

# WARRANTS AND THEIR UNDERLYING STOCKS: MICROSTRUCTURE EVIDENCE FROM AN EMERGING MARKET

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## Abstract

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The Stock Exchange of Thailand provides an ideal platform for comparing the trading characteristics of warrants and their underlying stocks since both of them trade in the same market under identical trading rules. If their patterns diverge significantly, it may be possible for an astute trader to devise profitable arbitrage strategies during the life of the warrants. We find that both their patterns 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 document that flow toxicity is negatively related to spread and positively related to depth, market order flow ratio, trade size, trading volume, and volatility.

**Keywords:** Warrants, Spreads, Depths, Intraday Pattern, Thailand

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## 1. INTRODUCTION

Numerous studies (Admati and Pfleiderer 1988; Brock and Kleidon 1992; Foster and Viswanathan 1990; Jain and Joh 1988; McNish 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 patterns (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.

In this research, we ask the question of how the Stock Exchange of Thailand (SET)'s underlying market architecture affects the intraday patterns of derivative securities. We do this by using the limit order book of the SET, which 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.

## 2. 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 the 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 depth 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 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 bid-ask spread pattern as in 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.

*H1: Warrants and stocks 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 the 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 a 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 market indices are computed 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 non-tradable securities. In addition, investors may opt to trade at the market open in order to adjust their portfolio imbalances during the prior 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) lead to the following hypothesis:

*H2: Trading volume is higher at market opening and closing than at other times.*

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. Bernile, Hu, and Tang (2016), who examine informed trading ahead of U.S. macro-news announcements, find evidence that is consistent with informed trading.

King and Wadhvani (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 leads to the following hypothesis:

*H3: 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, 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 the bid or lowering the ask quote 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 the price. As a result, the asymmetric information component in the bid-ask spread declines and causes the total bid-ask spread to fall throughout the trading day. Easley, Lopez, and O'Hara (2012) consider order flow to be toxic if liquidity is provided at a loss. They develop a measure of flow toxicity based on the volume synchronized probability of informed trading for capturing the microstructure dynamics

of asymmetric information. Foucault, Kozhan, and Tham (2016) find that more frequent toxic arbitrage opportunities and faster responses to these opportunities impair liquidity.

Although McNish and Wood (1992) find a U-shaped 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 their underlying stocks. While both options and stocks have a widespread at the open, at the close, the spreads of options narrow, while the spreads of stocks widen again. They explain that the difference in spread variation arises from differences in the market architecture used by the two markets. On the 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 are expected to hold.

*H4: The bid-ask spread is high at the opening and declines throughout the day.*

*H5: 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 earnings announcement period specialists quote a widespread 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 leads to the following hypotheses.

*H6: Depth is low at the market opening and increases throughout the day.*

*H7: 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 to the number of limit orders submitted near the best quotes, i.e., at or above the best three quotes level on the limit order book, the following hypothesis should hold.

*H8: 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 the 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). VPIN is useful in measuring the high-frequency dynamics of asymmetric information that are

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. Van Ness, Van Ness, and Yildiz (2017) investigate the relation between high-frequency trading, order flow toxicity, stock price volatility during normal and high order flow toxicity periods. Employing the VPIN measure, they find a negative relation between high-frequency trading and order flow toxicity. 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 often 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 lead to the following hypotheses.

*H9: Flow toxicity is positively associated with liquidity measured by spread, depth, market order flow ratio.*

*H10: Flow toxicity is positively associated with volatility as the price is moved by trading of informed traders.*

### 3. 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 sessions from 10:00 am to 12:30 pm and 2:30 pm to 4:30 pm. The trading system uses a call market mechanism to determine the closing price of the day and the opening price in each trading session. Traders can place several order types - limit, at-the-open, at-the-close, immediate-or-cancel, fill-or-kill, and conditionally published orders.<sup>1</sup> 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 their underlying stocks. The trade file contains the trade time, record type (trade or quote), trade price, trading volume (in a 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.

Figure 1 shows that from 1996 to 2012 trading in warrants is quite active, especially after the second half of 1997 when the July trading volume is even higher than that of the underlying stocks. During the study period of 1996-2012, 270 companies were identified to have warrants trading on the SET. These warrants represent an average

monthly trading volume more than half of the volume traded by their underlying stocks.<sup>2</sup>

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 suggests that a higher frequency interval is more appropriate. We use a 1-minute interval and only select actively traded securities to a tradeoff between non-synchronous trading problems and stale trading problems.<sup>3</sup> Ding and Charoenwong (2003) have shown 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 the 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 a 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. Ninety-one pairs of warrants and stocks meet these criteria with each having an average of 261 trading days. These 91 warrants and stocks in the final sample represent more than 80% of the trading volume and the market capitalization of the original sample. They thus 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 maturity ranges 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 value in baht of the orders which are 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 two levels of the limit order book. The depth concentration is the ratio of market depth and the best three levels 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 arrived 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%.<sup>4</sup> The warrants have an average spread of 1.24%, which is higher than the stocks' spread of 0.66%. The higher percentage

<sup>2</sup> The high warrant trading volume is not surprising since there are several turbulent events in the data sample including: 1997 which was the year that the Asian Financial Crisis began; the 1998 Russian bond crisis; in 2001, the dot-com bubble burst; the 2007-2012 US subprime mortgage meltdown; and the 2011-2012 European debt crisis. The stock market was especially volatile in 1997 and warrants are the ideal vehicle for capitalizing on the volatility.

<sup>3</sup> Ideally, the intraday interval should be as short as possible to capture the details of the patterns.

<sup>4</sup> 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%.

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

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 1 shows 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 any significant 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 reflect the high level of information asymmetry given the overnight information that is yet to be incorporated into prices. This is consistent with studies that document lower information content earlier in the trading day (e.g., Biais et al. 1995). Hu (2017) documents that options listing increases both informed and uninformed trading, with an asymmetrically larger uninformed trading component. In unreported results, we find that 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 the minimum tick size in December 1997, combined with the growth in trading volume over time, results in a decline in spreads over time.

Market depth, the sum of 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 five levels 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 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 warrant traders use more aggressive limit orders in the morning while stock traders submit more aggressive limit orders in the afternoon. Warrants and stocks have a higher market order flow 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 volume of warrants is higher in the morning than in the afternoon while the opposite holds for the stock trading volume.

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 options and stock markets (e.g., McNish and Wood 1992). 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 their trades in accordance with the availability of liquidity.

### 3. RESEARCH METHODOLOGY

#### 3.1. Intraday variation of spreads, depth, market order, volume, volatility, and VPIN

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

$$Y_t = \hat{\alpha} + \sum_{h=1}^9 \beta_h dtime_{h,t} + \sum_{k=1}^5 \hat{\gamma}_k dweek_{k,t} + \hat{\epsilon}_t$$

subject to (1)

$$\sum_{h=1}^9 \beta_h = 0, \sum_{k=1}^5 \hat{\gamma}_k = 0$$

where  $Y_t$  represents the 1-minute interval of the bid-ask spread, market depth, next 2-level depth, depth concentration, market order flow, number of trades, trade size, trade volume, volatility, and VPIN.  $dtime_{h,t}$  are dummy variables that capture the 30-minute intraday variation and  $dweek_{k,t}$  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 the 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 ( $\alpha$ ) represents the cross-sectional average value of the variable of interest. Note that the numbers of observations for each stock are not equal because non-active 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.

While the 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.

According to Madhavan (1992), asymmetric information is resolved through trading. This explains the downward intraday pattern of spreads and the upward intraday pattern of market depth. In order to test whether asymmetric information falls over the course of trading, this study measures the high-frequency dynamics 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 flow toxicity. VPIN has an advantage over other measures when measuring asymmetric information at a high-frequency interval as it does not require an intermediate numerical estimation of unobservable parameters. Menkveld (2016) reviews the economics of high-frequency trading to single out the economic channels by which such trading affects market quality. Further, Brogaard, Carrion, Moyaert, Riordan, Shkilko, and Sokolov (2018) find that high frequency traders provide liquidity during extreme price movements by absorbing imbalances created by non-high frequency traders.

## 4. EMPIRICAL EVIDENCE

### 4.1. Pattern of spreads

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 the 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).<sup>5</sup> The intraday variation of relative spreads of warrants and stocks is shown in Tables 2 and 3. The bid-ask spread is highest between 10:00 a.m. to 10:30 a.m. Warrant and stock spread during 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 the trading day are significantly negative. For stocks, the dummy coefficients are significantly negative for the interval just before the morning session break and two 30-minute intervals before the end of the trading day. Nevertheless, the

<sup>5</sup> 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).

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.<sup>6</sup>

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 monopolistic specialist market of the NYSE. In contrast, warrants and their underlying stocks listed on the SET are traded under the same market structure and regulations, and both exhibit the same intraday reverse J-shaped 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 a downward trend in spreads over time; high spreads are observed after the market opens in both the morning and afternoon sessions.

### 4.2. Pattern of depths

Table 2 and Table 3 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 the opening and continually increase to their highest level at the closing. Compared to spreads, the intraday pattern of market depth is a reversed image of the intraday spread pattern. As shown in Figure 3, market depth is lowest at the opening and monotonically increases to its highest level at the 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 a U-shaped pattern with a 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, suggesting either that a limit order trader on average demands more compensation for providing liquidity than the spread or that there is a high degree of front-running activity among limit order traders. The U-shape pattern of depth concentration shown in

<sup>6</sup> 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.

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.

#### 4.3. The 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 2 and Table 3, 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 the lunch break, the market order ratio rises significantly. After the lunch break, the market order ratio falls during the first 30-minute interval before increasing. During the afternoon session, the market order ratio rises steadily and increases significantly during several periods before market closing. This pattern is likely to reflect the activity of day-trade investor who does not want to hold a 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 institutional liquidity traders, such as index fund managers, tend to use market orders. This observation is consistent with the results of this study, which show a large increase in market orders during market 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 2 and 3, the coefficients of a number of trades, trade size, trading volume, and volatility are significantly positive at the first and last trading intervals. There is evidence of a U-shaped pattern in the number of trades, trade size, and trading volume, confirming the same pattern found in many other markets, including U.S. markets, which have specialists and dealers to provide liquidity as a last resort, and pure limit order markets, such as those on the TSE, the Paris Bourse, and the HKSE. Figure 6 shows that the intraday variation of warrants and stocks trading volume on SET follows a U-shaped pattern. Consistent with previous studies, volatility of both warrants and stocks also exhibits a U-shaped 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.

#### 4.4. VPIN and flow toxicity

As shown in Table 2 and 3, the cross-sectional mean of VPIN varies from 19.9% to 33.7% for warrants and from 24.9% to 40.3% for stocks. VPIN is high at the market open but falls monotonically over time until the lunch break, after which it starts to rise again until its highest level at market closing. Figure 8 shows the U-shaped 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 can be resolved by trading. This implies that on the 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 a higher adverse selection component at the close. This may 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<sup>7</sup> 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 compensation for having to face a higher asymmetric information cost. However, as noted by Ahn et al. (2002), all of the models assume that 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 trades and quotes, the vector autoregressive model of Hasbrouck (1988) may be more appropriate.

#### 4.5. 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 volume, and volatility, when the intraday pattern is and is not controlled. Table 4 and 5 show that without controlling for intraday intervals, the flow toxicity is negatively associated with a 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 related to depths for both warrants (0.27) and stocks (0.27). This suggests that the presence of an 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 not only seek liquidity but they also design their order strategy so as to minimize trading costs and maximize the benefits from their information advantage by using market orders with a large trade size. Flow toxicity is positively

<sup>7</sup> A marketable limit order is a limit order placed at the best quote.

associated with volatility. Consistent with the price discovery process, trading by informed traders incorporates information into prices, thereby moving the price toward its fundamental value and increasing 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 4 and 5, 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 between flow toxicity and other variables.

## 5. CONCLUSIONS

The results of this study show that market structure has a significant effect on the intraday pattern of spreads, 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 the SET are compared in this study. If their patterns diverge significantly, it may be possible for an astute trader to devise profitable arbitrage strategies during the life of the warrants. This paper finds that the intraday patterns of spreads, depth, market order ratio, volatility, and volume are similar for both warrants and stocks. 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 volume, 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 market closing. The depth concentration, trading volume, volatility and flow toxicity have a U-shaped pattern. The volatility of warrants is higher than stocks, but the flow toxicity of stocks is higher than that of warrants.

This study also shows the negative association of flow toxicity and spreads. Depths, market order ratio, trade size, trading volume, and volatility all have a 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 between flow toxicity and market order ratio implies a strategic market order submission by an informed trader. The positive association of flow toxicity and volatility is evidence of permanent price movement as a result of informed trading.

Given recent advances in trading platforms and new technologies, it would be interesting for future research to examine patterns of trades and orders from online trading platforms that capture even higher frequencies of trading and even more precise timestamps in the nano-seconds, which are absent in the current research.

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## APPENDIX

## VPIN Measurement

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

$$VPIN \approx \frac{\sum_{\tau=1}^n |v_{\tau}^B - v_{\tau}^S|}{nV} \quad (2)$$

where  $v_{\tau}^B$  and  $v_{\tau}^S$  represent buy and sell volumes included in the  $\tau$  volume bucket, and  $n$  is the number of buckets used to approximate the expected trade imbalance. Following Easley, Lopez and O'Hara (2012), we use  $n=50$  buckets so  $V$  is 1/50 of the average daily volume. We classify each trade based on the Lee and Ready (1991) algorithm. A trade is buyer-initiated if price is above the midpoint, and vice versa.

**Table 1.** Descriptive statistics of limit order book and trade of warrants and stocks

	Morning			Afternoon				
	Mean	Median	S.D.	Mean	Median	S.D.	Mean Diff	t-stats
<i>Panel A: Warrants</i>								
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 volume	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
<i>Panel B: Stocks</i>								
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 volume	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 the limit order book and trades 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 baht at the best quotes in the limit order book. Next 2-Level depth is the sum of shares in hundred 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 the number of market orders to the number of limit orders submitted at or better than the 3<sup>rd</sup> level in the limit order book. Trade size and trading volume are measured in hundreds of baht. Volatility is the absolute percentage price change. VPIN is the volume synchronized probability of informed trading computed by the Easley, Lopez and O'Hara (2012) method.

Table 2. Intraday patterns of warrants

	Spread	At the market depth	Next 2-level depth	Depth concentration	Market order flow	Number of trades	Trade Size	Trading volume	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:

$$Y_t^{1-min} = a + \sum_{h=1}^9 \beta_h dtime_{h,t} + \sum_{k=1}^5 y_k dweek_{k,t} + \varepsilon_t$$

subject to

$$\sum_{h=1}^9 \beta_h = 0, \sum_{k=1}^5 y_k = 0$$

where  $Y_t^{1-min}$  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 3. Intraday patterns of stocks

	Spread	At the market depth	Next 2-level depth	Depth concentration	Market order ratio	Number of trades	Trade Size	Trading volume	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:

$$Y_t^{1-min} = a + \sum_{h=1}^9 \beta_h dtime_{h,t} + \sum_{k=1}^5 y_k dweek_{k,t} + \varepsilon_t$$

subject to

$$\sum_{h=1}^9 \beta_h = 0, \sum_{k=1}^5 y_k = 0$$

where  $Y_t^{1-min}$  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 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 4.** Spearman correlation of flow toxicity (VPIN) with limit order book and trade characteristics of warrants

	<i>Spread</i>	<i>At the market depth</i>	<i>Next 2-level depth</i>	<i>Depth concentration</i>	<i>Market order ratio</i>	<i>Trade Size</i>	<i>Trading volume</i>	<i>Volatility</i>
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***

Note: The computation of the volume synchronized probability of informed trading (VPIN) follows the procedure suggested by Easley, Lopez and O'Hara (2012). VPIN measures the flow toxicity and is captured by:

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

We use n=50 bucket so V is 1/50 of the average daily volume and classify each trade based on the Lee and Ready (1991) algorithm. A trade is buyer-initiated if price is above the midpoint, and vice versa. Statistical significance is based on signed tests of the estimated coefficients, where \*\*\*, \*\*, and \* indicate a 99%, 95% and 90% significance level, respectively.

**Table 5.** Spearman correlation of flow toxicity (VPIN) with limit order book and trade characteristics of stocks

	<i>Spread</i>	<i>At the market depth</i>	<i>Next 2-level depth</i>	<i>Depth concentration</i>	<i>Market order ratio</i>	<i>Trade Size</i>	<i>Trading volume</i>	<i>Volatility</i>
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***

Note: The computation of the volume synchronized probability of informed trading (VPIN) follows the procedure suggested by Easley, Lopez and O'Hara (2012). VPIN measures the flow toxicity and is captured by:

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

We use n=50 bucket so V is 1/50 of the average daily volume and classify each trade based on the Lee and Ready (1991) algorithm. A trade is buyer-initiated if price is above the midpoint, and vice versa. Statistical significance is based on signed tests of the estimated coefficients, where \*\*\*, \*\*, and \* indicate a 99%, 95% and 90% significance level, respectively.

Figure 1. Daily trading volume of warrants and stocks

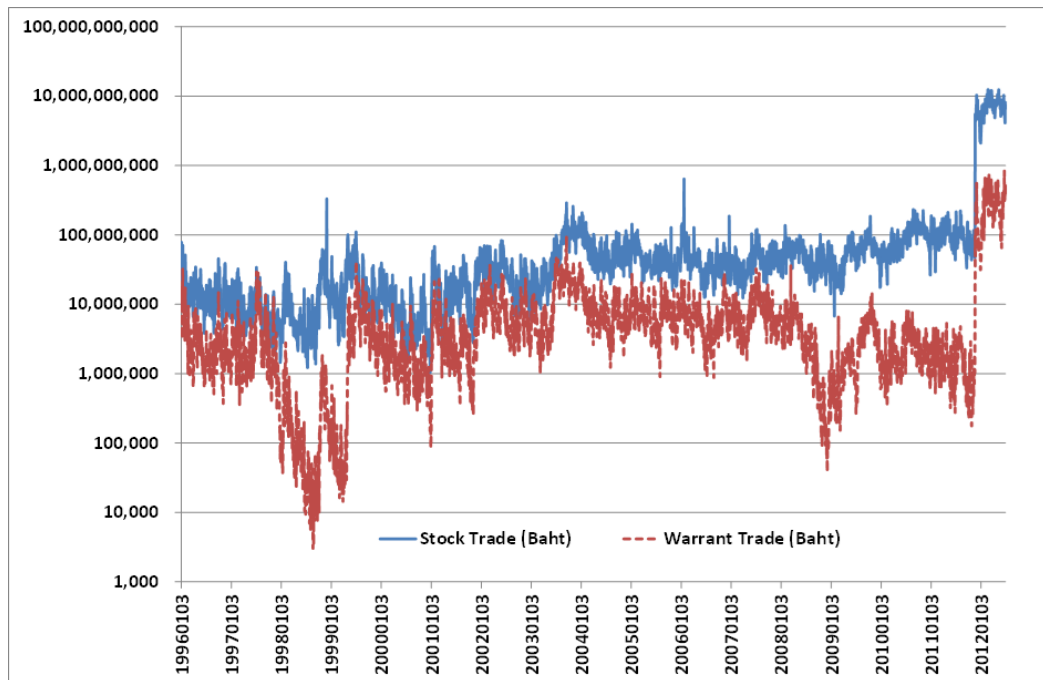
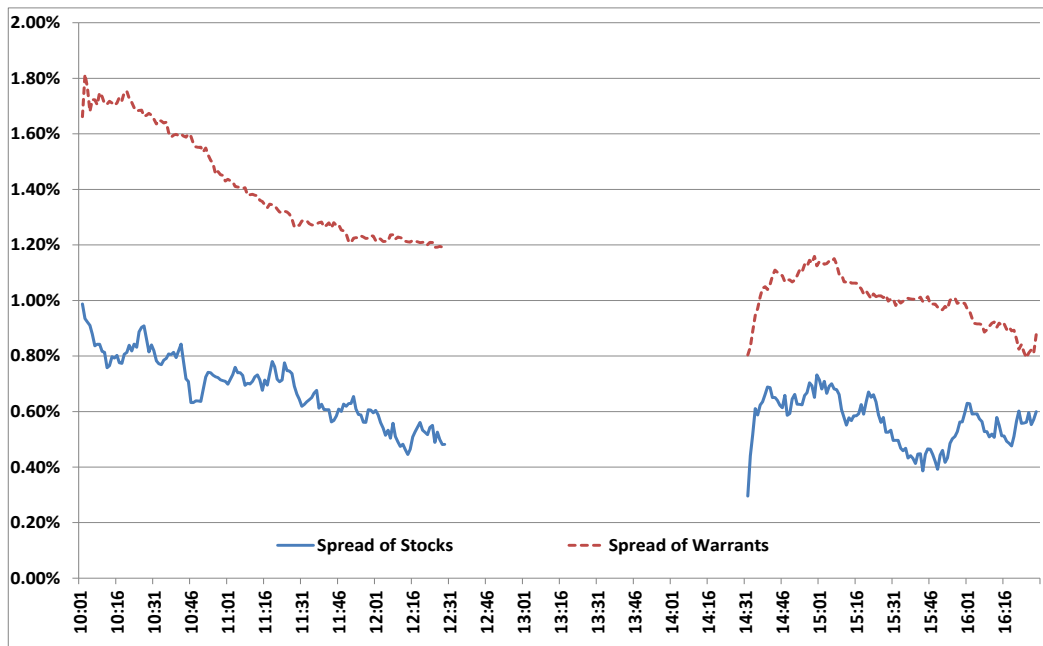
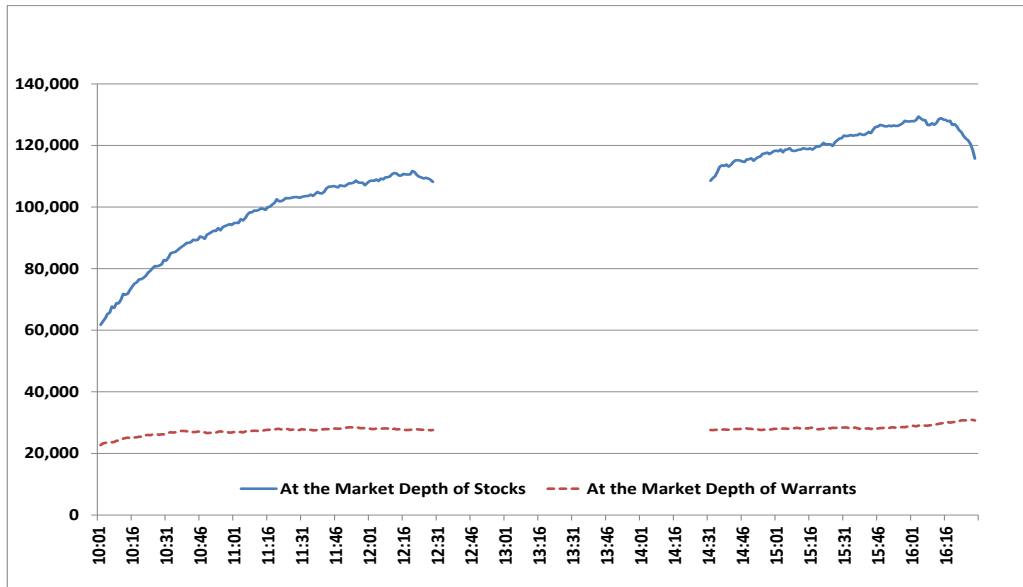


Figure 2. Intraday spread of warrants and stocks



**Figure 3.** Intraday pattern of at the market depth of warrants and stocks



**Figure 4.** Intraday pattern of depth concentration of warrants and stocks

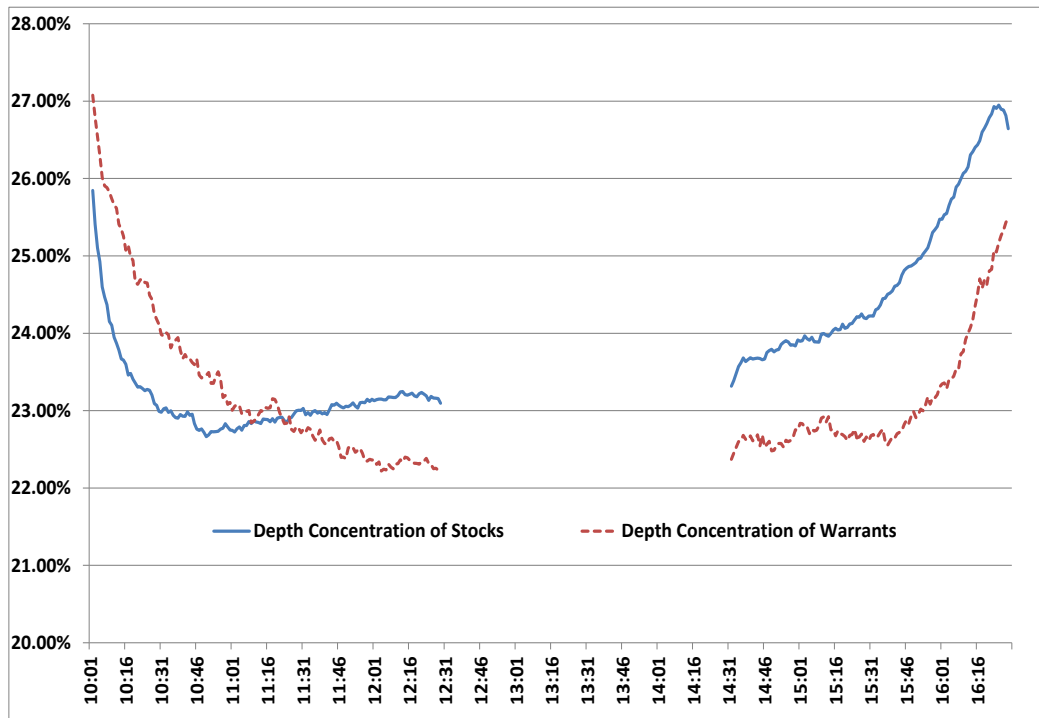




Figure 5. Intraday pattern of market order flow of warrants and stocks



Figure 6. Intraday pattern of trading volume of warrants and stocks

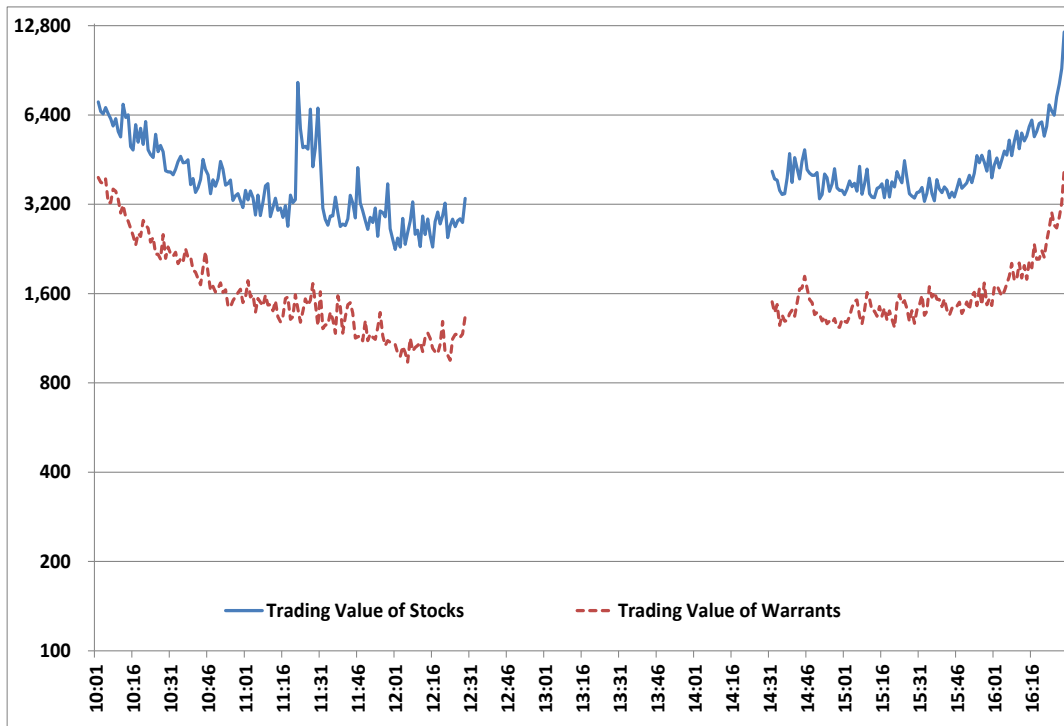


Figure 7. Intraday pattern of volatility of warrants and stocks

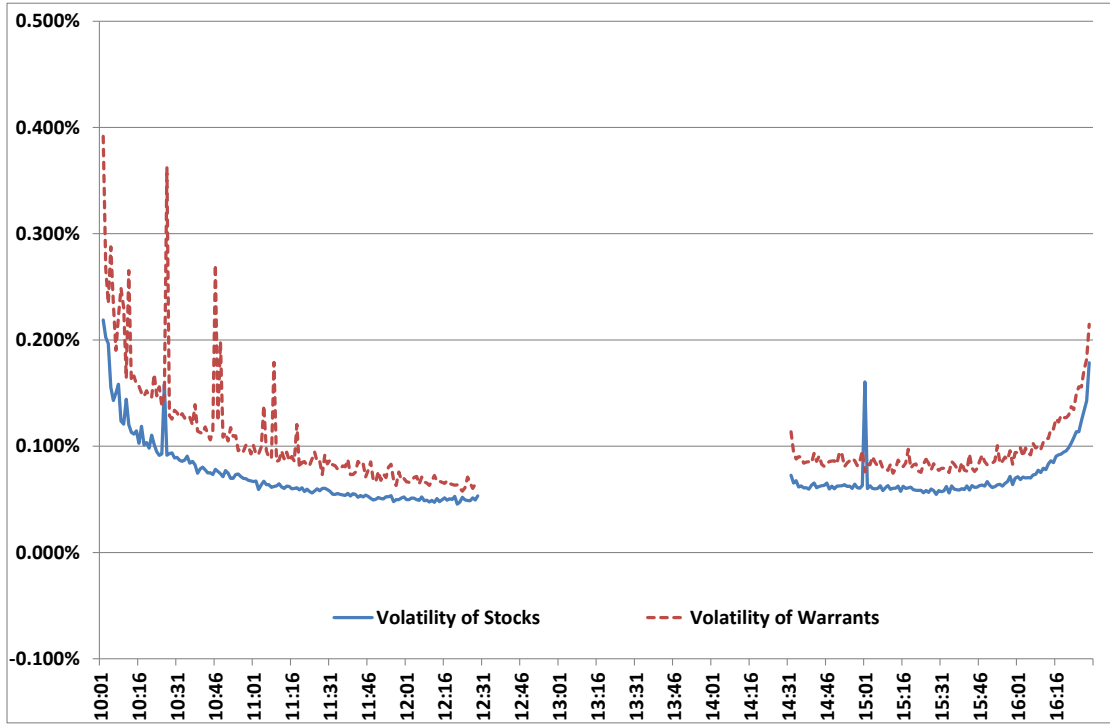


Figure 8. Intraday pattern of VPIN of warrants and stocks

