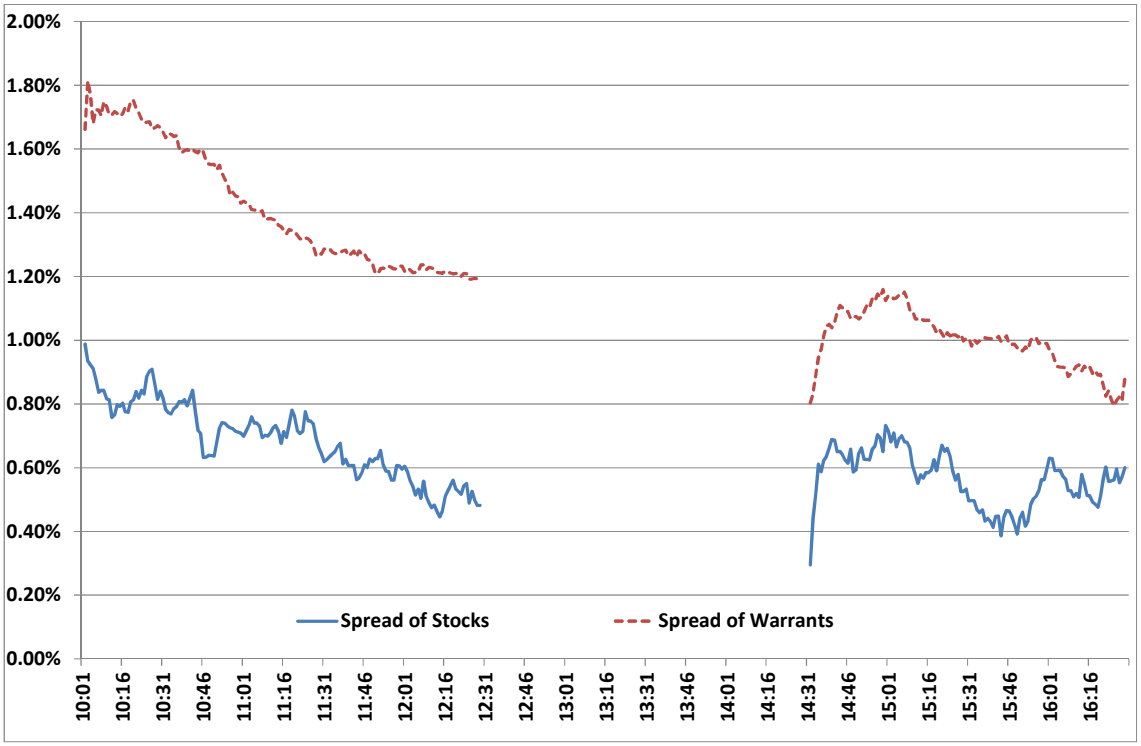

Figure 2
Intraday Spread of Warrants and Stocks

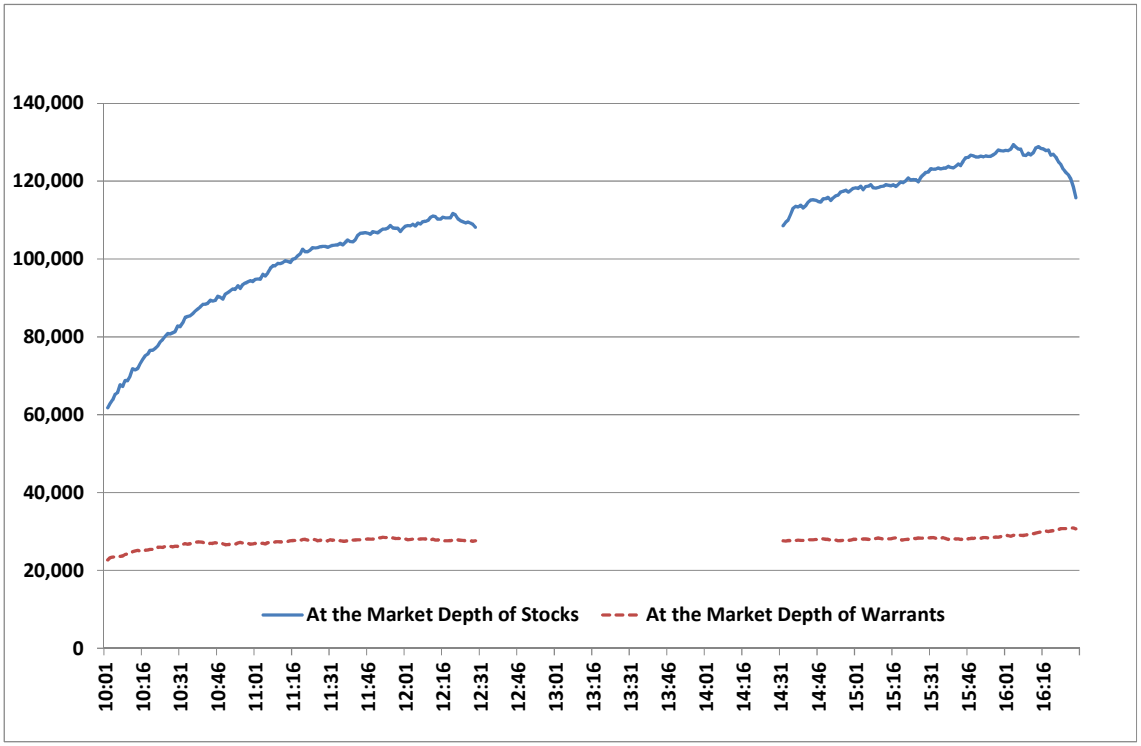

Figure 3
Intraday Pattern of At the Market Depth of Warrants and Stocks

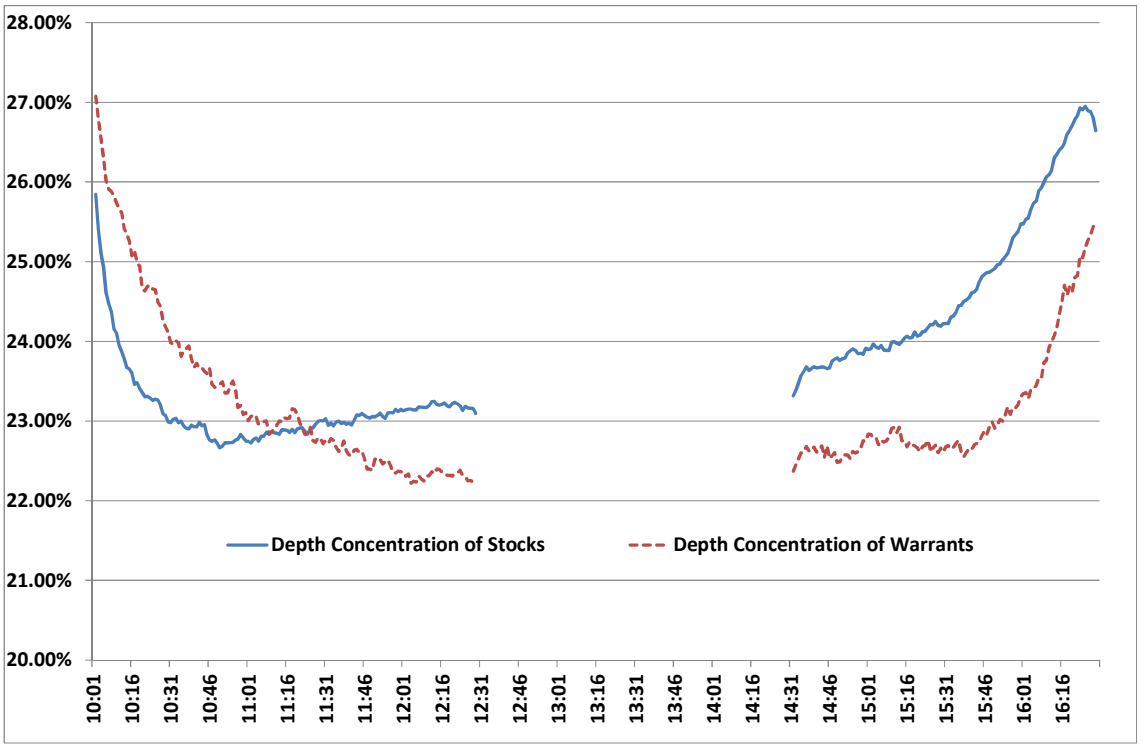

Figure 4
Intraday Pattern of Depth Concentration of Warrants and Stocks

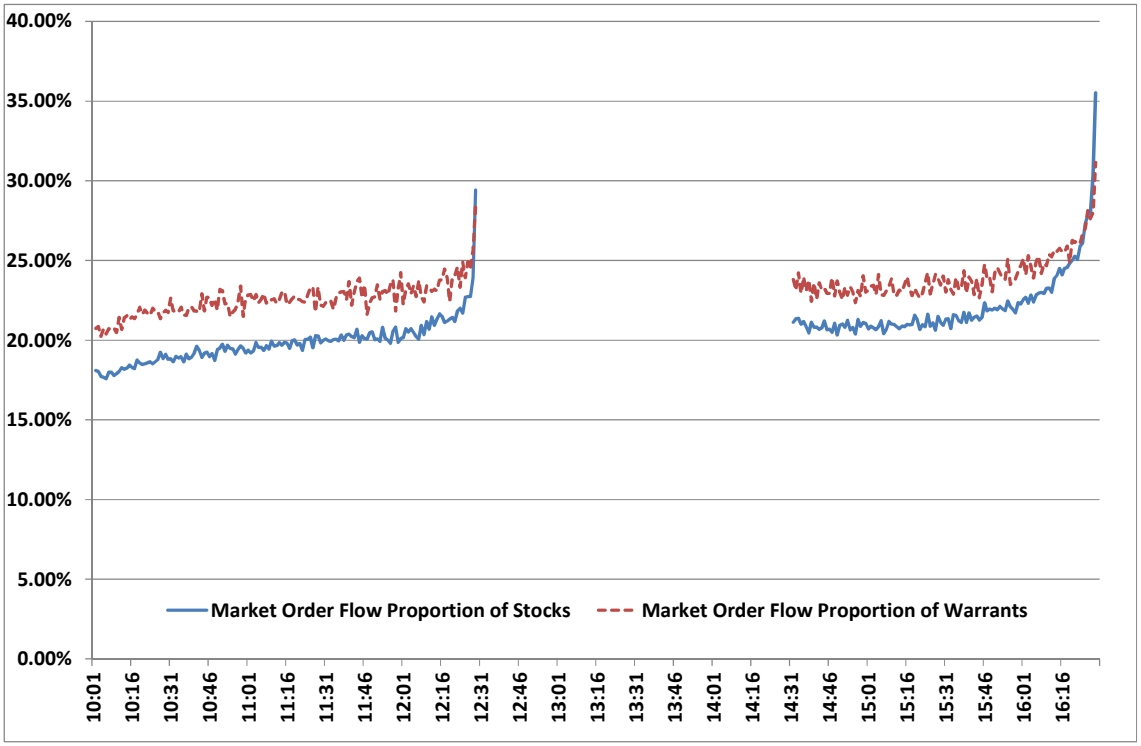

Figure 5
Intraday Pattern of Market Order Flow of Warrants and Stocks

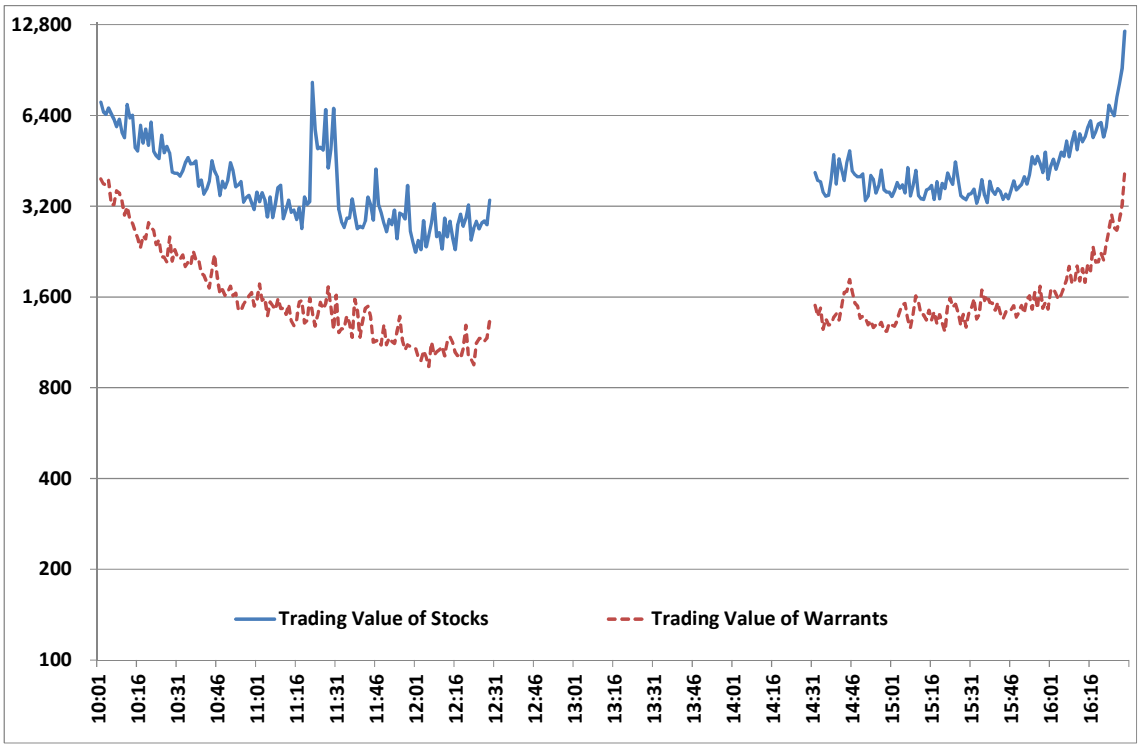

Figure 6
Intraday Pattern of Trading Value of Warrants and Stocks

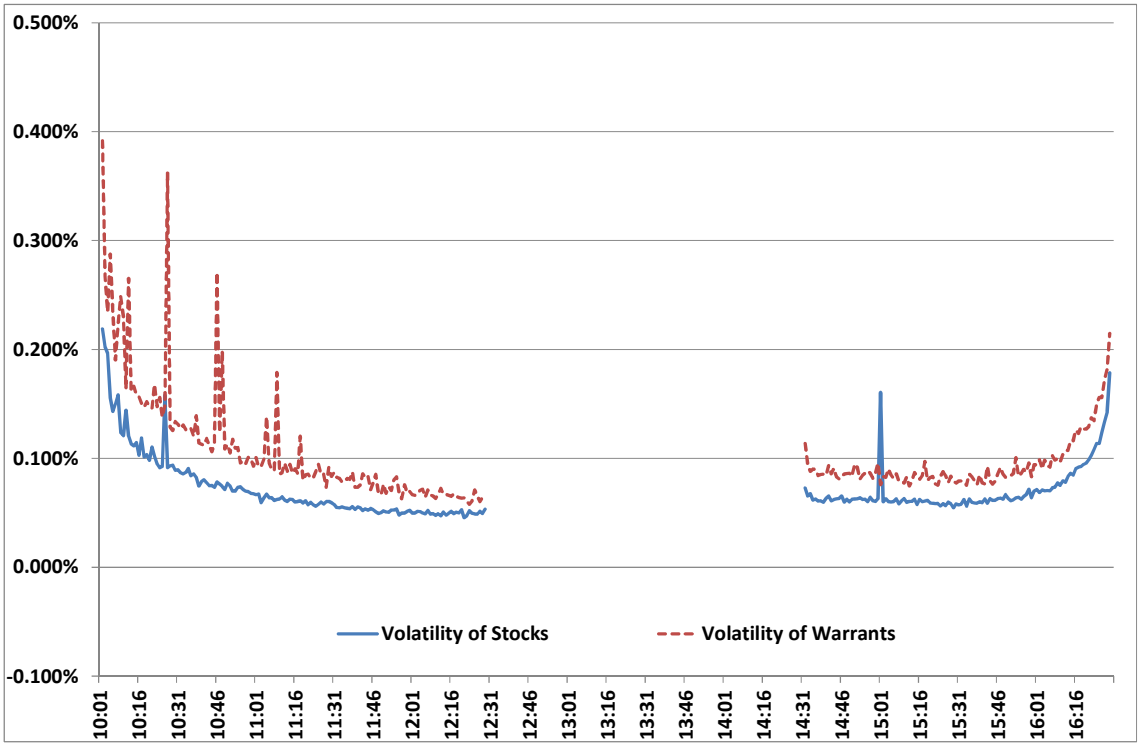

Figure 7
Intraday Pattern of Volatility of Warrants and Stocks

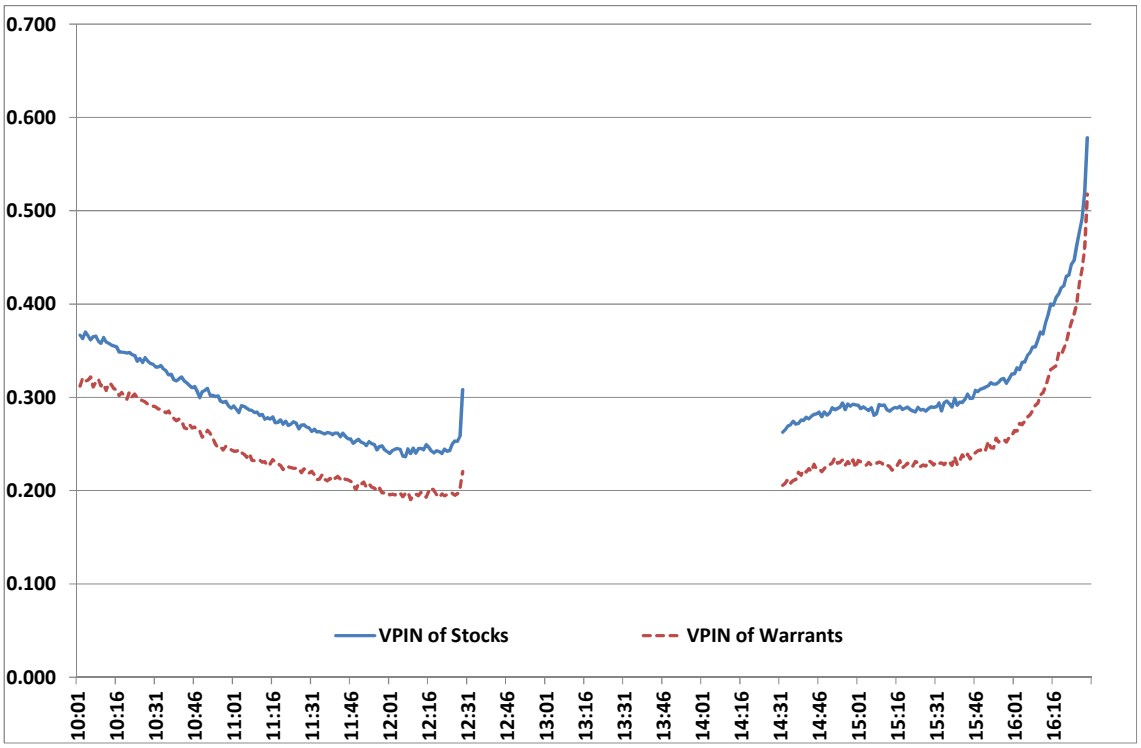

Figure 8
Intraday Pattern of VPIN of Warrants and Stocks