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Spread, Depth, and Order Flow Patterns of Warrants and their Underlying Stocks on the Stock Exchange of Thailand

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Abstract

This study compared the trading characteristics of warrants and their underlying stocks. The Stock Exchange of Thailand provided 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. Hence, the impact of trading protocol on intraday variation and an informed trader's decision to buy warrants or stocks was controlled. The paper found that they have a similar downward sloping pattern of spreads, adverse selection component, and liquidity immediacy, U-shaped for volatility and trading volume, and upward-sloping for depth and market order ratio. After controlling for the intraday patterns, spreads are positively associated with liquidity immediacy and negatively related to the market order ratio and total depth. The results indicate that the market structure does affect the intraday pattern of trading characteristics.

JEL Classifications: G10; G82

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

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Warrants and Their Underlying Stocks

1. Introduction

Numerous studies have reported and explained the existence of an intraday pattern of quote- and trade-related variables on the stock market, but little research has been done on the intraday pattern of warrants in a limit order market. Early studies by Wood, McInish, and Ord (1985), McInish and Wood (1992), Foster and Viswanathan (1990), and Jain and Joh (1988) document the reversed-J shape pattern of spreads and U-shape pattern of volume for NYSE stocks. Admati and Pfleiderer (1988) use a game-based model to show that traders use clustering to benefit from the liquidity provided by other traders. Brock and Kleidon (1992) investigated the effect of periodic market closures on volume and bid ask spreads. During market closing, investors' holdings deviate from the optimal portfolio due to their inability to trade when new information arrives, which results in a high demand to trade at the opening to reestablish the optimal portfolio. The higher trading activity before market closing reflects the demands of day traders and fund managers, who trade to minimize index-tracking errors because most indices are computed with the closing price. Consequently, the high trading demand after the opening and before the closing increases trading volume and lowers bid-ask spreads compared to the rest of the day.

The intraday patterns of spread and volume do not only exist in quoted markets such as the NYSE or NASDAQ. Lehman and Modest (1994) and Ahn and Cheung (1999) document an intraday variation of the bid-ask spread and volume on the Tokyo Stock Exchange (TSE) and on the Hong Kong Stock Exchange (HKSE), which operate without market makers. However, 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 has been

conducted to investigate the intraday behavior of such securities traded in a pure order driven market.

This study of the limit order book on SET aimed to provide evidence about the importance of the underlying market architecture to the intraday patterns of derivative securities. For this study, it was important for tests to be performed on both the warrant and stock markets while controlling for the underlying market architecture. Fortunately, The Stock Exchange of Thailand (SET) trades both warrants and their underlying stocks on the same board under the same trading rules and market setup. Trading of the securities occurs in an automated limit order trading system in which the warrants are actively traded relative to their underlying stocks. The volume of the warrants traded was 26.9% and 51.3% of the underlying stocks in 1994 to 1996 and 1997, respectively. The intraday pattern of bid-ask spreads and order flows of the warrants together with their underlying stocks was compared in this study. If the market structure has an influence on intraday patterns (see Chan, Chung, & Johnson, 1995), both warrants and stocks should exhibit a similar intraday pattern of spreads and volume.

In addition, the intraday order flow pattern of warrants and stocks was examined. Bae, Jang, and Park (2003) found that on the NYSE the mean proportion of limit orders was highest during the market opening when the spread was large and volatility was high. As such, the proportion of limit orders monotonically declined to its lowest level at the market closing when the spread was small and volatility was low. Their results show that limit order traders may choose to wait before they trade, submit a market order, or submit a limit order away from the best bid or ask quote. Moreover, by controlling for the intraday pattern, this present study aimed to shed light on the competition among limit order traders and strategic order submissions in

both stocks and warrants trading. The findings of this study should be of interest to regulators, traders, and international portfolio managers.

This study found that the intraday spreads for both warrants and stocks were highest at the market open and declined during the day. Because these securities trade under the same market structure and trading rules, the findings strengthen the argument that market architecture does affect the intraday pattern of spreads (see Chan et al., 1995). In addition, market depth and total depth increased over time. The liquidity immediacy, a ratio between market depth and total depth, became lower over the trading day. The market order proportion increased throughout the trading day, and market orders were highest at the closing. SET exhibited the typical U-shaped pattern for volatility and volume. In general, there were no statistical differences between the various intraday patterns of warrants and their underlying stocks.

After controlling for the intraday pattern, it was found that stock and warrant spreads were not associated with market depth, but spreads were negatively associated with total depth. In addition, spreads were positively associated with liquidity immediacy but negatively related to market order submissions. The positive association of spreads and liquidity immediacy supports the idea of competition among limit order traders. Higher spreads imply a higher expected reward for limit order trades and attract more immediate liquidity from liquidity providers. Spreads, which are a cost of immediacy to market order traders, were negatively related to the market order ratio of both warrants and stocks. This suggests that traders avoid using market orders compared to limit orders when execution costs are high.

The rest of this paper is organized as follows. Section 2 reviews the pertinent literatures and develops the hypotheses. Section 3 describes the market architecture of the SET, data and methodology. Section 4 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. Section 5 summarizes and concludes.

2. Literature Review and Hypotheses

Many studies show that trading mechanisms have a significant effect on the intraday pattern of trade and quote variables. Amihud and Mendelson (1980) found 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 stems from the fact that market makers try to stabilize prices and alleviate their cumulative inventory imbalance. They conclude that the open-to-open returns would capture the price behavior in a call market used at the opening trade, while the price impact of market makers' influence should be examined in the close-to-close returns. Chan, Christie, and Schultz (1995) and Chan et al. (1995) argue that the difference of market power between the specialists in the NYSE and the dealers in NASDAQ and CBOE cause intraday variations in bid-ask spreads. They found that bid-ask spreads for NYSE stocks follow a U-shaped pattern, but spreads of NASDAQ stocks and CBOE options traded near the market closure are narrower.

Besides the trading mechanisms, intraday patterns were 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 & Rendleman, 1982; Stephan & Whaley, 1990; Vijh, 1990) investigated the interrelationship between option and stock markets, but they did not find enough evidence to pinpoint where

informed traders initiate their trades. Chan, Chung, and Fong (2002) suggest that the lower liquidity in options markets compared to stock markets makes the informed trader hesitate to initiate trade in options markets.

Easley, O'Hara, and Srinivas (1998) show that depending on the depths and the availability of leverage informed traders 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 participate in trading around closing period more than 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 should 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, explain that these 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 make a profit out of their information, whereas market makers have full knowledge of the order flows and 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. Hence, for the price to be informative, the presence of the liquidity trader is necessary.

Admati and Pfleiderer (1988) show that liquidity traders decide to concentrate their trades in periods close to the realization of their demand. The trading concentration would, in turn, attract informed traders to trade against them. However, it is still an optimal strategy for liquidity traders because the trading cost is minimized when they trade around the same time of the day. This model implies that during periods of high trading volume prices are relatively informative and trading costs are low.

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. Liquidity traders can receive private information by waiting for public announcements. If the information accumulated by an informed trader is higher during the weekend, assuming that the accuracy of a public announcement during the weekend is not different from an overnight announcement, the adverse selection problem would be more severe on Monday than on other days. This situation results in low trading volumes and high trading costs on Monday, when informed traders exercise their private information because they know their information has a short

lifespan. The trading pattern should be more pronounced for firms with more and better public information. Consequently, informed traders trade aggressively before the information is released to the public, and liquidity traders delay their trading. Therefore, it is possible to infer the private information from that period. Again, when the trading volume is lower, prices are more informative, and trading costs are higher.

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 the 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 the performance of these funds is measured on how closely the fund tracks an index. The tracking error would be smaller when trading at the end of a period because the index is calculated using closing prices. Moreover, their model predicts that liquidity risk is higher when holding on to 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. A higher volume at the end of a period may also come from the trades of institutional investors to mimic an index. 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 the opening and at the closing.*

Price volatility could be a result of a permanent price movement due to new information, a temporary price change due to liquidity trading, or both. Observing

high volatility during trading periods does not reveal the source of the volatility. On one hand, high volatility during trading periods could stem from temporary price changes due to liquidity trading. On the other hand, new public information arrives frequently during business hours and results in high volatility during trading periods. French and Roll (1986) separate these two arguments about volatility. They compared the volatility over a special event, when the New York Stock Exchange closed for 2 days and other business entities stayed opened, with the volatility over the normal weekday period. If information is the only source of volatility, the variance over a 2-day exchange holiday should be double that of normal weekday variance. Their results show that the variance of a 2-day exchange holiday was only 14% higher than those of the normal period. This result supports the argument 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 found that because of a concentration of U.S. macroeconomic announcements on Thursday and Friday the volatility in the U.S. foreign exchange market was higher for all currencies during the first hour of Friday trading. In addition, a contagion effect caused an increase or decrease of volatility in one market as a result of activity in another market. King and Wadhwani (1990) proposed a model where traders in one market infer information from another market, resulting in market integration. They predicted 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, Fong, Kho, and Stulz (1996) found 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. 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 at the closing of trading sessions.*

Previous literature view the bid-ask spread as a measure of trading costs or a 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. Hence, the inventory imbalance would likely be most severe at the closing 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 should be 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 should decline and make the total bid-ask spread fall throughout the trading day.

Although the early study by McInish and Wood (1992) describes the U-shape pattern of spreads for stocks listed on the NYSE, the intraday patterns of spreads found on other exchanges are different. Chan et al. (1995) compared the intraday pattern of spreads for actively traded CBOE options and their NYSE-traded underlying stocks. They found that the bid-ask spread pattern of options is different from that of the underlying stocks. While both options and stocks have a wide spread

at the open, their spreads are different at the close. At the close, the spreads of options are narrow, while the spreads of the stocks become wide again. They explain that the difference in spread variation arises from the differences in the market architecture used by the two markets. On CBOE, market makers compete with each other, whereas the market making at the NYSE is monopolistic. Consistent with the competing hypothesis, Chan et al. (1995) and Affleck-Graves, Hedge, and Miller (1994) found 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: *An adverse selection component in bid-ask spread falls throughout the day.*

Copeland and Galai (1983) point out that the bid and ask quotes placed by market makers can be viewed as a straddle option, where the difference of straddle prices forms the bid-ask spread. Lee, Mucklow, and Ready (1993) found that during the 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. Hence, 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 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. Trading at the market close could help minimize tracking errors because the index level is generally computed from the closing prices of its constituency stocks. Moreover, day traders also use market orders to close their positions around the closing period. Thus, if the market order ratio is defined as the number of market orders divided by the number of total orders, the following hypothesis should hold:

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

While the bid-ask spread compensates limit order traders for providing liquidity immediacy, it is a cost for market order traders. Biais, Hillion, and Spatt (1995), Chung, Van Ness, and Van Ness (1999), and Bae, Jang, and Park (2003) found 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, it is an optimal strategy to use market orders when the cost of doing so is low and to use limit orders when the cost is high. In addition, among limit order traders, the competition to provide liquidity is higher when the compensation (i.e., spread) of doing so is high. These arguments led to the following hypotheses:

Hypothesis 9: *There is a positive relationship between bid-ask spread and liquidity immediacy.*

Hypothesis 10: *There is a positive relationship between bid-ask spread and market order ratio.*

3. Market Architecture, Data and Methodology

3.1 Market Architecture of Stock Exchange of Thailand

SET had operated under the open auction through the trading floor since its inception on April 30, 1975. After May 31, 1991, the trading system was changed to an automated limit order trading system called the Automated System for the Stock Exchange of Thailand (ASSET). The exchange has five trading boards: main, foreign, big lot, odd lot, and special. Common stocks, preferred stocks, warrants, and unit trusts are traded on the main board, big lot board, and odd lot board. Only stocks registered under foreigners' names are traded on the foreign board. Government and state enterprise bonds, debentures, and convertible debentures are traded on the special board. Each trading unit, called "board lot," contains 100 shares of a security, but for stocks trading at 500 baht or more for 6 consecutive months, one board lot equals 50 shares. Orders of less than one board lot are traded on the odd lot board, while orders of more than 3 million baht or 1 million shares are traded on the big lot board.

The ASSET system consists of two trading possibilities: Automatic Order Matching (AOM), which is the main system; and Put-Through (PT), which is the support system. Under AOM, brokerage firms submit their orders on-line to the ASSET system, and the orders are arranged according to price-then-time priority. Under PT, brokers can deal and negotiate directly between each other, and the price can be changed and may not follow the price spread rules. When the negotiation is complete, the result is sent to the ASSET system for approval. Only trading on the special board and the big lot board can be done on the PT system. The foreign board can use both the AOM and PT systems.

Trading on SET occurs from Monday to Friday, excluding public holidays, in two trading sessions each day. The morning and afternoon sessions operate from 10:00 a.m. to 12:30 p.m. and 2:30 p.m. to 4:30 p.m., respectively. The local time of Thailand is GMT + 7 hours. ASSET determines the opening price of each security in the morning and afternoon sessions using a call market system. The opening price is determined according to three criteria: First, the opening price must generate the highest trading volume; second, if more than one price has the highest trading volume, the price closest to the preceding closing price will be chosen; and third, after fulfilling the first two criteria, if there is still more than one price, the highest price becomes the opening price. Note that the last criteria could result in a bullish bias. Currently, the call market system is used to calculate the opening and closing price of a security at opening and closing times, but during the year 1997, the call market system did not exist at closing time.

ASSET allows traders to place seven order types: market order, limit order, at-the-open order, at-the-close order, immediate-or-cancel order, fill-or-kill order, and conditioned published order. Market order is simply an order to buy or sell securities at the best prevailing price. Limit order is an order to trade at a price no worse than the limit price specified. If no trade occurs, the order will stand as an offer to trade in the limit order book. At-the-open orders and at-the-close orders are orders to buy or sell securities at the opening price or at the closing price. The immediate-or-cancel order is an order to buy or sell securities immediately at a specific price. If there is any unmatched volume, the remaining volume will be canceled. The fill-or-kill order is an order to buy or sell the whole ordered volume at a specific price. If this condition cannot be met, the order will be canceled. The conditioned published order is an order that allows a trader to reveal some portion of his or her order size and hide the

remaining order from the public. The volume of a published order must be at least 10 board lots and indicate an equal number of shares to be published or revealed. When the revealed portion is transacted, the next portion is placed in the queue until the whole ordered volume is completely transacted.

3.2 Data Description

The data set provided by SET contains orders and trades for all warrants and underlying stocks from January 2, 1997 to December 31, 1997. Each record in the order file consists of the order arrival time stamped to the nearest one-hundredth of a second, the order identification (ID), the buy- or sell-order indicator, the ordered price, the number of shares ordered, and the order instructions. The status of an order by the end of a trading day is also included in the order file. This order status can be only one of the following four types: opened, matched order, canceled by firms, or canceled by the system. The trade file contains the traded time, the trade ID, the traded price, trading volume in number of shares, and the IDs of the corresponding bid and ask orders.

This study covers the period from January 2, 1997 to November 1997. The month of December 1997 is truncated to control for the possible impact of the new ceiling floor rule implemented on December 1, 1997. Both warrants and their underlying stocks were used in this study. Figure 1 shows that during 1997 the average trading volume of warrants averaged 6,541 million baht a month, which was 51.3% of the volume traded by their underlying stocks. In order to compare trading activities across different time periods, the trading volume was collected from 1994 to 1996, available on the Integrated Stock Exchange of Thailand Information Management System (usually called I-SIMS CDs), and the average monthly trading

volume of warrants was computed. During 1997, the average monthly trading volume of warrants was about 4,473 million baht, or 26.9% of the volume traded by their underlying stocks. These preliminary results show that the warrants on SET were actively traded. In addition, the warrant to stock trading ratio in 1997 had almost doubled from the previous period. In fact, during July 1997, the trading volume of warrants exceeded that of their underlying stocks. In 1997, a financial crisis in Thailand swept through much of Asia. It began when the Thai government freely floated the baht on July 2, 1997. Hence, the high trading activity of warrants supports the argument that traders use warrants to take advantage of volatile trading.

For the intraday analysis, a 30-minute interval was used as a tradeoff between non-synchronous trading problems and stale trading problems. If a 1-hour interval is chosen, trades and quotes in the same interval but on different days may not be comparable. In addition, using long intervals would not provide enough intervals per day, and the intraday variations might not stand out clearly. On the other hand, if a 1-minute interval is used, order- and trade-related variables may not be informative or computed because too many intervals are without orders and/or trades.

Thirty-nine warrants were traded on SET in 1997. A number of these warrants and their underlying stocks were not traded on every trading day. A recent study by Ding and Charoenwong (2003) shows that the bid-ask spread of thinly-traded futures contracts computed from days with trades are more informative than those computed from days without trades. In light of this finding, the following criterion was used for the sample selection. Each of the sample warrants and underlying stocks must have had at least 40 synchronously trading days with more than 20 trades a day. This criterion reduced the data from 39 pairs of warrants and stocks to 26 pairs. As discussed earlier, securities with very low prices could be constrained by minimum

tick size and, consequently, have very large relative spreads. To reduce the impact of minimum tick size on relative spreads, the trading days when either warrants or stocks traded below 5 baht were not included. This additional criterion reduced the sample to 19 pairs of warrants and underlying stocks, with an average of 129 trading days for each security.

Table 1 contains detailed characteristics about the sample warrants and underlying stocks. Given the above sample selection criteria, it is not surprising that the sample securities mostly came from the finance and securities industry (11 out of 19) because this industry is the most actively traded on SET. Most of the sample warrants were long-term call options, whose maturity ranged from about 1 year to almost 5 years. Given the long maturities, it is not surprising that most warrants were issued as deep-out-of-the-money options. The average prices of the warrants and underlying stocks varied from 9.1 to 85.57 baht and from 17.65 to 331.23 baht, respectively.

Traded and quoted variables were measured as follows. The bid-ask spread was defined as the difference between the best bid and best ask prices divided by the midpoint of the quotes. The market depth was based on the total number of shares posted at the best bid and best ask prices. The total depth or thickness of the book was the total number of shares from orders currently standing in the book. In addition, volatility, trading volume, and market order ratio were computed, where volatility was the average value of absolute returns, trading volume was the sum of trading volume in the interval and measured in terms of million baht, and market order ratio was the number of market orders that arrived in the interval divided by all orders that arrived in the same interval.

Most of warrants and stocks in the data set ranged in price from 10 to 50 baht and had a minimum tick size of 0.5% to 2.5%. The warrants had an average spread of 2.7%, higher than the stocks' spread of 1.7%. The minimum nominal price change was not uniform across prices because, as mentioned earlier, SET aims to balance the percentage of minimum price change, so there are different tick sizes for different prices. A stock with a trading price of 5 baht had a minimum price change of 2%, while a stock price of 20 baht had a minimum price change of 1%. Low-priced securities tended to have a higher spread. The cross-sectional average market depths were 45,766 shares for warrants and 74,189 shares for stocks. In terms of volume, there were five warrants in the top 20 for trading volume during 1997, indicating a relatively high liquidity of warrants compared to stocks.

Table 2 and Table 3 show the cross-section statistics of order file, limit order book, and trade file in the morning and afternoon sessions of warrants and stocks, respectively. The parametric paired t-test and the non-parametric signed rank test were used to find the difference between variables in the morning and afternoon sessions. Warrants and stocks had a higher number of orders in the morning than in the afternoon. The number of morning orders of warrants and stocks was 366 and 331 orders, respectively, while the number of afternoon orders of warrants and stocks was 264 and 229 orders, respectively. The proportions of fully executed orders were higher in the morning: 9.04% for warrants and 4.21% for stocks. Both stocks and warrants had a higher rate of marketable order arrivals and larger marketable order sizes in the afternoon than in the morning. A comparison of the order file in the morning and in the afternoon suggests the possibility of an intraday variation of orders.

For the limit order book, the absolute spread was the difference between the best ask and best bid, and the relative spread was the absolute spread divided by the average of the bid and ask. The relative spreads of warrant were 2.92% in the morning and 2.41% in the afternoon. Similarly, the relative spreads of stock were high in the morning (1.86%). The spreads fell in the afternoon (1.5%). The absolute spread was also higher in the morning than in the afternoon. Market depth, a sum of the shares standing at the best bid and the best ask of the limit order book, was lower in the morning than in the afternoon. The morning market depth of warrants was 42,411 shares, and it rose to 49,960 shares in the afternoon. The market depths of stocks were 65,582 shares in the morning and 84,948 shares in the afternoon.

Two other types of depth were computed in this study. The displayed depth referred to the orders standing in the book that were visible to the trader. Specifically, the displayed depth was the sum of the orders at the best three quotes on the bid and ask side. The total depth was the average total limit orders in the book. Both displayed depth and total depth of warrants and stocks were statistically higher in the afternoon than in the morning.

In this study, liquidity immediacy was defined as the ratio between the market depth and the total depth in the order book. Liquidity immediacy was defined in order to investigate whether an increase of total depth arose from the depth at the market or from the depth away from the market. For warrants, the morning liquidity immediacy was 8.36%, and it fell to 6.57% in the afternoon. Liquidity immediacy of stocks was 11.73% in the morning, but it rose slightly to 11.84% in the afternoon. From the comparison of the order book in the morning and in the afternoon, it was evident that the characteristics of an order book may follow a time-varying pattern.

The number of trades of warrants was higher than stock trades, and the trades occurred more frequently in the morning than in the afternoon. There were 270 and 206 trades of warrants and 231 and 195 trades of stocks in the morning and afternoon, respectively. Trade size, measured in number of shares, was higher for warrants than stocks. The warrant trade sizes were 2,708 and 2,628 shares, while the stock trade sizes were smaller at 1,976 shares and 2,081 shares for the morning and afternoon sessions, respectively. Furthermore, warrants had a positive return in the morning and negative return in the afternoon, but stocks did not have a statistical difference between morning and afternoon returns. Both stocks and warrants had a higher return volatility in the morning than in the afternoon.

3.3 Intraday Variation Analysis

In this study, a regression was used in the intraday variation analysis of spreads, depths, liquidity immediacy, volume, volatility, and market order ratio of the warrants and their underlying stocks traded on SET. Each of the variables was regressed against two control variables and a set of dummy variables to capture both intraday and interday patterns. Formula 1 shows the regression model:

(1)

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

where Y_t is the variable of interest, which was the bid-ask spread, market depth, displayed depth, total depth, liquidity immediacy, volatility, order volume, and market order ratio. The regularity patterns were captured by 9 intraday 30-minute dummy variables (dtime) and 5 day-of-the-week dummy variables (dweek). Each intraday interval was 30 minutes. 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, were included. This constraint helped to avoid the perfect multicollinearity. This scheme of dummy variables was used in several recent studies of intraday pattern (see, for example, Ahn & Cheung, 1999; Lehman & Modest, 1994). The regression was performed for 19 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 was not equal because nonactive trading days were truncated.

3.4 Adverse Selection Component of Spread

The hypotheses that spread has a downward intraday pattern and market depth has an upward intraday pattern have been explained by Madhavan (1992): That is, asymmetric information is resolved through trading. In order to test if asymmetric information falls over the course of trading, this study computed the intraday variation of proportion of asymmetric components in the spreads. From the liquidity providers' point of view, spread compensates for three costs: order processing, inventory, and adverse selection. Among many decomposition models, adverse selection cost was estimated using six widely cited models: Three models are based on trade price, and three models make use of the quote midpoint price.

Madhavan, Richardson, and Roomans (1997) derived the adverse selection cost using price and trade indicator variables while allowing correlated order flows as follows:

(2) The MRR97 model

$$\Delta P_t = (\alpha + \beta)Q_t - (\beta + \rho\alpha)Q_{t-1} + \varepsilon_t$$

where P_t is the trade price; Q_t is the trade indicator, which equals 1 for buy-initiated trades and -1 for sell-initiated trades; α measures the adverse selection component; β measures the inventory and order processing component; and ρ measures the autocorrelation of trade indicators. The parameters α, β, and ρ were estimated by the Generalized Method of Moment (GMM) with Newey and West's (1987) Heteroscedasticity and Autocorrelation Consistent (HAC) covariance matrix. The moment conditions were as follows:

(3)

$$f(x_t, \omega) = \begin{pmatrix} Q_t Q_{t-1} - \rho Q_t^2 \\ \varepsilon_t - \theta \\ (\varepsilon_t - \theta) Q_t \\ (\varepsilon_t - \theta) Q_{t-1} \end{pmatrix}$$

De Jong, Nijman, and Roell (1996) decomposed the price effects of trading on the Paris Bourse into transitory and permanent parts. They extend the model of Glosten (1994), where there were no explicit order processing costs, and use trade price, trade size, and trade indicator as input variables:

(4) The DNR96 model

$$\Delta P_t = \mu + R_0 \Delta Q_t + R_1 \Delta(q_t Q_t) + e_0 Q_{t-1} + e_1 q_{t-1} Q_{t-1} + \varepsilon_t$$

$$\text{Order-processing component} = R_0 - e_0 - e_1 \frac{Median(q_t)}{\log_e 2} + (R_1 - 0.5 e_1) q_t$$

$$\text{The adverse selection component is } e_0 + e_1 \frac{Median(q_t)}{\log_e 2} + 0.5 e_1 q_t$$

where P_t is the trade price at time t; Q_t is the trade indicator variable; and q_t is the round lot trade size. The model in this study was estimated by the Ordinary Least

Square (OLS) and adjusted the standard errors using Newey and West's (1987) method.

Glosten and Harris (1988) constructed one of the earliest decomposition models. Their model is based on the trade indicator variable, which could be integrated into the De Jong, Nijman, and Roell (1996) context as follows:

(5) The GH88 model

$$\Delta P_t = \mu + c_0 \Delta Q_t + c_1 \Delta(q_t Q_t) + z_0 Q_{t-1} + z_1 q_t Q_t + \varepsilon_t$$

where P_t is the transaction price at time t; Q_t is the trade indicator variable; and q_t is the trade size measured in multiples of minimum trading units, which was 100 shares. The adverse selection component is $z_0 + z_1 q_t$; and the order processing component is $c_0 + c_1 q_t$.

George, Kaul, and Nimalendran (1991) allowed the serial dependent of expected return to have the same impact on trade and quote midpoint returns. Their model is as follows:

(6) The GKN91 model

$$2(\Delta P_t - \Delta M_t) = \beta + (1-\alpha) s_q \Delta Q_{t-1} + \varepsilon_t$$

where P_t is the transaction price at time t; Q_t is the trade indicator variable; M_t is the quote midpoint; and s_q is the quoted spread. The order processing cost and adverse selection cost are β and α.

Lin, Sanger, and Booth (1995) developed empirical estimates of the bid-ask spread component following Huang and Stoll (1994), Lin (1992), and Stoll (1989). In their model, the quote revision changes in response to a trade, and the revision is a fraction of the effective spread:

(7) The LSB95 model

$$\Delta M_t = \alpha\left(P_{t-1} - M_{t-1}\right) + \varepsilon_t$$

where P_t is the transaction price at time t; and M_t is the quote midpoint. The adverse selection cost is α.

Huang and Stoll (1997) reconciled the decomposition model based on the trade indicator and quote midpoint and developed a general model that allows a three-way decomposition of adverse selection, inventory, and order processing costs:

(8) The HS97 model

$$\Delta M_t = (\alpha + \beta)\left(\frac{S_{t-1}}{2}\right)Q_{t-1} - \alpha(1 - 2\pi)\left(\frac{S_{t-2}}{2}\right)Q_{t-2} + \varepsilon_t$$

where Q_t is the trade indicator variable; M_t is the quote midpoint; S_t is the quoted spread prior to trade; and π is the probability that the trade indicator at time t is opposite in sign to the trade indicator at time t-1. The parameters α, β, and $1-\alpha-\beta$ refer to the adverse selection cost, the inventory holding cost, and the order processing cost, respectively. The model in this study was constructed using the Generalized Method of Moment (GMM) with Newey and West's (1987) Heteroscedasticity and Autocorrelation Consistent (HAC) covariance matrix. The moment condition of the regression is as follow:

(9)

$$E\left(Q_{t-2} \mid Q_{t-1}\right) = (1 - 2\pi)Q_{t-2}$$

4. Empirical Results

4.1 Intraday Pattern of Spreads

From the regression in equation 1, the cross-sectional average bid-ask spread of warrants was 2.7%, wider than the 1.7% of the stocks spread. This result indicates a higher execution cost in warrant trading compared to stock trading. The relative

spread of stocks on SET was higher than the 0.6% of stock spreads on the NYSE and higher than the 1.15% of stock spreads on the Tokyo Stock Exchange (TSE). However, it was lower than the 1.73% of stock spreads on the Hong Kong Stock Exchange (HKSE).[1] The intraday variation of relative spreads of warrants and stocks is shown in Table 4 and Table 5. The relative bid-ask spread was highest 10:00 a.m. to 10:30 a.m. Warrant and stock spreads in this period were 1.13% and 0.71% higher than the average relative spread in other periods. The dummy coefficients of other intervals were weakly negative, and some of them were statistically insignificant. Nevertheless, the magnitude of the dummy interval coefficient monotonically declined to the lowest value of -0.45% for warrants and -0.24% for stocks during the last 30 minutes of the trading day. Hence, the spreads of both warrants and stocks have a similar downward pattern over trading time, where spreads are highest right after the opening and lowest before the market close.

This result confirms the effect of market structure on the intraday pattern documented in Chan et al. (1995). The options traded on the Chicago Board Options Exchange (CBOE), which is a competitive dealer market, had narrower spreads at the closing period compared to wider spreads of their underlying stocks traded on the monopoly specialist NYSE. In contrast, warrants and their underlying stocks listed on SET were traded under the same market structure and regulations, and both exhibited 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 & Cheung, 1999; Lehman & Modest, 1994; McInish & Wood, 1992). The impact of market closure also appeared at the day of the week pattern. As

[1]The average NYSE spread is from the 1994 *NYSE fact book*; the average TSE spread is from January 1991 to April 1993 (see Lehaman & Modest, 1994). The average HKSE spread is from October 1996 to March 1994 (see Ahn & Cheung, 1999).

shown in Tables 4 and 5, the spreads of warrants and stocks were highest on Mondays, and they were 0.25% and 0.06% higher than other days of the week.

4.2 Intraday 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 were 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. It was thought that a comparison of liquidity immediacy across different periods might reveal the change of market depth relative to total depth.

Table 4 and Table 5 show that the cross-sectional active trading day weighted market depths of warrants and stocks were 45,766 shares and 74,189 shares, respectively. Active stocks were likely to have thick depths and more active trading days, so stocks had higher cross-sectional day weighted market depths than the cross-sectional average market depth. The active trading day weighted displayed depths of warrants and stocks were 188,825 shares and 190,710 shares, respectively, while the active trading day weighted total depth of warrants and stocks was 712,856 shares and 567,240 shares, respectively. All three types of depth were low at the opening and continually increased to highest at the closing. Compared to spread, the intraday pattern of market depth was a reverse image of the intraday spread pattern.

As shown on Figure 2, the market depth was lowest at the opening and monotonically increased to highest at the closing. Total depths also had similar upward intraday patterns. While both market depths and total depths increased over the course of the trading day, the liquidity immediacy of warrants monotonically

declined, but the liquidity immediacy of stocks followed the U-shape pattern. The cross-sectional average of the liquidity immediacy of warrants and stocks was 7.56% and 11.78%. The liquidity immediacy ratio could be viewed as a proxy for the degree of the limit order trader's willingness to supply liquidity. The high liquidity immediacy indicates the high degree of competition between limit order traders to supply liquidity. The pattern of liquidity immediacy was similar to the pattern of spread, suggesting that limit order traders compete to supply liquidity. Because spread is compensation for liquidity suppliers, wide spread and high liquidity immediacy reflected the higher competition among limit order traders. 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. The pattern of total depths and liquidity immediacy are shown on Figure 3.

4.3 Intraday Pattern of Market Order

The average values of the market order ratio across all time intervals were 39.72% for warrants and 40.07% for stocks. As shown in Table 4 and Table 5, the market order ratio was lowest during the first 30-minute interval and increased over time to reach the highest at the last 30-minute interval. There was also a lunch-break effect for market order submissions. After lunch, the market order ratio dropped during the first 30-minute interval before increasing again. During the afternoon session, the pattern of market order ratio was the U-shape. An increase in market order submissions was consistent with the increase of market depths and the decrease of spreads. Market order traders consumed the liquidity supplied by the 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 the market depths are high (low) (see Bae, Jang, & Park, 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 market order ratio between warrants and stocks is shown on Figure 4, which illustrates the similarity of intraday pattern of market ratio between warrants and stocks.

4.4 Intraday Pattern of Volatility and Volume

It is well-known that the intraday pattern of returns, volatility, and volume follow a U-shape pattern.[2] Brooks and Chiou (1995), Harris (1986, 1989), and Vijh (1988) document the increase in NYSE stock prices on the last trade of the day and suggest that this is the result of increases in trades at ask prices, which may reflect the demand to cover a short-selling position or the intention to affect the closing price. Holden and Subrahmanyam (1992) explain the high opening return as a result of information asymmetry arising from the concentration of informed trading at the opening. As noted in Brock and Kleidon (1992) and Gerety and Mulherin (1994), the accumulation of overnight information and the inability to trade hinder the price discovery process and cause a reduction in an optimal portfolio, resulting in high opening volatility and volume.

[2]See Wood, McInish, and Ord (1985) for intraday return patterns. For the intraday patterns of return and volatility, see Brock and Kleidon (1992), Foster and Viswanathan (1993), and Jain and Joh (1988).

As shown in Table 4 and Table 5, the coefficients of volatility and order volumes were statistically positive at the first and the last trading intervals. Consistent with previous studies, the volatility of both warrants and stocks exhibit the U-shape pattern. The volatility at the first trading interval of the day was the highest level, and it fell as time went by before increasing again at the closing interval. The impact of trade discontinuity due to the 2-hour lunch break appeared in the intraday volatility pattern: Volatility was higher during the first 30 minutes in the afternoon session. Large firms were likely to have smaller volatility. Furthermore, there was evidence of the U-shape pattern in order volume, confirming the same pattern found in many other markets, including the U.S., which has specialists and dealers to provide the liquidity of the last resort, and the pure limit order markets such as the TSE, the Paris Bourse, and the HKSE. Figure 5 and Figure 6 show that the intraday variation of warrants and stocks on SET follows the U-shape pattern.

4.5 Adverse Selection Proportion of Spread

In this study, the cross-sectional statistics and intraday variation of the proportion of asymmetric information were computed for all six models. Three models (MRR97, DNR96, and GH88) use only trade data that are highly significant and have strong positive correlations among themselves. The other three models (GKN91, LSB95, and HS97) employ both the trade and quote data, and their estimates are positively significant with moderate correlations.

As shown in Table 6, the cross-sectional mean of the adverse selection proportion varies from 12.6% to 60.9% for warrants and from 13.5% to 47.9% for stocks. The maximum estimation comes from the GKN91 model, while the HS97 model gives the minimum estimation. The adverse selection cost proportions

estimated from the other models lies between 10% and 30%. The adverse selection cost proportions were usually highest after the market has been open for 30 minutes. Most of the models show that the lowest adverse selection proportions occur at the closing intervals. Lin et al. (1995) show that the adverse selection costs of warrants and stocks consist of 23.3% and 31.6%, respectively, of total spread during the opening period. These proportions fell to 19.1% and 15.3% at the closing period for warrants and stocks, respectively.

The findings in this study are consistent with the explanation 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 was higher than during trading intervals throughout the day, and it was 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, but if no execution occurs before the 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, Cai, Hamao, and Ho (2002), all of the models considered here 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.

4.6 Association of Spreads, Depths, Liquidity Immediacy, and Market Order Ratio

The results of the investigation into intraday pattern in the previous section show that over the trading day spread and liquidity immediacy decline, while market depth, displayed depth, total depth, and market order ratio have an upward pattern. This study also examined the correlation between spreads and other variables, including depths, immediacy, and market order ratio when the intraday pattern is and is not controlled. Without a control of intraday intervals, there was no evidence of a relevant association between spreads and market depths for both warrants and stocks. However, spreads were negatively associated with total depth for both warrants and stocks. The correlations of spread and depth were -0.17 for warrants and -0.14 for stocks. Furthermore, the correlations of spreads and liquidity immediacy were statistically significant, with 0.21 for warrants and 0.19 for stocks. Finally, the correlation of spreads and market order submissions was statistically significant, with -0.16 for warrants and -0.13 for stocks.

However, the correlation of spreads and the other variables may arise purely from a strong relationship in a certain period of the day, especially from the opening and closing period. A close examination of correlation at each trading interval would confirm whether such relationships occur at a specific period of a trading day. As shown in Table 5.7, the association of spread and other variables across the time intervals of the day and across weekdays was not sharply different from the relationship without controlling the time variation. This shows that the intraday effect has little impact on the relationship of spreads and other variables.

In this study, spread had a negative association with total depths, which implies that limit order traders use both spreads and depths to provide liquidity, which is consistent with the results reported by Lee et al. (1993). Spread had a positive correlation with liquidity immediacy, confirming the hypothesis of competition among liquidity providers. Limit order traders received the bid-ask spread to compensate for providing liquidity. When the compensation was higher, limit order traders competed among themselves to offer more competitive prices.

Spread was negatively correlated to the market order ratio. This implies that market order traders observed the spread and strategically designed their strategy to minimize their trading costs. They preferred to use the market order when the cost of trading, measured by spread, was low.

5 Conclusion

The results of this study support the idea that the market structure has a significant effect on the intraday pattern of spread, depth, market order ratio, volatility, and volume. In other words, financial instruments traded under the same market mechanisms should have the same pattern. Chan et al. (1995) found that the spread of the CBOE options was narrower at the close, while stock spreads were wider. They explain that the opposite closing patterns between options and stocks were a result of differences in market structure, which are competitive dealers on CBOE and a single specialist on the NYSE. Chan et al. (1995) also show that NASDAQ stocks have a narrow spread near the close due to the absence of market power among NASDAQ dealers. For both warrants and stocks, the results of the present study show wider spreads at the open and gradually narrower spreads before the spreads reach the minimum level at the close. Because warrants and stocks are

traded under the same market structure, the similar pattern of intraday spreads supports the idea that market structure influences intraday patterns.

The intraday pattern of trade and quote variables for both warrants and stocks were compared in this study. On SET, five warrants were in the top 20 for trading volume during 1997, indicating a relatively high liquidity of warrants compared to stocks. Generally, the intraday spreads, depths, volatility, volume, and market order ratio of warrants and stocks had a similar pattern. Percentage spreads were the highest at the opening, monotonically decreased during the later trading period, and became lowest at the closing. Moreover, warrant spreads were higher than stock spreads for the whole period. The market depths, total depths, and market order ratio were at their lowest level in the opening and increased to the highest level at the closing. The volatility of warrants was higher than stocks, and both had the U-shape pattern similar to the U-shape pattern of return and volume. The intraday pattern of liquidity immediacy of warrants and stocks was different. For warrants, liquidity immediacy had a downward shape, while it was relatively constant for stocks. This suggests that competition among limit order traders to supply liquidity in warrant trading was not as high as for stocks. However, to confirm this hypothesis, a formal test is required and should be the subject of future research.

This study also shows the negative association of spreads and total depths and spreads and market order ratio and the positive association of spreads and liquidity immediacy. These three relationships occurred in all time intervals, so they did not occur because of a strong relationship in a specific interval. The inverse relationship between spread and depth supports the notion that limit order traders use both spread and depth to manage their submission strategy. However, there was an insignificant association between spreads and market depths, but the negative correlation of

spreads and market order ratio implied a strategic market order submission. The positive association of spreads and liquidity immediacy can be interpreted as competition among limit order traders.

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Table 1 Profile of Selected Warrants and Their Underlying Stocks

This Table presents the details of 19 warrants and their underlying stocks. The selection criteria are as follows. First, both warrants and their underlying stocks must have at least 20 trades a day, and their price must be greater than 5 baht. Second, warrants are selected if the number of trading days that satisfy the first condition is more than 40 trading days. The adjusted warrant price is the average warrant price divided by the exercise ratio. The exercise ratio shows the number of stocks received when one warrant is exercised. For instance, the exercise ratio 1:2 means 1 warrant can be exercised for 2 common stocks. The days to maturity are the time to maturity of warrants in days as of January 1, 1997. The expiration date is the date that all issued warrants expire. Days of active warrant trading are the number of days with at least 20 warrant trades. The average warrant and stock price is the average price during active trading days, which are the days with at least 20 trades.

Industry	Company name	Exercise price (baht)	Exercise ratio (W:S)	Days to maturity	Expiration date	No. of issued warrants ($x10^6$ units)	Days of active warrant trading	Average warrant price (baht)	Average stock price (baht)
Banking	Industrial Finance Corp.	57.00	1:1.18846	310	7-Nov-97	59.90	137	12.21	58.73
	Nakornthon Bank	46.74	1:1.06978	334	1-Dec-97	21.50	85	12.50	55.13
	Thai Farmer Bank	181.69	1:1.00000	1,002	30-Sep-99	75.00	236	14.86	102.81
Finance	CMIC Finance and Sec.	90.00	1:1.00000	1,565	15-Apr-01	31.50	102	10.95	19.50
	Dhana Siam Finance	89.87	1:3.62883	665	28-Oct-98	12.00	235	32.76	30.95
	Ekachart Finance and Sec.	98.74	1:1.60018	867	18-May-99	15.75	112	9.20	19.13
	Finance One	133.11	1:2.80976	803	15-Mar-99	24.00	46	25.34	33.87
	General Finance and Sec.	96.05	1:2.34261	727	29-Dec-98	5.00	111	21.55	21.59
	Kiatnakin Fin. and Sec.	102.00	1:1.00000	1,184	30-Mar-00	7.51	96	12.49	21.79
	National Finance	100.00	1:1.03522	1,048	15-Nov-99	62.66	228	12.26	28.15
	Nithipat Finance	129.79	1:1.00159	1,078	15-Dec-99	18.00	48	9.13	24.78
	Securities One	284.09	1:1.07359	1,354	16-Sep-00	15.00	211	18.03	34.07
	Siam General Factoring	30.00	1:1.00000	1,506	15-Feb-01	5.48	74	9.10	19.85
	Wall Street	144.10	1:1.15891	730	1-Jan-99	4.79	59	9.12	31.70
Property	Italian Thai Development	314.00	1:1.00000	1,379	11-Oct-00	17.50	159	9.81	86.09
	Land and House	175.00	1:1.64195	406	11-Feb-98	10.00	137	11.08	92.78
	Quality House	41.00	1:1.19063	1,029	27-Oct-99	13.60	86	11.34	17.65
Comm.	United Communication	391.41	1:1.00406	1,225	10-May-00	11.07	224	14.65	123.85
Energy	Banpu	288.00	1:1.00000	683	15-Nov-98	6.00	66	85.57	331.23
Average		146.98	1:1.38261	942		21.91	129	18.00	60.72

Table 2 Descriptive Statistics of Order, Limit Order Book and Trade of Warrants

This Table presents the cross-sectional statistics of order file, limit order book, and trade file in the morning and afternoon sessions. Matched orders are the proportion of orders that are totally executed. Opened orders are the proportion of orders that are partially or never executed. Marketable orders are the orders that are executed immediately after being placed. Relative spread is the best ask minus the best bid prices divided by the midpoint of the bid and ask prices. Absolute spread is the difference between the best bid and ask prices. Market depth is the sum of shares at the best quotes in the limit order book. Total depth is the total orders in the limit order book. Liquidity immediacy is the ratio between market depth and total depth. Mid-quote price is the average of best bid and best ask prices.

	Morning			Afternoon			Paired t-test				Signed Rank test			
	Mean	Median	S.D.	Mean	Median	S.D.	Mean of Diff	N(+) Sig.	N(-) Sig.	Av. t-stats	Median of Diff	N(+) Sig.	N(-) Sig.	Av. t-stats
Panel A: Order file														
Number of orders	366	294	282	264	212	205	102	17	0	5.61	77	18	0	5.79
Matched orders	79.73%	80.39%	3.52%	70.69%	70.78%	2.99%	9.04%	18	0	6.84	9.4%	18	0	6.01
Opened orders	20.27%	19.61%	3.52%	29.31%	29.22%	2.99%	-9.04%	0	18	-6.87	-9.4%	0	18	-6.01
Marketable orders	38.27%	38.72%	2.26%	41.54%	41.32%	1.99%	-3.27%	0	16	-4.06	-3.15%	0	13	-2.93
Order size (shares)	4,805	4,287	2,465	4,981	4,611	2,555	-176	1	6	-1.54	-118	0	6	-1.46
Marketable order size (shares)	2,255	2,034	1,194	2,342	2,172	1,224	-87	0	12	-3.07	-82	0	9	-2.53
Panel B: Limit order book														
Relative spread	2.92%	2.29%	1.34%	2.41%	2.13%	0.78%	0.52%	12	0	2.47	0.21%	12	0	3.14
Absolute spread	0.55	0.33	0.91	0.41	0.30	0.54	0.14	12	0	2.85	0.03	18	0	3.86
Market depth (thousand shares)	42.41	18.79	51.33	49.96	22.10	61.56	-7.55	0	6	-1.86	-2.05	0	12	-2.97
Displayed depth (thousand shares)	170.10	74.73	209.36	212.23	93.24	267.42	-42.12	0	17	-5.03	-13.05	0	18	-5.41
Total depth (thousand shares)	601.40	397.36	667.35	852.18	570.09	950.76	-250.79	0	19	-13.28	-172.72	0	19	-10.60
Liquidity immediacy	8.36%	8.58%	2.38%	6.57%	6.51%	2.14%	1.78%	17	0	4.45	1.75%	19	0	5.12
Mid-quote price	18.29	12.45	18.05	18.11	12.32	18.02	0.18	14	0	2.98	0.14	15	0	3.52
Panel C: Trade file														
Number of trades	270	209	221	206	162	170	64	15	0	3.86	51	13	0	3.04
Trade size	2,708	2,543	1,332	2,628	2,460	1,263	80	2	0	0.55	58	2	0	0.61
Trading volume	36,433	35,042	16,089	34,203	31,081	14,680	2,230	5	0	1.18	1,887	6	1	1.13
Return	1.70%	1.39%	0.92%	-0.87%	-1.06%	0.99%	2.57%	13	0	2.73	2.91%	12	0	3.00
SD of return	0.98%	0.60%	0.57%	0.63%	0.58%	0.39%	0.04%	8	0	1.81	0.03%	12	0	2.24

Table 3 Descriptive Statistics of Order, Limit Order Book and Trade of Stocks

This Table presents the cross-sectional statistics of order file, limit order book, and trade file in the morning and afternoon sessions. Matched orders are the proportion of orders that are totally executed. Opened orders are the proportion of orders that are partially or never executed. Marketable orders are the orders that are executed immediately after being placed. Relative spread is the best ask minus the best bid prices divided by the midpoint of the bid and ask prices. Absolute spread is the difference between the best bid and ask prices. Market depth is the sum of shares at the best quotes in the limit order book. Total depth is the total orders in the limit order book. Liquidity immediacy is the ratio between market depth and total depth. Mid-quote price is the average of best bid and best ask prices.

	Morning			Afternoon			Paired t-test				Signed Rank test			
	Mean	Median	S.D.	Mean	Median	S.D.	Mean of Diff	N(+) Sig.	N(-) Sig.	Av. t-stats	Median of Diff	N(+) Sig.	N(-) Sig.	Av. t-stats
Panel A: Order file														
Number of orders	331	177	338	229	119	222	102	15	0	5.43	49	15	0	4.87
Matched orders	75.61%	76.91%	5.15%	71.40%	71.98%	3.78%	4.21%	7	1	1.97	3.75%	6	1	1.73
Opened orders	24.39%	23.09%	5.15%	28.60%	28.02%	3.78%	-4.21%	1	6	-1.91	-3.75%	1	6	-1.69
Marketable orders	37.75%	37.89%	4.06%	43.97%	43.86%	3.23%	-5.22%	0	16	-6.77	-4.58%	0	19	-6.19
Order size (shares)	3,478	3,333	1,193	4,357	4,482	1,505	-879	0	5	-4.30	-677	0	15	-5.22
Marketable order size (shares)	1,568	1,473	575	2,072	2,118	759	-504	0	14	-4.43	-447	0	18	-5.98
Panel B: Limit order book														
Relative spread	1.86%	1.85%	0.71%	1.50%	1.46%	0.42%	0.36%	12	0	3.21	0.36%	16	0	3.98
Absolute spread	1.12	0.52	1.78	0.85	0.46	1.22	0.27	13	0	3.49	0.10	17	0	4.34
Market depth (thousand shares)	65.58	26.61	55.69	84.95	33.03	96.59	-19.37	0	10	-2.60	-12.08	0	18	-5.39
Displayed depth (thousand shares)	169.05	64.82	169.96	217.79	97.88	222.04	-48.74	0	15	-4.21	-25.81	0	18	-6.45
Total depth (thousand shares)	485.72	167.37	584.23	669.14	267.56	817.08	-183.42	0	19	-9.34	-82.37	0	19	-9.74
Liquidity immediacy	11.73%	11.43%	3.60%	11.84%	10.53%	3.10%	-0.11%	1	3	-0.38	-0.02%	1	0	0.41
Mid-quote price	61.28	31.96	74.06	61.31	31.91	74.51	-0.03	14	0	2.59	0.19	14	0	2.49
Panel C: Trade file														
Number of trades	231	130	244	195	93	195	36	6	3	2.75	19	5	6	-0.01
Trade size	1,976	2,020	667	2,081	1,932	752	-105	0	4	-2.02	-54	0	8	-2.46
Trading volume	85,478	67,900	60,232	93,690	78,077	68,678	-8,213	0	6	-2.95	-3,065	0	7	-2.27
Return	-0.14%	-0.03%	0.74%	0.19%	0.11%	0.73%	-0.33%	1	3	-1.10	-0.01%	1	4	-0.34
SD of return	0.44%	0.42%	0.31%	0.39%	0.37%	0.20%	0.06%	12	0	5.54	0.05%	12	0	2.98

Table 4 Intraday Patterns of Warrants

The intraday patterns of interested variables are estimated as follows:

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

where Y^k_t denotes the variables of interest, which consist of spread, market depth, displayed depth, total depth, immediacy, market order ratio, volatility, and order volume. 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 and the adjusted R^2. The statistical significance is based on the signed tests on the estimated coefficients, where ** and * indicate a 99% and 95% significance level, respectively.

	Spread	Market depth	Displayed depth	Total depth	Liquidity immediacy	Market order ratio	Volatility	Order volume
Constant	0.02695**	45,766**	188,825**	712,856**	0.07564**	0.39721**	0.00650**	442,217**
10:00–10:30	0.01128**	-8,177**	-56,208**	-273,964**	0.03046**	-0.06175**	0.00305**	462,681**
10:30–11:00	0.00265	-2,490**	-23,934**	-154,701**	0.01348**	-0.01039	0.00052	59,429**
11:00–11:30	-0.00021	-1,731**	-9,407**	-87,402**	0.00380**	-0.00959	-0.00070**	-94,369**
11:30–12:00	-0.00102**	-1,756*	-3,824**	-41,210**	-0.00195	0.00548	-0.00104**	-148,828**
12:00–12:30	-0.00125**	-2,622**	-232	-30	-0.00616**	0.00361	-0.00105**	-208,693**
14:30–15:00	-0.00172	-1,014*	1,826**	49,333**	-0.00882**	0.02971**	-0.00058*	-122,825**
15:00–15:30	-0.00214	343	11,965**	102,521**	-0.01182**	0.00452	-0.00027*	-121,051**
15:30–16:00	-0.00306*	4,533**	26,826**	157,865**	-0.01063**	0.00460	-0.00094**	-64,527**
16:00–16:30	-0.00452**	12,915**	52,988**	247,589**	-0.00835**	0.03380**	0.00100**	238,184**
Monday	0.00250**	-4,403*	-16,987*	-56,948*	0.00125	-0.01554**	-0.00007	-57,692**
Tuesday	-0.00114*	-549	-7,224	-7,104	-0.00138	0.00310	0.00005	-14,476
Wednesday	-0.00121**	1,066	5,515	7,895	0.00318	0.00901**	-0.00002	18,358
Thursday	-0.00068	4,974	12,431	6,243	0.00176	0.00457	-0.00031**	22,554**
Friday	0.00052	-1,088	6,265	49,914**	-0.00480**	-0.00114	0.00035	31,256

Table 5 Intraday Patterns of Underlying Stocks

The intraday patterns of interested variables are estimated as follows:

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

where Y^k_t denotes the variables of interest, which consist of spread, market depth, displayed depth, total depth, immediacy, market order ratio, volatility, and order volume. 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 and the adjusted R^2. The statistical significance is based on the signed tests on the estimated coefficients, where ** and * indicate a 99% and 95% significance level, respectively.

	Spread	Market depth	Displayed depth	Total depth	Liquidity immediacy	Market order ratio	Volatility	Order volume
Constant	0.01697**	74,189**	190,710**	567,240**	0.11778**	0.40069**	0.00418**	300,538**
10:00–10:30	0.00713**	-13,313**	-57,222**	-201,051**	0.01151	-0.09295**	0.00254**	246,810**
10:30–11:00	0.00189	-8,208**	-28,367**	-107,544**	-0.00180	-0.03216**	0.00026	10,918
11:00–11:30	0.00024	-9,765**	-15,111**	-62,356**	-0.00454**	-0.01239*	-0.00044**	-69,308**
11:30–12:00	-0.00047*	-6,945**	-5,033**	-29,400**	-0.00275	0.00707	-0.00038**	-104,101**
12:00–12:30	-0.00083**	-4,806**	-2,581	-7,238	-0.00486*	0.01429*	-0.00067*	-132,929**
14:30–15:00	-0.00148**	2,752**	10,375**	32,990**	-0.00215	0.03901**	-0.00049**	-44,034**
15:00–15:30	-0.00192**	7,542**	20,433**	82,720**	-0.00086	0.01419**	-0.00059**	-36,801**
15:30–16:00	-0.00219**	10,160**	28,778**	121,775**	-0.00013	0.01078*	-0.00066**	-30,776
16:00–16:30	-0.00235**	22,583**	48,728**	170,104**	0.00560*	0.05215**	0.00044	160,222**
Monday	0.00064	-10,344**	2,996	23,609**	-0.00366	-0.01066**	-0.00003	29,664
Tuesday	-0.00040	-16,574	-27,015	-46,399	0.00350	-0.00092	-0.00006	-40,443
Wednesday	-0.00010	-13,131	-21,917	-64,368	0.01004	0.00808*	-0.00002	-11,643
Thursday	-0.00039*	42,043	43,139	62,377	-0.00357	0.00093	-0.00019	2,556
Friday	0.00025	-1,994	2,796	24,782	-0.00631*	0.00258	0.00032**	19,866

Table 6 Intraday Variation of Adverse Selection Cost

This Table presents the intraday variation of the adverse selection estimated from six decomposition models: Madhavan et al. (1997), De Jong et al. (1996), Glosten and Harris (1988), George et al. (1991), Lin et al. (1995), and Huang and Stoll (1997).

	MRR97	DNR96	GH88	GKN91	LSB95	HS97
Panel A: Adverse selection component of warrants						
10:00–10:30	0.215	0.254	0.257	0.552	0.233	0.041
10:30–11:00	0.221	0.275	0.276	0.780	0.265	0.141
11:00–11:30	0.229	0.280	0.321	0.755	0.252	0.138
11:30–12:00	0.206	0.292	0.292	0.742	0.254	0.172
12:00–12:30	0.222	0.354	0.387	0.715	0.216	0.152
14:30–15:00	0.251	0.276	0.315	0.660	0.214	0.153
15:00–15:30	0.218	0.293	0.309	0.761	0.260	0.140
15:30–16:00	0.211	0.276	0.287	0.741	0.231	0.155
16:00–16:30	0.176	0.197	0.216	0.728	0.191	0.114
Mean	0.211	0.256	0.274	0.609	0.216	0.126
Median	0.213	0.261	0.273	0.669	0.206	0.105
SD	0.103	0.153	0.168	0.148	0.084	0.064
Panel B: Adverse selection component of stocks						
10:00–10:30	0.175	0.253	0.265	0.495	0.316	0.092
10:30–11:00	0.182	0.324	0.328	0.657	0.242	0.142
11:00–11:30	0.159	0.265	0.265	0.671	0.205	0.168
11:30–12:00	0.150	0.291	0.267	0.684	0.212	0.140
12:00–12:30	0.132	0.246	0.240	0.625	0.186	0.149
14:30–15:00	0.145	0.246	0.233	0.542	0.167	0.136
15:00–15:30	0.158	0.254	0.266	0.619	0.173	0.140
15:30–16:00	0.134	0.230	0.229	0.577	0.195	0.128
16:00–16:30	0.146	0.209	0.215	0.546	0.153	0.094
Mean	0.155	0.246	0.256	0.479	0.164	0.135
Median	0.164	0.245	0.242	0.474	0.197	0.125
SD	0.063	0.152	0.166	0.220	0.093	0.060

Table 7 Correlations of Spread with Market Depth, Total Depth, Liquidity Immediacy and Market Order Ratio for 15-Minute Intervals

This Table presents the correlations of spread with market depth, total depth, immediacy, and market order proportion for all 15-miniute intervals in a day. Spread is the difference between the best ask price and bid price divided by the midpoint of the bid and ask prices. Market depth is the number of shares at the best bid price and best ask price. Total depth is the number of shares standing in the limit order book. Immediacy is the ratio between market depth and total depth. Market order proportion is the ratio between the number of market order arrivals and the number of total order arrivals. The reported correlations are the averages of correlations of individual warrants and underlying stocks. The statistical significance is based on the signed tests on individual correlations, where ** and * indicate a 99% and 95% significance level, respectively.

Interval	Correlations of warrant spread with					Correlations of underlying stock spread with				
	Market depth	Displayed depth	Total depth	Immediacy	Market order ratio	Market depth	Displayed depth	Total depth	Immediacy	Market order ratio
10:00–10:30	-0.159**	-0.165*	-0.239**	0.183**	-0.299**	-0.023	-0.013	-0.198**	0.261**	-0.205**
10:30–11:00	-0.081	-0.114	-0.178**	0.206**	-0.187**	0.052	0.038	-0.142**	0.231**	-0.154**
11:00–11:30	-0.060	-0.108*	-0.171**	0.229**	-0.157*	0.059	0.050	-0.130**	0.209*	-0.071
11:30–12:00	-0.040	-0.080*	-0.163**	0.211**	-0.125**	0.050	0.057	-0.101**	0.147	-0.083**
12:00–12:30	-0.036	-0.082	-0.158**	0.204**	-0.097*	0.065	0.078	-0.103**	0.170	-0.070
14:30–15:00	0.000	-0.051	-0.125*	0.162**	-0.089**	0.020	0.033	-0.088**	0.083	-0.045
15:00–15:30	-0.021	-0.056	-0.143**	0.161*	-0.105**	0.115	0.111	-0.048	0.167**	-0.072**
15:30–16:00	-0.026	-0.045	-0.124**	0.141**	-0.089**	0.090	0.085	-0.074*	0.151**	-0.025
16:00–16:30	-0.014	-0.054	-0.107**	0.171**	-0.085**	0.064	0.085	-0.075**	0.144**	-0.025
Monday	-0.134**	-0.141**	-0.230**	0.220**	-0.183**	-0.011	-0.049*	-0.211**	0.183**	-0.113*
Tuesday	-0.078**	-0.104*	-0.155**	0.134**	-0.165**	0.007	-0.012	-0.125**	0.131*	-0.116**
Wednesday	-0.079**	-0.124**	-0.181**	0.184**	-0.183**	0.012	0.005	-0.173**	0.186**	-0.160**
Thursday	0.005	-0.046	-0.179**	0.276**	-0.169**	0.055	0.072	-0.164**	0.224**	-0.140**
Friday	-0.048	-0.109*	-0.189**	0.256**	-0.118**	0.068	0.063	-0.117**	0.248**	-0.129**
All	-0.043	-0.084*	-0.168**	0.213**	-0.155**	0.034	0.026	-0.140**	0.192**	-0.132**

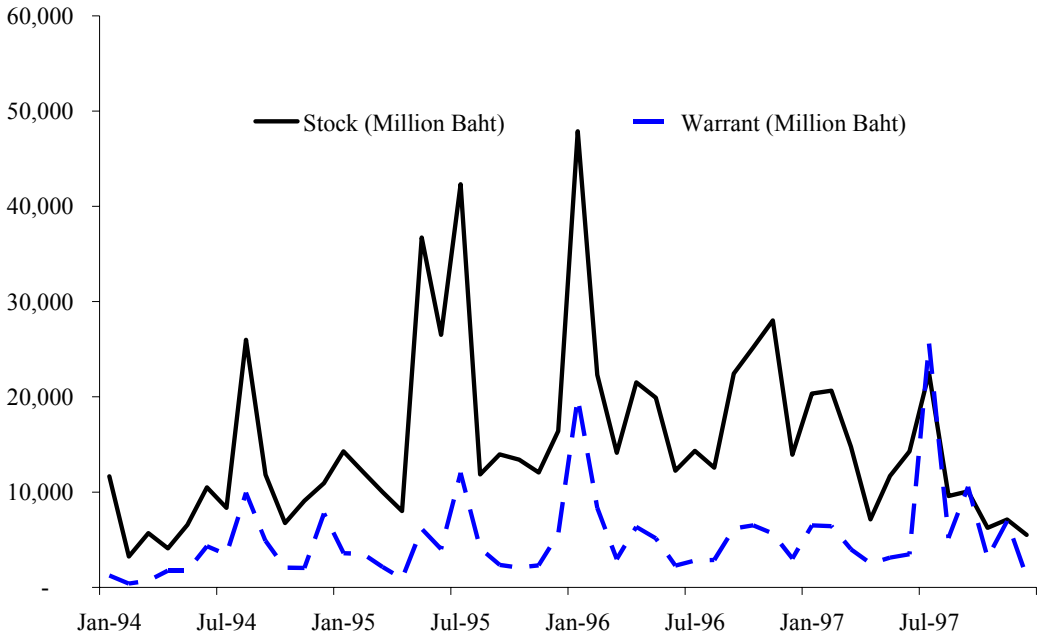

Figure 1 Trading Volume of Warrants and Their Underlying Stocks

This Figure presents the trading volume of warrants and their underlying stocks from January 1994 to December 1997. The volume is computed based on the warrants available for trading in 1997.

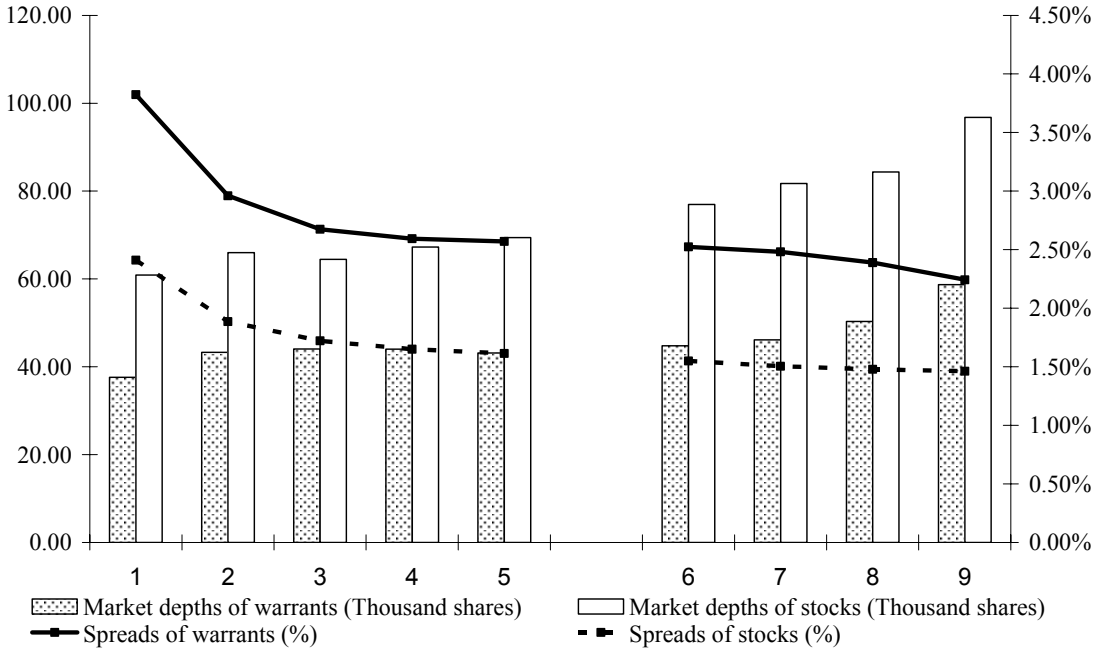

Figure 2 Intraday Patterns of Spread and Market Depth of Warrants and Stocks

This Figure shows the intraday pattern of average spread and average market depth in each 30-minute interval of warrants and stocks. The line represents spread, and the bar represents market depth.

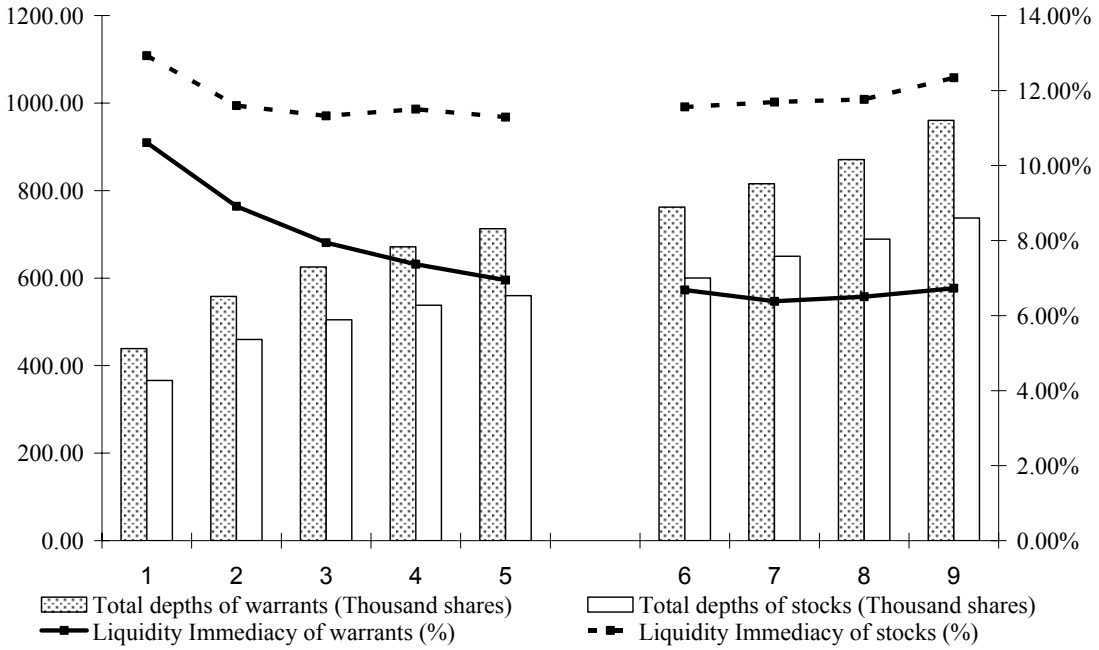

Figure 3 Intraday Patterns of Immediacy and Total Depth of Warrants and Stocks

This Figure shows the intraday pattern of average liquidity immediacy and average total depth in each 30-minute interval of warrants and stocks. The line represents liquidity immediacy, and the bar represents total depth.

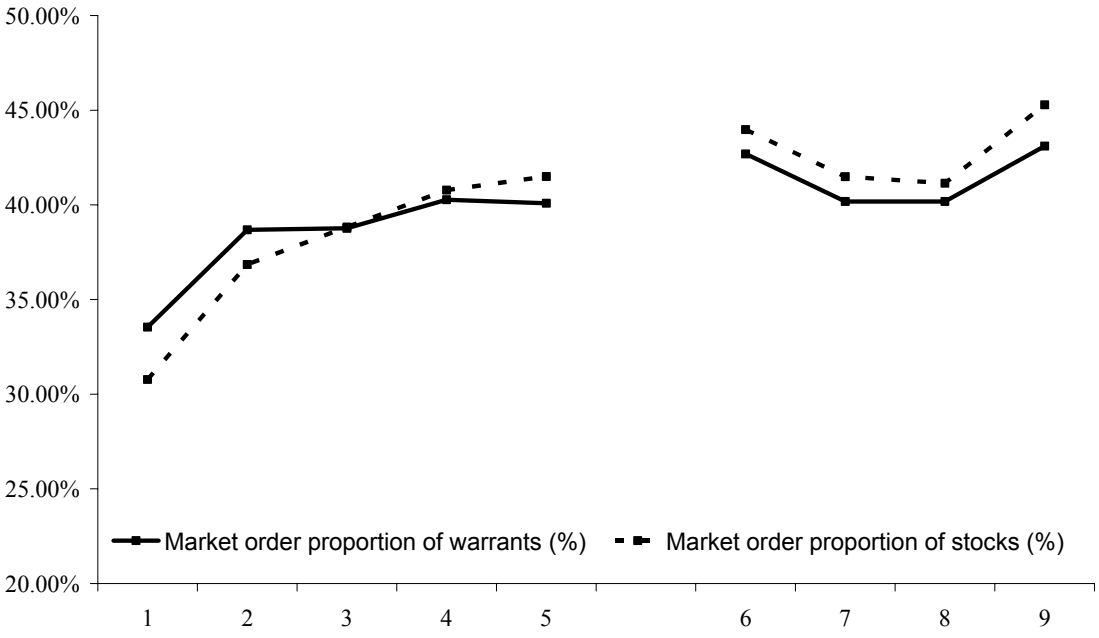

Figure 4 Intraday Patterns of Market Order Ratio of Warrants and Stocks

This Figure shows the intraday pattern of average market order ratio in each 30-minute interval of warrants and stocks. The market order ratio is the number of market orders divided by the number of total orders in the interval.

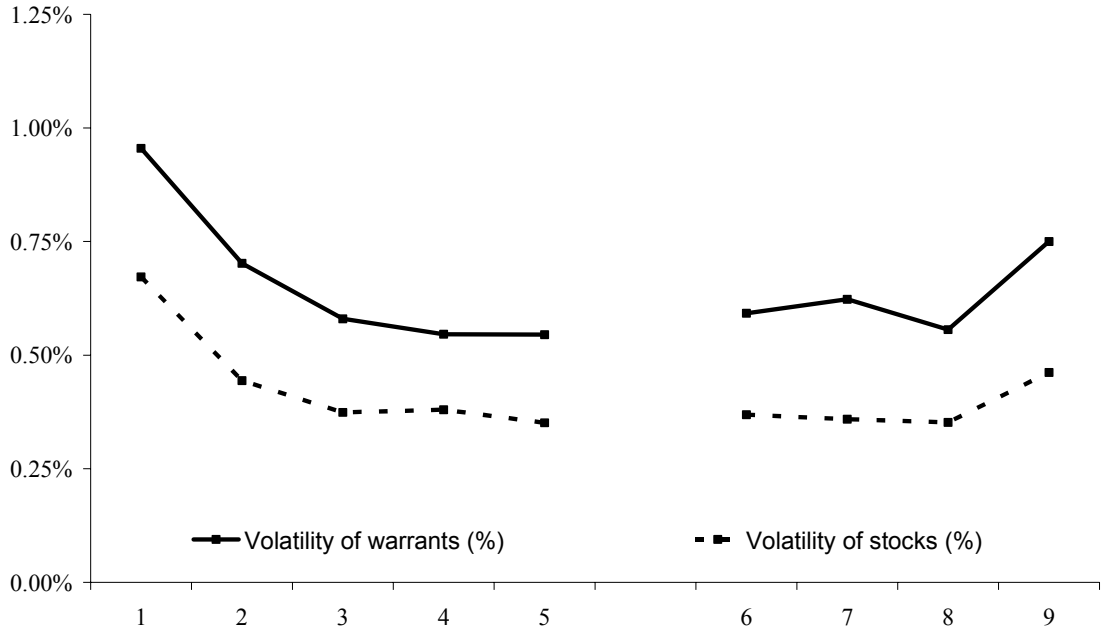

Figure 5 Intraday Patterns of Volatility of Warrants and Stocks

This Figure shows the intraday pattern of average volatility in each 30-minute interval of warrants and stocks. The volatility is the standard deviation of return in the interval.

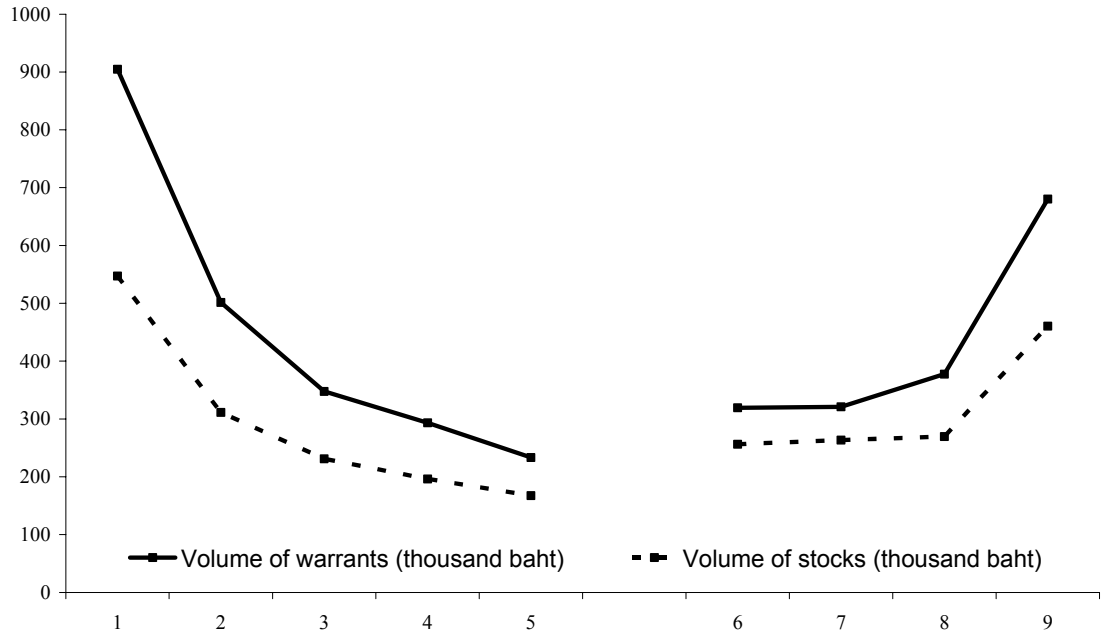

Figure 6 Intraday Patterns of Order Volume of Warrants and Stocks

This Figure shows the intraday pattern of average order volume in each 30-minute interval of warrants and stocks.