

2007

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Recommended Citation

Segara, Lydia and Sagara, Reuben, Intraday trading patterns in the equity warrants and equity options markets: Australian evidence, *Australasian Accounting, Business and Finance Journal*, 1(2), 2007, 42-60. doi:[10.14453/aabfj.v1i2.5](https://doi.org/10.14453/aabfj.v1i2.5)

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Abstract

This paper extends the microstructure literature, by examining the previously undocumented intraday trading patterns in trading volume, price volatility, order depth and relative spreads for both the warrant and option market in Australia. Comparisons of intraday variations across these derivative securities allows for insight to be drawn into competing market microstructure theories and provides the opportunity to examine whether market design differences explain variations in observed intraday patterns. We find that intraday trading patterns documented in the warrant and option markets can be explained by their market designs, along with theories relating to time-varying information asymmetry and time-varying hedging trades around nontrading periods.

Keywords

Warrants market; Options market; Australian Stock Exchange; Intraday trading behaviour



Intraday trading patterns in the equity warrants and equity options markets: Australian evidence

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ABSTRACT

This paper extends the microstructure literature, by examining the previously undocumented intraday trading patterns in trading volume, price volatility, order depth and relative spreads for both the warrant and option market in Australia. Comparisons of intraday variations across these derivative securities allows for insight to be drawn into competing market microstructure theories and provides the opportunity to examine whether market design differences explain variations in observed intraday patterns. We find that intraday trading patterns documented in the warrant and option markets can be explained by their market designs, along with theories relating to time-varying information asymmetry and time-varying hedging trades around nontrading periods.

JEL classification: G10; G14; G15

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* The authors are grateful to the Securities Industry Research Centre of Asia-Pacific (SIRCA) for the supply of the SEATS data. We are responsible for any remaining errors.

1. INTRODUCTION

A large body of empirical research has rapidly grown, which documents the existence of systematic regularities found in trading volume, volatility and bid-ask spreads across the trading day. The existence of U-shaped intraday trading volume and volatility patterns, characterized by high values at the open and close, as compared to periods within the day have been reported consistently across a number of stock markets.¹ Interestingly, intraday bid ask spread behaviour has not yielded similar patterns across all these markets. In the wake of this evidence, several competing theories have arisen to explain intraday trading behaviour across different market settings.² In this paper, additional evidence is brought to bear on these theoretical models by documenting intraday trading volume, volatility, order depth and spread patterns in the equity

¹ Much of the earlier work examining intraday trading patterns on stock markets has been predominately performed in the United States. For a more detail review of the extant microstructure literature, refer to Coughenour and Shastri (1999).

² These theories fall into four broad categories: inventory holding costs; market power; information asymmetry; and the learn by trading model and are discussed in Section 4.



warrants and equity options market. The paper contributes to the existing microstructure literature, where it represents the first documented examination of intraday trading patterns in the equity warrants and equity options market in Australia.

The examination of equity warrants and equity options provides the paper with the opportunity to examine whether market design (institutional) differences explain variations in observed intraday patterns. As an example of these market design differences, the equity warrants market operates under an electronic order-driven system, where any one person can establish a bid-ask spread. The equity warrants market can be characterized by a hybrid market, where both limit-order traders and a single market maker (i.e., the warrant issuer), jointly establish prices. By contrast, the equity options market operates under an electronically driven competitive market maker system, where any designated member can establish a market in the option.³ Unlike the warrant market, trading on the options market closes for a short lunch break and continues after the underlying market has closed. These trading hour differences also provide an opportunity to test the intraday trading behaviour in one related market, when another is closed.

The documentation of intraday trading patterns for equity warrants and equity options examined can provide market operators and/or regulators with better market intelligence with which to fine-tune the market surveillance discipline. Market surveillance is concerned with the identification of abnormal and possible illegal market behaviour such as insider trading or market manipulation for the purpose of maintaining market integrity. A key component of the task of identifying “abnormal” trading behaviour is the ability to identify “normal” trading behaviour. Documenting intraday patterns of metrics representing liquidity and volatility over long periods and observing how these patterns change as a result of institutional and other differences can assist regulators to minimise false positive alerts. From an academic perspective, variations in intraday trading patterns between these two related markets can have implications for modelling the lead/lag relations existing between these two markets, which in turn can help to better understand the contribution of each instrument to price discovery and the overall efficiency of the market.

The paper proceeds as follows. Section 2 describes the institutional details of the warrant and option markets. Section 3 provides a review of empirical work examining the intraday trading behaviour of options reported in other overseas exchanges. This is followed in Section 4 by an overview of relevant theoretical models constructed to explain observed intraday trading behaviour across distinct market settings. Section 5 outlines the data and method and Section 6 reports our results. Section 7 summarizes and concludes the paper.

2. INSTITUTIONAL DETAIL

2.1. THE EQUITY WARRANT MARKET

The equity warrant market in Australia commenced in 1991, fifteen years after the introduction of the first exchange traded option (ETO). Equity warrants are underwritten by third parties (usually investment banks), other than the underlying company.⁴ A call (put) equity warrant gives the

³ Market makers supply liquidity to the market by quoting bid prices, ask prices and number of shares at which they are willing to trade. Unlike a specialist system, no one designated member holds the ‘order book,’ which contains market information unavailable to others.

⁴ Traditionally, warrants are issued (i.e., written) by a company that permits the holder to convert the warrant into the shares of the company, upon exercising the warrant contract. If the warrant is exercised, additional shares are required to be issued by the company. This corresponds to a dilution in the ownership of existing investors in the company and consequently changes the company’s capital structure.



holder the right, but not the obligation to buy (sell) the underlying stock at a predetermined price on or before the expiry date. For this right, the warrant buyer pays the warrant issuer a premium, which represents the market price of the warrant. While there exists similarities between warrants and ETOs, several distinctions remain, namely; (i) warrants are not allowed to be short sold; (ii) no margin payments are required by issuer's to cover their obligations under the warrant; (iii) investors can purchase non-standard contract sizes; (iv) warrants are traded on a continuous basis without a lunchtime break; and (v) higher premiums are usually needed to enter the warrants market.

Warrants are traded on the Stock Exchange Automated Trading System (SEATS) in the same manner as shares and have typical expiry terms ranging from three to eighteen months, with the length likely to be twelve months.⁵ Normal trading in SEATS takes place on a continuous basis from 10:00 to 16:00 on Monday to Friday. Prior to the commencement of trading a call market operates on the ASX, where investors through their brokers are invited (called) to submit orders to SEATS. During the call market, orders are queued according to price time priority, where no trading occurs until the end of the call. The call market takes place from 7.00 to 10:00. A unique set of market opening procedures is used on SEATS to commence normal trading each morning. Opening takes place at 10:00 and lasts for about 10 minutes. During this phase, SEATS determines whether bids are higher than or equal to asks or vice versa. If there are bids higher than the lowest ask, an algorithm is employed to determine the opening price. From 10:00 to 10:09, opening times are staggered, depending on the starting letter of the ASX stock code. SEATS currently opens randomly for five different groups of stocks (in alphabetical order). Once stocks are opened, they trade continuously until 16:00 when they all close together. In order for third parties (hereafter termed issuers) to be granted trading status from the ASX, they are required to facilitate a market in the warrants issued, but are not obligated to do so. Hence, the equity warrants market can be seen as a hybrid market, in which both limit-order traders and an unofficial designated dealer (i.e., the warrant issuer) establish prices.

2.2 THE EQUITY OPTION MARKET

The equity option market in Australia commenced in 1976 and is managed by the Australian Stock Exchange Options (ASXO) division. Typically, option contracts that trade are American style and standardized by contract size (each contract representing 1,000 shares of the underlying stock), expiry date, and exercise price. The standardization of options permits easier transfer of rights and obligations of the contract. Expiration is usually nine months, though the ASXO occasionally lists spot monthly options and longer term options.

The options market operates using the Derivatives Trading Facility (DTF), which is a customised version of the CLICK system developed by the Swedish Options and Futures Exchange (SOFFEX).⁶ The DTF is a fully automated screen based system, which allows brokers to view and access the options market immediately. Normal trading in the options market occurs during two daily trading sessions: a morning session from 10:00 to 12:30 and an afternoon

In this paper, equity warrants considered are not issued by the company upon whose shares they are written, but instead are written by a third party. If a holder of ASX warrants decides to exercise his or her contract, no additional shares are issued from the company.

⁵ SEATS is a competitive and transparent electronic order book

⁶ CLICK is a fully electronic market, primarily for the trading of options and other derivative products. The CLICK Exchange System was developed by OM Technology (OMT), a subsidiary of the OM Group. The OM Group owns and operates the Swedish futures and options exchange, OM Stockholm.



session from 14:00 to 16.15. The DTF consists of the Central Orderbook and the Bulletin Board. Market makers transact in all series of all classes of options through the Central Orderbook for their clients. The Bulletin Board enables market makers to advertise their interest in trading and transacting particular option strategies. Market makers are required to provide orders in the at-and near-the-money series at a maximum spread for a minimum number of contracts.⁷ Where a market does not exist, market makers are obliged to provide two-way quotes in other series upon requests. An absence in liquidity in some option series may exist, dependent upon the level of activity in the underlying stocks and whether those option classes carry market making obligations. Unlike SEATS, the DTF does not allow orders to be inputted prior to the opening and does not carry forward unexecuted orders to the next trading day. Though the options market opens at 10:00, each option class remains suspended until the underlying stock is opened in SEATS. All orders on the DTF are transparent to market makers and are executed automatically on a price time priority basis.

3. REVIEW OF EMPIRICAL STUDIES

Empirical studies examining the intraday patterns on equity option markets is relatively scarce, largely due to the absence of data in these markets. Intraday trading behaviour in equity warrants has received no attention, a situation that this paper amends. This section reviews empirical studies, which document the intraday trading behaviour of trading volume, price volatility and bid-ask spreads in the equity options market.

3.1 TRADING VOLUME

Unlike the U-shaped patterns in trading volume documented across various overseas stock markets, Stephan and Whaley (1990) report a distinctly different intraday pattern for call options traded on the Chicago Board Options Exchange (CBOE). They report that trading volume is lowest at the open and rises to its highest level by approximately 45 minutes into the trading day. A decline in trading volume is then observed, but less pronounced than that documented for the underlying market. An increase in option trading volume before the close of the underlying market is then observed. This is followed by a sharp fall during the close of options trading. Easley, O'Hara and Srinivas (1998) also find a trading peak 45 minutes from market open for both call and put options traded on the CBOE. Despite these findings, trading volume peaks after market open have been documented to occur earlier in the trading day. Mayhew, Sarin and Shastri (1995) show that trading frequency peaks after the first 30 minutes of trading, whilst Chan, Chung and Johnson (1995a) report that trading volume peaks as early as 5 minutes after the market opens on the CBOE. The later peaks in trading volume in the options market are attributed to a number of differences. First, unlike underlying stock market of the New York Stock Exchange (NYSE), the CBOE does not use a sequential call opening procedure. Second, the competitive dealer structure of the CBOE necessitates traders to wait for the best dealer's quotes to arrive, unlike the NYSE where traders are provided with only one best quote from the specialist.

Empirical studies have examined the trading behaviour when option market trading hours continue after the close of the underlying market. Aggarwal and Gruca (1993) find that the rate of option trading on the CBOE rapidly increases in the 10 minutes following the end of

⁷ Market makers usually provide orders in the six option series, which have exercise prices closest to the current share price.



trading in the underlying market, but then decreases in the last 5 minutes. Chan et al. (1995a) also report that trading volume of call (put) options tends to decrease (increase) in the last 10 minutes of CBOE trading when the underlying market is closed. A plausible explanation for this result is that risk averse investors holding long positions in the underlying market will hedge their overnight exposure by buying put options.

The observed intraday patterns in trading volume on the CBOE are not only unique to this exchange. Berkman (1992) confirms a similar pattern for equity call options traded on the European Options Exchange (EOE), where option trading volume is low during the first 30 minutes. Thereafter, it peaks for the next two hours of trading and then falls off before increasing to a higher level for the last two hours of trading, though less pronounced than during the first two hours of trading. Niemeyer (1994) reports a comparable hump-shaped intraday pattern, where options traded on the Stockholm Options and Forwards Exchange (OM) take approximately 20 to 30 minutes to reach a peak following the market open.

3.2 PRICE VOLATILITY

Sheikh and Ronn (1994) document intraday variations in volatility for CBOE options across the trading day. They find that the variance of call and puts returns exhibit a familiar U-shaped pattern found in the underlying market across the trading day. Similarly, Chan, et al. (1995a) show that standardized mid-quote return volatility follows a U-shaped pattern, where returns for CBOE options are more volatile at the open relative to the close of trading in the underlying market. A decline in volatility during the last 10 minutes of CBOE trading (i.e. when the underlying market is closed) is then observed. This result is theoretically consistent with the explanation that the absence of a price for the underlying security will lead to a decline in options' trading.

3.3 BID-ASK SPREADS

Chan, et al. (1995a) compare the influence of differing market structures of the CBOE and the NYSE on the intraday behaviour of spreads. Unlike the U-shaped patterns found on the NYSE, they observe an L-shaped pattern for CBOE options, where spreads are wide at the opening period of the trading day and narrow near the close. Aggarwal and Gruca (1993) also find significant declines in bid-ask spreads towards the end of the trading day on the CBOE. Gwilym, Clare and Thomas (1998) confirm these L-shaped patterns in spreads for stock index options traded on the London International Financial Futures and Options Exchange (LIFFE), an open outcry market with competing market makers. By contrast, Berkman (1992) finds that the bid-ask spreads on the EOE during the trading day are high at the open, decline as trading progresses and then widen in the last two hours of trading. Berkman suggests that the opening of the NYSE increases price uncertainty in options traded on the EOE during the one-hour interval before the close.



4. THEORETICAL CONSIDERATIONS

Several theoretical models have been developed, which seek to provide an explanation for intraday trading patterns documented in the empirical literature across various overseas exchanges. The majority of these models analyse the process of price discovery through order arrival and quote revision under two distinct forms of market organization; a competitive market dealer system and a monopolistic specialist system. The examination of price formation in these models has principal implications for explaining intraday bid-ask spread behaviour. We note that predictions from these models are also applicable to explain intraday trading volume and volatility patterns across the trading day because of their close relations with spread. These models are classified into four broad categories: inventory holding costs; market power; information asymmetry; and the learn by trading model.

4.1 INVENTORY HOLDING COST MODEL

The inventory holding cost models of the bid-ask spread focus on the costs faced by risk-averse dealers who are forced to carry long or short positions in an asset that deviates from their preferred (optimum) holdings.⁸ This deviation is caused by temporal discrepancies between market buy and sell orders and the obligation to provide liquidity in the asset. The model implies that dealers will set bid-ask spreads as part of compensation for sub-optimal inventory positions (see Amihud and Mendelson, 1980), suggesting that spreads will increase with price and the risk of the security, and decrease with trading volume and the number of market makers.

Lee, Mucklow and Ready (1993) show that in a specialist dealer market, these models imply positive relations between trading activity and bid-ask spreads as a specialist may be forced to accumulate an unwanted inventory position during periods of intense trading activity. Hence, bid ask spreads may widen at the open and close of trading reflecting the elevation in trading activity. By contrast, since competing market makers can avoid accumulating excessive short or long positions during periods of high trading activity, spreads may narrow. An empirical investigation conducted by Chan et al. (1995a) and Chan, Christie and Schultz (1995b) supports the inventory model by documenting a narrowing in spreads before market closure on the CBOE and Nasdaq and widening of spreads on the NYSE.⁹ Consequently, it is anticipated that equity warrant and equity option spreads should narrow immediately preceding a non-trading period.

4.2 MARKET POWER MODEL

Brock and Kleidon (1992) develop a model of a specialist market maker with monopolistic power. They show, that a monopolistic market maker will extract rents from traders by widening spreads during periods of high inelastic transaction demand. Their model recognises that shifts in optimal portfolio holdings of market agents are likely to occur before and after a trading break (e.g. overnight), leading to a greater probability of increased inelastic transaction demand. Subsequently, they suggest that spreads, volume and volatility in a specialist dealer market will be elevated in the intervals following non-trading periods. This is consistent with intraday patterns documented for NYSE (a specialist dealer market). It is recognised that on competitive exchanges, where dealers do not have market power, a similar pattern cannot be predicted.

⁸ Inventory holding cost models of the bid-ask spread can be traced back to Stoll (1978) for specialist dealer markets, and Ho and Stoll (1980; 1983) for competitive dealer markets.

⁹ Kleidon and Werner (1996) also show that bid-ask spreads narrow near the close of trading on the competitive dealer market of the London Stock Exchange (LSE).



Empirical tests of the market power model revolve around comparisons of spreads immediately around the overnight trading break on the NYSE and other competitive dealer markets including the CBOE (Chan et al., 1995a) and NASDAQ (Chan et al., 1995b). These papers show that spreads appear to widen before trading breaks on the NYSE, but not in competitive dealer markets. Extending these results to the warrants market with a monopolistic dealer, the market power model suggests that the intraday pattern of spreads will be high at both the open and close of trading. By contrast, spreads are not expected to widen immediately preceding and following a trading break in a market with competitive dealers such as that found on the ASXO.

4.3 INFORMATION ASYMMETRY MODEL

Information asymmetry models examine the averse information costs faced by dealers who trade with different types of participants (see Copeland and Galai, 1983, Glosten and Milgrom, 1985, and Admati and Pfleiderer, 1988). The model assumes that dealers are confronted with both liquidity motivated traders and ones that carry superior information. The model predicts that the dealer will set the spread wide enough to ensure that the expected gains from trading with liquidity traders exceed or match the expected losses from trading with informed traders during periods of high information asymmetry.

Empirical papers, which contribute towards the information asymmetry model suggests that bid-ask spreads are expected to be wide at the opening of trading and gradually decline throughout the trading day. French and Roll (1986) suggest that the flow of public information will arrive more frequently during trading hours, where private information is gradually impounded into asset prices during the trading day. This is consistent with Madhavan's (1992) information model, which suggests that information asymmetry is gradually resolved during the trading day. Subsequently, this leads to reductions in the bid-ask spread across the trading day. Foster and Viswanathan (1994) develop an asymmetric information model with two informed traders that predicts high volume, volatility and bid-ask spreads at the start of the trading day. More recently, Hong and Wang (2000), model a continuous-time stock market with periodic market closures in which investors optimally trade for both allocation and information reasons.¹⁰ Their model predicts that time-varying hedging demand dominates the market open and the effect of time-varying information asymmetry dominates the market close. In line with this result, it is anticipated that there will be wider bid ask spreads are both the open and close of trading in both the equity warrants and equity options market.

4.4 LEARN BY TRADING MODEL

There is a growing body of literature with models of 'learn-by-trading' (e.g. Grundy and McNicols (1989), Dow and Gorton (1993), Leach and Madhavan (1993) and Romer (1993)). In these models, equilibrium prices are 'discovered' through the trading process, where uninformed traders infer the information held by informed traders by trading with (or against) them. Consequently, following a period of trade suspension, uninformed traders will experiment with a series of 'trial' prices, learning the true equilibrium price through the responses of informed traders. Leach and Madhavan (1993) show that market makers will widen spreads to reduce the relative number of noise traders to

¹⁰ These trades are referred to as hedging trades and speculative trades. Hedging trades are those where investors adjust their asset portfolio by trading the stock in order to hedge the risk of illiquid assets. Trades motivated by private information are referred to as speculative trades.



obtain a cleaner information signal from trade prices and order flow. Overall, 'learn-by-trading' models predict that the loss in price discovery associated with trade suspensions will result in wider spreads when trading resumes. Extending this model to the equity warrant and equity option market, it is anticipated that there will be wider bid-ask spreads following a non-trading period, as a result of heightened price experimentation.

5. DATA AND RESEARCH METHOD

Data for individual trades for warrant and option contracts are obtained from two separate databases, which are acquired from the Securities Industry Research Centre of Asia-Pacific (SIRCA). The first is the high frequency SEATS database, which provides full details of all equity warrant orders and trades placed on the ASX. These records provide details of security code, price, volume, date, broker and time to the nearest hundredth of a second for every order and trade. The second, the DTF database, provides a complete time-stamped history of quotes and traded prices for all equity option series traded on the ASXO. Additionally, the ASX Signal E database is used to identify the listing dates, expiration dates, exercise price and security type for all warrant and option series traded. We collect this data from 1 January 2000 to 30 June 2000 (i.e., 123 trading days).

In our analysis, only warrant and option contracts that have identical underlying stocks to one another are examined. To avoid problems associated with non-trading in derivative assets, we employ a matching algorithm to identify the most actively traded options and warrants covering a particular stock. Each day, the most active traded call (put) warrant series is matched against its most active traded call (put) option series covering the same stock. Warrant and option contracts trading within five days or less to maturity are excluded from the matching algorithm to avoid any expiration effects. For each underlying stock, there can be at most 123 matched option and warrant days (i.e., a day for which a matching sample of warrant and option data is available). Those stocks with fewer than 20 option and warrant days are excluded from our sample. Our final sample consists of 215 (21) equity call (put) warrant series and 998 (222) equity call (put) option series over 32 (7) underlying stocks. All intraday analysis is partitioned into fifteen-minute observation intervals. Fifteen-minute intervals are chosen to obtain estimates of variables analysed.

5.1 VARIABLES USED IN THE ANALYSIS

The variables of interest in this paper include trading volume, price volatility, order depth and relative bid-ask spreads. Warrant and option trading volume are represented by the number of warrant contracts and option contracts traded for the chosen interval, respectively. Price volatility is calculated as the time-weighted standard deviation of prices using bid-ask midpoints. The use of quote midpoints avoids bid-ask bounce, which imparts an upward bias in price volatility estimates based on trade prices (see Venkatesh, 1992). Order depth is measured by summing the total volume of all orders on each side of the bid-ask schedule at the end of each interval. Following McInish and Wood (1992), a time-weighted relative bid-ask spread measure is calculated. For each quotation during an interval, the relative spread is measured as the ratio of the quoted bid-ask spread to the quote midpoint price. This measure is then time-weighted, where the weighting procedure is based on the number of seconds the quotation exists in each interval.



All variables analysed in this paper are standardized by subtracting their mean and dividing by the standard deviation. This procedure allows the analysis to control for cross-sectional differences across derivative securities. For each interval, the means of these standardized variables are then reported for the warrant and option markets. To determine whether trading variables used in the analysis exhibit distinctive intraday patterns, a number of analyses of variance tests is performed. F-statistics examine differences in mean trading variables in one time interval against those in other time intervals across the trading day.

6. RESULTS

Table 1 through 2 reports the cross-sectional mean values for intraday standardized trading volume, price volatility, order depth and relative spreads for both classes (calls/puts) of warrants and options, respectively. Figures 1 through 4 plot the intraday distributions for each variable of interest for warrants and options.

Table 1:
 Intraday trading patterns in the equity warrants market

Time	ASX Call warrants				ASX Put warrants			
	CVOLUME	CVOLAT	CDEPTH	CRSPR	PVOLUME	PVOLAT	PDEPTH	PRSPR
1) 10:00 to 10:15	0.4075	0.8241	0.3053	2.0400	0.3989	0.5292	0.1516	1.2978
2) 10:15 to 10:30	0.2436	0.2778	0.1689	0.2822	0.2186	0.3589	0.1430	0.3568
3) 10:30 to 10:45	0.1168	0.1425	0.1146	0.1253	0.1274	0.1117	0.1301	0.1449
4) 10:45 to 11:00	0.1136	0.0930	0.0895	0.0317	0.1135	0.1140	0.1178	0.0891
5) 11:00 to 11:15	0.0547	0.0516	0.0710	-0.0135	0.0198	0.0346	0.1469	-0.0365
6) 11:15 to 11:30	0.0411	0.0071	0.0846	-0.0715	0.0536	0.0358	0.0979	-0.0578
7) 11:30 to 11:45	0.0186	-0.0135	0.0210	-0.0929	0.0812	0.0269	0.1314	-0.0371
8) 11:45 to 12:00	-0.0463	-0.0608	0.0230	-0.1081	-0.0795	-0.0967	0.0673	-0.0419
9) 12:00 to 12:15	-0.0658	-0.0926	-0.0048	-0.1151	-0.0369	-0.0419	0.0707	-0.1267
10) 12:15 to 12:30	-0.0870	-0.0899	-0.0604	-0.1197	-0.1210	-0.1416	0.0063	-0.1411
11) 12:30 to 12:45	-0.1377	-0.1586	-0.2355	-0.0864	-0.0458	-0.0652	-0.3671	-0.0639
12) 12:45 to 13:00	-0.1476	-0.1646	-0.4960	-0.1172	-0.1853	-0.1693	-0.4254	-0.0541
13) 13:00 to 13:15	-0.1774	-0.1831	-0.5802	-0.1097	-0.1692	-0.1570	-0.5217	-0.0844
14) 13:15 to 13:30	-0.1829	-0.1956	-0.5835	-0.1237	-0.1687	-0.1779	-0.5317	-0.1841
15) 13:30 to 13:45	-0.1905	-0.1933	-0.5239	-0.1289	-0.1306	-0.1715	-0.5023	-0.1341
16) 13:45 to 14:00	-0.1510	-0.1717	-0.3397	-0.1383	-0.0882	-0.0957	-0.2883	-0.1579
17) 14:00 to 14:15	-0.0816	-0.0839	0.0453	-0.1704	-0.0086	-0.0272	0.0338	-0.1222
18) 14:15 to 14:30	-0.0344	-0.0470	0.1028	-0.2112	-0.0227	0.0056	0.1384	-0.1847
19) 14:30 to 14:45	-0.0034	-0.0172	0.1321	-0.1950	-0.0689	-0.0560	0.0195	-0.1171
20) 14:45 to 15:00	0.0048	-0.0303	0.1266	-0.1688	-0.0552	-0.0749	0.0808	-0.1132
21) 15:00 to 15:15	0.0385	0.0008	0.1239	-0.1533	-0.0484	-0.0789	0.1502	-0.1016
22) 15:15 to 15:30	0.0447	0.0095	0.1700	-0.1608	-0.0183	-0.0205	0.2046	-0.0557
23) 15:30 to 15:45	0.1429	0.0941	0.2262	-0.1671	0.0613	0.0645	0.0787	-0.0660
24) 15:45 to 16:00	0.4166	0.3136	0.6050	-0.1208	0.4477	0.3459	0.4362	0.0343
F _{All}	86.6***	166.6***	309.6***	813.7***	10.8***	15.5***	33.6***	44.7***
F _{open}	232.9***	1158.3***	177.0***	8983.9***	29.6***	54.9***	0.2	492.1***
F _{close}	282.4***	231.6***	701.5***	10.3***	70.4***	57.2***	52.2***	7.7***
F _{open/close}	0.1	160.6***	169.6***	2909.4***	0.2	3.1*	19.8***	166.8***
F _{lunch/other}	114.8***	148.3***	1598.9***	19.8***	11.1***	15.7***	239.4***	1.37

The table shows the mean values of the standardized trading volume, price volatility, order depth and relative spreads of both classes of warrants (calls/puts) covering ASX stocks for each fifteen minute time interval during the trading day. Trading metrics are standardized by applying the formulae: $(X_{it} - \mu_t) / \sigma_t$, where X_{it} is the raw variable, μ_t is the mean for the day and σ_t is the standard deviation for the day. The trading variables are identified as: CVOLUME = the number of call warrant contracts traded on the ASX; CVOLAT = the time-weighted standard deviation of call warrant prices using bid-ask midpoints; CDEPTH = total call warrant orders on either side of the bid-ask schedule; CRSPR = the time-weighted relative spread for the call warrant; PVOLUME = the number of put warrant contracts traded on the ASX; PVOLAT = the time-weighted standard deviation of put warrant prices using bid-ask midpoints; PDEPTH = total put warrant orders on either side of the bid-ask schedule; PRSPR = the time-weighted relative spread for



the put warrant. Our sample consists of actively traded call warrants (215 warrants) and puts (21 warrants) between 1 January 2000 and 30 June 2000. F-statistics report on the significance of intraday differences, where:

- F_{All} is the F-statistic testing the difference across all 24 time intervals.
- F_{open} is the F-statistic testing the difference for interval 1 from intervals 2 to 8.
- F_{close} is the F-statistic testing the difference for interval 24 from intervals 19 to 23.
- $F_{open/close}$ is the F-statistic testing the difference between interval 1 and interval 24.
- $F_{lunch/other}$ is the F-statistic testing the difference for intervals 11 to 16 from intervals 9 to 10 and intervals 17 to 18.

*** Significant at the 0.001 level.

** Significant at the 0.01 level.

* Significant at the 0.10 level.

Table 2:
 Intraday trading patterns in the equity options market

Time	ASXO Call options				ASXO Put options			
	CVOLUME	CVOLAT	CDEPTH	CRSPR	PVOLUME	PVOLAT	PDEPTH	PRSPR
1) 10:00 to 10:15	-0.1975	-0.4149	-0.4628	1.2364	-0.1339	-0.4011	-0.5734	1.2795
2) 10:15 to 10:30	0.1204	-0.0262	0.1263	0.6409	0.1364	0.0483	0.0050	0.6593
3) 10:30 to 10:45	0.1598	0.0684	0.3151	0.2552	0.2419	0.2830	0.2376	0.2941
4) 10:45 to 11:00	0.1716	0.1438	0.3903	0.0568	0.2422	0.2778	0.3696	0.1112
5) 11:00 to 11:15	0.1646	0.1463	0.4288	-0.0730	0.1572	0.2325	0.4034	-0.0804
6) 11:15 to 11:30	0.1448	0.1407	0.4903	-0.1512	0.1997	0.2406	0.5500	-0.1621
7) 11:30 to 11:45	0.0843	0.1288	0.4746	-0.1890	0.2458	0.2195	0.5385	-0.2379
8) 11:45 to 12:00	0.0990	0.1333	0.4718	-0.2178	0.0747	0.1998	0.5343	-0.1964
9) 12:00 to 12:15	0.0594	0.0920	0.4414	-0.2568	-0.0257	0.1672	0.5520	-0.2299
10) 12:15 to 12:30	-0.0025	0.0770	0.1837	-0.2130	-0.0474	0.0556	0.1973	-0.2090
Lunchtime trading break (12.30 to 14.00 covering intervals 11 to 16)								
17) 14:00 to 14:15	0.0725	0.2930	0.4356	-0.0072	0.0761	0.3231	0.4992	-0.0743
18) 14:15 to 14:30	0.0546	0.2463	0.4543	-0.2203	0.0133	0.2914	0.5662	-0.2202
19) 14:30 to 14:45	0.1002	0.2813	0.5065	-0.2778	0.1305	0.3237	0.5800	-0.3119
20) 14:45 to 15:00	0.1357	0.2816	0.5328	-0.3078	0.1590	0.2855	0.6354	-0.3803
21) 15:00 to 15:15	0.1510	0.3165	0.5411	-0.3022	0.1360	0.2978	0.6511	-0.3889
22) 15:15 to 15:30	0.1529	0.3554	0.5655	-0.3036	0.0727	0.2986	0.6865	-0.3567
23) 15:30 to 15:45	0.2267	0.4221	0.5811	-0.3166	0.1755	0.3388	0.7209	-0.4130
24) 15:45 to 16:00	0.3084	0.6156	0.3018	-0.2394	0.3824	0.6285	0.3348	-0.4001
25) 16:00 to 16:15	0.0397	0.2341	-0.1973	0.3276	-0.0314	0.0431	-0.2476	0.1998
F_{All}	121.5***	469.5***	2023.0***	342.1***	21.2***	84.7***	433.2***	62.1***
F_{open}	241.5***	739.0***	2694.7***	2613.8***	28.8***	128.9***	585.1***	433.9***
F_{close}	1.3	31.5***	1830.1***	394.8***	0.8	0.4	355.5***	30.5***
$F_{open/close}$	368.6***	1674.3***	1475.5***	2049.9***	46.6***	206.0***	331.3***	406.1***

The table shows the mean values of the standardized trading volume, price volatility, order depth and relative spreads of both classes of options (calls/puts) covering ASX stocks for each fifteen minute time interval during the trading day. Trading metrics are standardized by applying the formulae: $(X_{it} - \mu_t) / \sigma_t$, where X_{it} is the raw variable, μ_t is the mean for the day and σ_t is the standard deviation for the day. The trading variables are identified as: CVOLUME = the number of call option contracts traded on the ASXO; CVOLAT = the time-weighted standard deviation of call option prices using bid-ask midpoints; CDEPTH = total call option orders on either side of the bid-ask schedule; CRSPR = the time-weighted relative spread for the call option; PVOLUME = the number of put option contracts traded on the ASXO; PVOLAT = the time-weighted standard deviation of put option prices using bid-ask midpoints; PDEPTH = total put option orders on either side of the bid-ask schedule; PRSPR = the time-weighted relative spread for the put option. Our sample consists of actively traded call options (998 options) and puts (222 options) between 1 January 2000 and 30 June 2000. F-statistics report on the significance of intraday differences, where:

- F_{All} is the F-statistic testing the difference across all 25 time intervals.
- F_{open} is the F-statistic testing the difference for interval 1 from intervals 2 to 8.
- F_{close} is the F-statistic testing the difference for intervals 24 to 25 from intervals 19 to 23.
- $F_{open/close}$ is the F-statistic testing the difference between interval 1 and interval 25.

*** Significant at the 0.001 level.

** Significant at the 0.01 level.

* Significant at the 0.10 level.

6.1. INTRADAY PATTERNS OF TRADING VOLUME FOR WARRANTS AND OPTIONS



6.1.1 EQUITY WARRANTS

Equity warrant trading volume (for both calls and puts) shows a distinct U-shaped pattern across the trading day. Trading volume at both the open and close of trading are found to be significantly higher than at other periods in the day. Though higher levels of trading volume are reported at trading end, it is not found to be significantly different from trading volume at market open. During lunchtime closure in the option market, a significant drop in equity warrant trading volume is observed. The intraday trading volume patterns in the equity warrant market suggest that inelastic demand is higher at the open and close of trading. The higher trading volume at these points in time can be explained by the trading activities of both hedge and speculative traders. In a similar argument used by Jain and Joh (1988), we suggest that hedge traders will be motivated to establish positions at both these points in time to protect their open stock positions executed across the trading day and to manage those positions which they cannot monitor or change overnight. By contrast, speculative traders will be motivated to trade near market open, to take advantage of the arrival of information during overnight closure that has not yet been incorporated into asset prices.

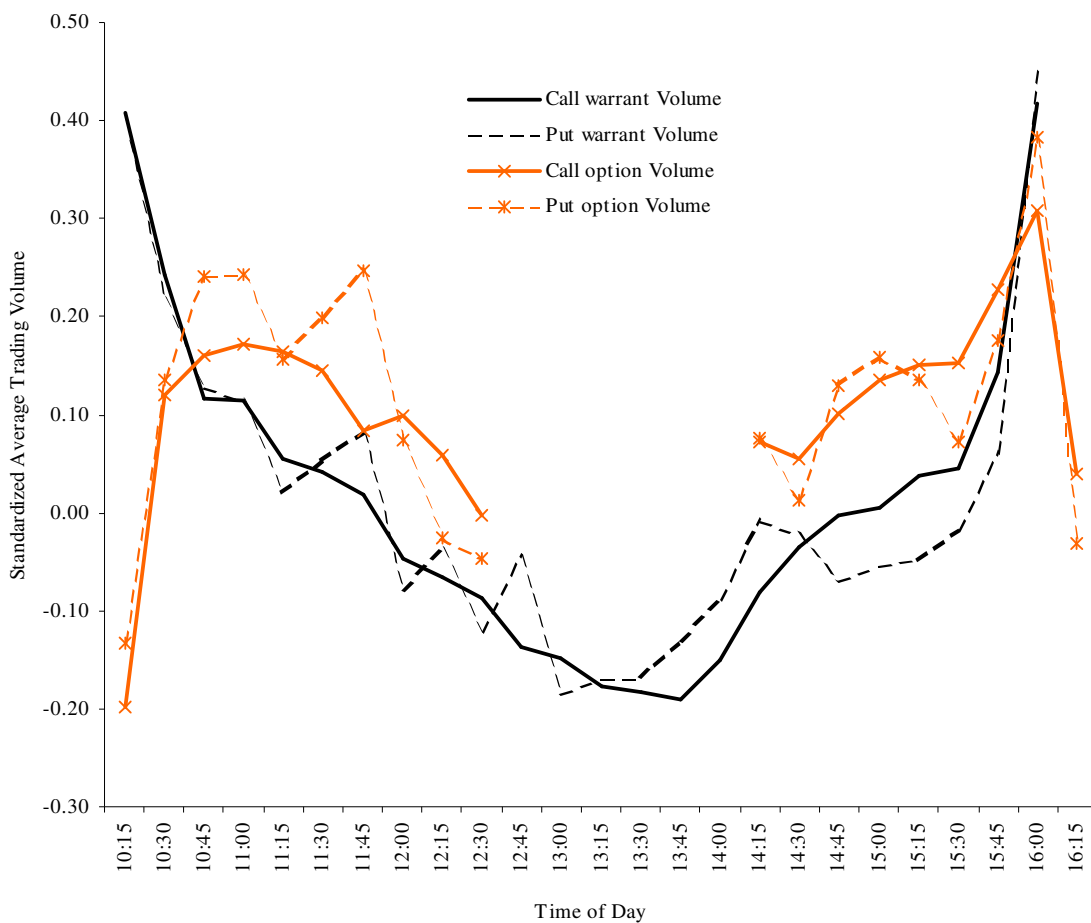




Fig. 1. This figure shows the standardized average trading volume of equity warrants and equity options for each fifteen-minute interval of the trading day across the sample period 1 January 2000 to 30 June 2000. The standardized variable is computed using the formulae: $(X_{it} - \mu) / \sigma$, where X_{it} is the raw variable, μ is the mean for the day and σ is the standard deviation for the day.

6.1.2 EQUITY OPTIONS

The intraday trading volume pattern in the equity option market (for both calls and puts) is clearly distinct from those observed for the equity warrant market. The intraday variation in trading volume shows an M-shaped pattern (on an upward incline). Trading volume is found to be relatively low at the open and builds to a peak approximately one hour after market open. This trend is reversed and continues in that direction up to the close of the morning session. A sporadic build up of trading volume occurs during the afternoon session, where it reaches its highest level at the close of the underlying market. A sharp fall in trading volume follows in the next interval. The market structure of the option market is likely to contribute to an intraday pattern divergent from those reported above for equity warrants. These differences are explained by the lack of a call opening procedure in the option market and the presence of market makers. The delay in open trading volume is attributed directly to the trading procedure employed in the ASXO. In the equity option market, whilst the trading system opens at 10:00, each class of options remains suspended until the underlying stock is opened in SEATS. This suggests that market maker response obligations to provide two-way quotes for their designated stocks starts at least ten minutes after the official stock open procedure.¹¹ Additionally, market makers may not be prepared to provide continuous quotes until they can estimate option values more accurately. Subsequently, option traders may not react based on their expectations of how the underlying stock responds to new information flow, but rather on actual stock price response. In this situation, market makers will limit their provision of liquidity services during the first fifteen minutes of trading, to alleviate the risk exposure they bear due to the greater leverage of the option. The increase in trading volume after market open is attributed to a reduction in information asymmetry and higher hedging demand up to the close of the underlying stock market. The significant fall in option trading volume (for both calls and puts) at the end of trading is explained by higher information asymmetry, since no inferences can be drawn from underlying stock price behaviour at this time. The variations in trading volume across the trading day are consistent with empirical literature from competitive dealer markets in various overseas exchanges. Stephan and Whaley (1990), Berkman (1992) and Niemeyer (1994) report similar wave-like intraday patterns in the CBOE, EOE, and the Swedish Options and Forwards Exchange (OM) respectively.

6.2. INTRADAY PATTERNS OF PRICE VOLATILITY FOR WARRANTS AND OPTIONS

6.2.1. EQUITY WARRANTS

Price volatility in the warrant market is found to follow a U-shaped pattern, which is significantly elevated in the first and last fifteen minutes of the trading day. Following the open, price volatility declines to midday, after which a reversal of this trend occurs fifteen to thirty minutes from the open of afternoon trading on the option market. While price volatility at the open is significantly higher than at the close for call warrants, similar results cannot be drawn for put warrants. For call warrants, this result suggests that at market open, traders have greater divergences of opinion

¹¹ From industry consultation, several market makers have indicated that they start their option trading desks after the end of the opening procedure for the underlying stocks.



expressed by higher price volatility, relative to the close. During lunchtime closure in the options market, price volatility is found to have a significantly weaker U-shaped pattern. Lower volatility during this period occurs at a time when information asymmetry and trading volume is at its lowest. The intraday patterns of price volatility corroborate the positive relations found between trading volume and price volatility in past empirical work (see French and Roll, 1986 and Schwert, 1989).¹²

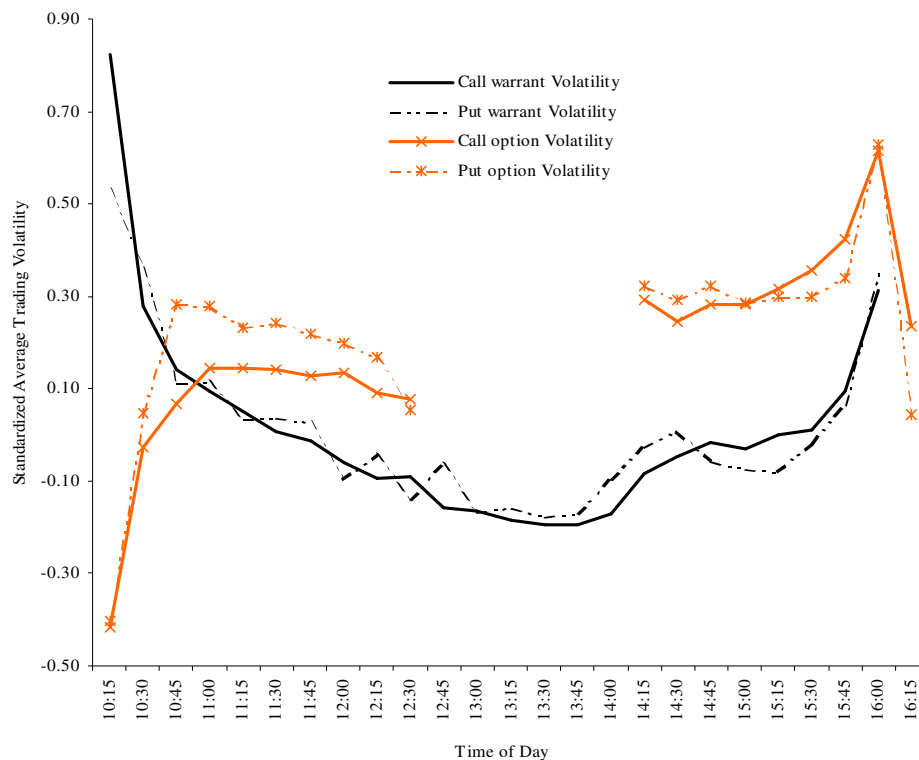


Fig. 2. This figure shows the standardized average trading volatility of equity warrants and equity options for each fifteen-minute interval of the trading day across the sample period 1 January 2000 to 30 June 2000. The standardized variable is computed using the formulae: $(X_{it} - \mu_t) / \sigma_t$, where X_{it} is the raw variable, μ_t is the mean for the day and σ_t is the standard deviation for the day.

6.2.2. EQUITY OPTIONS

The intraday price volatility in the equity option market (for both calls and puts) is distinct from that reported in overseas exchanges.¹³ Price volatility at the open is at its lowest level compared to other intervals in the trading day. Following the open, price volatility is observed to increase to its highest point at the second last interval of afternoon trading. This rise again demonstrates the link between trading volume and price volatility. A significant drop follows this in the last interval. It is worthwhile recognising that volatility in the afternoon session is relatively higher

¹² French and Roll (1986) show that volatility is higher when the market is open than when it is closed, suggesting that trading activity is an important contributor of short run volatility. Schwert (1989) also finds that growth in trading volume is positively related to an increase in monthly stock return volatility.

¹³ Sheikh and Ronn (1994) and Chan, Chung and Johnson (1995) examine the price volatility behaviour of CBOE options. They find that variances of call and put returns are found to follow a U-shaped pattern across the trading day.



than in the morning session. There are three explanations that we posit for intraday volatility patterns on the ASXO. First, a combination of no orders being allowed prior to opening on the DTF, and a reluctance of market makers to provide a firm quote and lower trading activity at the start of trading is most likely to explain the low price volatility levels during the first fifteen minutes of trading. Second, the increase in volatility in the second last interval of trading is likely to be as a result of heightened quote requests from hedge traders attempting to adjust their positions according to their risk tolerances in preparation of overnight closure. Third, lower price volatility in the option market following the close of the stock market is consistent with the theoretical model of King and Wadhvani (1990), who predict a drop in price volatility upon the closure of an associated financial market.

6.3. INTRADAY PATTERNS OF ORDER DEPTH FOR WARRANTS AND OPTIONS

6.3.1. EQUITY WARRANTS

The intraday pattern of order depth across the trading day for equity warrants (for both calls and puts) displays an almost U-shaped pattern. Order depth is documented to be significantly higher at both the open and close of trading, with its highest level reached at trading end. During lunchtime closure, a deep narrow U-shaped pattern is observed.

The intraday pattern in order depth is explained by the market design of the warrant market. In Section 2, we described that the ASX warrant market is characterized by a hybrid market, where both limit-order traders and a single market maker (i.e. the warrant issuer) establish prices. While warrant issuers are not obliged to facilitate a market in their warrants, they have a material interest in ensuring a liquid and efficient market for their issue. Warrant issuers have developed a reputation for assuring investors a liquid market place through active participation in the secondary market.¹⁴ We suggest that higher order depths at both the open and close is consistent with warrant issuers placing a range of limit orders in the bid-ask schedule during periods of high inelastic transaction demand, in order to ensure a liquid market for their products. The decline in order depth across midday in the warrant market is explained by the lunchtime trading break in the options market. During lunchtime closure, the probability of informed traders participating in the warrant market increases. In turn, we suggest that this heightens adverse selection costs causing a decline in order depth.

¹⁴ Market research into the ASX warrant market during 1996 revealed that specific warrant issuers accounted for 42 percent to 57 percent of turnover for three of the most actively traded warrant series (by open position).

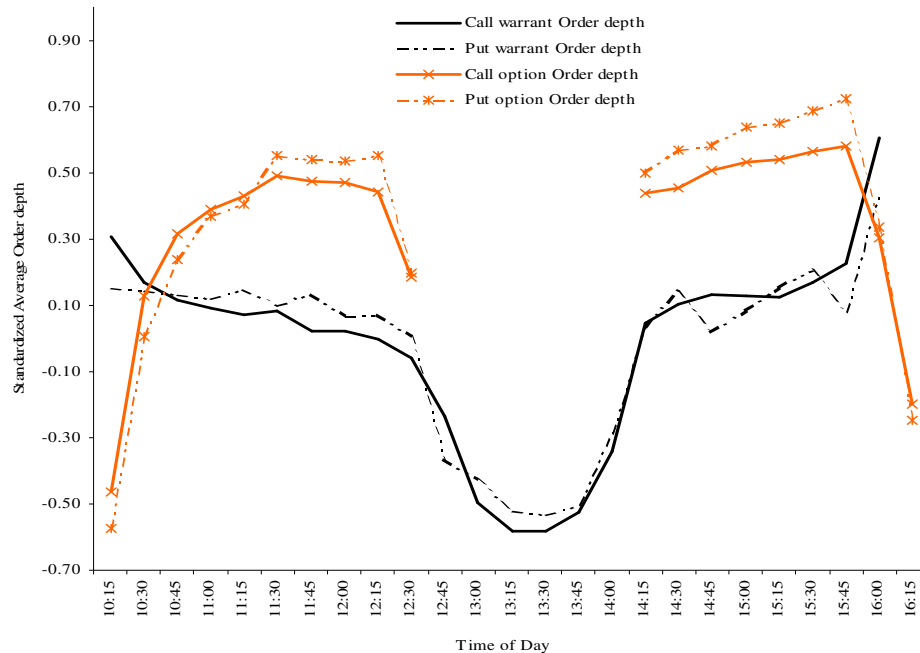


Fig. 3. This figure shows the standardized average order depth of equity warrants and equity options for each fifteen-minute interval of the trading day across the sample period 1 January 2000 to 30 June 2000. The standardized variable is computed using the formulae: $(X_{it} - \mu_t) / \sigma_t$, where X_{it} is the raw variable, μ_t is the mean for the day and σ_t is the standard deviation for the day.

6.3.2 EQUITY OPTIONS

Order depth in the equity options (for both calls and puts) market exhibits a similar M-shaped pattern exhibited for trading volume. At the open of trading in the morning session, order depth is at its lowest level than at any other time of the trading day. Two explanations are posited for this occurrence. First, as all orders on the DTF are deleted at the end of the trading day, order depth will be low as limit orders take time to be inputted into the trading system. Second, wider quoted spreads reported at market open are unlikely to attract new limit orders during this time. Following the first fifteen minutes of trading, order depth builds up, remains relatively stable and then declines in the last fifteen minutes before lunchtime closure. At the open of afternoon trading, order depth is relatively high and stable. A decline in order depth occurs during the second last interval of trading, where a significant drop at trading end is found. The sharp fall in order depth before lunchtime closure and at the close of trading is explained by higher information asymmetry at these times, as market makers will be reluctant to offer liquidity services because of the risk of trading with an informed investor.



6.4. INTRADAY PATTERNS OF RELATIVE SPREAD FOR WARRANTS AND OPTIONS

6.4.1. EQUITY WARRANTS

The intraday pattern of relative spread for equity warrants is observed to follow an almost L-shaped pattern. Relative spreads at the open relative to the close are more pronounced and significantly higher at both these points in time than at other intervals. Of particular note is that relative spreads for call warrants are significantly wider during lunchtime closure in the option market. This result highlights that the closure of one market (i.e. the option market), affects the pricing dynamics in another related market (i.e. the warrant market). The wider relative spread patterns reported for equity warrants are explained by higher levels of information asymmetry present during market open, lunchtime closure and trading end. We suggest that during these periods, relative spreads are wide because warrant issuers and traders alter the pricing of their limit orders to avoid being taken advantage of by informed traders.

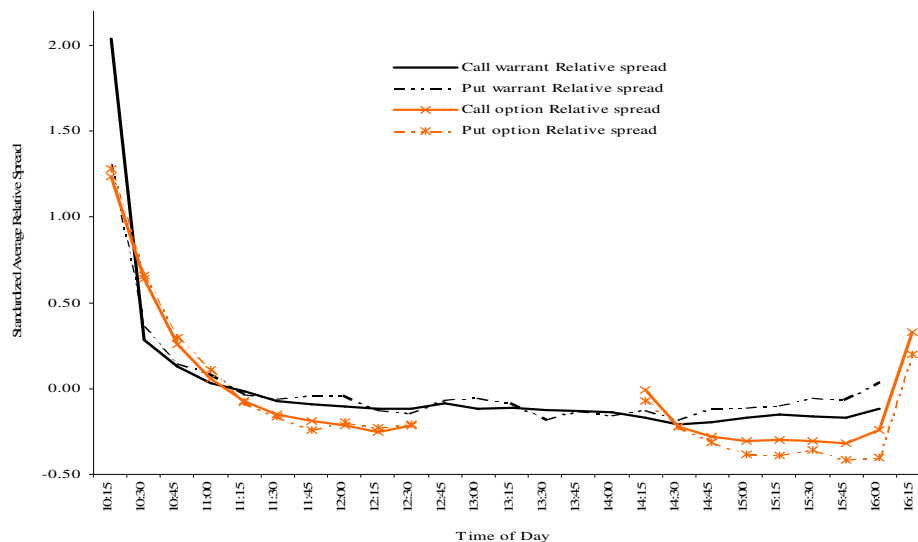


Fig. 4. This figure shows the standardized average relative spread of equity warrants and equity options for each fifteen-minute interval of the trading day across the sample period 1 January 2000 to 30 June 2000. The standardized variable is computed using the formulae: $X_{it} - \mu_t / \sigma_t$, where X_{it} is the raw variable, μ_t is the mean for the day and σ_t is the standard deviation for the day.

6.4.2 EQUITY OPTIONS

The intraday pattern of relative spread for equity options is at its widest level immediately after the open of morning trading. A steady decline then ensues until the last fifteen minutes of the morning session. This decline is consistent with a reduction in price uncertainty as information flow is disseminated into the market. After lunchtime closure, a narrowing of spreads is observed. This trend is reversed, during the last fifteen to thirty minutes in the afternoon session. These results contradict with those of Chan, et al. (1995a) who do not find an increase in relative spreads during the last interval of trading in the competitive market dealer setting of the CBOE. Chan et al. (1995a) attribute these results to the inventory holding cost model. We suggest that the intraday pattern of relative spreads observed in the ASXO is suited to the 'learn-by-trading' theoretical model, which anticipates a loss in price discovery associated with non-trading periods will result in wider spreads when trading resumes. It is noteworthy that institutional features of



the options market also explain the observed relative spread variations around lunchtime closure. Prior to lunchtime, theoretical option prices (indicative prices for at-the-money, in-the-money and out-of-the-money series for each class) are broadcast at a pre-determined bid-ask spread by the options exchange. However, this information signal is not broadcast following lunchtime closure in the options market, indicating a period characterized by market maker price experimentation. We find that consistent with this institutional feature, relative spreads are observed to be wider after lunchtime closure and not before.

7. SUMMARY AND CONCLUSIONS

This paper examines intraday patterns of trading volume, price volatility, order depth and relative spread for both the equity warrant and equity option markets in Australia. The paper contributes towards the microstructure literature, where it is the first to document the intraday trading behaviour for both these derivative securities. We also compare and contrast the intraday patterns in these securities, which each operate in markets with unique market designs. This allows the paper to draw inferences into competing market microstructure theories and examine whether market design differences explain variations in observed intraday patterns. The data used to analyse intraday patterns is collected from 1 January 2000 to 30 June 2000. Comparison between the intraday trading patterns of warrants and options is enhanced with the employment of high frequency databases, which allow for the identification of every order and trade time-stamped to the nearest one hundredth of a second.

We find that trading volume for equity warrants display a U-shaped pattern, which is significantly higher at both the open and close of trading. It is suggested that high levels of inelastic demand exist during these points in time, as investors exchange risk positions before overnight closure and transfer them back when the market re-opens. At midday (corresponding to the lunchtime closure in the option market), trading volume for the equity warrant market is significantly lower. By contrast, equity options exhibit an M-shaped intraday pattern in trading volume, where it is observed to be at its lowest at market open, increase to its highest point at the close of the underlying market and sharply fall at the end of trading. These patterns are attributed to the market design specific to the option market, in particular to the existence of official market makers. Price volatility in the warrant and option markets are found to be similar to that observed for trading volume. These results support existing literature, which find evidence of positive relations between trading volume and price volatility (e.g., French and Roll, 1986 and Schwert, 1989). Intraday variations in order depth for warrants and options are found to be distinct from one another. For equity warrants, order depth displays a U-shaped pattern across the trading day. By contrast, order depth on the equity option market follows an M-shaped pattern, similar to that observed for trading volume. Divergences in order depth intraday patterns between the warrant and option market are explained by differences in risk tolerances of market-maker(s) and the differences in trading protocols and mechanisms used across both these markets. Relative spreads are reported to be wide at the open and close of trading for both the warrant and option markets. Wider relative spreads at the open and close are explained by theories relating to information asymmetry and price experimentation. While the market power model cannot be ignored for the relative spread behaviour in equity warrants, the inventory holding cost argument is not applicable in either market. Overall, we conclude that specific market design features together



with information asymmetry models are important forces on the trading behaviour in the markets, as reflected by their intraday trading patterns.

Our paper finds some clear evidence that trading behaviour in one market affects the trading behaviour in another related market. During lunchtime closure in the option market, wider relative spreads are found in the warrant market, indicative of a loss in price discovery. A similar result is found in the option market following the close of trading in the stock market. A clear area of future research is to examine the price discovery linkage between equity warrants and equity options. A step in this direction will provide a better understanding of the price discovery process and possible arbitrage opportunities existing between these markets.

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