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Do Warrants Lead the Underlying Stocks and Index Futures?

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ABSTRACT

The lead-lag relation between options and stocks has been a subject of controversy for years with conflicting findings in the literature. In this thesis, we present an intuitive method to examine the lead-lag relation, if any, in the tick-by-tick data of covered warrants and their underlying stocks or underlying index futures. Our method is non-parametric and needs no assumptions which are critical to the regression-based methods.

We find that the electronically traded warrants do not lead stocks or index futures; the movements in the warrants' quotes provide little information about the quotes of the underlying stocks or index futures. Instead, our analysis shows that the stocks and index futures lead the warrants. Moreover, if all transaction costs are ignored, we can use the movements of underlying assets' quotes to generate profits by trading warrants that are both statistically and economically significant. However, as soon as the bid-ask spread is accounted for, the profits disappear and sizable losses are incurred instead. These findings are consistent with a central tenet of financial economics: arbitraging two intimately related markets for a profit is not possible in the presence of market frictions.

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1. INTRODUCTION

The pricing theories by Black and Scholes (1973) and Merton (1973) clearly show that, at any given time, the price of an option is dependent on its underlying security. Only *after* the stock price is known can the option price be determined. But if material information is discovered earlier in the equity option market as a result of the trades by informed traders who want to take advantage of the leverage that options provide, then the option price may "front-run" the underlying stock price.

Many researchers including Mayhew et al. (1995), Easley et al. (1998) have investigated the option and stock price behaviors from the perspective of information asymmetry. They find that informed traders do trade actively in the option market. The implication of this finding is that, if more informed traders leverage on options to generate a return higher than the return from trading stocks, then the option price will move ahead of the stock price in impounding the information from the informed traders.

However, with regard to which market is leading the other, the empirical studies in the literature are mixed. For example, Manaster and Rendleman (1982) and Anthony (1988) find that option market is leading, while Stephan and Whaley (1990) and Chiang and Fang (2001) conclude that stocks are leading options. Moreover, some other papers including Chan et al. (1993) find virtually no evidence of any leading effect from price changes of option markets to stock markets. Bakshi et al. (2000) even find that, oftentimes, call options and their underlying equities move in the opposite direction.

In view of these inconclusive findings in the literature, this thesis attempts to address the important question concerning the lead-lag relation between the warrant and its underlying security.[1] Other than some institutional features, the economic function of warrants is no different from options. These derivatives are leveraged securities that give investors the exposure to the underlying assets at a fraction of the cost, and the opportunity to enjoy geared returns when the market moves in favor, or to limit and hedge the risk of an existing portfolio in a falling market.

1.1 Structured Warrants

The success of structured or covered warrants has been a worldwide phenomenon in the last couple of years. It has become a popular derivative in Europe, Australia, and Asia. In Singapore, the market of structured warrants started in early 2004. With only four issues initially, the warrant market grew rapidly with 250 issues a year later, and by April 2007, there are more than 680 issues listed on the SGX. The trading volume in Q1 2007 has increased by 31% year-on-year to 18.5 billion lots, and the transaction value rose to 5.2 billion Singapore dollars, an increase of 64%.

[1] The term “warrant” used throughout this thesis refers to the covered or structured warrant issued by investment banks and not by companies.

In contrast to equity options, most warrants are traded on the same exchange as their underlying securities. Each warrant is a security issue listed by an investment bank on the stock exchange. The bank pays the stock exchange for issuing warrants and assumes the role of market maker. As market maker, the bank is committed to place firm quotes on a regular basis to ensure that trading of warrants is made available to market participants at all time when the market is open. Due to this institutional difference, warrant price is not directly determined by the market supply and demand, or trading volumes; rather, the issuers price the warrant according to models such as the Black and Scholes model. However, the market maker is, by no means, unconditionally obligated to the pricing with no regard for market orders. Under certain conditions when the orders are largely unbalanced and exceed the market maker's hedging limit, the price will be adjusted to reflect the market makers' excess risks and added cost in market making.

As warrants are traded along side the underlying stocks on the same platform, the clock used for recording the time stamp of each trade or quote is the same for both securities. The problems in ensuring the temporal order of trades and quotes as they arrive do not arise. This feature is critical to research that examines lead-lag price movements at the tick level. If the derivatives are traded on a different exchange as in the case of options in the U.S. markets, the timing devices used by the option and stock exchanges are unlikely to be perfectly synchronized; the clock in the option exchange may be ahead of the clock in the stock exchange by a few seconds. As a result, it is not possible to be absolutely certain that the temporal order is preserved, and the findings of any lead-lag relation may be spurious or misleading.

1.2 Research Focus

Our empirical analysis uses high-frequency trade and quote data at one-second time resolution from the Singapore Exchange (SGX), which operates a purely electronic trading platform with a central limit order book. The warrants traded on the SGX are issued by global investment banks such as Deutsche Bank, Societe Generale, BNP Paribas, and Macquarie. These banks have a large market share (87%) of the warrant market in Singapore, though some U.S. investment banks such as Merrill Lynch, Goldman Sachs, and J.P. Morgan are present as well. As at end of 2006, the annual turnover in trading value is in excess of 9 billion U.S. dollars. If the global investment banks replicate the same market making strategies in Singapore market as in other larger markets such as Euronext, then the findings of this thesis will be helpful in gaining insight into the lead-lag relation between warrant and its underlying stock and index futures in the global setting and not restricted only to Singapore market.

This thesis contributes to the literature in three aspects. First, we propose a counting method to study the lead-lag relation between warrants and the underling securities. This method is efficacious in examining the lead-lag relation at the tick-by-tick frequency with a time resolution of one second. It is non-parametric and the assumptions critical to the regression approaches are not needed. Second, our empirical analysis provides strong evidence that stocks are leading the respective warrants when such lead-lag relation is examined under the microscope of irregularly spaced tick data with synchronized time stamps. Third, we look into trading strategies that take advantage of the lead-lag relation. Our results suggest that the trading strategies are able to generate an average of 1 to 1.16 Singapore dollars per transaction if trades of one round lot could be executed at the quote midpoint and traders need not pay other transaction costs such as brokerage commission.[2] However, if we take the bid-ask spread into consideration, we find that these trading strategies not only are non-profitable but also result in heavy losses. These findings make economic sense; for otherwise, no investment banks will have any incentive to issue warrants and to be the market makers at all.

The rest of the thesis is organized as follows. In Section 2, we present our literature review. Section 3 provides some background of the warrant markets worldwide and documents the tick data we use in our empirical study. In Section 4, we present our non-parametric counting method; and in Section 5, we test the null hypothesis of no lead-lag relation between the warrant and its underlying stocks. Section 6 provides an analysis of the profit and loss for trading strategies that exploit the lead-lag relations. We present a robustness check on recent equity warrants in Section 7. Section 8 tests the same null hypothesis on index warrants and index futures, as well as evaluates the strategies used for trading on index warrants. And the thesis is concluded in Section 9.

[2] Each round lot is 1,000 shares in Singapore market. The brokerage commission plus other costs is about 0.35% of the trading value.

2. LITERATURE REVIEW

Covered warrants are derivatives traded on the stock exchanges in Europe, Asia, and Australia. Despite the meteoric rise in trading activity, there has been limited academic research on covered warrants. One of the reasons is that covered warrants have a relatively short history and traded mainly in non-US markets. By contrast, a lot of research works have been done on a closely related and more mature product: options. These research works, especially those on the information flow and lead-lag effect between options and their underlying stocks, could provide a guide and reference to our study on warrants.

We begin our review with a hypothesis in the literature that informed traders choose to trade in the option market rather than the equity market because of the lower capital required and the leverage that options provide. In view of this possibility, many researchers and market players alike are interested in the price discovery process in these two markets, and whether there is any lead-lag relation. For example, Easley et al. (1998) empirically test the informational role of transaction volume in option markets and conclude that informed traders do trade in the option market and that some option trade volumes provide information on stock price movements.

Manaster and Rendelman (1982) compare the daily closing price with the stock price implied from the Black-Scholes model. They find evidence that option is leading the stock, although they are unable to attribute the finding to the possibility that material information arrives earlier in the option market than in the stock market. Bhattacharya (1987) uses implied intraday transaction prices and find a weak information discovery from option prices. However, Bhattacharya's test can only detect if the option market is leading the stock market but not the other round. The test cannot preclude the possibility of stock price changes predict option price changes.

Anthony (1988) finds that information arrives earlier in the option market than in the stock market. He is inclined toward interpreting his results from the perspective of non-synchronous market closing times. Chakravarty et al. (2004) apply the method of information share proposed by Hasbrouck (1995) to measure directly the percentage of price discovery across the stock and option markets. They use intraday transaction data to compute the information share for each day and conclude that option market contributes 17% to price discovery. However, since the data are drawn separately from NYSE and CBOE, there is a potential clock synchronization issue at the per-second accuracy of their study.

Stephan and Whaley (1990) use five-minute transaction prices to perform multivariate time-series analysis and find that stocks lead options by fifteen minutes. However, Chan et al. (1993) point out that Stephan and Whaley's results could be spurious because the leading effect might be induced by infrequent trading of options, and the relatively larger option tick size might cause option prices to appear lagging stock prices. They use bid-ask quotes, which arrive in the market at a much higher frequency than transaction prices do. With the Gibbons (1982) multivariate system equation, they find no evidence that options lead stocks.

Chiang and Fong (2001) study the spot, futures, and option markets for the Hang Seng Index and find that the option returns are lagging the cash index return. They attribute this lag to the young option market that experiences very thin trading. Chan et al. (2002) perform intraday analysis of order flows and price movements for actively traded options and stocks. Their results show that stock's net trade volume has predictive power for both stock and option price revision, but option trade volume has no incremental predictive ability. Kang et al. (2006) examine the Korean KOSPI200 spot, futures and options markets They conclude that the futures and options markets are leading the spot market by up to 10 minutes in terms of returns, and by 5 minutes in terms of volatilities. They also find the KOSPI200 options market returns both lead and lag futures market by 5 minutes using Granger's regression. The results are attributed to the lower transaction costs in the derivatives, particularly the futures market.

In these papers, it is noticeably a concern that any daily price or volume comparison between the options and stocks suffers from the problem of non-synchronization in the two markets. In particular, CBOE closes ten minutes after the closure of NYSE, and any additional information disseminated into the marketplace within that period would lead to a technical "front-run." Even with intra-day data, the statistical analysis of high frequency time series is often hampered by the fact that the clock time intervals between different markets may vary.

In terms of research approach, one of the often used methods is Granger's lead-lag regression, or multivariate regression model first used in finance by Gibbons (1982), as shown below:

$$\Delta C_{i,t} = a_{i,t} + \sum_{K=-3}^{3} b_k h_i \Delta S_{i,t+k} + \varepsilon_{i,t} \quad i = 1, 2, \ldots N; \qquad t = 1, 2, \ldots T \tag{1}$$

Here, $\Delta C_{i,t}$ and $\Delta S_{i,t}$ are, respectively, the call price change and stock price change for firm *i* from time *t*-1 to time *t*, h_i is the delta value, b_k is the lead-lag coefficient, *N* is the number of option days in the sample, and *T* is the number of intervals during in a trading day. The same equation applies to put options. The coefficients, $a_{i,t}$, b_k, and h_i could be estimated from equation (1), and the sign and significance are used to interpret the lead-lag relation between price changes in the two markets.

With respect to data sampling, the usual approach is to splice the time axis into fixed time interval of 5 minutes, and use the last observation recorded in that interval in the regression and statistical analysis. However, de Joneg and Nijman (1995) point out two important drawbacks of this approach: first, the non-synchronous trading associated with short intervals and infrequent trading; and second, the loss of information during busy trading and long intervals, which render the statistical analysis less efficient.

Beyond the lead-lag relationship, Bakshi et al. (2000) study some properties shared by all one-dimensional diffusion models. They find that intraday call (put) prices often go down (up) even as the underlying price goes up, and they conclude that one-dimensional diffusion option models cannot be completely consistent with option price dynamics.

ter Horst and Veld (2002) study the Netherlands markets where both equity call warrants and call options co-exist. They fin that the warrants are strongly overvalued by 25 to 30% from various pricing models. They attribute this over-pricing mainly to the marketing differentiation by issuing investment banks, and the retail investors' preference toward warrants than options.

In terms of trading cost, Petrella (2006) investigates the determinants of covered warrants' bid-ask spread from the viewpoint of market makes. A model is developed to consider the hedging cost for delta risk exposure and the order processing cost. He concludes that the bid-ask spread of a warrant is closely related to the spread of underlying equity. Market makers do consider the hedging and scalping risks in setting bid-ask spread for protection, and to prevent arbitrage by traders.

3. WARRANT MARKETS AND DATA

We provide in this section some background of warrant markets and show that the warrants issued by investment banks have taken off in major international markets across the world. Korea warrant market, in particular, had a monthly trading value of 41 million US dollars in December 2005, and the turnover shot up by more than 88.8 times to an average of 3.64 billion dollars per month in the following year. By contrast, equity options are not actively traded in Korea despite an earlier start.[3]

3.1 Background of Warrant Markets

Other than some institutional features, options and warrants are virtually the same instrument in that they give the holders the right to buy or sell the underlying assets at the strike price. Intriguingly, the equity option market is inactive in most parts of the world. By contrast, covered warrants are actively traded on the stock exchanges in Europe, Asia, and Australia.

Table 3-1 shows the numbers of warrants listed by year end and the volume traded in US dollars. These figures are compiled from the annual market statistics published by the World Federation of Exchanges. In Europe, the warrant markets have been thriving even before 2002. By end of 2006, there are 5,841 warrants listed in the pan-Europe exchange, Euronext, with trading value of 42 billion US dollars. The largest warrant turnover in Europe

[3] The Korea warrant market was launched in December 2005 with 34 issues.

is Italy, with trading volume valued at more than 90 billion US dollars in 2006. In Asia, Hong Kong is the leading warrant market, which has a turnover exceeding that of Italy since 2003, and by 2006, the trading value exceeded 230 billion US dollars. Other Asian markets had a late start, but they too have seen a meteoric rise in trading values.

Market	**2002**	**2003**	**2004**	**2005**	**2006**
Panel A: Number of warrants listed by year end					
Euronext	4,595	3,770	4,991	4,913	5,841
Borsa Italia	3,571	2,594	3,021	4,076	4,647
Spanish EX	1,509	1,056	1,308	1,344	2,627
London SE	311	545	644	213	416
Australia SE	1,201	1,395	1,771	2,447	3,091
HK EX	347	530	863	1,304	1,959
Taiwan SE	102	272	191	540	694
Singapore EX	-	3	146	455	521
Korea EX	-	1	3	72	1,387
Panel B: Trading value in USD (million)					
Euronext	15,242	10,345	8,605	16,414	42,304
Borsa Italia	17,317	12,319	20,507	62,159	90,588
Spanish EX	1,062	1,830	2,274	2,654	3,676
London SE	N.A.	420	814	610	1,346
Australia SE	1,730	1,634	2,810	4,986	7,311
HK EX	14,459	33,920	67,337	110,168	230,411
Taiwan SE	2,156	3,440	6,252	4,424	5,388
Singapore EX	-	14	871	6,521	9,156
Korea EX	-	-	6	41	43,689

Table 3-1. Numbers of warrants listed and annual turnovers

The Singapore warrant market started in late 2003 with only three issues. The warrant market grew rapidly a year later to 146 issues. In 2006, the number of warrants jumped to 455 and the turnover exceeded 9 billion US dollars. By April 2007, there are more than 680 issues listed on the Singapore Exchange (SGX). The trading volume in the first quarter of 2007 increased by 31% to 18.5 billion round lots, and the trading value is 5 to 10% of the SGX total daily turnover.

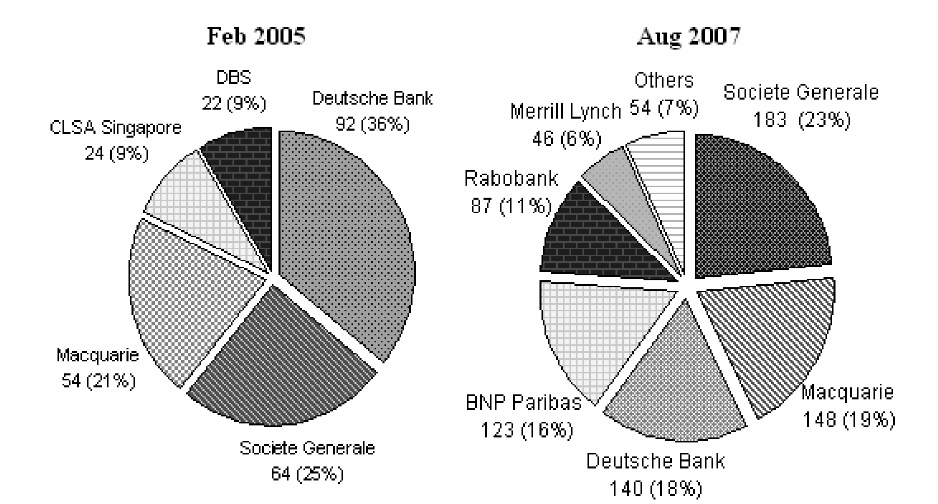

Figure 3-1: Warrant market shares by investment banks in Singapore

Although Singapore is a relatively new market for warrants, the major players in Singapore are in fact no strangers. They are the same investment banks that have developed the more mature markets in Europe and Hong Kong. As shown in Figure 3-1, in Feb 2005, Deutsche Bank's market share in the Singapore warrant market alone is 36%; together with Societe Generale and Macquarie, these banks issued 82% of the warrants traded on the SGX in 2005. More banks joined the warrant market in 2007, but top five issuers still covered 87% of the market. Thus, it is reasonable to believe that the pricing, quoting, and hedging strategies used for the Singapore market are very similar, if not the same as the strategies used in the mature warrant markets.

From Table 3-1, we note that the Singapore warrant market has a median turnover among the 9 markets. For these reasons, we choose the Singapore warrant market and our study will be helpful for understanding both the mature and the emerging warrant markets.

3.2 Data Description

The SGX intraday quote movement data were obtained from ShareInvestor. It provides all the quote and trade prices logged into the Singapore Exchange, with time stamp up to one second. This high data frequency allows us to explore the possible lead/lag effect in the market. Three groups of data were used in this study.

Our main data set consists of 20 blue-chip stocks and their 171 warrants traded on the SGX from January through March, 2005 (57 trading days), total sample size is 6,862 warrant-days. These 20 stocks represent 57.8% of the value-weighted Straits Times Index during our sample period, while the 171 warrants represent 66.8% of a total of 256 issues. Of the 171 warrants analyzed in this thesis, 146 (85.4%) of them are call warrants and 25 (14.6%) are put warrants. There are more call warrants in the market than put warrants, both because traditionally investors are in favor of long rather than short securities, as well as the issuing banks cannot have naked short sell but have to borrow for any put issues, which effectively increases the cost of put warrants. Refer to Appendix A-1 for the detail breakdown of the warrants on companies.

For the period of February to March 2007, when the stock market experienced a large adjustment, we obtain 174 issues of warrants on the five most heavily weighted stocks in the Straits Times Index. These data are used for robustness check and for indicating market changes since 2005. A list of these warrants is shown in Appendix A-2.

Index warrants form the third group of our sample. They are warrants on Nikkei 225 (NKY), Straits Times Index (STI) and Taiwan Weighted Index (TWII), as well as the underlying futures contracts of Nikkei, SIMSCI and MSCITW. All these warrants and index futures are listed on the Singapore Exchange. There are 41 issues and 1,677 warrant-days collected between December 2006 and March 2007. Different from the equity warrants, the call and put warrants consist about 50% each in the sample. This is partially because index futures in the major markets are very commonly traded with high volumes compared to any single stock, hence issuing banks have little difficulty in hedging. A detailed breakdown of the index warrants is listed in Appendix A-3.

Data Groups	Usable Data Windows
Equity warrants & Stocks	09:00:00 ~ 12:29:59 14:00:00 ~ 16:59:59
Nikkei 225 warrants & Futures	09:00:00 ~ 10:14:59 11:15:00 ~ 12:29:59 14:00:00 ~ 14:29:59
STI warrants & SIMSCI	09:00:00 ~ 12:29:59 14:00:00 ~ 16:59:59
TWII warrants & MSCITW	09:00:00 ~ 12:29:59

Table 3-2: Usable data windows

In SGX the trading sessions for stocks and warrants are from 9 am to 12:30 pm and 2 pm to 5 pm. In addition, there is a pre-open routine from 8:30 am to 9 am, and a pre-close routine from 5 pm to 5:05 pm. For simplicity, we ignore the quotes during pre-open and pre-close sessions and only use the quotes entered during normal trading hours, thus we use the trading hours from 9:00:00 to 12:29:59 and 14:00:00 to 16:59:59 for the study on equity warrants.

The index futures have different trading hours compared to warrants. The Nikkei futures contracts are traded during 7:45 am to 10:15 am and from 11:15 am to 2:30 pm; SIMSCI is traded during 8:45 am to 12:30 pm and 2 pm to 5:15 pm; and the MSCITW is traded during 8:45 am to 13:45 pm with no lunch break. In order to match all the trading times, we use warrants and futures data only when both markets are open for trading, and the usable data windows for this study are listed in Table 3-2.

3.3 Descriptive Statistics for Equity Warrants and Stocks

The descriptive statistics for a total 6,862 warrant-days are shown in Table 3-3. The average warrant price is 27.4 cents in local currency.[4] Within the price range from 0.5 cent to 165 cents, there are 598 warrant-days (8.71%) for which the price is below 5 cents, and 600 warrant-days (8.74%) for which the price falls between 5 to 10 cents. We note that trading volume is very volatile; some warrants are very actively traded in certain days, but thinly traded in other days. The trading volume is skewed to the right, with 30.82%

[4] Unless otherwise stated, the currency used henceforth will be in local currency. In 2005, one US dollar can exchange for 1.6 to 1.7 Singapore dollars.

of the warrant-days have no trading at all, but 22.37% are traded more than 1,000 round lots a day. On average, daily trading volume is 868 lots.

In Table 3-3, we also report the number of movements in the quote midpoint, the range of these movements in cents and in percent. On average, a warrant moves its price by 43 times a day, with 136 (1.98%) warrant-days not having any movements, and 1311 (19.11%) warrant-days with less than 10 movements. The daily price movement for warrants ranges from $0 to $0.8, with average movement of only 2.65 cents. As the warrant's quote midpoint is small in value, the movement in percentages is large, and each movement in the midpoint is a change of 12.5% on average.

Equity Warrants	**Mean**	**Std**	**Min**	**Median**	**Max**
Average Price (cent)	27.5	21.1	0.50	21.9	164
Number of Quote Update	43.0	43.1	0	31.0	469
Price Movement Range (cent)	2.65	2.82	0.00	2.00	80.0
Price Movement Range (%)	12.5	12.7	0.00	9.23	148
Daily Trading Vol (lot)	868	1919	0	125	29,805

Table 3-3: Descriptive statistics for equity warrants' prices and movements

Table 3-4 presents the statistics of the 20 underlying stock in our sample. The average stock price is $6.08, with minimum price at 89 cents and maximum at $27.0. On average, the price movement is 36.8 times a day, with 158 (13.86%) of the 1140 stock-days have less than 10 movements. The daily price movement for stocks ranged from 0 to $1.50, with average movement of 10.5 cents. Due to the relatively higher stock price, this percentage of daily price movement is only 2.19% on average.

The average daily trading volume on each stock was 5,000 lots, about 5.7 times the average of any respective warrant, which was only 868 lots with many of them not traded on certain days. However, we note that the aggregate trading volume of the warrants on the same underlying stocks exceeded stocks trading. During the sample period, the aggregate daily trading volume of warrants was 104 thousand lots, compared to 98 thousand lots for the stocks.

Socks	Mean	Std	Min	Median	Max
Average Price ($)	6.08	6.09	0.89	2.74	27.0
Number of Quote Update	36.8	36.0	0.00	28.0	760
Price Movement Range (cent)	10.5	12.6	0.00	6.00	150
Price Movement Range (%)	2.19	1.73	0.00	1.80	34.4
Daily Trading Vol (lot)	5000	6113	82	2843	52,640

Table 3-4: Descriptive statistics for stocks' prices and movements

Figure 3-2 gives a scatter plot of the average numbers of daily quote midpoint movement for warrants and the respective underlying stocks. There is a nice linear relationship between the two quotes movements at days when the stock price is stable, or when the stock quote moves less than 60 times a day. For more volatile days, the average movements of warrant quotes also vary considerably, and appear to be less correlated to the stock quotes.

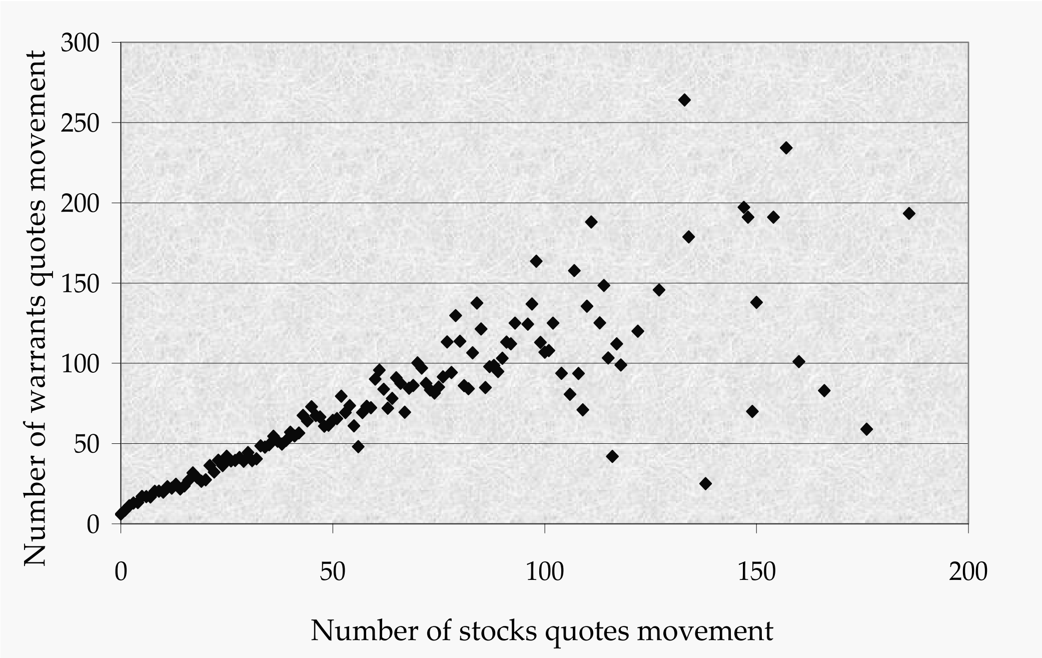

Figure 3-2: Relations between the quote movements of stocks and warrants

3.4 Index Warrants and Futures Data Statistics

The second group of data consists of three index futures on Nikkei 225, SIMSCI, and MSCITW, as well as their 41 warrants during December 2006 and March. 2007 (74 trading days). Among these 41 warrants, 23 of them are issued on Nikkei 225 futures, 14 are on SIMSCI and only four issued on TWMSCI. Calls and puts have the same proportion for these warrants.

Index futures and warrants	**Mean**	**Std**	**Min**	**Median**	**Max**
Avg warrant Price (cent)	43.4	56.0	0.50	26.3	336
Warrants trading Vol (lot)	242.6	593	0	2	7150
Future trading Vol (lot)	10,038	7,712	523	8,389	36,347

Table 3-5: Descriptive statistics for index futures and warrants

The statistics of the total 1,677 index future warrant-dates are shown in Table 3-5. The average warrant price is 43.4cents, with minimum price at 0.5 cent and maximum at $3.36. Within this price range, there are 374 warrant-dates (22.3%) that the price of a warrant falls below 5 cents, and 112 warrant-dates (6.68%) that the price of a warrant falls between 5 to 10 cents. Compared to their underlying index futures, the index warrants are much less traded in Singapore. The average trading volume of an index warrant is only 242 lots, only 2% of an index future of 12,614 lots. In fact among the 1,677 warrant-days, 835 (49.8%) of them are not traded, and only 213 (12.7%) of them are traded more than 500 lots a day. This volume is significantly less than equity warrants.

4. THE COUNTING METHOD

Traditionally Granger lead-lag regression or nonlinear multivariate regression model is used to study the lead-lag effect in any related time series of securities returns. As described in section 2, the method relies on regressing the return or price changes of related securities at a fixed time interval (5-minutes) and tries to identify any lead-lag relationships from the significance of the estimated coefficients. While this method is supported by econometric theory, and has been widely used since more than 20 years ago, it is not always relevant, as the regression approach depends on actual market settings and the nature of available data. Particularly in this study, the regression approach is not suitable for two reasons.

Firstly, the regression approach typically uses 5-minute returns. Considering the relatively lower warrant volume than stock volume but more frequent quote update by the market maker, 5-minute and even 1-minute interval is deemed too long for unraveling the lead-lag relation, if any, between a pair of related securities at the tick-by-tick frequency. Hence, to avoid tossing out useful information in the tick-by-tick data, a different method is in order.

Secondly, a seemly straightforward modification is to apply the same regression method with a reduced time interval to minimize the risk of information loss. However, in high-frequency data, the quote changes are usually small, and the quote midpoint in our sample always moves by discrete steps. Each step or tick is of the minimum size specified by SGX as shown in Table 4-1. Since most of the warrant prices are below \$1.00, the actual quote midpoint movement is mostly 0.5 cent and in some cases 1.0 cent. With the quote changes fixed and effectively limited to one tick size, the usual notion of return in high-frequency study, either in relative or absolute terms, would be inapplicable as it inherits the step-wise feature from the discrete price grid.

These considerations motivate us to develop a method that does not dismiss any midpoint movement, and uses the irregularly spaced quote updates as they are recorded without imposing a fixed time interval to avoid any information loss.

Security price range	**SGX tick size (cents)**	**Min. % of price**	**Max % of price**
< \$0.10	0.5	5.0%	50%
\$0.10 < \$0.20	0.5	2.5%	5.0%
\$0.20 < \$0.50	0.5	1.0%	2.5%
\$0.50 < \$1.00	0.5	0.5%	1.0%
\$1.00 ~ \$5.00	1.0	0.2%	1.0%

Table 4-1: SGX minimum tick sizes and percentage of price

4.1 A Non-Parametric Counting Method

We propose a non-parametric counting method to avoid making assumptions that are required in the regression approaches. These assumptions are not met in tick data, in which trades and quotes are recorded as they arrive. As illustrated in Figure 4-1, our counting method begins with the assignment of price change directions to the two time series separately. In other words, we convert the series of quote midpoints to a series of up tick, zero tick, and down tick. An up (down) tick occurs when the current quote midpoint is higher (lower) than the last quote midpoint. If there is no change in the midpoint, but only the bid or ask size is updated, we refer to such quote update as zero tick. Thus, the times series of quotes are transformed into a series comprising of only three outcomes, +1, 0, or -1, for each update. These three outcomes are, up tick, zero tick, and down tick, respectively. We refer to the resulting time series as signed updates, as each quote update is signed by the straightforward rule that depends only on the direction of change in the quote midpoint.

We then merge the two time series of signed updates by their time stamps. It is noteworthy that at the resolution of one second, the occurrences of an update for both series at the exact time of, say, 11:16:18, are rare. Even if it does occur, there is no impact on our methodology because our object of study is not contemporaneous relation.

To examine the lead-lag relation, we perform a two-way analysis. For clarity, we refer to the two signed series as S and W. We first examine the sign of the W series for each non-zero sign in the S series. As discussed earlier, every sign corresponds to a quote update, and a non-zero sign indicates either an upward movement, or a downward movement of the quote midpoint. When the sign of the W series is analyzed upon the occurrence of every non-zero sign in the S series, we are looking for the leading or causal effect from the S series to the W series. In the reverse scenario, when the sign of the S series is analyzed, we are examining any leading effect that the W series may have on the S series. This two-way analysis, as the name suggests, involves the study of not only the extent by which S is leading W, but also the other way round with W leading S.

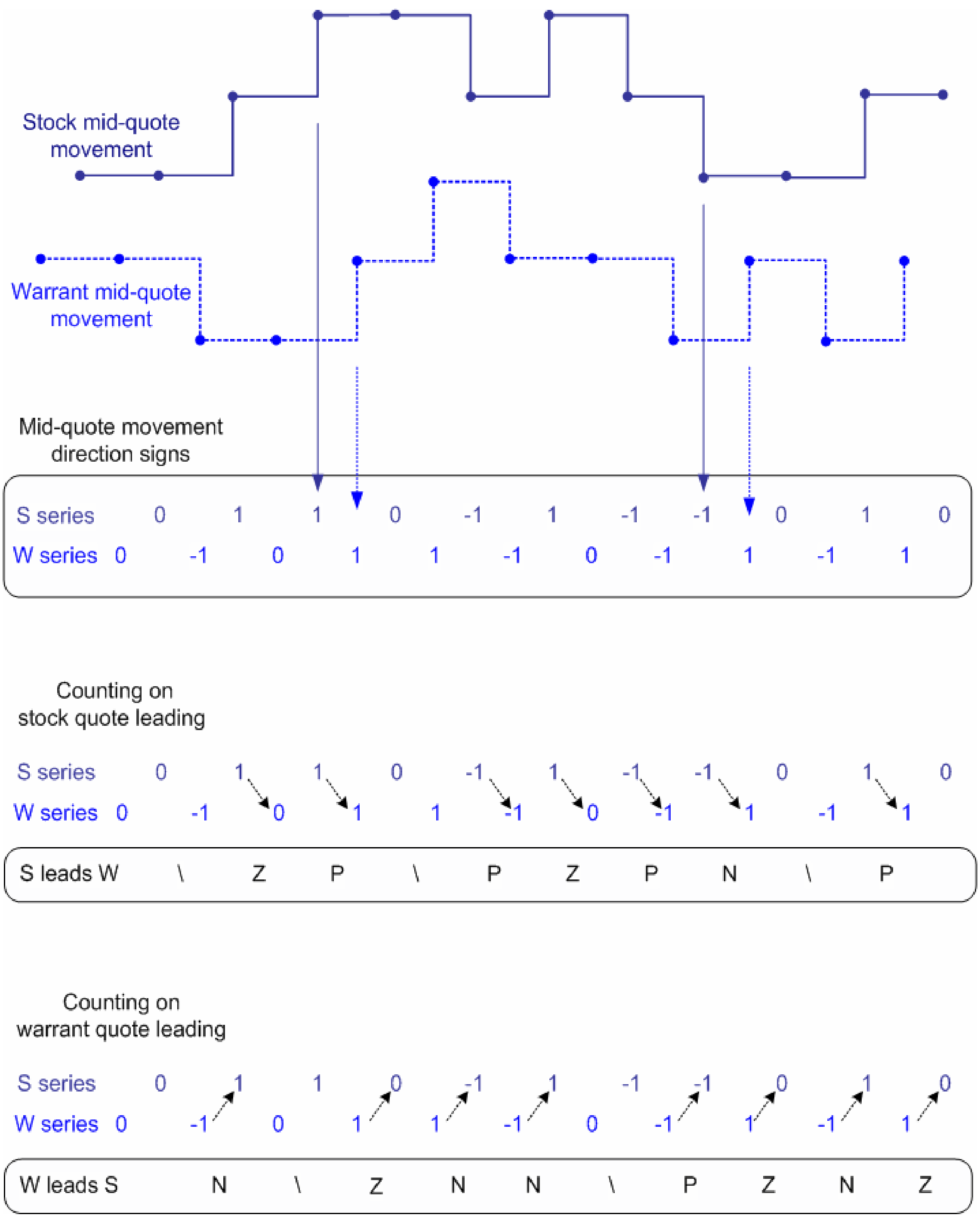

Figure 4-1: Illustration of the counting method on a call warrant

When an up tick is followed by a down tick, or a down tick is followed by an up tick, we use the symbol 'N' for these two possibilities. In this case, the product of these two signs is negative as the two series move in the opposite direction.

Thus far, we use the call warrant to illustrate our counting method. For put warrants, the symbol 'P' is assigned to the case for which an up tick is followed by a down tick, or a down tick is followed by an up tick. This is because when the S series moves upward, the W series of a put option should move downward, and vice versa. In the same vein, the symbol 'N' is assigned to the case for which an up tick in the S series is followed by an up tick in the signed series of put warrant, or when a down tick is followed by a down tick.

In short, the symbol 'P' indicates the economically correct movement according to the nature of the relation between a call or a put warrant with the underling security. On the other hand, we use the symbol 'N' to code the wrong movements.

Next, we turn to the frequency of quote updates. If one of the series, say the W series, has more quote updates than the other series (S series), then there will be several quote updates in the W series before a quote update occurs in the S series. Thus, a non-zero quote update may not have a corresponding quote update in the S series because there is another non-zero quote update in the W series and in between these two updates, there is no quote update in the S series. For this type of non-zero quote update, we assign the symbol 'Z' since no quote update is equivalent to zero tick from the standpoint of change in midpoint.

The bottom portion of Figure 4-1 illustrates the leading effect of W series of call warrant. The first non-zero sign in the W series is -1, a down tick. It is followed by +1 in the S series and the symbol 'N' is assigned for this opposite movement. The next non-zero sign in the W series is +1, which is followed by no movement in the S series, and the symbol 'Z' is assigned for this temporal pair. We continue the assignment until the last non-zero sign of the W series.

4.2 Statistical Tests

Having assigned the symbols of 'Z', 'P', or 'N' to each update of quote midpoint, we count the numbers of these three symbols. These numbers allow us to quantify the leading effect of the S series on the W series. If there is no leading effect between the S or W series, the quote updates must be simultaneous and random, and we shall observe only a small portions of 'P' and 'N', appear randomly in the series. And most importantly, the number of leads observed shall be the same from either S or W series, with neither of them count significantly larger than the other. However, if one security is leading the other in quote update, we shall be able to observe different amount of leading counts from S or W series. Besides, the number of 'P' symbols, which represents economically correct movement according to the nature of the relation, should be larger than the number of 'N' symbols.

To test the statistical significance of the difference between these two numbers, we use the chi-square statistic. There is only one degree of freedom from either a positive or a negative lead-lag movement.

In addition to the Pearson chi-square test, we also consider Yate's chi-square test. The latter is a modification of Pearson's by reducing the absolute value of each difference between observed and expected frequencies by 0.5 before squaring. This modification results in a lower chi-square value and thus increases its p-value and prevents overestimation of statistical significance for small samples. However, a caveat is that Yates' correction may tend to overcorrect and can result in an overly conservative result that fails to reject the null hypothesis when it should.

We denote the observed frequencies of 'P' and 'N' by O_i, the expected frequency by E_i, and the number of distinct events by *K*. The Pearson and Yate chi-square statistics are computed as follows:

$$\chi^2_{Pearson's} = \sum_{i=1}^{K} \frac{(O_i - E_i)^2}{E_i} \qquad \chi^2_{Yate's} = \sum_{i=1}^{K} \frac{(|O_i - E_i| - 0.5)^2}{E_i} \tag{2}$$

5. ANALYSIS ON EQUITY WARRANTS

For each warrant and each day, we perform the two-way analysis according to the method described in Section 4. We also compute the chi-square statistic for each warrant-day. In this section, we document the results obtained from our analysis. The test results provide evidence that warrants do not lead stocks. Rather, we find that warrants move in the same direction as the stocks have moved.

5.1 Distribution of Equity Warrants

The warrants distribution was studied according to the trading volume, moneyness, and prices. As the warrants are not evenly distributed for each of the characteristics, the purpose for such study is to effectively group the warrants in a most representative way for studying the lead-lag relation.

Trading volumes

Many warrants are issued on the same underlying stocks, with different maturities and strike prices by different investment banks. Often some of the warrants are more attractive to investors than others. Figure 5-1 shows the distribution of warrants according to trading volumes. Note that about one third of the warrants are almost not traded in a day, and with 5% heavily traded. The average trading volume is 868 lots, and the maximum amount is 29.8 thousand lots.

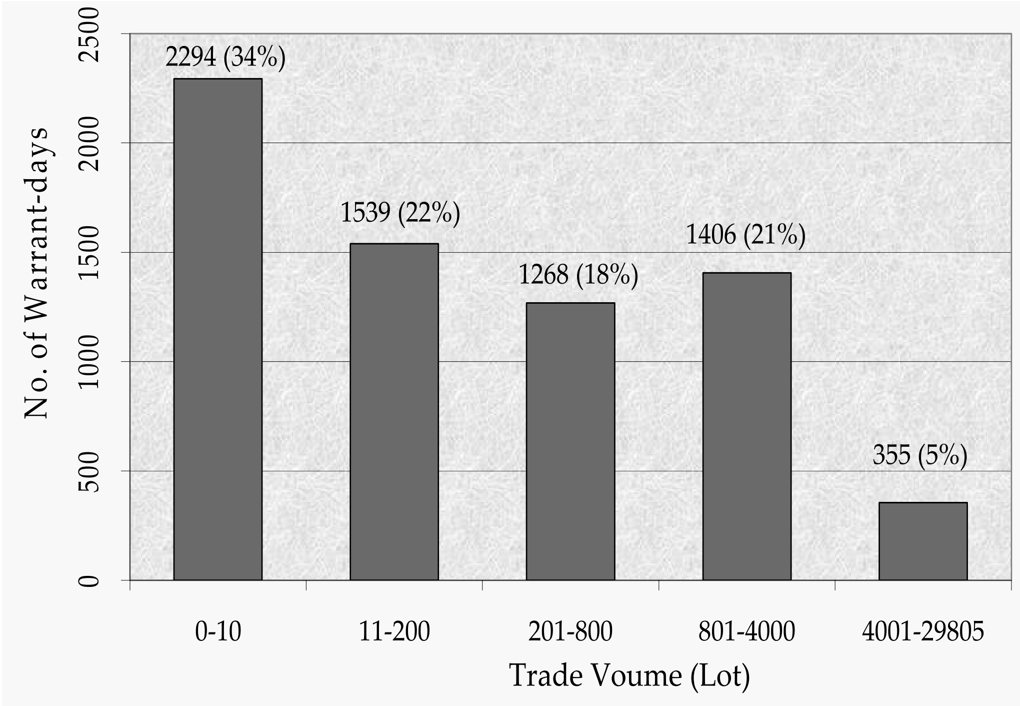

Figure 5-1: Equity warrants daily trading volumes

Moneyness

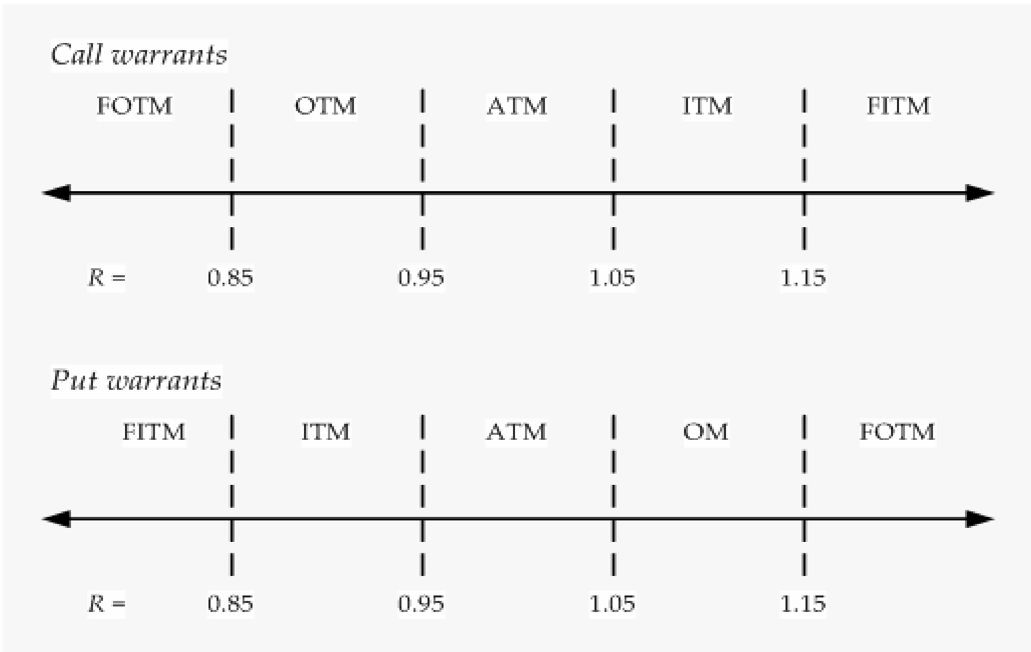

Figure 5-2: Definition of moneyness

One of the major characteristics of a warrant is its moneyness. The level of moneyness does not only determine the warrant price, but also receives different investor preference. For both call and put warrant, we take the ratio of underlying equity price over warrant strike price to be *R*, an R value of $1 \pm 5\%$ is considered as at-the-money (ATM), and if the ratio *R* moves out of $1 \pm 15\%$, we define them as far-in-the-money (FITM) or far-out-of-money (FOTM). As depicted in Figure 5-2.

Moneyness and trading volumes

Figure 5-3 shows the average daily trading volumes of the warrants according to the moneyness. Obviously investors are more interested in those warrants that are ITM compared to OTM, and the trading volumes are five times larger. The most popular warrants are those just turned ITM, traded on average 2,319 lots a day. While those FOTM warrants are only traded 260 lots.

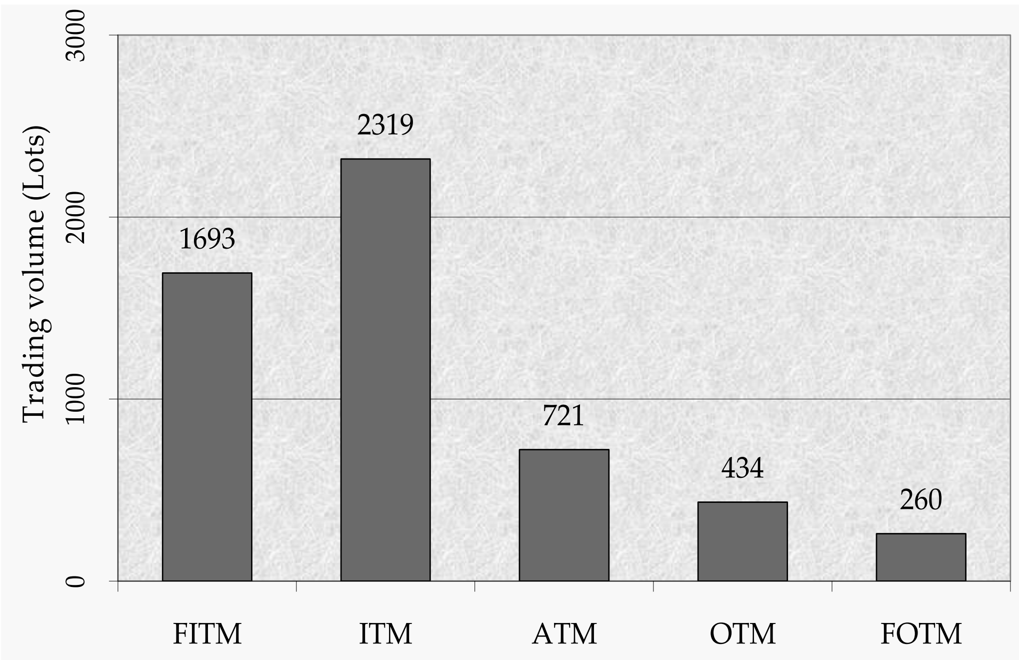

Figure 5-3: Equity warrants' moneyness and trading volumes

Moneyness and prices

The price of a warrant depends on its moneyness, and it is especially sensitive when the warrant is near-the-money. Figure 5-4 shows the average warrant prices according to their moneyness. FITM warrants are on average priced at $0.52. The price of an ATM warrant is in the range of 10~20 cents and those FOTM warrants are priced at only 3 cents.

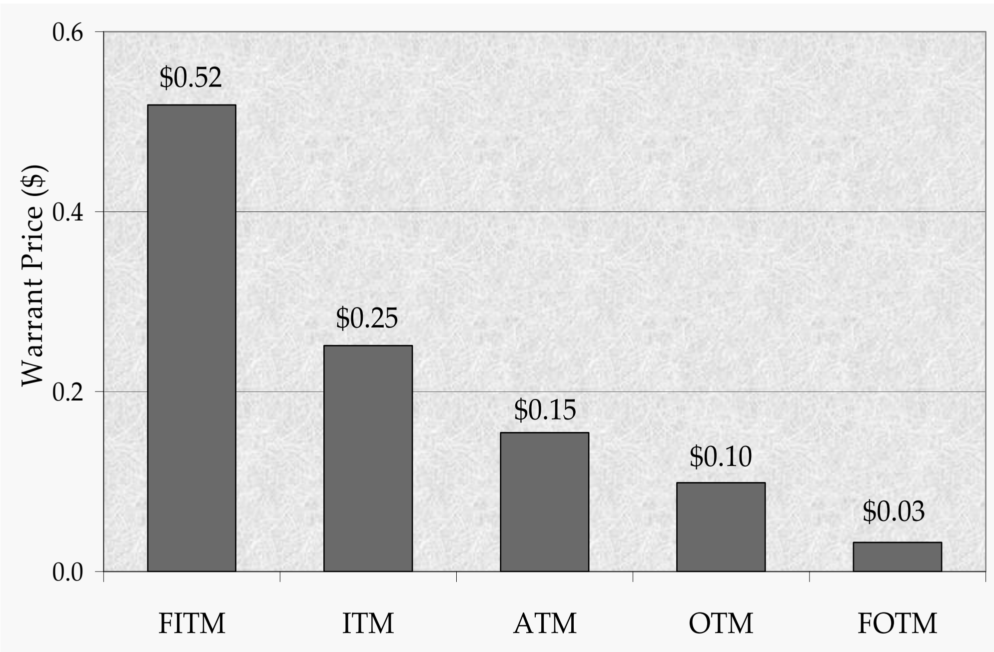

Figure 5-4: Equity warrants' moneyness and prices

5.2 Equity Warrant Data Groups

The minimum tick size for SGX varies with the price level. For security issues that trade below a dollar per share, the minimum tick size is 0.5 cent. When the extremely FOTM warrants are price lower than 10 cents per share, a price change of one tick is larger than 5%, with such large ticker size, the warrant price would be insensitive to any market changes and information flows. Thus we exclude these warrants that typically have few quote updates and no trading activity.

After excluding those warrants that are priced below 10 cents, our sample size is 5,617 warrant-days. We then categorize the warrants by trading volume into 5 groups. The group of low-volume warrants is particularly useful in exploring the market makers' behavior, with little interference from investors' buying or selling pressure. Warrants with high trading volume, on the other hand, allow an analysis of investors' trading on market maker's quotes.

Table 5-1 provides a summary of these 5 data groups. About 30% of the warrants only traded less than 10 lots a day, and the top 5% have more than 4000 lots of transactions. The middle groups are evenly separated at 200 lots and 800 lots, each consists of around 21%.

Group	Number of Warrant-Days	Percentage
All warrants priced ≥ 10 cents	5,617	100%
G1. 0 to 10 lots	1,674	29.8%
G2. 11 to 200 lots	1,279	22.8%
G3. 201 to 800 lots	1,101	19.6%
G4. 800 to 4,000 lots	1,251	22.3%
G5. More than 4,000 lots	312	5.55%

Table 5-1: Five groups of warrants by trading volumes

Quote update frequencies

The counting method produces the numbers of quote updates for both stocks and warrants. Table 5-2 shows a breakdown of the average daily quote movement for the different groups. We note that for both stocks and their warrants, the proportions of upward quote movements and downward quote movements are almost the same, with 51% movements going upward, and 49% downward. Moreover, the warrants quotes are updated more frequently at 57% compared to that of stocks. Particularly for the group with active trading, the warrant quote movements are 1.92 times more frequent.

	Average number of S quote movements			**Average number of W quote movements**			**W/S**
	Total	**Up tick**	**Down tick**	**Total**	**Up tick**	**Down tick**	
All	30.3	15.4	14.9	47.5	24.0	23.5	1.57
G1	17.4	8.8	8.7	24.5	12.3	12.3	1.41
G2	28.9	14.7	14.2	41.6	20.8	20.7	1.44
G3	31.8	16.1	15.7	47.5	23.8	23.7	1.49
G4	41.2	21.1	20.1	69.2	35.3	33.9	1.68
G5	56.4	29.0	27.4	108	55.5	52.5	1.92

Table 5-2: Numbers of average stocks and warrants quote updates

On those non-traded warrants, their quotes move 1.41 times more than the underlying stocks. But for the heavily traded warrants, the ratio goes up to 1.92 times. The increased warrant price movement is due to the pricing pressure on the market makers to adjust their quotes more frequently. The question of interest is whether the pricing pressure is large enough to influence the warrant price so that it moves faster and ahead of the underlying stock.

5.3 Do Warrants Lead Stocks ?

Based on the movement in the midpoint of warrant's quotes, we first use our counting method to examine the midpoint movement of the underlying stock. The results are presented in Table 5-3. As before, we refer to the warrants as W series and the stocks as S series. As a reminder, the symbol 'Z' refers to no movement, 'P' refers to movement in the same direction, and 'N' refers to movement in the opposite direction.

Group	**Non-zero W sign**	**No S move 'Z'**	**Positive S move 'P'**	**Negative S move 'N'**	**Pearson chi-square**	**Yate chi-square**
All	266,863	242,071 (90.7%)	11,681 (4.38%)	13,111 (4.91%)	0.96	1.20
G1	41,052	36,284 (88.4%)	2,273 (5.54%)	2,495 (6.08%)	0.92	1.10
G2	53,187	47,053 (88.5%)	2,786 (5.24%)	3,348 (6.29%)	1.00	1.31
G3	52,318	47,676 (91.1%)	2,155 (4.12%)	2,487 (4.75%)	0.97	1.23
G4	86,612	79,422 (91.7%)	3,449 (3.98%)	3,741 (4.32%)	1.01	1.26
G5	33,694	31,636 (93.9%)	1,018 (3.02%)	1,040 (3.09%)	1.18	1.49

Table 5-3. Counts (percentages) of warrants leading stocks

We note that out of 266,863 non-zero signs in the W series (non-zero W sign), more than 90% of the changes in the warrant's midpoint do not lead to any midpoint movements ('Z') in the underlying stocks. For the remaining 9.3% of the changes in warrants' midpoint, 4.38% are followed by positive movements ('P') and 4.87% are followed by negative movements ('N') in the underlying stocks. In other words, these two percentages are not much different.

If there is any leading effect from warrants to stocks, the movement directions must either be mostly 'P', or mostly 'N', and not equally distributed. However, the percentages of 'P' and 'N' shown in Table 5-3 are almost equal. The two small percentages of directional movements in the underlying stocks are most likely random. To test the null hypothesis of equally likely distribution, we run the Pearson and the Yate tests for each warrant-day. We then take an average for all the warrant-days. The chi-square statistics shown in Table 5-3 fail to reject the null hypothesis.

Thus, we conclude that whenever there is a change in the warrant's quote midpoint, the underlying stock is equally likely to move in the same direction or in the opposite direction. In other words, we find no significant leading effect from the warrants to the underlying stocks

5.4 Do Stocks Lead Warrants?

The statistics in Table 5-4 paint a very different picture when we examine the directional movement in the warrant upon a non-zero change in the midpoint of the stock. Although we have a majority of the stock movements not leading to any warrant movements, the percentage of 68.2% is considerably lower than the corresponding percentage in Table 5-3. More importantly, the directions of warrants' movements are no longer random. Overall, 25.6% of the movements in the warrants are positive, 4 times more frequent than the negative movements. The average chi-square tests also reveal that the distribution of 'P' and 'N' are not equally likely at the 5 to 10% significance level.

We note that the percentages for 'Z', 'P', and 'N' all decrease from the least traded group (G1) to the most traded group (G5). An interpretation of this result is that for warrants that are thinly traded, their prices are primarily determined by the issuing banks. The issuers, who are the market makers, possibly update the warrant quotes based on some pricing model such as the Black-Scholes formula. However, for heavily traded warrants, the market makers cannot ignore the trading activity. As a result, the issuers may not price the warrants strictly according to the theoretical model, hence making the leading effect less significant.

Group	Non-zero S sign	No W move 'Z'	Positive W move 'P'	Negative W move 'N'	Pearson chi-square	Yate chi-square
All	170,375	116,206 (68.2%)	43,662 (25.6%)	10,507 (6.17%)	4.95**	4.17**
G1	29,203	17,255 (59.1%)	9,605 (32.9%)	2,343 (8.02%)	4.62**	3.85**
G2	36,998	22,760 (61.5%)	11,425 (30.9%)	2,813 (7.60%)	5.45**	4.64**
G3	35,010	24,756 (70.7%)	8,340 (23.8%)	1,914 (5.47%)	4.77**	4.03**
G4	51,580	37,393 (72.5%)	11,417 (22.1%)	2,770 (5.37%)	5.54**	4.69**
G5	17,584	14,042 (79.9%)	2,875 (16.4%)	667 (3.79%)	5.58**	4.65**

Table 5-4: Counts (percentages) of stocks leading warrants
Two asterisks indicate 5% significance level.

Overall, the counting method has discovered a leading effect of stock prices on the respective warrants prices. This leading effect is stronger on less frequently traded warrants. When a warrant is heavily traded, however, such leading effect is diluted

5.5 The Time Delay

Group	Time delay of warrants in seconds (s)		Cumulative percentage of the delay distribution		
	Mean	Skewness	< 1s	< 3s	< 5s
Panel A: 'P' Movement					
All	3.29	18.5	56.2%	90.1%	94.2%
G1	2.79	19.3	56.5%	89.7%	93.8%
G2	3.07	17.1	58.8%	90.3%	94.7%
G3	3.79	17.1	58.8%	90.3%	94.7%
G4	3.59	20.2	57.6%	89.7%	93.5%
G5	3.65	17.6	54.1%	89.5%	93.8%
Panel B: 'N' Movement					
All	5.37	13.2	43.8%	84.3%	87.5%
G1	3.89	13.2	48.3%	86.4%	90.7%
G2	4.82	12.8	45.6%	88.3%	87.8%
G3	6.17	13.6	39.5%	83.7%	85.9%
G4	6.61	13.4	41.7%	81.4%	84.6%
G5	5.97	11.8	43.2%	85.6%	89.2%

Table 5-5: Time delay in the warrant quote update

Since there is evidence that warrants lag stocks, we move on to the question of how long is the delay. In this subsection, we document the time delays for both positive (P) and negative (N) warrant movements.

Panel A in Table 5-5 shows the delay times of the warrants' quotes update lagging that of stocks. The average delay for the 'P' movement (correct movement) is 3.29 seconds. For G1, the delay is only 2.79 seconds, 24% faster than 3.65 seconds for G5. A possible explanation is that the market makers may need to interpret the trading information before re-pricing the warrants, especially when trading activity is high, as in G5. We also note that the overall distributions of the delays are highly skewed; 56% of the delays are less than 1 second, and more than 90% of the quote updates occur within 5 seconds. These results indicate that the warrant issuers are efficient in updating the quotes.

The delays for 'N' movements are shown in Panel B of Table 5-5. Although the delay times are longer than those of the correct 'P' movements, the difference is only 2 seconds, not significantly slower. Similar to the 'P' movements, the distribution is also highly skewed. This result suggests that the 'N' movements are not entirely random and may even contain some information. The finding also agrees with Bakshi et al. (2000) that the intraday call (put) prices often go down (up) even as the underlying price goes up. They find such 'violation' occurs at about 11% for a 30-minute sampling interval, and they attribute this to market microstructures and additional state variables.

By contrast, as shown in Table 5-6, if we assume that warrant quote movements lead the stock and measure the average delay time, we find that it is about 20 seconds, six times longer than the corresponding delay time when stock quote movements lead the warrant. We note that the six times longer delay time is much larger than the movement ratio, W/S, in Table 5-2.

In summary, the leading effect of stock on warrant disappears within 3 to 5 seconds. We attribute this quick disappearance to the automated pricing model, and more importantly, automated submission and alteration of electronic orders. To be successful, warrant issuers or market makers must be able to update their quotes quickly.

Group	**Time delay of stocks in second (s)**		**Cumulative percentage of the delay distribution**		
	Mean	**Skewness**	**< 2s**	**< 5s**	**< 20s**
			Panel A: 'P' movement		
All	20.1	11.2	21.0%	37.2%	78.8%
G1	22.9	10.4	20.3%	36.3%	75.6%
G2	21.3	8.6	20.8%	37.0%	77.8%
G3	18.1	11.5	21.6%	37.9%	78.5%
G4	16.5	10.2	22.6%	38.4%	79.4%
G5	15.7	12.3	23.7%	39.5%	80.0%
			Panel B: 'N' movement		
All	24.6	11.0	18.2%	32.8%	74.6%
G1	30.9	10.5	16.7%	30.1%	73.4%
G2	28.4	11.7	17.6%	31.2%	73.9%
G3	25.1	10.2	18.1%	32.7%	74.4%
G4	23.5	11.3	18.8%	33.5%	75.1%
G5	21.8	11.9	19.3%	34.3%	75.3%

Table 5-6: Time delay in the stock quote update

6. TRADING STRATEGIES

In the previous section, our analysis shows that 16.4 to 32.9% of the movements in the stock's midpoint are associated with subsequent movements of the same direction in the warrant's midpoint. On the other hand, only 3.8 to 8.0% of the warrant movements are in the opposite direction. In this section, we explore various strategies to trade warrants based on this knowledge. For all the strategies considered, we take intra-day positions, either long or short, and all positions are closed out before the end of the trading day. No position is allowed to be held overnight.

6.1 An Intraday Strategy

The intra-day strategy works as follows: We monitor a stock quote midpoint movement, and whenever a stock's midpoint moves up, we immediately take a long position in all the warrants on that stock. Each trade is one round lot. For example, if there are 6 warrants written on the stock, we have a long position of 6 lots. In the same fashion, whenever a stock's midpoint moves down, we sell one lot for each related warrant. Prior to the end of each trading day, we close out the net position for each warrant.[5]

Without bid-ask spread

[5] All our trading strategies can be implemented by computer programs since the rules are straightforward.

First, we consider an ideal trading environment without bid-ask spread and other trading costs. We assume that all the trades are executed at the midpoint of the bid and ask quotes.

	All	**G1**	**G2**	**G3**	**G4**	**G5**
Average P&L per day ($)	36.65	15.97	28.88	38.86	60.16	73.85
Standard deviation	93.23	58.40	84.63	97.21	114.44	126.39
t-statistics	29.5***	11.2***	12.2***	13.2***	18.6***	10.3***
% of profitable days	77.1%	71.6%	73.7%	79.8%	82.7%	89.1%
Average number of trades	31.73	21.50	29.10	31.82	41.35	56.77
Average P&L per trade ($)	1.16	0.85	1.08	1.26	1.49	1.43
Standard deviation	2.623	2.459	2.758	2.757	2.652	2.000
t-statistics	33.1***	14.1***	13.9***	15.1***	19.9***	12.6***
Min. P&L per trade ($)	-16.15	-14.29	-16.15	-12.08	-7.34	-1.82
5 percentile ($)	-1.56	-2.50	-2.14	-1.67	0.42	-1.27
25 percentile ($)	0.00	-0.09	-0.11	0.06	14.19	0.33
50 percentile ($)	0.71	0.50	0.61	0.78	-0.23	0.94
75 percentile ($)	1.81	1.54	1.76	1.84	1.18	1.69
95 percentile ($)	5.23	4.52	5.06	5.18	4.29	3.53
Max. P&L per trade ($)	38.29	26.25	29.00	38.29	30.74	17.93

Table 6-1: Profits and losses (P&L) without bid-ask spread
Three asterisks indicate 1% significance level or better.

The results are presented in Table 6-1. On average, given that the volume of each trade is one lot, we earn $36.65 per day from trading warrants. The profit increases from $15.97 to $73.85 as we go from the group of least actively traded warrants (G1) to the group of most actively traded warrants (G5). Although the leading effect is stronger for less active warrants, but because the time delay for such lagging by warrants are so short and the trader does not make the best profit from trading this group of warrants. The best profit comes from trading on the more active warrants, which have weaker lagging effect, but provide longer time delay for the trader to act upon such indicators. All the *t*-statistics for the 5 groups are significant at 1% level or better. And the probability of making profit ranges from 71.6% to 89.1%, all above the 50% benchmark.

The average number of trades per day ranges from 21.50 to 56.77, which are also the average number of changes in the stock's midpoint per day. The average profits per trade are $0.85 for G1 and $1.43 for G5, respectively. Again, the t-statistics for profit per trade are all significant at 1% level or better. In Table 6-1, we also tabulate the profit per trade at different percentiles as well as the minimum and maximum profit and loss. All the statistics provide evidence that the trading strategy works well in the ideal market with no trading cost.

With bid-ask spread

Next, we carry out the same analysis in a market with bid-ask spread. We are to buy at the ask price and sell at the bid price. As shown in Table 6-2, the strategy incurs significant losses across all groups of warrants.

While trading with the bid-ask prices, it is not possible for the strategy to be profitable, and trading on all groups of warrants incur significant losses. On average, the loss is -$113.56 per day from trading warrants. All the *t*-statistics for the 5 groups are negatively significant, and the probability of making profit falls to only 4.8 ~ 9.8%, far below the 50% benchmark.

The average loss per trade is as high as -$4.07. This significant loss is expected due to the relatively large bid-ask spread for warrants. The average price for the warrants is only $0.33, and the size of the bid-ask spread is either 1.0 cent or 0.5 cent. Thus, the bid-ask spread is equivalent to 1.5 to 3% of the warrant price, implying that a trader is paying this amount whenever he trades. As a result, the percentage of profitable days is only 7.7%, and the average loss is economically significant.

	All	**G1**	**G2**	**G3**	**G4**	**G5**
Average P&L per day ($)	-133.56	-114.11	-157.93	-131.98	-135.90	-131.66
Standard deviation	210.42	189.99	245.60	178.90	197.82	284.25
t-statistics	-47.5***	-24.57***	-23.0***	-24.4***	-24.3***	-8.2***
% of profitable days	7.7%	8.2%	4.8%	7.5%	9.8%	9.0%
Average number of trades	31.73	21.50	29.10	31.82	41.35	56.77
Average P&L per trade ($)	-4.07	-4.82	-5.02	-3.81	-2.87	-1.99
Standard deviation	4.185	4.251	4.891	3.956	3.328	1.971
t-statistics	-72.8***	-46.3***	-36.7***	-31.9***	-30.4***	-17.8***
Min. P&L per trade ($)	-62.00	-31.58	-62.00	-32.00	-32.90	-10.88
5 percentile ($)	-11.00	-13.75	-13.33	-11.39	-7.50	-5.75
25 percentile ($)	-5.34	-6.25	-6.46	-4.83	-4.04	-3.08
50 percentile ($)	-3.33	-4.46	-4.30	-3.17	-2.66	-2.14
75 percentile ($)	-2.03	-2.39	-2.50	-2.05	-1.75	-1.40
95 percentile ($)	0.00	0.00	-0.31	0.00	0.92	0.00
Max. P&L per trade ($)	25.50	17.50	18.50	23.82	25.50	11.19

Table 6-2: Profits and losses (P&L) with bid-ask spread
Three asterisks indicate 1% significance level or better.

The case of warrants leading stocks

Does the profit and loss occur by chance? What would the profitability be if we assume that warrant quotes are leading? The second column of Table 6-3 summarizes the profit and loss from trading each stock using the information on the warrant quote movements. For comparison, we list the profit and loss from our earlier trades on warrants in the third column. Even without bid-ask spread, we find that the average loss is $2.10 per trade and average loss per day is $60.50. If bid-ask spread is taken into account, the loss increases to $33.5 and $1,014, respectively.

	Trade on Stocks	**Trade on Warrants**
Panel A: Trade without bid-ask spread		
Average P&L per day ($)	- $ 60.50	$36.65
Average P&L per trade ($)	-2.10	1.16
t-statistics	-9.92	29.47
% of profitable days	34.9%	77.1%
Panel B: Trade with bid-ask spread		
Average P&L per day ($)	- $1,014	- $113.56
Average P&L per trade ($)	-33.5	-4.07
t-statistics	-77.7	-47.57
% of profitable days	3.3%	7.7%

Table 6-3: Profits and losses (P&L) from trading warrants by stock quote movements

6.2 Alternative Strategy

We implement an alternative strategy to verify the impact of bid-ask spread on profitability. This strategy still acts according to the midpoint movement of the underlying stock. But different from the previous strategy of trade one lot per time, this time the trader wants to hold as small a position as possible at any given time of the trading day. To illustrate this alternative strategy, we use an example. At the beginning of each trading day, the trader has zero holding. Suppose there are three consecutive up ticks in the stock's midpoint, and he will have accumulated 3 round lots of a warrant over 3 trades. Next, a down tick occurs in the stock. In the previous strategy, the trader will sell one lot, and the net position is 2 lots. For the alternative strategy, he sells 4 lots, and the position becomes -1 lot. If the fifth stock movement is a down tick, the trader follows the usual rule of selling another lot. But if it is an up-tick, the trader will buy 2 lots of warrants to close the short position and at the same time establish a long position of 1 lot. This strategy is more aggressive in a way as it fully interprets and forecasts the signal from the underlying stock.

Table 6-4 shows the profit and loss of this alternative strategy, when the trader can trade at the quote midpoint. The alternative strategy effectively doubles the total trading volume, and results in 82.1% increase in average daily profit to $66.74 (compared to $36.65 from the previous strategy). The profit for each group also increases, to as high as $126.20 per day. The average profit per trade per lot is $1.07.

However, when the trader has to pay for the bid-ask spread, the alternative strategy ends up with heavier losses as shown in Table 6-5. The average daily loss surges to -$251.37, compared to only -$133.56 for the earlier strategy. These results show that, in a perfect market when a trader is able to trade at the midpoint of the bid and ask quotes, he is able to profit from the tick-by-tick information provided by the stock in warrant trading. However, in the real market, any gain from trading on the stock signal is unable to cover the bid-ask spread. In the best case, the trader still suffers a loss of -$114.11 per day, or -$2.87 per trade per lot.

	All	**G1**	**G2**	**G3**	**G4**	**G5**
Average P&L per day ($)	60.74	29.61	51.10	62.76	92.83	126.20
Standard deviation	115.22	71.39	115.51	111.36	137.28	149.79
t-statistics	39.5***	16.9***	15.8***	18.7***	23.9***	14.9***
% of profitable days	82.7%	75.7%	79.8%	85.4%	89.6%	95.2%
Average number of trades	61.75	41.37	56.48	61.91	80.94	111.73
Average P&L per trade ($)	1.07	0.89	1.10	1.13	1.19	1.17
Standard deviation	1.948	2.061	2.232	2.018	1.519	1.142
t-statistics	41.1***	17.7***	17.6***	18.6***	27.7***	18.0***
Min. P&L per trade ($)	-15.76	-13.75	-15.76	-11.67	-4.79	-1.05
5 percentile ($)	-0.89	-1.43	-1.25	-0.77	-0.64	-0.31
25 percentile ($)	0.17	0.00	0.07	0.20	0.34	0.50
50 percentile ($)	0.80	0.63	0.76	0.82	0.91	0.89
75 percentile ($)	1.63	1.51	1.67	1.62	1.67	1.35
95 percentile ($)	3.75	3.68	4.08	3.64	3.26	2.36
Max. P&L per trade ($)	31.76	31.76	26.25	24.81	16.53	9.69

Table 6-4: Alternative strategy's profits and losses (P&L) without bid-ask spread
Three asterisks indicate 1% significance level or better

All these result again shows that any exploitation of the leading effect is futile in the real market with trading costs. We believe that the investment banks use the conversion ratio to design their warrants in such a way that the warrant price is below certain price level, so that by quoting even a tight bid-ask spread of the minimum tick size, the banks are still able to run a profitable business in making the market.

	All	G1	G2	G3	G4	G5
Average P&L per day ($)	-251.37	-209.69	-291.62	-244.59	-267.89	-261.61
Standard deviation	379.18	368.86	453.32	335.48	334.51	391.27
t-statistics	-49.6***	-23.2***	-23.0***	-24.1***	-28.3***	-11.8***
% of profitable days	5.1%	6.6%	4.1%	4.9%	4.9%	3.5%
Average number of trades	61.75	41.37	56.48	61.91	80.94	111.73
Average P&L per trade ($)	-3.83	-4.48	-4.60	-3.54	-2.88	-2.08
Standard deviation	3.674	3.911	4.371	3.519	2.543	1.329
t-statistics	-78.1***	-46.8***	-37.7***	-33.4***	-40.0***	-27.6***
Min. P&L per trade ($)	-58.96	-26.50	-58.96	-31.00	-31.39	-7.32
5 percentile ($)	-10.00	-13.00	-11.82	-10.57	-7.12	-5.49
25 percentile ($)	-5.00	-5.83	-5.82	-4.51	-3.71	-2.75
50 percentile ($)	-3.06	-4.09	-3.90	-2.86	-2.50	-2.14
75 percentile ($)	-2.00	-2.30	-2.34	-2.00	-1.83	-1.61
95 percentile ($)	0.00	0.00	-0.63	-0.36	-0.33	-0.69
Max. P&L per trade ($)	22.65	22.65	16.47	19.74	14.17	5.88

Table 6-5: Alternative strategy profits and losses (P&L) with bid-ask spread
Three asterisks indicate 1% significance level or better.

7. ROBUSTNESS CHECKS

In this section, we perform the same analysis for a different sample period from February 26 to March 30, 2007. This is a period when the stock market is highly volatile, and STI fluctuates by more than 9.8%. The data from this sample period are used for verifying the robustness of our earlier results. We obtain qualitatively the same results presented in this thesis.

7.1 Data for Robustness Checks

The new data set consists of 174 warrants on the five most heavily weighted stocks in STI, and there are 3,640 warrant-days in the new sample. A detailed list of the warrants is shown in Appendix A-2.

Trading volumes

The number of structured warrants has doubled in the recent two years. The total trading volumes have also increased significantly compared to stocks. However, most of the trades are still concentrated on 20.2% (734 issues) of the active warrants. Figure 7-1 shows the distribution of warrant trading volumes. The percentage of non-traded warrants has increased to 45%, while the heavily traded issues account for 8%. The average trading volume increases to 971 lots per day. We note that the total trading volume has jumped from 5,227 lots to 29,454 lots, an increment of 5.63 times within two years.

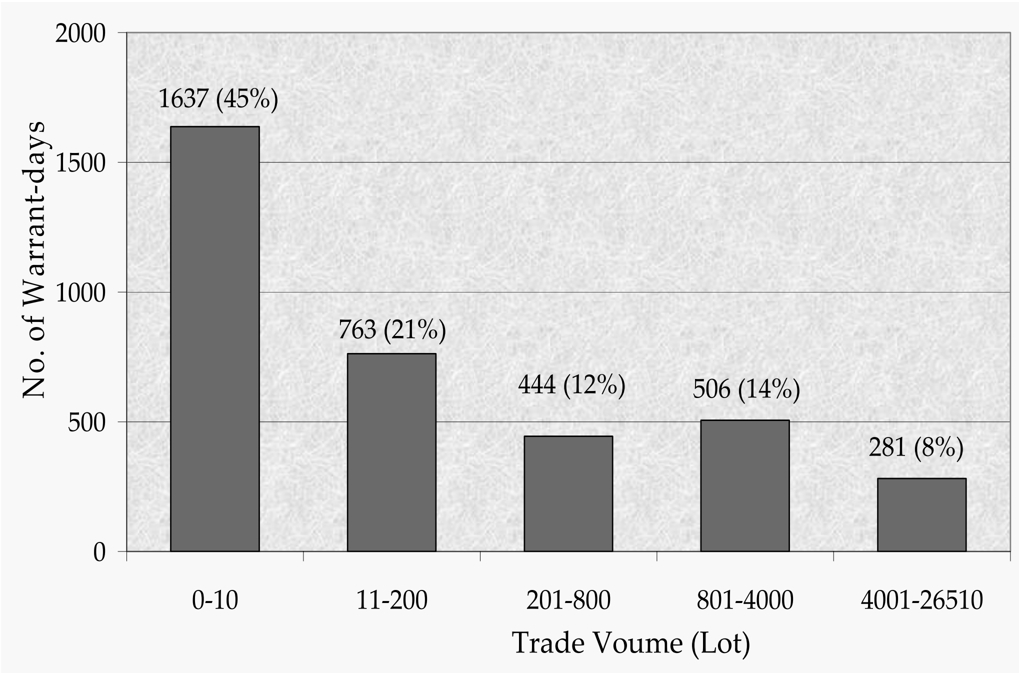

Figure 7-1: Equity warrants daily trading volumes (2007)

Moneyness and trading volumes

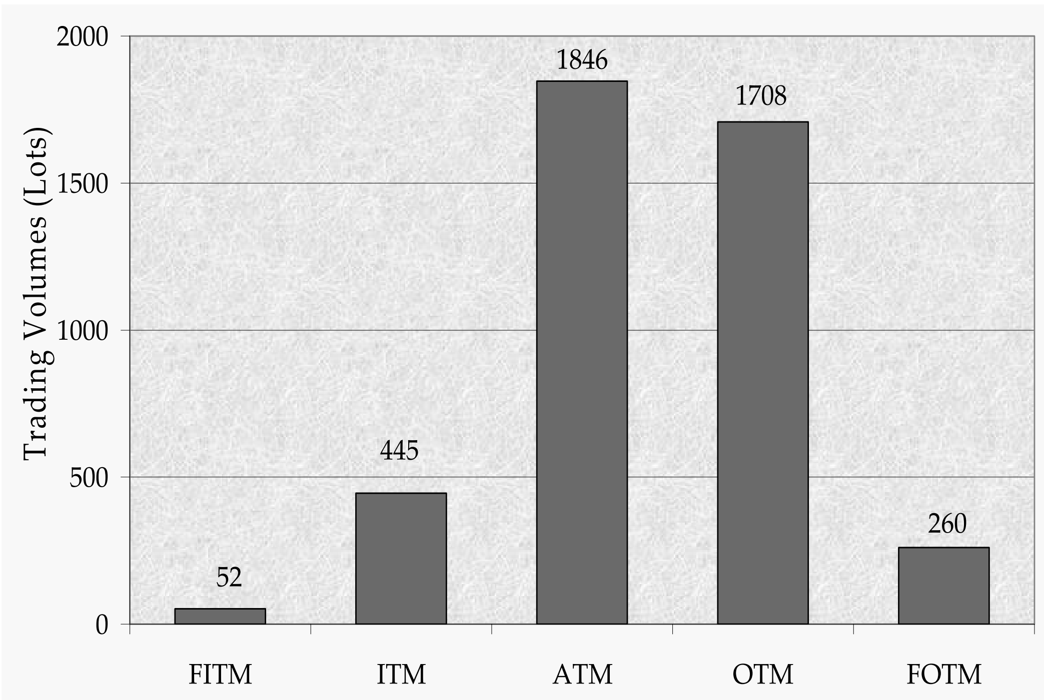

Figure 7-2: Equity warrants’ moneyness and trading volumes (2007)

We apply the same moneyness definition to the warrants and find that the trading volumes have moved from in-the-money (ITM) to out-of-the money (OTM) warrants. In 2005, on average there were 2,319 lots traded on the ITM warrants, but the number reduced to only 445 lots in 2007. On the other hand, at-the-money (ATM) and OTM warrants are more popular in March 2007. Their average trading volumes increased by 2 to 4 times.

Moneyness and prices

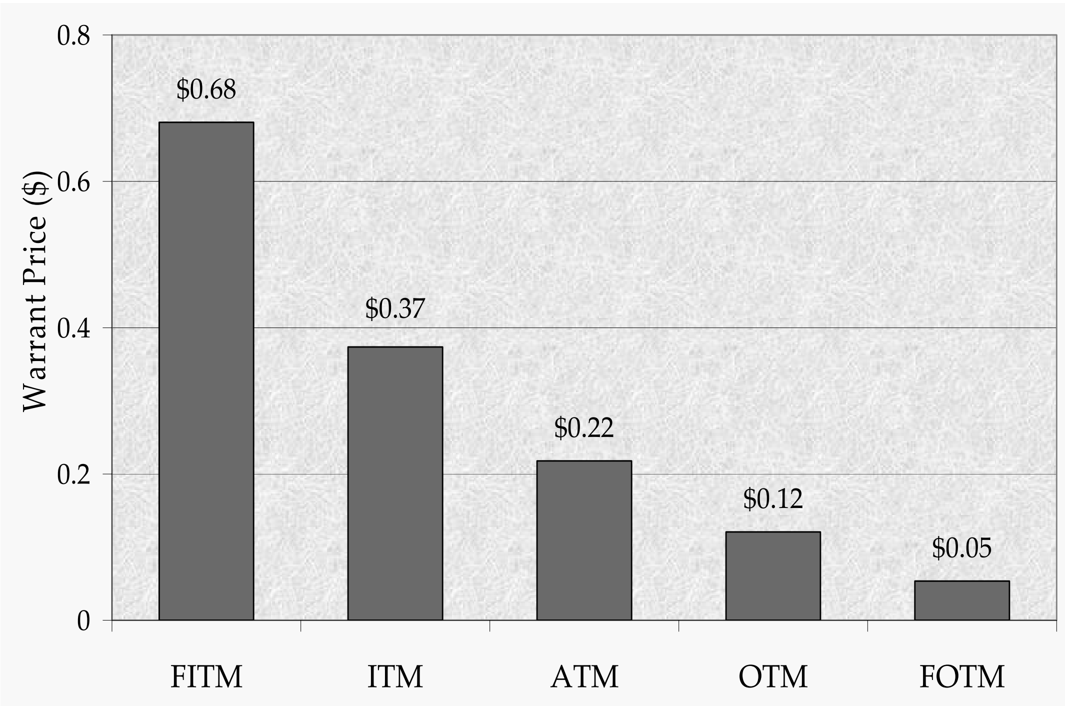

Figure 7-3: Equity warrants' moneyness and prices (2007)

From Figure 7-3, we observe that the warrants are priced higher for all groups regardless of the moneyness during the new data period. The increment ranges from 2 cents for far out-of-the-money warrants, to 16 cents for far in-the-money warrants. One of the possible reasons is that the stock market was undergoing a period of high volatility, especially during the end of February to March 2007 when an unexpected slump in China's stock markets spilled over to most other stock markets around the world. The higher volatility has increased the option premium.

Figure 7-4 compares the STI 10-day volatility during January through March in 2005 and 2007. On average, the STI volatility is 8.36 points higher in 2007 compared to that of 2005. In particular, from February 28, the large swing in stock market dramatically increases the volatility by about 20 points higher than the same period in 2005.

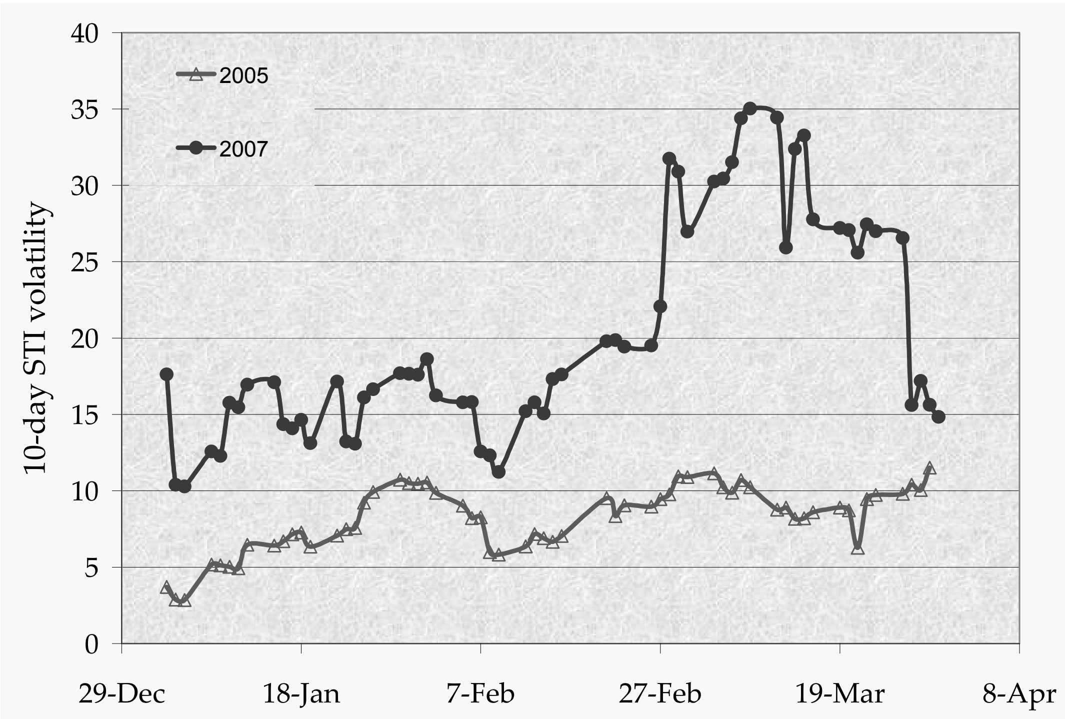

Figure 7-4: STI volatility in 2005 and 2007

Moneyness and trading volumes

We again exclude those warrants priced below 10 cents, and group the usable data according to the same criteria of trading volumes into 5 groups. The group of low-volume warrants is particularly useful in exploring the market makers' behavior, with little interference from investors' buying or selling pressure. Warrants with high trading volume, on the other hand, allow an analysis of investors' trading on market maker's quotes. Table 7-1 provides a summary of these 5 data groups. About 45% of the warrants only traded less than 10 lots a day, and the percentage has increased from 30% in 2005. This indicates that although more warrants are available in the market, investors choose more carefully and only half of the issues are actively traded. On the other hand, the top 8% of warrants have more than 4,000 lots of transactions. The middle groups are separated at 200 lots and 800 lots.

Group	Number of Warrant-Days	Percentage
All warrants priced ≥ 10 cents	3,640	100%
G1. 0 to 10 lots	1,624	44.6%
G2. 11 to 200 lots	765	21.0%
G3. 201 to 800 lots	446	12.3%
G4. 800 to 4,000 lots	517	14.2%
G5. More than 4,000 lots	288	7.91%

Table 7-1: Five groups of warrants by trading volumes (2007)

7.2 The Lead-Lag Effect

As shown in Table 7-2, over 93% of the changes in the warrant midpoints do not lead to any midpoint movements ('Z') in the underlying stocks, which is similar to our earlier result. For the remaining 6% of the changes in warrant midpoints, the percentages of 'P' and 'N' moves are not different, and we do not observe significant leading effect from the warrants on the underlying stocks.

Group	Non-zero W sign	No S move 'Z'	Positive S move 'P'	Negative S move 'N'	Pearson chi-square	Yate chi-square
2007-All	237,039	222,682 (93.9%)	7,248 (3.06%)	7,109 (3.00%)	1.51	0.73
2007-G1	99,269	92,460 (93.1%)	3,478 (3.50%)	3,331 (3.36%)	1.61	0.82
2007-G2	49,405	46,392 (93.9%)	1,529 (3.09%)	1,484 (3.00%)	1.53	0.75
2007-G3	31,338	29,619 (94.5%)	897 (2.86%)	822 (2.62%)	1.52	0.73
2007-G4	33,990	32,227 (94.8%)	829 (2.44%)	934 (2.75%)	1.34	0.58
2007-G5	23,037	21,984 (95.4%)	515 (2.24%)	538 (2.34%)	1.25	0.55

Table 7-2: Counts (percentage) of warrants leading stocks (2007)

On the other hand, we observe the same leading effect from stocks to the warrants in 2007. The counts for stocks leading warrants are shown in Table 7-3. The number of 'P' movements far exceeds the amount of 'N' movements by more than 8 times, indicating an even stronger leading effect from stocks to warrants compared to year 2005. The decrease of 'P' and 'N' percentages from the least traded group (G1) to the most traded group (G5) is consistent with the results in 2005. We again attribute this phenomenon to the increased complexity in updating quotes for heavily traded warrants.

Group	Non-zero S sign	No W move 'Z'	Positive W move 'P'	Negative W move 'N'	Pearson chi-square	Yate chi-square
2007-All	114,913	77,402 (67.4%)	33,418 (29.1%)	4,093 (3.56%)	8.14***	6.78***
2007-G1	48,161	30,093 (62.5%)	16,335 (33.9%)	1,733 (3.60%)	9.39***	7.96***
2007-G2	24,734	17,031 (68.9%)	6,704 (27.1%)	999 (4.04%)	7.46***	6.16**
2007-G3	15,230	11,002 (72.2%)	3,656 (24.0%)	572 (3.76%)	6.95***	5.71**
2007-G4	16,456	11,695 (71.1%)	4,277 (26.0%)	484 (2.94%)	7.14***	5.78**
2007-G5	10,332	7,581 (73.4%)	2,446 (23.7%)	305 (2.95%)	6.99***	5.69**

Table 7-3: Counts (percentage) of stocks leading warrants (2007)
Two and three asterisks indicate 5% and 1% significance levels respectively.

Group	Time delay of warrants (s)	Cumulative percentage of the delay distribution		
		< 1 s	< 3 s	< 5 s
2005 All	3.29	56.2%	90.1%	94.2%
2007 All	1.86	51.9%	93.4%	98.2%
2007 G1	1.77	52.4%	94.4%	98.9%
2007 G2	1.99	48.2%	92.0%	97.6%
2007 G3	2.03	48.5%	91.3%	97.7%
2007 G4	1.92	53.1%	92.8%	97.6%
2007 G5	1.81	62.3%	93.4%	97.4%

Table 7-4: Delay times of warrants (2007)

The leading effect has become more significant in 2007, with most of the chi-square tests being more significant at even the 1% level. One of the explanations is that as the warrant market becomes more mature, the issuing banks are motivated to improve the quoting strategies and processes and to track the underlying stocks more closely. This explanation is consistent with the reduced average delay time. As shown in Table 7-4, the average delay time is significantly reduced from 3.29 seconds to 1.86 seconds.

7.3 Trading Profits and Losses

The trading strategy is repeated, based on the leading stock movements, with and without bid-ask spread. Table 7-5 and Table 7-6 show average daily profits and losses from the two intraday strategies to trade warrants. Also we assume a delay of one second for the traders to response to the changing stock prices.

Qualitatively, we obtain similar profit and loss using the two strategies compared to 2005. For the first intraday strategy, the profit without bid-ask spread increases from $36.65 to $75.89 per warrant-day (or from $1.16 to $2.38 per trade). The profit generated by using the alternative strategy also increases from $60.74 to $149.28 per warrant-day (or $1.07 to $2.40 per trade). The average probability of a profitable day is 71.6% and 76.0% respectively. However, when the bid-ask spread is applied, both strategies suffer huge losses, range from of -$357.8 to -$627.4 per trading day, or -$9.38 to -$10.35 per trade.

	All	G1	G2	G3	G4	G5
Panel A: Trade without bid-ask spread						
Average P&L per day ($)	75.89	72.68	90.86	93.74	60.31	57.07
Standard deviation	672.2	996.8	128.5	130.6	74.9	70.5
t-statistics	8.80***	4.95***	19.53***	15.12***	18.11***	13.57***
% of profitable days	71.6%	69.2%	72.5%	70.3%	76.3%	77.2%
Average number of trades	32.8	31.2	33.4	36.1	32.1	36.2
Average P&L per trade ($)	2.38	2.39	2.75	2.73	2.00	1.60
Standard deviation	18.4	27.3	3.18	3.45	2.27	1.55
t-statistics	7.82***	3.55***	23.8***	16.7***	19.8***	17.2***
Min. P&L per trade ($)	-899.1	-899.1	-5.52	-4.83	-3.75	-2.36
50 percentile ($)	1.96	2.50	2.08	1.77	1.47	1.29
Max. P&L per trade ($)	184.8	184.8	19.04	23.00	22.88	8.08
Panel B: Trade with bid-ask spread						
Average P&L per day ($)	-357.8	-583.7	-262.9	-183.4	-88.9	-86.8
Standard deviation	1901.9	2802.4	400.2	394.3	111.5	114.3
t-statistics	-11.3***	-8.43***	-18.2***	-9.80***	-17.9***	-12.7***
% of profitable days	4.7%	2.6%	3.8%	8.1%	8.3%	7.8%
Average number of trades	32.7	31.2	33.4	36.1	32.1	36.2
Average P&L per trade ($)	-10.35	-18.04	-7.13	-4.26	-2.61	-2.20
Standard deviation	43.3	77.3	6.96	4.92	2.55	1.79
t-statistics	-14.4***	-9.4***	-28.2***	-18.3***	-23.0***	-20.6***
Min. P&L per trade ($)	-1999.2	-1999.2	-43.83	-49.31	-14.50	-13.27
50 percentile ($)	-4.58	-8.33	-5.17	-3.44	-2.50	-2.21
Max. P&L per trade ($)	124.5	124.5	6.92	11.16	7.95	3.85

Table 7-5: Profit and loss (P&L) for trading warrants (2007)
Three asterisks indicate 1% significance level and better.

	All	G1	G2	G3	G4	G5
Panel A: Trade without bid-ask spread						
Average P&L per day ($)	149.2	163.0	159.9	162.3	105.8	103.1
Standard deviation	695.1	1019.0	191.4	188.2	114.8	100.6
t-statistics	12.9***	6.47***	23.1***	18.1***	20.7***	17.2***
% of profitable days	76.0%	73.8%	76.5%	75.0%	79.8%	81.5%
Average number of trades	64.01	61.13	65.19	70.44	62.40	70.60
Average P&L per trade ($)	2.40	2.67	2.57	2.43	1.78	1.53
Standard deviation	9.08	13.32	2.36	2.37	1.56	1.09
t-statistics	15.9***	8.1***	29.9***	21.6***	25.6***	23.4***
Min. P&L per trade ($)	-249.0	-249.0	-5.29	-4.82	-5.73	-0.79
50 percentile ($)	2.05	2.50	2.19	1.95	1.52	1.34
Max. P&L per trade ($)	237.6	237.6	18.16	22.33	10.73	7.15
Panel A: Trade with bid-ask spread						
Average P&L per day ($)	-627.4	-990.8	-489.4	-352.6	-166.4	-168.8
Standard deviation	2761.9	4030.3	731.1	747.5	193.8	214.7
t-statistics	-13.7***	-9.9***	-18.5***	-9.9***	-19.3***	-13.2***
% of profitable days	2.9%	2.3%	2.8%	3.4%	4.9%	2.8%
Average number of trades	64.01	61.13	65.19	70.44	62.40	70.60
Average P&L per trade ($)	-9.38	-15.51	-6.63	-4.13	-2.49	-2.09
Standard deviation	41.03	60.29	6.44	4.48	2.14	1.39
t-statistics	-13.8***	-10.4***	-28.5***	-19.5***	-26.2***	-25.1***
Min. P&L per trade ($)	-1567.3	-1567.3	-41.90	-48.70	-17.29	-8.33
50 percentile ($)	-4.06	-7.50	-4.50	-3.10	-2.27	-2.03
Max. P&L per trade ($)	100.0	100.0	7.50	5.00	5.00	4.21

Table 7-6: Alternative strategy's profit and loss (P&L) (2007)
Three asterisks indicate 1% significance level or better.

This increase in theoretical profit is attributed to the increase in positive leading effect of quote movements from stocks to warrants, and more importantly, the increase in the number of correct following by the warrants. However, when the bid-ask spread taken into account, it is again not possible to make any arbitrage profit from the lead-lag effect. The average loss is $627.4 per warrant-day, or $9.38 per trade.

The robustness checks using warrant data from February through March 2007 have shown the same results as we have obtained for the same period in 2005. These checks support the findings that the equity market is leading the covered warrant market in quote movements, by about 2 seconds. From the perspective of trading, the leading effect is highly significant in the ideal case, but does not result in any profit due to the large bid-ask spread in percentages incurred in trading warrants.

8. INDEX FUTURES AND WARRANTS

In this section, we study the lead-lag relation of index futures on Nikkei 225, SIMSCI, and MSCITW with their warrants on, respectively, Nikkei 225 (NKY), Straits Times Index (STI), and Taiwan Weighted Index (TWII). Both the futures and the warrants are traded on the Singapore Exchange. Using the same counting method, we find that warrants are lagging index futures in the quote updates. Our trading strategies show significant profit from such delay in warrant quote update if there is no bid-ask spread. Bu again no profit is possible when bid-ask spread is taken into account.

8.1 Distribution and Grouping of Index Warrants

The index warrants were obtained for the sample period of December 2006 to March 2007 from the same data vendor, ShareInvestor. A total of 41 issues and 1,677 warrant-days were collected. Different from equity warrants, the call and put index warrants are 50% each in the sample. This is partially because index futures have much higher trading volume compared to stocks. Hence, issuing banks have little difficulty in hedging their portfolios, either against the rising market, or the falling market. A detailed breakdown of the warrants on index futures in our sample is tabulated in Appendix A-3.

We analyze the index warrant data according to the trading volume, moneyness, and price.

Moneyness and trading volumes

The moneyness of the index warrants are defined in the same way as equity warrants in Section 5. Figure 8-1 shows the average daily trading volumes of the index warrants according to the moneyness. Like their equity counterparts, investors are more interested in those warrants that are ATM and ITM compared to OTM. Their trading volumes are five to ten times larger. The maximum daily volume is only 7,150 lots.

Overall, the average trading volume is 242 lots, which is much less than the equity warrants. A reason could be that sophisticated investors would rather trade the index futures, which also provide leverage via the margin account. Above all, futures markets are much more liquid.

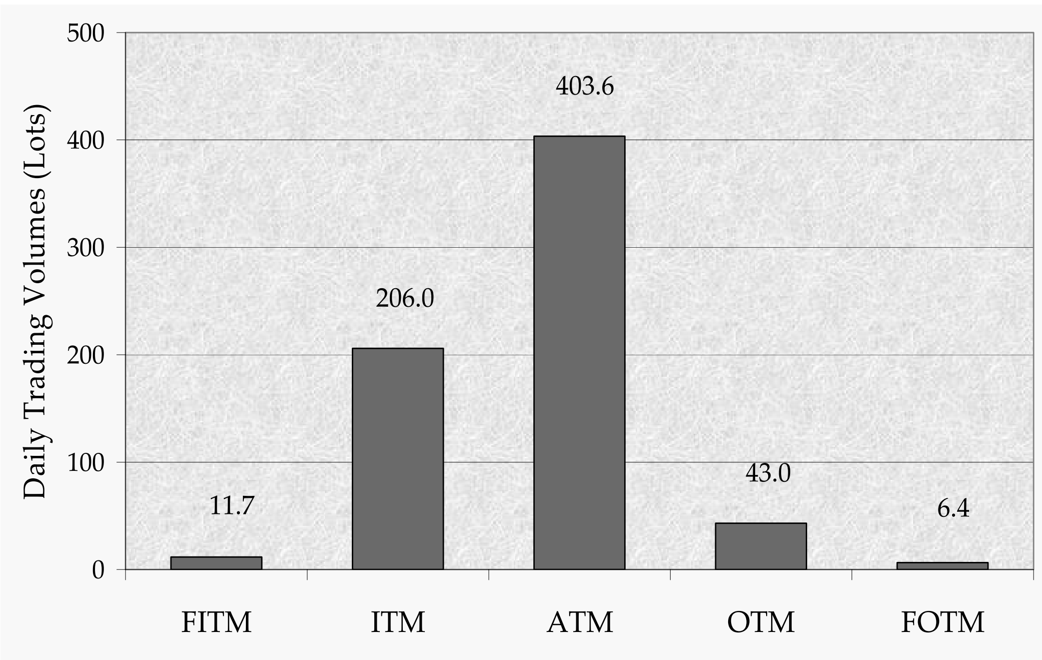

Figure 8-1: Daily trading volumes of index warrants

Moneyness and warrant prices

Figure 8-2 shows the average warrant prices according to their moneyness. FITM warrants are on average priced at $1.96, and the price of an ATM warrant is in the range of 20 to 40 cents. The FOTM warrants, on the other hand, are priced at only 2 cents on average. At this price level, the minimum tick size is large in percentage terms, and the warrant price is not as sensitive to changes in the futures market. For this reason, we exclude the warrants that are priced below 5 cents, and the sample size is reduced to 1351 warrant-days.

We group the warrants based on the trading volume. As before, the low volume warrants are useful in exploring the market makers' pricing behavior with little interference from investors' buying or selling pressure. The high volume warrants, on the other hand, facilitates an investigation of investors' trading impact on warrant pricing.

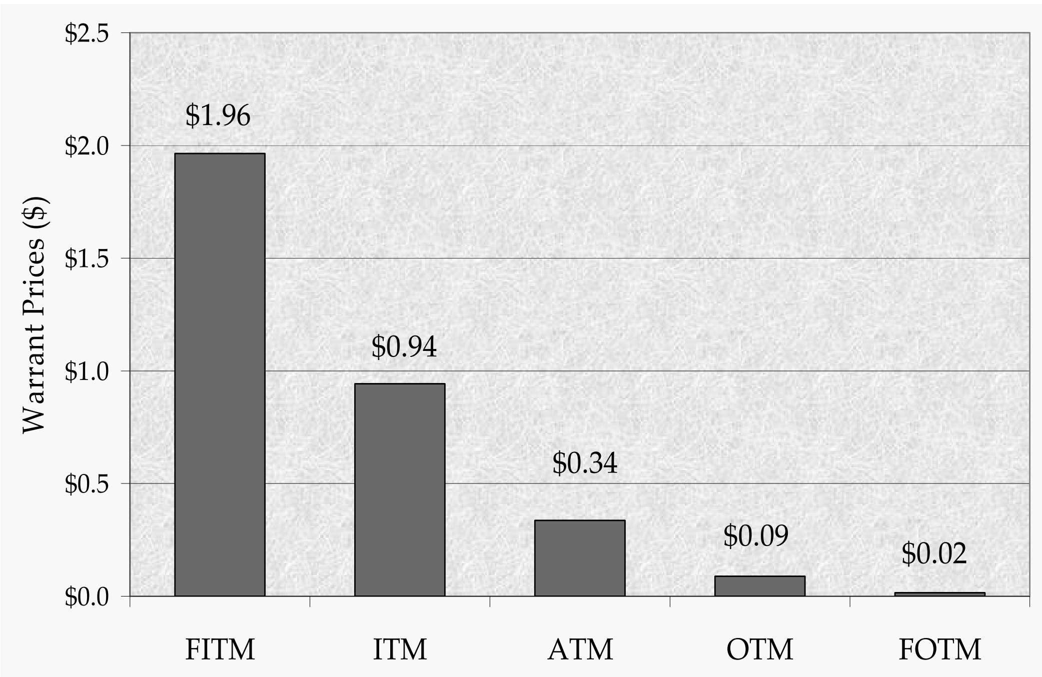

Figure 8-2: Prices of Index warrants

Grouping of index warrants

Table 8-1 summarizes the 4 data groups. Note that about 41.9% of the warrants were not traded at all, and the top 6.2% have more than 1200 lots of transactions. The middle two groups comprise approximately 25% each in our sample.

Groups	Number of warrants	Percentage
All index warrant issues	1,677	
All warrants priced ≥ 5 cents	1,351	100%
G6. Vol. 0 lots	566	41.9%
G7. Vol. 1 to 200 lots	375	27.8%
G8. Vol. 201 to 1200 lots	326	24.1%
G9. Vol. > 1200 lots	84	6.2%

Table 8-1: Grouping of index warrants

Quote update frequencies

	Average number of F quote move			Average number of W quote move			F/W
	Total	**Up tick**	**Down tick**	**Total**	**Up tick**	**Down tick**	
All	579.0	289.2	289.8	163.7	82.0	81.7	3.54
G6	599.8	298.6	301.2	181.8	90.7	91.1	3.30
G7	508.1	253.9	254.2	140.0	70.1	70.0	3.63
G8	586.5	293.7	292.8	155.6	77.7	77.9	3.77
G9	725.9	366.1	359.9	179.0	92.9	86.1	4.06

Table 8-2: Count of average index futures and warrants' quote updates

We count the average numbers of quote updates for both the index futures and the warrants. Table 8-2 shows a breakdown of the average quote movements for the different groups. We note that the proportions of quotes moving up and down are almost equal.

Furthermore, it is worth noting that in the case of index futures, there are more quote updates than warrants. On average, a warrant price quote is updated 163.7 times a day, whereas the quote of an index future is updated 579 times, 354% more frequent than warrants.

8.2 Leading Effect of Index Futures on Index Warrants

We apply the counting method to analyze the lead-lag relation between index futures and warrants. For the case of warrants leading futures, Table 8-3 lists the total F quote movements and the numbers of subsequent moves by the warrants. We note that more than 90% of the F movements are not followed by any W quote updates, and only about 7% of the F movements can be identified as 'P' or 'N' movements. This can be attributed to the fact that futures are more frequently traded and there are more quote updates for futures than on warrants. There are slightly (about 2%) more correct 'P' movements than the wrong 'N' movements. However, their difference is too small to be statistically or economically significant, as shown by the chi-square test. Hence, there is no evidence of a leading effect from the index warrants on the futures.

On the other hand, we obtain significant evidence of futures leading warrants. In Table 8-4, 16% of W quote movements are led by F updates in the 'P' direction, which indicates a correct price response of warrants to futures price. The large and significant chi-square values suggest that at the

99% confidence level, warrants' quotes tend to follow that of future prices in the same direction. In short, as in the case of equity warrants, our counting method finds a leading effect of index futures on the respective warrants.

Group	All F move	No F move 'Z'	Positive F move 'P'	Negative F move 'N'	Pearson chi-square	Yate chi-square
All	782,211	727,014 (92.9%)	36,621 (4.68%)	18,576 (2.37%)	1.98	1.74
G6	339,504	314,544 (92.7%)	16,837 (4.96%)	8,123 (2.39%)	1.98	1.75
G7	190,533	177,290 (93.1%)	8,963 (4.70%)	4,280 (2.25%)	2.27	2.00
G8	191,196	178,072 (93.1%)	8,446 (4.42%)	4,678 (2.45%)	1.79	1.56
G9	60,978	57,108 (93.7%)	2,375 (3.89%)	1,495 (2.45%)	1.35	1.16

Table 8-3: Counts (percentage) of warrants leading futures

Group	All W move	No W move 'Z'	Positive W move 'P'	Negative W move 'N'	Pearson chi-square	Yate chi-square
All	221,190	172,956 (78.2%)	35,479 (16.0%)	12,755 (5.77%)	7.69***	6.91***
G6	102,922	81,099 (78.8%)	16,309 (15.9%)	5,514 (5.36%)	7.51***	6.77***
G7	52,518	41,003 (78.1%)	8,598 (16.4%)	2,917 (5.55%)	8.12***	7.26***
G8	50,717	39,276 (77.4%)	8,174 (16.1%)	3,267 (6.44%)	7.64***	6.84***
G9	15,033	11,578 (77.0%)	2,398 (15.9%)	1,057 (7.03%)	7.57***	6.79***

Table 8-4: Counts (percentage) of futures leading warrants
Three asterisks indicate 1% significance level or better

8.3 Delay Times of Index Warrants

We also investigate the time delays of index warrants for both positive and negative movements.

Group	Time delay of warrant in seconds (s)	Cumulative percentage of the delay distribution		
		< 1 s	< 3 s	< 5 s
		Panel A: Positive 'P' movement		
All	3.49	39%	83%	91%
G6	3.11	40%	84%	91%
G7	3.12	42%	84%	91%
G8	5.07	36%	82%	91%
G9	5.14	18%	70%	87%
		Panel B: Negative 'N' movement		
All	4.74	34%	84%	88%
G6	3.77	41%	86%	92%
G7	3.50	45%	85%	92%
G8	9.06	25%	69%	82%
G9	10.5	19%	63%	76%

Table 8-5: Delay times of index warrants

Panels A and B in Table 8-5 show the delay times of the warrants' quote midpoint movements lagging those of index futures. The average delay for 'P' movement is 3.49 seconds, 1 second faster than the 'N' movement. The overall distributions of the delays are quite comparable: about 30 to 40% of the delays are within 1 second, and approximately 90% of the warrants' quote updates complete within 5 seconds. This result is similar to that of equity warrants, which shows once again that warrant issuers are quick in updating their quotes.

In summary, same as equity warrants, the leading effect of index futures on the warrant prices disappears within 3 to 5 seconds.

8.4 Intraday Trading Profits and Losses

We examine the trading strategies of using the index futures price as signal to trade warrants. Table 8-6 and Table 8-7 show the average daily profits and losses from the first intraday strategy of strictly one lot of warrant per trade.

Qualitatively, we obtain similar profit and loss as for the equity warrants – significant profits when there is no bid-ask spread, and more significant losses when the bid-ask spread is taken into account. Because the quotes of index futures and warrants are more frequently updated compared to stocks and equity warrants, the trade numbers have increased by more than 10 times to 426.3 trades per day. This increase in trades leads to a higher daily profit of $260.1 when there is no bid-ask spread, and also a larger daily loss of -$3,381 with bid-ask spread. All the *t*-statistics for the 4 groups are significant at the 1% level or better, and the probability of making a profit each day ranges from 76.5% to 84.9%, well above the 50% benchmark.

The average profit per trade is $0.64, and the range is from $0.18 to $0.79 across different groups of index warrants. This average profit is lower than $0.85 in the case of equity warrants. One reason could be that index futures' quotes are more actively updated than warrants, hence a large portion of F movements do not have corresponding W movements. One would expect a trade on warrant will make no profit if it is done at the midpoint of the bid and ask prices. Nevertheless, the *t*-statistics shows that the profit per trade is still significantly above zero at 1% level or better.

In Table 8-6, we also tabulate the profit per trade at different percentiles as well as the minimum and maximum profit and loss. All the statistics provide evidence that the trading strategy works well in the ideal market with no trading cost.

	All	**G6**	**G7**	**G8**	**G9**
Average P&L per day ($)	260.1	306.5	218.8	194.7	115.9
Standard deviation	1,219	1,562	489.0	659.2	234.6
t-statistics	6.86***	4.70***	7.20***	3.84***	2.88***
% of profitable days	80.1%	78.2%	84.9%	79.9%	76.5%
Average number of trades	426.3	407.4	436.8	456.2	515.0
Average P&L per trade ($)	0.64	0.79	0.53	0.35	0.18
Standard deviation	2.087	2.591	1.336	0.968	0.372
t-statistics	9.80***	7.33***	6.41***	4.75***	2.83***
Min. P&L per trade ($)	-13.22	-13.22	-7.30	-0.92	-0.39
5 percentile ($)	-0.49	-0.81	-0.20	-0.17	-0.29
25 percentile ($)	0.00	0.00	0.05	0.02	-0.11
50 percentile ($)	0.15	0.14	0.18	0.14	0.13
75 percentile ($)	0.48	0.67	0.52	0.35	0.19
95 percentile ($)	3.67	4.49	2.47	1.59	0.81
Max. P&L per trade ($)	22.98	22.98	8.73	10.59	1.34

Table 8-6: Profit and loss (P&L) for index warrants without bid-ask spread
Three asterisks indicate 1% significance levels or better.

Next, we analyze the realistic case with bid-ask spread. When buying at the ask price and selling at the bid price, Table 8-7 shows significant losses across all groups of warrants. On average, the loss is as high at -$3,381 per day from trading warrants because the number of trades is 10 times higher than the case of equity warrants. All the *t*-statistics for the 4 groups are negatively significant at the 1% level, and the probability of making a daily profit falls to less than 3.1%. The average loss per trade is as high as -$6.93.

	All	**G6**	**G7**	**G8**	**G9**
Average P&L per day ($)	-3,381	-4,856	-1,759	-1,293	-1,279
Standard deviation	6,706	8,620	1,974	934.2	409.0
t-statistics	-16.2***	-13.5***	-14.3***	-17.9***	-18.2***
% of profitable days	1.4%	0.9%	3.1%	1.2%	0.0%
Average number of trades	426.3	407.4	436.8	456.2	515.0
Average P&L per trade ($)	-6.93	-9.77	-3.85	-2.87	-2.52
Standard deviation	8.891	10.88	3.446	1.374	0.346
t-statistics	-25.1***	-21.5***	-17.9***	-27.1***	-42.4***
Min. P&L per trade ($)	-87.85	-87.85	-31.72	-7.40	-3.23
5 percentile ($)	-21.92	-24.52	-9.43	-5.58	-3.09
25 percentile ($)	-7.62	-10.33	-4.83	-3.12	-2.77
50 percentile ($)	-3.69	-7.37	-2.67	-2.61	-2.60
75 percentile ($)	-2.54	-2.77	-2.42	-2.42	-2.42
95 percentile ($)	-1.82	-2.22	-0.93	-1.57	-1.98
Max. P&L per trade ($)	7.13	6.85	3.56	7.13	-1.56

Table 8-7: Profit and loss (P&L) for index warrants with bid-ask spread
(***) Three asterisks indicate 1% significance level or better.

Besides the relatively high bid-ask spread, this huge loss is partially a result of index warrant quote changes being significantly less frequent than the futures; a large portion of F movements are not immediately followed by a W movement. Thus, many trades are made without any warrant price changes, resulting in traders paying the bid-ask spread.

8.5 Alternative Trading Strategy

	All	G6	G7	G8	G9
Average P&L per day ($)	459.6	477.1	477.5	383.7	404.7
Standard deviation	755.9	995.4	252.4	193.2	112.6
t-statistics	9.78***	5.74***	15.2***	12.9***	10.5***
% of profitable days	91.4%	87.6%	98.1%	94.1%	91.2%
Average number of trades	850.6	812.9	871.6	910.5	1028.0
Average P&L per trade ($)	0.68	0.81	0.59	0.45	0.38
Standard deviation	0.775	1.006	0.308	0.250	0.091
t-statistics	14.2***	9.61***	15.5***	11.8***	12.1***
Min. P&L per trade ($)	-7.83	-7.83	-0.46	-0.06	-0.01
5 percentile ($)	0.00	-0.03	0.01	0.00	-0.01
25 percentile ($)	0.06	0.03	0.09	0.10	0.15
50 percentile ($)	0.19	0.20	0.20	0.16	0.19
75 percentile ($)	0.37	0.47	0.36	0.26	0.24
95 percentile ($)	1.52	1.91	0.98	0.90	0.34
Max. P&L per trade ($)	6.41	6.41	1.58	38.39	0.35

Table 8-8: Alternative strategy's P&L for index warrants without bid-ask spread
Three asterisks indicate 1% significance level or better.

We verify the profitability with the alternative strategy described in section 6.2. Table 8-8 presents the profit and loss of this alternative strategy, if the trader could trade at the quote midpoint. For the alternative strategy, the total trading volume is almost doubled, and average daily profit increases to $459.6. The probability of a profitable trading day is 91.4% on average. All the *t*-statistics are significant at 1% level or better.

	All	G6	G7	G8	G9
Average P&L per day ($)	-6740	-9,609	-3,577	-2,714	-2,515
Standard deviation	12,970	16656	3,944	1,638	846.6
t-statistics	-16.7***	-13.8***	-14.6***	-21.5***	-17.3***
% of profitable days	0.0%	0.0%	0.0%	0.0%	0.0%
Average number of trades	850.6	812.9	871.6	910.5	1,028
Average P&L per trade ($)	-7.26	-10.32	-3.93	-2.92	-2.45
Standard deviation	12.164	15.516	3.276	1.073	0.199
t-statistics	-19.2***	-15.9***	-19.3***	-35.4***	-72.0***
Min. P&L per trade ($)	-212.3	-212.3	-30.92	-7.47	-3.32
5 percentile ($)	-21.36	-22.04	-9.32	-5.46	-2.80
25 percentile ($)	-7.50	-10.00	-4.76	-3.04	-2.54
50 percentile ($)	-3.74	-7.40	-2.51	-2.50	-2.39
75 percentile ($)	-2.44	-2.57	-2.34	-2.38	-2.36
95 percentile ($)	-2.12	-2.25	-1.84	-2.12	-2.26
Max. P&L per trade ($)	-0.92	-1.33	-0.92	-0.98	-2.23

Table 8-9: Alternative strategy's P&L for index warrants with bid-ask spread
Three asterisks indicate 1% significance level or better

As anticipated, when the bid-ask spread is taken into account, the alternative strategy ends up suffering heavier losses as shown in Table 8-9. The average daily loss surges to -$6,740. The profitability drops to zero, and in no days could a trader make profit from the alternative strategy when bid-ask cost is incurred.

The results from index warrants are in line with the equity warrants. Based on futures quote movement, statistically significant profit from the warrant trading is possible if and only if there is no bid-ask spread. However, once the bid-ask spread is turned on, the profit from exploiting the lead-lag relation is not even sufficient to recover the trading costs imposed by the market makers, who use the conversion ratio to structure their warrants in such a way that they are able to consistently make a profit at least from the bid-ask spread.

9. CONCLUSION

There is some suspicion in the literature that the option price might "front-run" the stock price due to informed traders taking advantage of the leverage that options provide. In this thesis, we examine covered warrants and their underlying stocks at the tick-by-tick frequency. In contrast to options, warrants and stocks are trading alongside each other on the same exchange, and the problem of non-synchronicity in recording the time stamps of trades and quotes does not arise.

We propose an intuitive method to track the temporal order of quote updates, which occur at the irregularly spaced time interval. Our counting method is non-parametric and differs significantly from the regression-based approaches such as the information share. Our empirical analysis using the high-quality data from a median-size warrant market suggests that warrants do not lead stocks. On the contrary, whenever there is an increase in the quote midpoint of the underlying stock, the warrant quotes tend to increase as well. In the same vein, upon a downward quote update, the warrant's midpoint tends to decrease. The delay by warrants' midpoints are on average, only 3 to 5 seconds.

In addition, we design two day-trading strategies to trade warrants based on the directional movements of the stocks or the futures. In the absence of market friction such as the bid-ask spread, we obtain trading profits that are both statistically and economically significant. The profits, however, disappear when traders have to pay for the bid-ask spread. Moreover, traders will suffer heavy losses in the best case of our sample.

To the best of our knowledge, this thesis is among the first in studying the lead-lag relation between covered warrants and stocks. Our study produces evidence that the warrant market maker has little risk in trading against better informed traders. This could be a reason why the warrant market flourishes in Europe, Australia, and Asia especially.

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APPENDIX

A.1 Group One Equity Warrants (January through March 2005)

Company Name	STI Weight % (Mar-05)	Warrant No. (Jan ~ Mar 05)	No. of Calls	No. of Puts
Capitaland	1.42	12	10	2
Chartered Semicon	0.73	9	9	0
City Development	2.29	6	6	0
Cosco	0.33	9	9	0
Creative	0.91	12	11	1
DataCraft	0.32	4	4	0
DBS	13.27	15	11	4
Hyflux	0.00	3	3	0
Keppel Corp	3.47	12	10	2
Keppel Land	0.54	6	6	0
Noble	0.00	6	6	0
NOL	2.06	9	7	2
People Food	0.42	1	1	0
SembCorp	1.40	8	8	0
SIA	4.63	13	9	4
SingTel	10.21	13	10	3
SPC	0.00	2	2	0
StatsChP	0.45	6	6	0
UOB	12.56	12	9	3
Venture	2.83	13	9	4
Total	58 % of STI	171 67% of market	146 85%	25 15%

Table A-1: List of equity warrants (January through March 2005)

A.2 Group Two Equity Warrants (February through March 2007)

Company Name	STI Weight % (31-Mar-07)	Warrant No. (Feb ~ Mar 07)	No of Calls	No of Puts
UOB	11.26	27	23	4
SingTel	10.33	24	19	5
DBS	9.93	43	29	14
OCBC	9.33	23	18	5
Capitaland	5.37	57	39	18
Total	46% of STI	174 26% of mkt	128 (74%)	46 (26%)

Table A-2: List of equity warrants (February through March 2007)

A.3 Group Three Index Warrants (December 2006 through March 2007)

Index future Name	No of Warrants (Dec 06 ~ Mar 07)	No of Calls	No of Puts
Nikkei 225	23	12	11
SIMSCI	14	7	7
MSCITW	4	2	2
Total	41	21 (51%)	20 (49%)

Table A-3: List of index warrants (December-2006 through March-2007)

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